Wastewater reclamation and re-use in the Clear Lake watershed, Riding Mountain National Park, Manitoba

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Abstract: Wasagaming/Clear Lake in Riding Mountain National Park is a major attraction to the general public throughout the summer months. This has required the construction of appropriate infrastructure to treat sewage and other wastewater. The current system consists of three stabilization ponds in series. Research indicates that this lagoon cell system generally operates well and produces an effluent that consistently complies with Manitoba license effluent requirements. The third cell routinely has been discharged in late June into Ominnik Marsh, which connects to Clear Lake.

Recent policy decisions require that additions of nutrients to Clear Lake from all sources be reduced. This paper assesses the feasibility of fertigating hayland with sewage effluent as a means of avoiding further nutrient enrichment of Ominnik Marsh/Clear Lake.

Data gathered on effluent chemistry and toxicology support the reuse of this wastewater in an ecologically sustainable manner.

The biomass harvests of a 3-fold increase in the volume of fertigation wastewater per unit area were compared to the 1-fold wastewater fertigation per unit area and zero fertigation (controls). The 3-fold application of wastewater effluent resulted in no significant increase in yield or quality.

Pre and post fertigation soil sample were used to assess the cumulative and or negative impacts on soil chemistry, fertility and other physical properties and the potential for nitrite contamination of groundwater was examined. Soil chemistry and fertility showed no significant differences between fertigated plots and the control plots. There was no indication of nitrite or phosphorus build-up or leaching.

Forage biomass was assessed for toxicology, nutritional quality and commercial value in each replicated treatment both in an early and late harvest. Forage yields were consistent in biomass and nutritional quality. There were no significant differences between fertigated yields and the control yields.

Introduction

Proper treatment of municipal and industrial wastewater can provide water of such quality that should not be wasted but put to beneficial use. This thesis coupled with the increased frequency of water shortages, the high costs of water supply development and environmental protection, has provided an incentive to consider wastewater reclamation, recycling, and reuse in many parts of the world (Asano 1998; van de Graff *et al.* 2002; Magasan and Wang 2003; Velez *et al.* 2002). Among the variety of non-potable water reuse projects, agricultural and landscape irrigation have received the most research evaluation and actual implementation (Kubo and Sugiki 1977; Page and Chang 1984; Shelef 1990; Shuval *et al.* 1986; Strauss and Blumenthal 1990; U.S. EPA 1981).

During the last quarter century, the benefits of wastewater reuse as a means of supplementing water resources have been recognized by most state legislatures in the United States, as well as by most of the countries in the European Union. Since the 1960s, intensive research efforts have provided valuable insight into health risks and reliable treatment design concepts for water reuse engineering.

In the Canadian Prairies, too, it has been acknowledged that there is considerable potential for effluent irrigation (Hogg *et al.* 2003). While some jurisdictions view effluent irrigation as a means of wastewater disposal, others view effluent as a resource for economic development such as cash crop fertigation and golf course irrigation. Treated wastewater reuse is a well-established practice in western Canada where approximately 65 projects irrigating a total of 5700 ha (Alberta - 3050 ha; Saskatchewan - 2620 ha; Manitoba - 53 ha) have been established (Hogg et al. 2003). These projects, however, account for less than 5% of the total discharge of effluent on the prairies. Potentially 115,000 hectares could be irrigated if the practice were to be expanded (Hogg *et al.* 2003). Forage crops are favoured for treated wastewater irrigation because of their long growing season, high evapotranspiration demand and their ability to remove large quantities of nutrients from the biosystem.

At the Agricultural and Agri-Food Canada research facility in Lethbridge, Alberta, scientists have studied the use of wastewater for irrigation (Agriculture Canada 2001). Municipal sewage effluent applied to forage crops and supplemented with nitrogen fertilizer, proved to be a satisfactory source of nutrients for reed canarygrass, bromegrass, tall wheatgrass and Altai wildrye. Alfalfa, because of its nitrogen-fixing ability, did not require fertilizer. Potentially harmful bacteria in the wastewater were killed within 4 days of exposure to bright sunlight; within 2 weeks no risk of contamination remained for livestock consuming forage or for humans working on the land. This practice for the use and disposal of wastewater has been adopted by more than 25 municipalities and 30 agricultural industries (Agriculture Canada 2001).

In the late 1960s, the Federal-Provincial Okanogan Water Basin Study concluded that phosphorus from sewage treatment plants discharging into Okanogan Lake was a major cause of the proliferation of aquatic weeds in the lake. The City of Vernon, B.C., embarked on a project to reclaim its wastewater by using it to irrigate farmland adjacent to the city. After a 6 year pilot project, a full-scale system was put into operation in 1977. Since 1977, the irrigated land base has been continuously expanded to meet the increased wastewater flows. All the reclaimed water generated has been used beneficially for irrigation, except for three instances when the storage capacity of the reservoir was exceeded.

In Saskatchewan, there are three major centers, Swift Current, Moose Jaw and Lloydminster, and 28 smaller communities which conduct effluent irrigation (Cameron and Crosson 1994). A project was initiated as part of the Irrigation Sustainability component of the Canada-Saskatchewan Agriculture Green Plan Agreement (CSAGPA) to evaluate the long-term impact and sustainability of effluent irrigation practices in Saskatchewan. As part of that study a comprehensive literature review including a review of international criteria was completed (Cameron 1996 and 1997).

The Moose Jaw project was started in 1982. Approximately 1194 ha of agricultural land are irrigated with treated wastewater. Nineteen center pivots and gated pipes are used. Forage, cereal and oilseed crops are grown. An hydrogeological study identified a shallow drift and deep bedrock aquifer underlying the irrigation site. Aquifer deterioration was predicted to occur from downward migration of the high nitrate content effluent leachate (Menely 1975). A laboratory soil column study indicated that a 25% leaching was required to prevent soil productivity reduction due to salinity buildup from the high soluble salt content of the effluent (DeJong 1976). The Moose Jaw effluent had an average electrical conductivity (EC) of 1.69 dS m^{-1} and an average total dissolved solids (TDS) level of 1238 mg l^{-1}. The effluent had high levels of ammonium, nitrate nitrogen, total phosphorus and soluble phosphate. Heavy metals and trace element concentrations were low in the effluent. The moderate sodium adsorption ratio (SAR) level of 4 was not considered to be problematic. The surface soils of the irrigation site are predominantly loamy sand and there have been no reported permeability problems. Average salt levels have increased in the irrigated soil (EC values increasing from 0.75 dS m^{-1} to 1.60 dS m^{-1}).

Shallow ground water quality data from 1981 to 1989 indicate no effect on ground water quality upstream from the irrigated area. Entry of effluent into the groundwater within the project area, however, has resulted in increased concentrations of sodium, chloride, sulfate and bicarbonate. The deep aquifer appears to be unaffected. Nitrate-nitrogen levels varied from 0.03 - 33 mg l^{-1} in the groundwater samples and phosphorus levels ranged from 0.07 - 0.44 mg l^{-1}. Outward migration of salts was detected in piezometers indicating that lateral migration of soluble ions is occurring. There is no evidence of contamination of groundwater with infectious viruses or bacteria.

The Swift Current site began in 1973 as a pilot project conducted by the Agriculture and Agri-Food Canada Research Station (Jame *et al.* 1984). A full-scale project was initiated in 1978 using a total of 338 ha. Effluent is supplied from a secondary lagoon to 3 center pivots, 11 laterals, 2 volume guns and 3 hand-move sprinkler systems (Clifton Associates Ltd. 1993). The City of Swift Current initiated groundwater monitoring of wells and springs in 1976. Both a shallow drift aquifer and a deep bedrock aquifer are monitored.

