CONSTRUCTED WETLANDS FOR FEEDLOT RUNOFF TREATMENT IN MANITOBA

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ABSTRACT

Two treatment wetlands were designed and then constructed in the Interlake area of Manitoba to demonstrate and monitor alternative waste treatment technology for the livestock industry. The treatment systems consist of a runoff collection system, storage pond(s), and wetland treatment cell(s) vegetated with cattails and other emergent wetland species. Flow is pumped to the wetland on a seasonal basis beginning in late spring as water temperature within the holding pond(s) began to rise to late fall prior to freeze up. In this paper the design and construction process is reviewed and performance results from the first years of operation is presented.

INTRODUCTION

The Problem

Feedlot runoff and livestock wastes contain the major plant nutrients of phosphorus and nitrogen as well as high concentrations of organic material and bacteria, which contribute to water quality degradation in receiving streams and lakes. In prairie waters that are already nutrient rich, additional nutrient loading can greatly accelerate the process of eutrophication and the proliferation of aquatic plants and algae. This can impair recreational and biological values, as well as degrade water quality for domestic or livestock consumption.

Regulation

The Canadian livestock farming community is generally not required to meet the strict surface water discharge regulations imposed on municipalities and industries. However, this is rapidly changing with the advent of recent tragedies, in particular Walkerton, Ontario, and the public's growing awareness of the contribution from the farming community to receiving water eutrophication that results in algal blooms and fish kills. As farming operations continue to generate high levels of nutrients and bacteria that originate from manure storage and application areas, manure storage tank overflows, feedlot runoff, milkhouse washwater discharges, and aquaculture pond discharges, there is an ever increasing need to intercept and reduce these contaminant loads. Agricultural wastewater streams are increasingly being viewed by regulators and the general public as sources of pollution that are contaminating aquatic habitat, drinking water, and recreational waters and are demanding governments impose controls in the near future.

Currently in Manitoba, agricultural treatment wetlands do not require permitting although if there is federal funding or permitting required then they are subject to a federal environmental screening process. Manitoba livestock regulations do, however, prohibit release of manure to surface or groundwater.

Best Management Practices

The agricultural community, in particular the livestock industry, is intent on returning the valuable nutrients that manure holds back to the land as part of the sustainable philosophy that farming has always had. However, with the increasing size of many livestock operations, reuse through land application can become cost prohibitive due to transportation costs and the large storage requirements during the winter months. Best management practices can be implemented to reduce the wastewater volume and concentration to the lowest possible economic and practical level. Covered manure storage areas, high pressure/low volume hoses and nozzles for washing stalls, using dry rather than wet solid waste management, routing adjacent stormwater flows around manure storage areas, and water recycling where practical are examples of methods that help reduce the discharge of contaminants. Methods of interception of nutrient bearing solids include vegetated filter strips, holding ponds, and restored riparian zones.

Once the best management practices are in place, any flow that might enter surface water or groundwater (for example, direct discharge to a water course, stormwater runoff carrying ponded wastewater or waste material spread on open fields) must be treated to reduce the potential of receiving water contamination.

Wetlands – A Treatment Option

As effluent discharge limitations become more restrictive, innovative technologies may offer new, affordable methods of meeting compliance requirements. Constructed treatment wetlands provide one approach to meet these challenges. Treatment wetlands reduce many typical contaminants in agricultural, industrial, and municipal effluents, such as 5-day biochemical oxygen demand (BOD_5), suspended solids, nutrients, and metals. Constructed wetlands rely on the naturally occurring energies of the sun and wind to aid plant growth and provide oxygen for the aerobic processes carried out by microbial populations. Compared with many conventional technologies that rely on inputs of concentrated fossil fuels, the naturally occurring energies in treatment wetlands are diffused over larger land areas.

Wetland treatment can be implemented with ease on farms in cold climates. These low-technology, solar-driven systems are passive and user-friendly. Farmers do not need to acquire the skills of wastewater treatment plant operators since the operation of a wetland system ties in to current farming practices. Just like any crop the farmer may plant, the wetland system requires sunlight, nutrients, and water but does not need to be harvested. The treatment wetland plants can tolerate relatively high concentrations of nutrients and must be established in an environment where the soil will be saturated with water for most of or preferably, all of the time.