The effluent has a high salt load with a mean EC of 2.6 dS m^{-1}. Preliminary results indicated that a leaching fraction of 10 - 15% was needed to ensure sufficient leaching to maintain salt content in the root zone below deleterious levels. After 8 years of effluent irrigation, steady-state soil salinity profiles developed, approaching the salinity of the effluent. Beginning in June of 1995 Sask Water has conducted an electromagnetic survey (EM 38) of the irrigated lands in the project area which also indicates that the soil salinity levels have risen to levels found in the effluent.

Changes in the shallow groundwater quality from 1978 to 1991 displayed increases in chloride, hardness, sodium, magnesium and total dissolved solids (Clifton Associates Ltd. 1993). Values for sulfate in one well were 414 mg l^{-1} indicating contamination by effluent applications. There has been no observed change in water quality for the deep bedrock aquifer. Groundwater bacteriology has found faecal coliforms present at greater than 30 most probable number (MPN) in the shallow wells. These observations contradict the pilot project study (Biederbeck and Bole 1979b).

The Northminster Effluent Irrigation Project is located approximately 11 kilometers north of Lloydminster and began operation in 1989. The project stores effluent received from the City of Lloydminster in a reservoir. The effluent is pumped to ten individual parcels of land through pressurized pipelines. One additional parcel receives effluent directly from the City's discharge line. The effluent is used to irrigate forage and annual crops. Soil salinity and trace metal monitoring have shown that soil salinity of the irrigated lands has increased marginally. These increases were in sodium, chloride and sulphate. The effluent has an EC of 1.6 dS m^{-1} and an moderate

SAR of 3.3. Expected increases in EC and SAR have been observed on the irrigated sites. Abnormally low precipitation in recent years has limited leaching. Water quality analysis of samples from most of the piezometers has shown some increase in nutrient concentrations, however it is not apparent if this increase is from the effluent supply or from fertilization. Major ion analysis suggests that there is little change over the background levels.

Roblin, Manitoba uses a lagoon to treat its residential sewage like many communities on the prairies. Typically, towns using this type of sewage system discharge effluent into local streams or rivers often during periods of high water flow. This was not an option for Roblin since they were prohibited from discharging sewage effluent into the nearby Shell River.

In January 1996 Roblin purchased 80 acres of land next to its lagoon system of which 40 acres is used for wetland and 20 acres for a poplar plantation. By the summer of 2001 the wetland was fully operational and complements the irrigation system. A total of 12,500 hybrid poplar trees were planted around the wetland and these can act as an additional user of wastewater in high precipitation years. Roblin won a 2002 FCM-CH2M Hill Sustainable Community Award for its wetland project. It was noted that salt accumulation on irrigated land has become a problem over time (Boddy 2003).

In March of 1993, a workshop entitled “A Vision for Water Quality in the Clear Lake Basin” identified the principal pollution related threats to water quality in the Clear Lake watershed. Among these were sewage disposal systems and particularly the Wasagaming Lagoons/Ominnik Marsh System (Figure 1b). Of specific concern was suspected leakage from the forcemain and lagoon cells and the effectiveness of the marsh to absorb sewage effluent discharged from the lagoon system.

A three-year (1999-2002) performance evaluation of the Wasagaming lagoons/Ominnik Marsh system followed. Highlights of the unpublished report include: the lagoon cells contained the required motile green algae essential to the oxidative degradation of the wastes and the minimization of odour problems. There is minimal sludge buildup over many years of operation in a cold climate due to fungal bulking of sludge in cell 1. Final nutrient polishing is accomplished by submerged aquatic plants which contribute through their photosynthetic activity super-saturation with oxygen in cell 3 during summer daylight hours, resulting in no problems in the effluent with unionized ammonia which is extremely toxic to aquatic biota. Cell 3 also develops a very rich population of invertebrates indicating that the polished effluent does not present toxicity problems for aquatic organisms. The polished effluent still contains some nutrients and these have the potential to contribute to eutrophication in Ominnik Marsh and by through flow to Clear Lake.

Belke and McGinn (2003) carried out measurements of a number of physical and chemical parameters at various points in the Ominnik Marsh system (Figure 1b). The study found support for the leaking forcemain hypothesis. Other observations were: that there was effective uptake by marsh vegetation of nutrients released during the spring freshet. That a significant area of marsh was being short-circuited during the annual lagoon discharge release in June and that during this release significant concentrations of sediment bonded phosphorus were being released by discharge agitation. Following this report and on-going evaluation by Parks Canada and their consultants the decision was made to relocate the forcemain so as to bypass the marsh. Consultant engineers also examined the issue of upgrades to the sewage system to avoid the addition of nutrients to Ominnik Marsh and eventually to Clear Lake. The proposed changes included a sand filtration system at the exit to lagoon cell 3 (discharge channel) added aeration and the prevention of any leakage from the lagoons cells. Estimated costs might exceed $4.5 million (Stantec 2003).

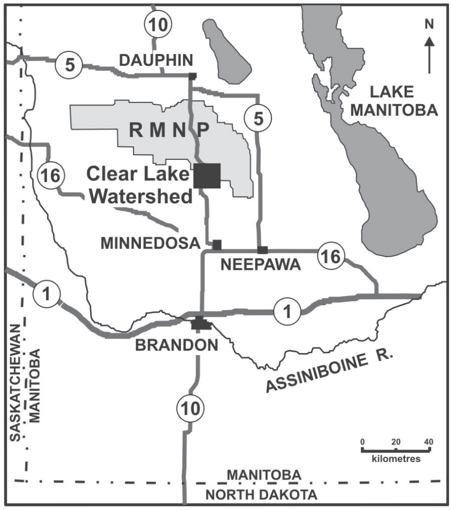

Figure 1a: *General location of the town of Wasagaming and the Clear Lake watershed.*

Objectives of the Study

The objective of this study is to assess the feasibility of fertigating hayland with treated (polished) sewage effluent as more cost efficient means of avoiding additional nutrient enrichment of Ominnik Marsh, South Lake and Clear Lake.