Setting the Stage

As the agricultural industry in Canada continues investigating the use of constructed treatment wetlands to manage livestock operations effluent and runoff water quality many provincial and federal agriculture departments are holding workshops and training sessions to provide their staff with an understanding of wetland treatment capabilities and design principles and are piloting wetland treatment alternatives. Since about 1990, more than 20 full-scale and pilot-scale constructed wetland treatment systems have been installed across Canada for the treatment of high strength agricultural runoff.

Realizing the potential for wetland applications in Manitoba, PFRA conducted a limited survey in the province to determine which farmers had interest in this technology and willingness to form partnerships for designing and building a full scale demonstration project. Several site tours were conducted to see how others had used the technology and what they had learned. PFRA organized a wetland workshop at the Ducks Unlimited Oak Hammock (Manitoba) facility in June of 1996 and invited CH2M HILL Canada Limited, among others, to present papers on treatment wetlands. Based on the level of interest and the advanced state of the treatment technology, PFRA and Manitoba Agriculture invested in developing two full scale demonstration projects to treat feedlot runoff.

PROJECT OBJECTIVES

Demonstration of the treatment wetland technology was the prime objective in constructing two full scale wetland systems in Manitoba. Evaluation of treatment performance was also important so as to provide local data on the technology to producers and regulators. Comparison of the wetland system to other treatment and disposal methods was also incorporated into the project in part to determine if cost was a likely constraint to use of the technology.

The project was developed to meet several objectives. They included:

- Develop two constructed wetland systems to treat feedlot runoff in Manitoba
- Evaluate the treatment performance through an intensive monitoring program

- Compare the cost and practicality of design, construction, and operation with other options
- Assess potential for adoption of treatment wetland technology in Agro-Manitoba

THE PROJECTS

In 1996 a Green Plan project was initiated to demonstrate constructed wetlands and evaluate the potential for use on Manitoba livestock farms. Wetland projects were constructed at two cattle feedlot operations in the Interlake Region of Manitoba. Both projects were designed to capture the feedlot runoff, store it in a holding pond and then treat the wastewater in constructed wetland cells. The wetlands operate for approximately 150 days each year from mid-May through mid-October and are set at an operating water depth of approximately 30 cm. The systems operate on a continuous flow basis during the growing season. In dry years there may be no outlet discharge due to water removal through high rates of evapotranspiration.

Actual operation is quite simple involving the setting of an automatic pump timer and flow control valves, and adjusting the height of stoplogs at the outlet. A submersible pump is installed in the wetwell each spring and removed in the fall. Periodic monitoring ensures pump operation and wetland water levels and controls.

The maintenance requirement for the system is minimal, as annual harvest of cattail is not required. It is estimated that the wetland cells may require clean-out of collected organic debris only after approximately 15 years or more. This will be based on reduction in wetland volume over time.

Site 1 – Near Riverton

The first site developed with a treatment wetland system is a 3ha 800 head feedlot operation that is located approximately one mile from Lake Winnipeg. Drains were constructed around the feedlot and empty into a settling pond. From here, accumulated water flows through the remainder of the treatment system during the late spring, summer, and early fall periods. The treatment wetland was commissioned in 1998. Each process component is described below.

Settling Pond

The 0.2 ha settling pond with a working volume of approximately 1,500 m^3 is where suspended solids and other debris settle out of the collected feedlot runoff providing primary removal of contaminants bound up with the solids. This pond will remain full during normal operation to maximize the treatment capability offered by the long hydraulic retention time. The overflow from the settling pond discharges to the holding pond. During periods of low precipitation when the holding pond can no longer supply water to the wetland and the wetland vegetation is in danger of being stressed, water from the settling pond can be pumped to the wetland cell.

Holding Pond

The 0.4 ha holding pond has a working volume of approximately 3,200 m^3. It can store seven months of accumulated precipitation from the drainage area during an average rainfall year. The average hydraulic retention time (HRT) in the pond is approximately two months during the operating season. The long HRT provides additional time for solids settling and for anaerobic reduction of BOD_5. The collected water is transferred to the treatment wetland by a pump since the topography does not allow for gravity flow. When pumping from the holding pond to the treatment wetland, a floating intake reduces the potential for drawing up accumulated settled solids from the bottom of the holding pond.

An emergency overflow is provided at the inflow end of the holding pond to prevent overtopping of the embankments in the event of high levels during high volume runoff that cannot be contained in the holding pond.

Treatment Wetland

The water is then pumped to a weir box where the flow is measured and discharged to the wetland. The wetland is a single cell 0.5 ha system with an average depth of 0.3 m and a working volume of 1,500 m^3. A gate valve controls flow to the wetland cell. The flow enters the wetland in the centre of the influent distribution deep zone where the flow is distributed across the width of the cell. After passing through the wetland, the flow is discharged at the effluent control structure where stop logs control the water surface elevation of the cell.

Site 1: Wetland Performance

The overall performance of the wetland at Site 1 has met expectations with significant reduction in organic strength and lesser reductions in phosphorus. The data that has been collected to date shows much lower wetland inflow concentrations than what was predicted using water quality data from other feedlot operations. It is apparent that the holding pond is providing considerable treatment of the stormwater prior to the wetland. This is in keeping with the focus on using the wetland for polishing rather than primary treatment. Table 1 presents the average annual data from monthly samples collected during each growing season of operation. Figures 1 to 8 provide graphical monitoring data for the three years of operation.

TABLE 1: SITE 1 – AVERAGE ANNUAL WETLAND INFLOW AND OUTFLOW DATA

Parameter	Average Value 1998		Average Value 1999		Average Value 2000	
	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
BOD_5 (mg/L)	11	4	6	9	17	4
NH_3-N (mg/L)	7.1	0.2	0.1	0.1	6.5	0.1
TKN (mg/L)	16	6	13	7	17	9
TP (mg/L)	1.7	1.6	1.2	1.2	2.9	2.5

TABLE 1:	SITE 1 – AVERAGE ANNUAL WETLAND INFLOW AND OUTFLOW DATA					
Parameter	**Average Value 1998**		**Average Value 1999**		**Average Value 2000**	
	Inflow	**Outflow**	**Inflow**	**Outflow**	**Inflow**	**Outflow**
TSS (mg/L)	52	12	43	17	28	10
PH	7.6	7.5	7.7	7.7	7.7	7.6
Conductivity (µs/cm)	1380	1430	2055	2590	2005	1662
COD (mg/L)	303	188	247	280	303	222
Fecal Coliform (col/100ml)	1508	182	534	31	276	87
Total Coliform (col/100 ml)	7242	1533	2150	4161	10426	556
D.O. (mg/L)	1.8	2.63	2.37	3.66	0.43	1.78