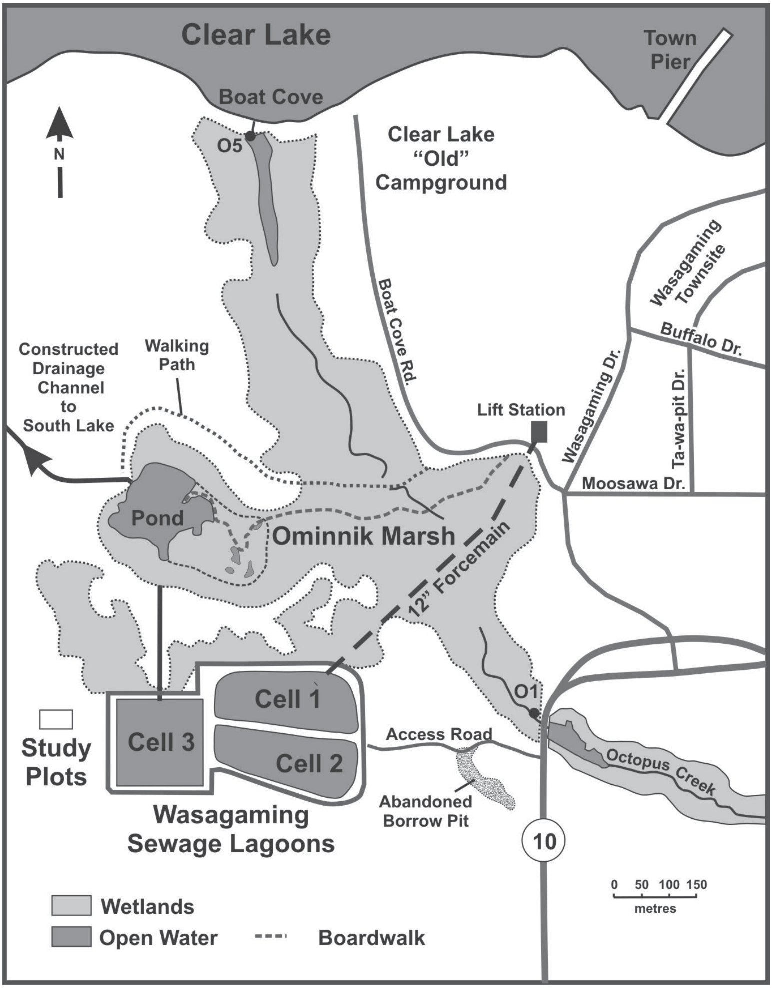

Figure 1b: *The Wasagaming Lagoons/Ominnik Marsh wastewater treatment system.*

Procedures and Methodology

Location of selected study plots:

To the west and adjacent to the Wasagaming lagoons are two parcels (19.8 ha and 13.7 ha) of non-gazetted hayland (Figures 1b and 2). The land has no present use, although in the past it had been harvested to provide forage for the livestock. A 30 m by 60 m study area was selected from the

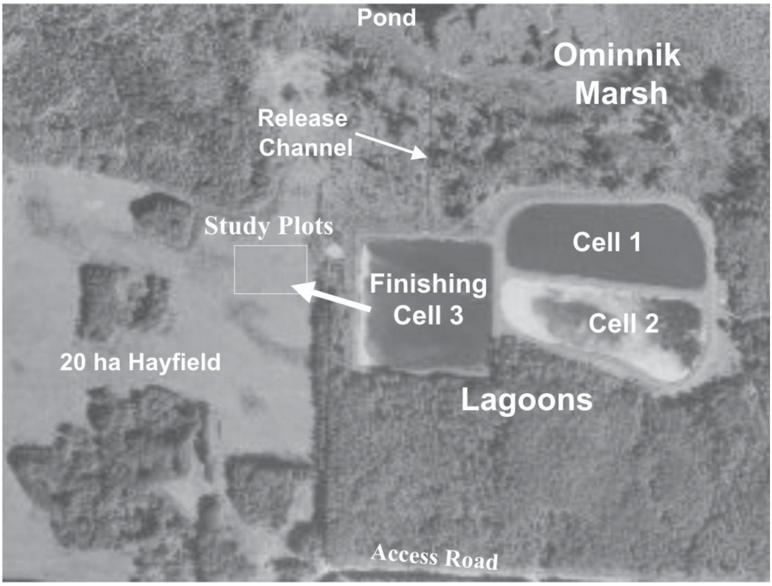

Figure 2: *Aerial photograph of the Wasagaming sewage treatment lagoons and the Hayfield study plots.*

larger hayfield and subdivided into 54 sample plots (Figure 3)**.** Each sample plot is 5 m by 5 m. All of study plots were within 300 m of the finishing lagoon cell 3.

Soils:

A 7.59 "Geoprobe" core was extracted from the west end of the study plot. The uppermost 2.72 m contains the Rackham Fine Sandy Loam, underlain by the medium sand glaciolacustrine parent material. Wet (saturated) fine to medium sands with occasional silt layers are found between 2.72 m and approximately 5.0 m below the surface. These glaciolacustrine complexes overlay an additional 2.5 m of deep-water rhythmiticly bedded fine sands and massive silt/clay. A fluctuating water table is estimated to lie between 2 and 4 m below surface, depending on annual precipitation.

A soil pit, approximately 1 m by 1.5 m by 1.5 m depth, exposed the Rackham Fine Sandy Loan soil profile and verified that the water table was deeper than 2.0 m below the surface. Four samples from the A-horizon (16 cm deep) were extracted every 2.5 cm. A fifth soil sample was taken at 30 cm depth in the B-horizon. All samples were tested for organic carbon (loss on ignition analysis, Oliver 2000).

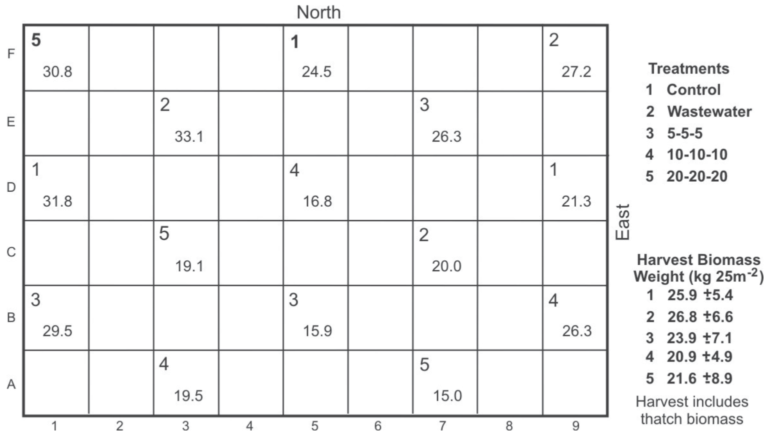

Figure 3a: *Hayfield study plots: biomass harvest September 23-30, 2003.*

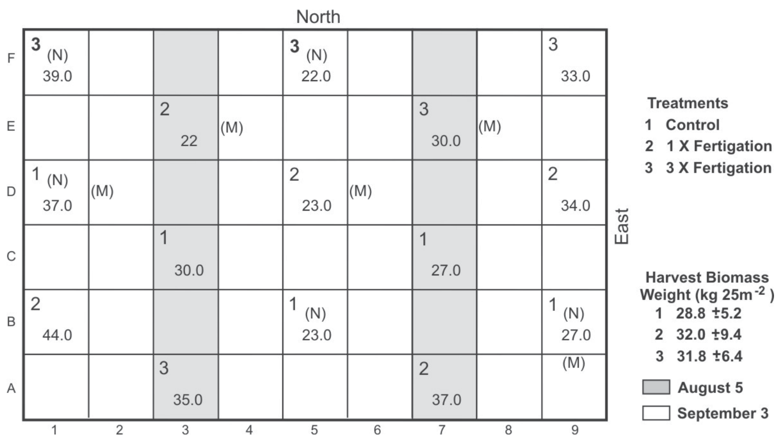

Figure 3b: *Hayfield study plots: biomass harvest August 5 and September 3, 2004.*

The Rackham Fine Sandy Loam is a Grey Wooded Soil, developed on medium texture glacial lacustrine sediments. The soil is considered to be friable, well drained and of moderate to high natural fertility (Ehrlich *et al*. 1956). The soil has been placed in the SCS hydrological soil group “A”; low overlandflow potential, high infiltration capacity, and a saturated hydraulic conductivity > 7.6 mm h^{-1} (Aho 1997). Organic carbon is estimated to be approximately 6% (Appendix 4). There is medium to low available nitrogen and phosphorus and good moisture retention. These soils are recommended for hay and controlled grazing and “Grass and legumes will produce well, especially when nutrient deficiencies are offset by nutrient application." (Ehrlich *et al*. 1956).

Vegetation:

The predominant forage present was brome grass (*Bromus inermis*), with lesser amounts of quack grass (*Agropyron repens*) and Kentucky blue grass (*Poa pratensis* and *Poa sp.*). No toxic species were present and no rare or endangered species were observed in the 30m by 60 m study area.

The 2003 Study

Treatments:

Five irrigation treatments were tested on 15 randomly stratified plots (Figure 3a). Three sample plots each were irrigated with lagoon-polished effluent (2); 5-5-5 NPK fertilizer (3); 10-10-10 NPK fertilizer (4); 20-20-20 NPK fertilizer (5) and three plots were left as a control (1) (Figure 3a). All plots were colour flagged and the wastewater (effluent) irrigation was carried as a one-time application on June 10, 2003. The effluent was pumped from lagoon cell 3 by fire hose and sprayed on to the selected plots. The volume of wastewater applied (the emptying of lagoon cell 3) was determined by dividing the total volume of cell 3 (27,600 m^3) by the total irrigable land available (334,670 m^2), giving an equivalent depth of effluent (0.082 m) required for each 25m^2 plot. The delivery rate of the pump and fire hose system was derived from determining the time to fill a 5-gallon pail (22.7 l) and then calculating the delivery time (8 minutes and 12 seconds) required to apply the desired depth of water. The NPK fertilizer plots were irrigated with an equivalent depth of fertilized water on June 11 and 12.

The 2004 Study

On June 9, 2004 five of the 2003 sample plots were fertigated with 3 times the fertigation volume (3) applied in 2003 (Fig 3b). Similarly, five sample plots received a one-time effluent fertigation treatment (2) and the remaining five 2003 sample plots were designated control (1) (Figure 3b). The five-plot sub-samples selected had, in the 2003 season, undergone one of five 2003 treatments. That is, application of one time polished effluent; 5-5-5 NPK fertilizer; 10-10-10 NPK fertilizer; 20-20-20 NPK fertilizer and control, respectively.

Sampling and Testing:

In 2003 and 2004 effluent samples were collected prior to fertigation and the annual release. Enviro.Test Laboratories of Winnipeg provided all sampling bottles reagents etcetera. Replicate analyses were carried out for elemental composition, microtox bioassay, phenols and other trace organics of potential concern in sewage effluents. September 3 2003, samples of Coons tail (*Ceratophyllum demersum L.*) the predominant plant in lagoon cell 3 were also collected, dried at 80 degrees Celsius and digested in 3 ml of sulphuric acid in Kjeldahl flasks. The digests were cleared dropwise with hydrogen peroxide and diluted to 100 ml with deionized water for elemental analysis. Chemical analyses indicate total phosphorus content of 23 mg P g^{-1} dry weight; Total Kjeldahl Nitrogen of 875 mg N g-1 dry weight (Appendix 5).

Maintenance:

The study plots were checked on a weekly basis for vandalism or other problems. The plots were also examined from time to time during the summer to determine the major plant materials present.

Harvest 2003:

On September 23, 2003, 6 plots were harvested before rain stopped work. The remaining 9 plots were harvested on September 30, 2003. A large tarp and spring balance were used to weigh the freshly cut forage.

Soil Analysis 2004:

Prior to fertigation, on May 5, 2004, soil core samples (15-20 cm deep) were extracted from five plot boundaries; two associated with a one-times application, two outside control plots and one sample adjacent to a three-times application plot. Similarly, on November 4, 2004, post application and the growing season, soil samples were extracted from the five sample plots that experienced fertigation applications: three from three-times application and two from control plots. All soil samples were analyzed for pH, electrical conductivity, total phosphorus, potassium, ammonium, nitrite and total Kjeldahl nitrogen.

Harvest 2004:

In 2004 the seven sample plots were “early” harvested on August 5 2004; two plots each of control and three-times application (3X) and three one-time application (1X) plots. On September 3, 2004 the remaining eight plots were harvested. The “green” harvest biomass was collected into a large tarp and weighed on a spring balance to the nearest kilogram.

Forage Analysis 2004:

Biomass yields were sampled and analyzed for total phosphorus, total Kjeldahl nitrogen and crude protein. In addition the samples were sent to Norwest Laboratories in Winnipeg for Near Infrared Reflectance Spectroscopy (NIRS) analysis; including fiber, crude protein, mineral content and relative feed value.

Results

Two weeks prior to the 2003 and 2004 discharge into Ominnik Marsh the effluent in lagoon cell 3 was tested by Parks Canada and found to meet license requirements for discharge, specifically, biological oxygen demand five day test (BOD5) and soluble solids were less than 25 mg l^{-1}; faecal coliforms less than 200 colony forming units (CFU) 100 ml^{-1} and total coliforms less than 1500 CFU 100ml^{-1}.

The 2003 inorganic chemical analysis of the effluent (Appendix 1) indicates that concentrations of heavy metals or other elements identified as an irrigation, surface or drinking water concern in Manitoba fall below the provincial guidelines (Williamson 2001). The wastewater, however, contains the macronutrients, nitrogen, phosphorus and potassium and the intermediate nutrients calcium, magnesium and sulphur and the micronutrients, boron, copper, iron, manganese and molybdenum (Appendix 1).

There are no trace organics present at levels above the detection limit (Appendix 2). Phenols were present in the wastewater but at extremely low levels, 0.005 mg l^{-1}, just above the limits of detection (0.002 mg l^{-1}).

The pH of the effluent was 7.1 and the electrical conductivity 410 mS cm^{-1}. The total phosphorus concentration was recorded to be 1.5 mg l^{-1} with a soluble phosphate concentration of 0.52 mg l^{-1}. Total Kjeldahl nitrogen was 5.2 mg l^{-1}. The Sodium Adsorption Ratio (SAR) was calculated to be 0.67 (Appendix 3).

Microtox bioassay tests found no toxicity to the test bacterium, *Vibrio fisheri* present when the effluent pH was adjusted to the test pH of 8.5. Slight toxicity to the bacterium was detected in the non-adjusted pH sample (8.91). May/June 1999-2004 coliform tests for lagoon cell 3 have never exceeded 10 CFU 100 ml^{-1} for faecal coliforms and 50 CFU 100 ml^{-1} for total coliforms. Although a detailed analysis was not conducted in 2004 there is no reason to assume that the results would vary significantly.

Biomass Yields:

2003: Biomass yields ranged from 15.0 kg $25m^{-2}$ to 31.8 kg $25m^{-2}$, including undergrowth of residual thatch. The greatest productivity was associated with a one-time fertigation application (a mean value of 26.8 kg $25m^{-2} \pm 6.6$). The 10-10-10 application resulted in the lowest biomass yield (20.9 kg $25m^{-2} \pm 4.9$). Control plots produced the second highest yields (25.9 $25m^{-2} \pm 5.4$). However, there was no significant difference in the mean yields regardless of fertigation application (Figure 3a).

2004: Biomass yields ranged from 23 kg $25m^{-2}$ to 44 kg $25m^{-2}$. In 2004, there was no undergrowth of thatch as that had been collected in the 2003 harvest. The greatest productivity was associated with a one-time application (a mean value of 32.0 kg $25m^{-2} \pm 9.4$). Control plots produced the lowest yields (28.8 $25m^{-2} \pm 5.2$). However as in the 2003 study, there was no significant difference in the mean yields regardless of fertigation application (Figure 3b).