Figure 1
Dissolved Oxygen - Site 1

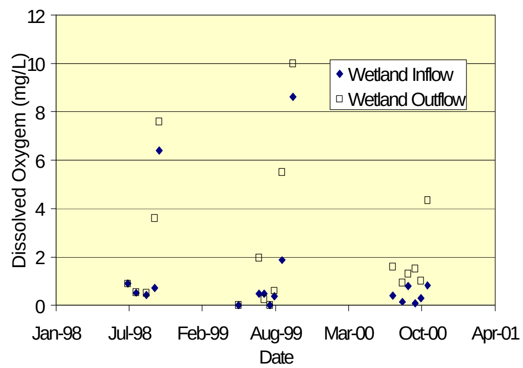


Figure 2
Conductivity - Site 1

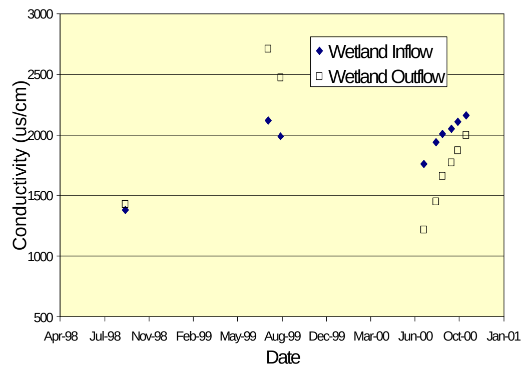


Figure 3
Total Phosphorus - Site 1

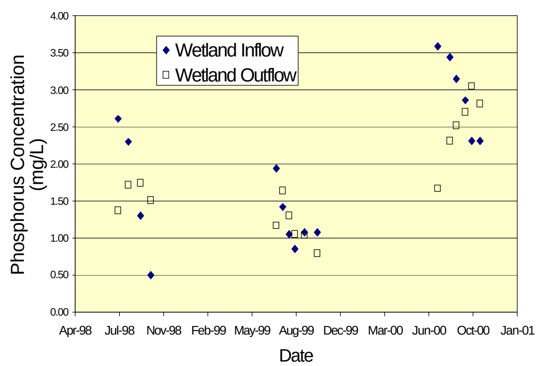


Figure 4
Total Suspended Solids - Site 1

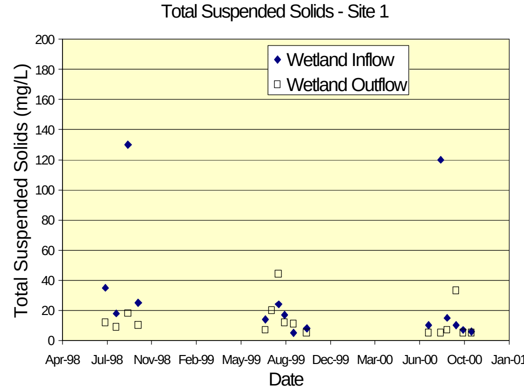


Figure 5
BOD_5 Concentration Reduction - Site 1

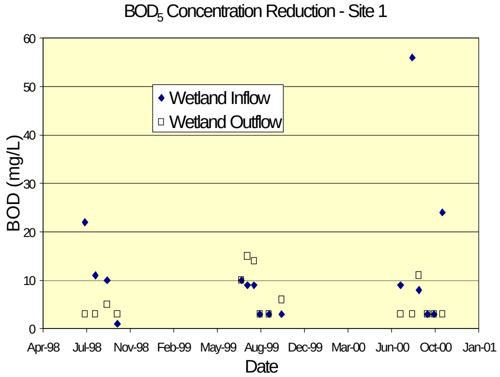
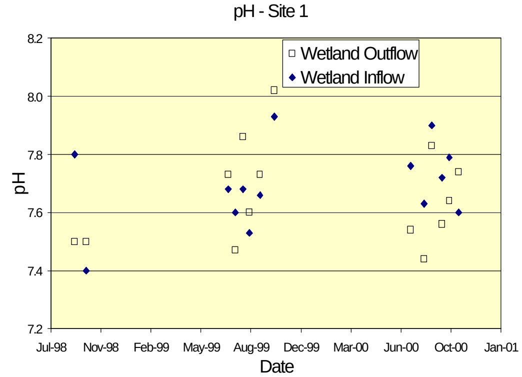
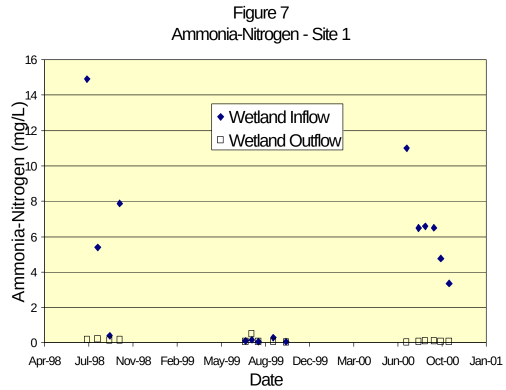
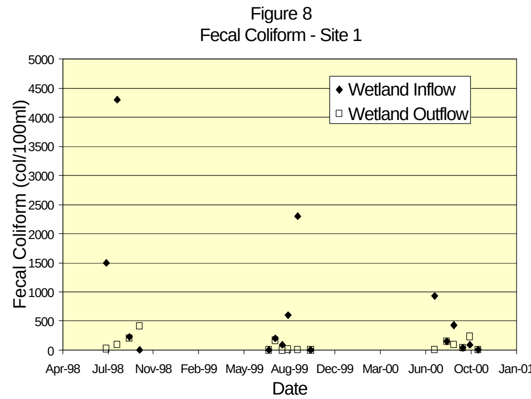


Figure 6
pH - Site 1







There was little water flow through the system in 1998 and 1999 since these were very dry years and there was little runoff from the feedlot. Some of the data, such as the wetland inflow ammonia concentration, reflect a very long hydraulic retention time within the holding pond, especially in 1999, resulting in almost complete nitrification. Comments on selected parameters are presented below.

- Despite wide variations in the wetland inflow ammonia concentrations, especially during 1998 and 2000, with inflow concentrations varying from less than 1 mg/L to 15 mg/L, the effluent ammonia-nitrogen was consistently less than 0.5 mg/L. This produced an effluent that met the Canadian Water Quality Guidelines for unionized ammonia concentration and was, therefore, safe for aquatic life.
- The wetland effluent BOD_5 was 15 mg/L or less throughout the three years that the system has been operating, bettering many wastewater treatment effluent guidelines. The higher outflow BOD_5 concentration versus the lower inflow concentration in 1999 reflects a dry year with little outflow from the wetland and may be related to the C*, or background wetland concentration, below which it is difficult to attain due to the presence of plant debris and the abundance of aquatic organisms that has erroneously been interpreted as an apparent elevated concentration.
- There was considerable variability in the phosphorus concentration with phosphorus reduction during some periods and higher outflow phosphorus concentrations than inflow concentrations during other periods. On average there was a reduction in the phosphorus concentration.
- Total suspended solids (TSS) reduction consistently produced an improved water quality during each year of operation.
- Discharge concentrations of many of the parameters were close to wetland background levels and below environmental guidelines. The results show that while the inflowing water is often quite variable in concentration the discharge quality is consistently of a high quality. The wetland effectively treats the raw runoff water to acceptable levels before release. Release of

water at these low concentrations is safe for fish and aquatic life and meets most Canadian Water Quality Guidelines.

Site 2 – Near Lake Manitoba Narrows

The second constructed wetland site developed was at an 1800 head feedlot bordering Lake Manitoba in the Interlake area. The treatment system was commissioned in 1998. The treatment wetland was constructed to reduce the nutrient and solids loading to Lake Manitoba.

Holding Pond

The 0.25 ha holding pond with a working volume of approximately 3,300 m^3 collects and stores contaminated runoff from the feedlot area during the late fall, winter, and early spring. The average hydraulic retention time (HRT) in the pond during the wetland operating period is approximately 2 months. The stored water is pumped, having been drawn through a floating intake, to the treatment wetland during the treatment period by a pump since the topography does not allow for gravity flow.

Treatment Wetland

The treatment wetland consists of two 0.5 ha cells operating in parallel with an average depth of 0.3 m and a working volume of 3,000 m^3. The holding pond effluent is pumped to a weir box at the inflow end of the wetland cells where the flow is measured. Flow to each of the wetland cells is controlled by gate valves. For normal operation, the gate valves at the weir box are opened to allow a maximum flow of about 100 L/min to each cell. The gate valves at the splitter structure also allow isolation of either cell or throttling of the flow to either cell. The flow enters the wetland in the centre of the length of the influent distribution deep zone where it is distributed across the width of each cell. After flowing through the wetland cells, the treated water is discharged at the effluent control structure through a weir box for flow measurement. The water surface elevation of each cell is controlled by stop logs at the effluent control structures.

Site 2: Wetland Performance

The overall performance of the wetland at Site 2 also has met expectations with significant reduction in contaminant concentration. The data that has been collected to date at this site also shows much lower wetland inflow concentrations than was predicted using water quality data from other feedlot operations. As was experienced at Site 1, the holding pond is providing considerable treatment prior to discharging the contaminated stormwater to the wetland. Table 2 presents the average annual data from monthly samples collected during each growing season of operation.

TABLE 2: SITE 2 - AVERAGE ANNUAL WETLAND INFLOW AND OUTFLOW DATA

Parameter	Average Value 1999		Average Value 2000	
	Inflow	Outflow	Inflow	Outflow
BOD_5 (mg/L)	20	4	27	7
NH_3-N (mg/L)	2.1	0.4	1.4	0.1
TKN (mg/L)	25	16	32	15
TP (mg/L)	6	4.3	8.5	5
TSS (mg/L)	21	6	73	31
PH	8.1	8.1	8.3	8.2
Conductivity (µs/cm)	3377	3139	3629	2954
COD (mg/L)	247	280	303	222
Fecal coliform (col/100ml)	420	201	1082	324
Total Coliform (col/100 ml)	11848	1496	14044	2558
D.O. (mg/L)	1.2	2.2	3.1	4.8