Soil Analysis:

The soil samples extracted on May 5, 2004 from the outer edge of the study plots (M on Figure3b) indicate that there is no significant difference in the physical and chemical parameters between pre-fertigation study plots designated as control, one-times fertigation and three-times fertigation (Table 1). Generally, total phosphorus (TP) and total Kjeldahl nitrogen (TKN) ion concentrations increase with depth. Potassium (K) ion concentrations decrease with depth.

The post fertigation soil samples collected November 4, 2004 (N on Figure 3b) from within study plots recorded parameter values similar to those measured in the pre-fertigation soil samples (Table 1). Generally, the Racham soil within the study control and three-times fertigation plots indicated a slight increase in total phosphorus, potassium ion concentration decrease with depth. Total Kjeldahl nitrogen arguably increases with depth. It is interesting to note that the slight increase in nutrient concentrations in the control plots post fertigation was actually greater than the nutrient increases in the three-times fertigation plots (Table 1; D1, B5, B9 vs. F1, F5).

Forage Analysis:

Table 2 summarizes the bulk forage analysis for total phosphorus (TP), total Kjeldahl nitrogen (TKN) and crude protein. Estimated nutrient values per kilogram biomass are relatively low, averaging 1.77 g kg^{-1} TP, 50.49 g kg^{-1} TKN and 30.7 % kg^{-1} of crude protein regardless of treatment. There was no significant difference in nutrient values among the treatments.

Table 1:

2004 RACKHAM FINE SANDY LOAM ANALYSIS

Date	Study Plot	Treatment	Sample Depth	pH	Conductivity (S cm^{-1})	TP (mg g^{-1})	K (ppm)	TKN (mg g^{-1})
05-May-04	D1	Control	1-5 cm	6.4	270	0.000	13	105
			5-10 cm	6.5	190	0.012	8	160
			10-15 cm	6.7	200	0.076	7	8
			25-20 cm	7.0	210	0.120	7	125
05-May-04	B9	Control	1-5 cm	5.6	420	0.000	15	175
			5-10 cm	6.2	180	0.000	7	175
			10-15 cm	6.5	110	0.024	9	159
			25-20 cm	6.7	90	0.080	7	
05-May-04	E3	1 X	1-5 cm	6.9	270	0.360	10	158
			5-10 cm	6.9	200	0.104	7	175
			10-15 cm	7.2	150	0.480	7	173
			25-20 cm					
05-May-04	D5	1X	1-5 cm	6.9	390	0.040	14	113
			5-10 cm	7.2	320	0.132	10	17
			10-15 cm	7.1	160	0.008	8	175
			25-20 cm	7.1	180	0.000	7	175
05-May-04	E7	3X	1-5 cm	6.0	370	0.020	12	175
			5-10 cm	5.8	180	0.040	8	141
			10-15 cm	6.0	190	0.000	10	12
			25-20 cm	6.3	140	0.000	5	5
04-Nov-04	D1	Control	1-5 cm	5.8	160	0.080	9	96
			5-10 cm	6.1	370	0.120	10	175
			10-15 cm	6.0	100	0.000	8	175
			25-20 cm					
04-Nov-04	B5	Control	1-5 cm	5.8	330	0.100	14	175
			5-10 cm	6.2	230	0.000	10	151
			10-15 cm	6.1	150	0.000	7	175
			25-20 cm					
04-Nov-04	B9	Control	1-5 cm	9.6	350	0.080	11	113
			5-10 cm	5.6	170	0.000	10	15
			10-15 cm	6.1	110	0.000	8	129
			25-20 cm					132
04-Nov-04	F1	3X	1-5 cm	6.7	300	0.000	10	105
			5-10 cm	6.4	260	0.000	10	175
			10-15 cm	6.9	200	0.080	7	175
			25-20 cm					
04-Nov-04	F5	3X	1-5 cm	7.1	280	0.200	13	148
			5-10 cm	6.8	350	0.000	25	175
			10-15 cm	6.5	190	0.000	5	88
			25-20 cm					

Table 2:

BULK FORAGE ANALYSIS

Date	Study Plot	Treatment	Bulk Weight (kg)	TP (g kg^{-1})	TKN (g kg^{-1})	Crude Protein (% kg^{-1})
5-Aug-04	3a	3X	35	3.30	68.9	43.1
5-Aug-04	3c	Control	30	2.40	51.2	31.9
5-Aug-04	3e	1X	22			
5-Aug-04	7a	1X	37	1.90	28.1	17.6
5-Aug-04	7c	Control	27	3.37	54.1	33.8
5-Aug-04	7e	3X	30	0.58	38.8	24.2
3-Sep-04	1b	1X	44	0.92	52.3	37.7
3-Sep-04	1d	Control	37	2.35	49.1	30.6
3-Sep-04	1f	3X	39	1.37	61.4	38.3
3-Sep-04	5b	Control	23	1.05	40.0	25.0
3-Sep-04	5d	1X	23	1.13	57.0	35.6
3-Sep-04	5f	3X	22	1.62	34.0	21.3
3-Sep-04	9b	Control	27	2.10	51.9	32.4
3-Sep-04	9d	1X	34	1.93	64.6	40.4
3-Sep-04	9f	3X	33	1.50	55.7	34.8

NUTRIENT SUMMARY

Nutrient	TP (g kg^{-1})	TKN (g kg^{-1})	Crude Protein (% kg^{-1})
Control Mean	2.25	49.27	30.7
Standard Deviation	0.83	5.48	3.4
1X Mean	1.47	50.47	32.8
Standard Deviation	0.52	15.76	10.3
3X Mean	1.6	51.74	32.3
Standard Deviation	0.9	14.88	9.3
All Sample Mean	1.77	50.49	31.9
Standard Deviation	0.75	12.04	7.7

Table 3 summarizes the NIRS analysis of the 2004 Harvest biomass as livestock feed including fiber, protein and mineral content. Upon completion of the NIRS analysis samples are assigned a relative feed index value that ranges from Prime, 1 to 5. The one-time fertigation received a grade of 2; three-times fertigation and control plots were graded as 3.

Table 3:

2004 FORAGE ANALYSIS BY NIRS

Replicate Samples	1X	3X	Control
Moisture	7.60%	7.60%	7.50%
Dry Matter	92.40%	92.40%	92.50%
Crude Protein	9.80%	8.90%	8.40%
Acid Detergent Fibre	32.40%	33.50%	33.30%
Neutral Detergent Fibre	49.00%	52.10%	51.10%
Available Protein	9.70%	8.60%	8.00%
Digestible Protein	6.60%	6.00%	5.70%
Heat Damaged Protein	1.10%	1.10%	1.10%
Non Structural Carbohydrates	23.60%	21.40%	22.90%
TDN	56.90%	56.10%	56.30%
DE	2.51 Mcal kg^{-1}	2.47 Mcal kg^{-1}	2.48 Mcal kg^{-1}
NE/GAIN	0.63 Mcal kg^{-1}	0.59 Mcal kg^{-1}	0.60 Mcal kg^{-1}
NE/LACT	1.29 Mcal kg^{-1}	1.27 Mcal kg^{-1}	1.27 Mcal kg^{-1}
NE/MAINT	1.28 Mcal kg^{-1}	0.24 Mcal kg^{-1}	1.25 Mcal kg^{-1}
Ca	0.90%	0.77%	0.81%
P	0.16%	0.16%	0.15%
K	1.13%	1.09%	0.89%
Mg	0.22%	0.20%	0.22%
Relative Feed Value (RFV)	**108**	**100**	**102**
Hay Grade	**2**	**3**	**3**
(Stokes and Prosko, 1998)			

HAY GRADES (RFV)

Prime	>150
1	125 - 150
2	103 - 124
3	87 - 102
4	75 - 86
5	< 75

Discussion

Water quality characterization is the first step in the evaluation of the biological and chemical safety of using reclaimed wastewater for forage irrigation. The inorganic chemical analysis of the 2003 and 2004 effluent indicated no problems with heavy metals or other elements identified as an irrigation, surface or drinking water concern in Manitoba. In this respect it is of interest to note that irrigation of pastures by treated and untreated sewage near Melbourne, Australia for more than a century was reported to have increased heavy metal concentrations in the soil, but did not increase their concentrations in the herbage or in the animal tissues of animals grazed on these pastures (van de Graaf *et al*. 2002). There are no trace organics present at levels above the detection limit; consequently, there will be no problems for use of the forage by herbivores. Phenols are also present in the effluent at extremely low levels and are not a concern from a pollution perspective. The wastewater, however, contains the macronutrients, nitrogen, phosphorus and potassium, the intermediate nutrients calcium, magnesium and sulphur and the micronutrients, boron, copper, iron, manganese and molybdenum.

Salts in soil and/or water can reduce water availability to the crop to such an extent that yield can be affected and as such salinity can be a serious problem for long-term sustainability of a wastewater irrigation projects. A measure of salt content in water is its electrical conductivity (EC) and for irrigation purposes a value of greater than 1000 mS cm^{-1} can affect the growth and yield of the most sensitive species (Manitoba Agriculture 1999). Electrical conductivity values measured in the 2003 and 2004 effluent from lagoon cell 3 (410 mS cm^{-1}) suggest that salinity buildup will not be a problem and no restrictions are required. Some dissolved salts, however, are worse than others and the concentrations of certain elements in relationship to each other are important. For example, the relative proportion of sodium cations to other cations can give rise to soil permeability problems. Specific ion toxicities may arise with sodium levels exceed 70 mg l^{-1} and chloride levels are greater than 100 mg l^{-1} (Halliwell *et al*. 2001). Sodium Adsorption Ratio values below 4 are considered safe (Peterson, 1999) and the irrigation wastewater is significantly below this standard (0.67; Appendix 3) and therefore suitable for crop irrigation.

In order to transmit infectious disease the infectious agent must be present and in numbers adequate for the infection of an exposed and susceptible individual. Domestic sewage can be contaminated with any microbial agent that can enter the sewer. The number and types of pathogens present in untreated wastewater is a function of the infectious disease prevalence in the community from which the waste is derived. A series of stabilization ponds like those at Wasagaming are suggested by the World Health Organization to be the most effective means to reduce helminthes ova to one or less per liter and a faecal coliform number of 1,000 MPN per 100 ml (WHO, 1989). The levels of faecal and total coliforms are consistently below the provincial and US EPA guidelines for the irrigation of forage crops.

Concerns about impacts of municipal wastewater on the normal soil microflora in Jordan were assessed by Malkawi and Mohammad (2003).

The bacteriological analysis of all the soils at the end of the growing season found no difference in total aerobic bacteria counts suggesting that the use of wastewater did not stimulate or inhibit these microflora.

The soil in the lagoon and irrigation area is the Rackham Fine Sandy Loam and the excavated soil pit confirmed the typical profile. This soil is considered to be of moderately high natural fertility. The available nitrogen, phosphorus and potassium is medium to low, but the soils are friable and have good moisture retention capacity. Grass and legume crops will produce well on these soils, especially if the deficiencies in natural fertility are offset by nutrient application (Ehrlich *et al*. 1956). The soil, however, is not suited to arable agriculture and it is recommended that the Rackham Fine Sandy loam be used for hay and controlled grazing, forestry, and the preservation of wildlife. No indication of groundwater presence was found at 2 m from the surface.

The 2003 Trials:

The irrigation trials in 2003 indicated best forage production on the wastewater plots but the variability was high and the differences between the controls and wastewater treatments were not statistically significant (Figure 3a). The fertilizer treatments resulted in lower than average yields. Unfortunately the very dry growing season may have influenced the results obtained on all plots. It should also be noted that the harvested yields included significant thatch from previous years growth. Indeed, calculations made from the biomass yields to assess production per hectare indicate values several fold greater than the average tame hay yields reported by Manitoba Agriculture over the past 20 years (Manitoba Agriculture and Food 2002). No significant inhibitory effects of the wastewater on forage growth were found.

The total nutrients added to Ominnik marsh from the lagoon cell 3 discharge in the 2003 season was 153 kg of nitrogen and 38 kg of phosphorus. This quantity of nutrients if used to fertilize the 19.8 hectare parcel of hayland would provide approximately 7.5 kg of nitrogen and approximately 2 kg of phosphorus per hectare. If the 13.8 hectare parcel was used then the fertilization provided by the wastewater would be approximately 11 kg of nitrogen and approximately 2.7 kg of phosphorus. Both of these scenarios represent very low fertilization rates.

The 2004 Trials:

The 2004 fertigation trials examined the potential buildup of salts and nutrients in the Rackham Sandy Loam, forage quality and biomass harvest as a response to fertigation volume; specifically control plots, a one-time fertigation volume (1X) and a three-times fertigation volume (3X).

Pre and post fertigation soil analyses of the 1X and 3X effluent treatments were comparable with the controls, regardless of depth of samples taken and demonstrate that the long-term viability of the soil will not be affected by fertigation. Nitrates are of concern because of downward mobility in the soil and the potential impacts on groundwater, however in this study, recorded NO_2 – N concentrations were below the detection limits of the instruments. Total Kjeldahl nitrogen, a measure of total organic and inorganic nitrogen, was insignificant in terms of comparison between control plots and the 1X and 3X effluent treatment plots. Soil samples taken early and late in the growing season to indicate insignificant short and long-term effects on the Rackham Fine Sandy loam following fertigation.

The 2003 trials demonstrated that the lagoon cell #3 polished effluent was safe to use for fertigating hayland, but for quality assurance, an analysis of the nutrients in the forage was required. This study assayed various nutrient concentrations in the control and treatment vegetation: total phosphorus, total Kjeldahl nitrogen, and crude protein.

A comparison of forage from control, 1X effluent and 3X effluent treatments revealed that these nutrient concentrations were not present at levels which are cause for concern, nor are there significant differences between the treatments and control (Table 4).

Two harvest dates were established for the purposes of examining the potential of short-term nutrient accumulation in forage following fertigation. The forage analysis from mid-season and late-season harvest did not demonstrate cause for concern in terms of nutrient levels. An interesting observation following the mid-season harvest was that growth seemed to be encouraged as there was a healthy population of clover, which was established shortly after harvest. The potential to achieve two abundant crops of hay could be possible in a fertigation program, depending on how early in the season the first crop could be harvested.

The variation in crude protein content of the forage from control and treatment was insignificant (Tables 2 and 3). The percent crude protein ranged from 8.4% to 10.6%, with the highest content found in the 1X treatment forage. This is comparable with the percentage of protein typically found in prairie hay, which is 5% (Porteous 1979). The relative feed value, obtained from the NIRS analysis, was used to grade the forage from the control, 1X and 3X effluent treatments, grade 3, grade 2, and grade 3 respectively (Stokes and Protsko 1998)

The volume of forage produced was comparable between the treatment and control plots, however the 1X treatment plots produced the highest average yield. The economic value of a production system such as this can be established by examining the overall yield. The biomass from the study can be compared with 2002 statistics from Manitoba Agriculture regarding average hay production (Manitoba Agriculture and Food 2003). From 1962-2002, tame hay production values were 3,899.3 kg ha^{-1}, whereas the 2004 trials produced an average of 2,677.51 kg ha^{-1}. The value of hay is approximately 6.6 cents kg^{-1}, which would mean the total biomass, would be worth $180.00 ha^{-1}. The entire area available for hay fertigation would therefore return about $4,300 per year in forage production.

Conclusions

A preliminary assessment of the feasibility of using polished effluent from the Wasagaming sewage lagoon system was carried out in 2003. Data gathered on effluent chemistry and toxicology support the reuse of this wastewater in an ecologically sustainable manner.

In the second year (2004):

a. The biomass harvests of a 3-fold increase in the volume of wastewater per unit area were compared to the 1-fold wastewater fertigation per unit area (the 2003 application rate) and zero fertigation (controls).
b. Pre and post fertigation soil sample were used to assess the cumulative and or negative impacts on soil chemistry, fertility and other physical properties and the potential for nitrite contamination of groundwater was examined.
c. Forage biomass was assessed for toxicology, nutritional quality and commercial value in each replicated treatment both in an early and late harvest.

The 3-fold application of wastewater effluent resulted in no significant increase in yield or quality. Soil chemistry and fertility showed no significant differences between fertigated plots and the control plots. There was no indication of nitrite or phosphorus buildup or leaching. Forage yields were consistent in biomass and nutritional quality. There were no significant differences between fertigated yields and the control yields.

The results of this study provide additional support for the use of lagoon wastewater for fertigating hayland in a sustainable irrigation program for the Town of Wasagaming, Riding Mountain National Park.

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References Cited

AGRICULTURE CANADA 2001 'Lethbridge Research Station 1976-1986: The eighth decade' Historical Series: Soil fertility 2

AHO, S. 1997 'A study of the hydrological properties of the soil associations of the Octopus Creek Watershed at Riding Mountain Manitoba' *Undergraduate Thesis in Geography* (Brandon: Department of Geography, Brandon University)

ASANO, T. 1998 'Wastewater reclamation and reuse' *Water Quality Management Library* 10 (Lanacaster-Basel:Technomic Publishing Co. Inc.)

BELKE, S.E. and MCGINN, R.A. 2003 'Monitoring anthropogenic nutrients in a modified natural wetland, Ominnik Marsh, Riding Mountain National Park, Manitoba' *Prairie Perspectives: Geographical Essays* 6: 16-33.

BODDY, S. 2003 'Engineered Wetland Brings Back Wildlife' *Peace and Environment News* April available online: <*http://perc.ca/PEN/2003-04/s-boddy.html*>

BIEDERBECK, V.O. and BOLE, J.B. 1979a 'Dispersal of sewage microorganisms during spray irrigation and response of soil microflora to effluent application' In: *Effluent Irrigation Under Prairie Condition* A Technology Transfer Conference Regina, Saskatchewan

BOLE, J.B. and BIEBERBEC, V.O. 1979b 'Soil and plant response to wastewater irrigation: Nutrient uptake and plant productivity In: *Effluent Irrigation Under Prairie Condition* A Technology Transfer Conference Regina, Saskatchewan

CAMERON, D.R. 1996 'Sustainable effluent irrigation phase I: Literature review international perspective and standards' Technical Report *Irrigation Sustainability Committee*, *Canada-Saskatchewan Agriculture Green Plan Agreement*

CAMERON, D.R. 1997 'Sustainable effluent irrigation phase II: Review of monitoring data Moose Jaw" Technical Report *Irrigation Sustainability Committee, Canada-Saskatchewan Agricultural Green Plan Agreement*

CAMERON, D.R. and CROSSON, L. 1994 'Impacts of effluent irrigation and intensive livestock operations on surface and groundwater quality: Information sources and research needs' Technical Report *Water Quality Technical Committee, Canada- Saskatchewan Agricultural Green Plan* Agreement

CLIFTON ASSOCIATES LTD. 1993 'Evaluation of the effects of sewage effluent irrigation' Technical Report *Effluent Irrigation Project, Swift Current, Saskatchewan*

DE JONG, E. 1976 'The use of sewage effluent for irrigation: Growth chamber studies and modeling' *SIP Publication* R175 (Saskatoon: University of Saskatchewan)

EHRLICH, W.A. , PRATT, L.E. and POYSER, E.A. 1956 'Report of reconnaissance soil survey of Rosburn and Virden map sheet areas' Manitoba Soil Survey *Soils Report 6* (Winnipeg: University of Manitoba)

HALLIWELL, D.J., BARLOW, K.M. and NASH, D.M. 2001 'A review of the effects of wastewater sodium on soil physical properties and their implications for irrigation systems' *Australian Journal of Soil Research* 39:6 1259-1267

HOGG, T.J., WEITERMAN, G. and TOLLEFSON, L.C. 2003 'Effluent irrigation: Saskatchewan perspective' PFRA available online. <*http://www.agr.gc.ca/pfra/csidc/csidpub5_e.htm*>

JAME, Y.W., BIEDERBECK, V.O., NICHOLAICHUK, W. and KORVAN, H.C. 1984 'Salinity and alfalfa yield under effluent irrigation in southwestern Saskatchewan' *Canadian Journal of Soil Science* 64: 323-332

KUBO, T. and SUGIKI, A. 1977 'Wastewater reuse in Japan' In: *Water Renovation and Reuse* Shuval, H.I. Ed (New York: Academic Press)

MAGESAN, G.N. and WANG, H.L. 2003 'Application of municipal and industrial residuals in New Zealand forests: An overview' *Australian Journal of Soil Research* 41:3 557-569

MALKAWI. H.I. and MOHAMMAD, M.J. 2003 'Survival and accumulation of microorganisms in soils irrigated with secondary treated wastewater' *Journal of Basic Microbiology* 43:1 47-55.

MANITOBA AGRICULTURE 1999 'Soil Fertility Guide. Soil pH and Salinity' available online: <*http://www.gov.mb.ca/agriculture/soilwater/soilfert/fbd02s14.html*>

MANITOBA AGRICULTURE and FOOD 2002 'Table 99 historical production and value of tame hay' *Manitoba Agriculture Yearbook* 129

MENELEY, W.A. 1975 'Moose Jaw effluent irrigation study' *Geology Division SRC*

OLIVER, H., LOTTER A.F. and LEMCKE, G. 2000 'Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results' *Journal of Paleolimnology* 25: 101-110 available online: <*http://hjs.geol.uib.no/hovedlab/analysis_gloedetap_eng.html*>

PAGE, A.L. and CHANG, A.C. 1984 'Fate of wastewater constituents in soil and groundwater: Trace elements' In: *Irrigation with reclaimed municipal wastewater: A guidance manual* Pettygrove, G.S. and Asano, T. Ed (Sacramento: California State Water Resources Control Board) Report No. 84-1wr Chapter 13: 1-16

PETERSON, H.G. 1999 'Water Quality Fact Sheet: Irrigation and Salinity' *Agriculture and Agri-Food Canada and PFRA* available online: <*http://www.agr.gc.ca/pfra/water/irrsalin_e.htm*>

PORTEOUS, 1979

SHELEF, G. 1990 'The role of wastewater reuse in water resources management in Israel' *Water Science Technology* 23: 2081-2089

SHUVAL, H.I., ADIN, A., FATTAL, B., RAWITZ, E. and YEKUTIEL, P. 1986 'Wastewater irrigation in developing countries. Health effects and technical solutions' *World Bank Technical Paper* 51

STANTEC CONSULTING LTD. 2003 'Riding Mountain National Park water and sewer study' *Public Works and Government Services Canada* Real Property Services for Parks Canada

SMITH, W.B. 1997 'Re: Soliciting ideas for pasture irrigation' *Clemson Cooperative Extension Service* available online: <*http://www.wiz.uni-kassel.de/kww/irrig_l/db/1997/01/msg00014.html*>

STOKES, SR. and PROTSKO, E.P. 1998 'Understanding forage quality analysis' *Texas Agricultural Extension Service Publication* L5198 (Texas A & M University System)

STRAUSS, M. and BLUMENTHAL, U.J. 1990 'Human waste use in agriculture and aquaculture: Utilization practices and health perspectives' *IRCWD Report* 09/90: (Deubendorf: International Reference Centre for Waste Disposal)

THORNTON, J.R. and SMITH, R.B. 1987 'Establishing a reclaimed water irrigation monitoring program' *Wastewater* 10: 535-542

U.S. ENVIRONMENTAL PROTECTION AGENCY 1981 'Process design manual: Land treatment of municipal wastewater' *EPA* 625/1-81-013 (Cincinnati: U.S. EPA Centre for Environmental Research Information)

VAN DE GRAAF, R.H.M., SUTER, H.C. and LAWES, S.J. 2002 'Long-term effects of municipal sewage on soils and pastures' *Journal of Environmental Science and Health Part A - Toxic/Hazardous Substances & Environmental Engineering* 37:4 745-757

VELEZ, O.R, FASCIOLA, G.E. and BERTRANOU, A.V. 2002 'Domestic wastewater treatment in waste stabilization ponds for irrigation in Mendoza, Argentina: Policies and challenges' *Water Science and Technology* 45:1 127-132

WILLIAMSON, D. A. 2001 'Manitoba water quality standards, objectives and guidelines' *Technical Draft Manitoba Conservation Report 2001-01* (Winnipeg: Manitoba Environment)

WORLD HEALTH ORGANIZATION 1989 'Health guidelines for the use of wastewater in agriculture and aquaculture' *WHO Technical Report Series* (Geneva: WHO Scientific Group)

Appendix 1

Effluent Analysis (Enviro.Test Laboratories)

Inorganics	Concentration	Manitoba Water Quality Guideline (Williamson, 2001)
Aluminum	0.42 mg l^{-1}	5.0 mg l^{-1}
Antimony	0.001 mg l^{-1}	none
Arsenic	0.0029 mg l^{-1}	0.1 mg l^{-1}
Barium	0.0466 mg l^{-1}	none
Beryllium	< 0.001 mg l^{-1}	0.1 mg l^{-1}
Bismuth	< 0.0001 mg l^{-1}	none
Boron	0.14 mg l^{-1}	0.5 - 0.6 mg l^{-1}
Cadmium	< 0.0002 mg l^{-1}	0.0051 mg l^{-1}
Calcium	44.8 mg l^{-1}	none
Cesium	< 0.0001 mg l^{-1}	none
Chromium	0.002 mg l^{-1}	none
Cobalt	0.0004 mg l^{-1}	0.05 mg l^{-1}
Copper	0.001 mg l^{-1}	0.2 – 1.0 mg l^{-1}
Iron	0.25 mg l^{-1}	5.0 mg l^{-1}
Lead	0.0007 mg l^{-1}	0.2 mg l^{-1}
Lithium	0.03 mg l^{-1}	2.5 mg l^{-1}
Magnesium	35.9 mg l^{-1}	none
Manganese	0.0239 mg l^{-1}	0.2 mg l^{-1}
Mercury	< 0.0003 mg l^{-1}	none
Molybdenum	0.0022 mg l^{-1}	0.01 - 0.05 mg l^{-1}
Nickel	< 0.002 mg l^{-1}	0.2 mg l^{-}
Phosphorus	1.15 mg l^{-1}	0.05 mg l^{-1}
Potassium	10.4 mg l^{-1}	none
Rubidium	0.0062 mg l^{-1}	none
Selenium	0.002 mg l^{-1}	0.02 - 0.05 mg l^{-1}
Silver	< 0.001 mg l^{-1}	none
Sodium	25 mg l^{-1}	none
Strontium	0.168 mg l^{-1}	none
Tellurium	< 0.001 mg l^{-1}	none
Thallium	< 0.001 mg l^{-1}	none
Tin	< 0.0005 mg l^{-1}	none
Titanium	0.0073 mg l^{-1}	none
Zinc	< 0.01 mg l^{-1}	1.0 - 5.0 mg l^{-1}
Uranium	0.0023 mg l^{-1}	0.01 mg l^{-1}
Vanadium	0.002 mg l^{-1}	0.1mg l^{-1}

Appendix 2

Trace Organics (Enviro.Test Laboratories)

All of the following potential pollutants were below the level of detection:

1-Methyl Naphthalene	2-Methyl Naphthalene
Acenaphene	Acenaphthylene
Anthracene	Benzene
Benzo (a) Anthracene	Benzo (a) Pyrene
Benzo (b) Fluoranthene	Benzo (g h i) Perylene
Benzo (k) Fluoranthene	Chrysene
Dibenzo (a h) Anthracene	Ethyl Benzene
Extractable Hydrocarbons (<100 μg l^{-1})	Fluoranthene
Fluorene	Indeno (1 2 3 cd) Pyrene
Naphthalene	Pentochlorophenol
Phenanthrene	Pyrene
Toluene	Volatile Hydrocarbons
Xylene (meta and para)	Xylene (ortho)
Xylene total.	

Appendix 3

Sodium Adsorption Ratio

The concentrations of calcium (Ca), magnesium (Mg), and Sodium (Na) were used to calculate the sodium adsorption ratio. Sodium Adsorption Ratio (SAR) describes the amount of excess sodium in relationship to calcium and magnesium.

$$SAR = \frac{0.043\ (Na)}{[0.025\ (Ca) + 0.04\ (Mg)]^{1/2}}$$

where the concentrations are in mg l^{-1}

$$SAR = \frac{0.043\ (25)}{[0.025\ (44.8) + 0.04\ (35.9)]^{1/2}}$$

$$SAR = \frac{1.075}{(2.556)^{1/2}} = 0.67$$

Appendix 4

Soil Analysis

Organic carbon content (LOI methodology, Oliver *et al*. 2000)

A1	6.6% (0.0 - 3.0 cm from surface)
A2	6.3% (4.0 - 7.0 cm from surface)
A3	5.7% (8.0 - 11.0 cm from surface)
A4	4.9% (12.0 - 15.0 cm from surface)

Mean 5.9% ± 0.8%

Appendix 5

Aquatic Plant Analysis (Coon's Tail) – September 9, 2003

Total Kjeldahl Nitrogen	875 mg N g^{-1} dry weight
Total Phosphorus	23 mg P g^{-1} dry weight