Figure 9
Dissolved Oxygen - Site 2

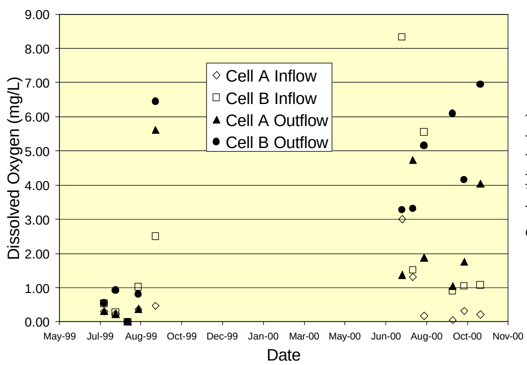


Figure 10
Conductivity Change - Site 2

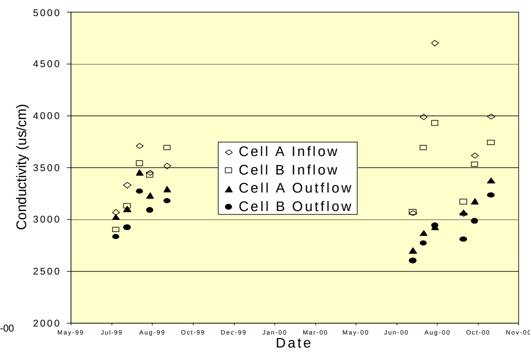


Figure 11
Total Phosphorus - Site 2

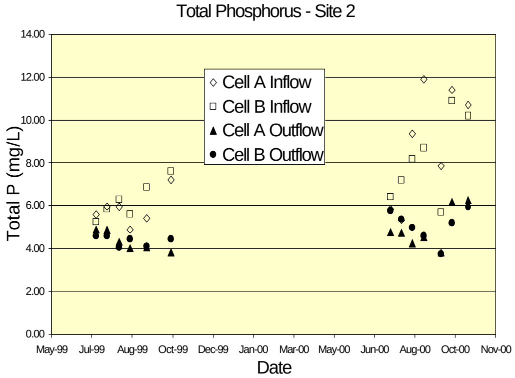


Figure 12
Total Suspended Solids - Site 2

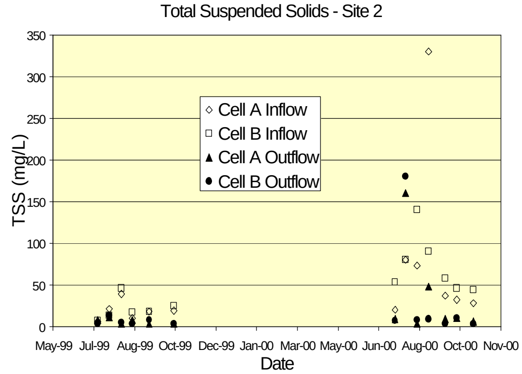


Figure 13
BOD5 - Site 2

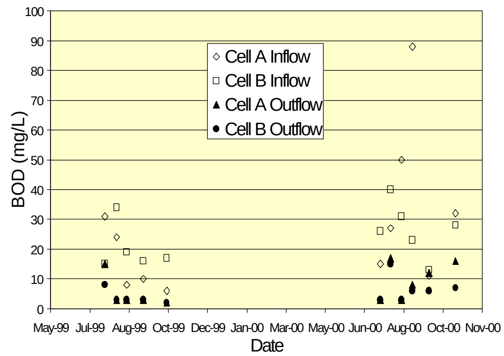


Figure 14
pH - Site 2

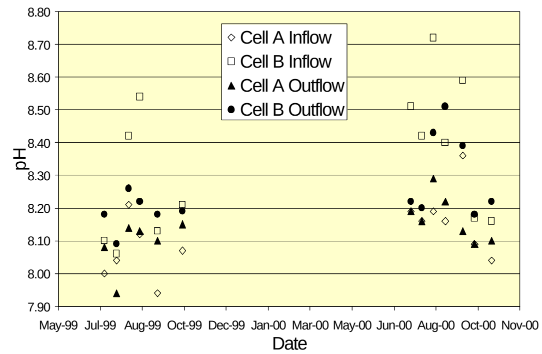


Figure 15
Ammonia-Nitrogen - Site 2

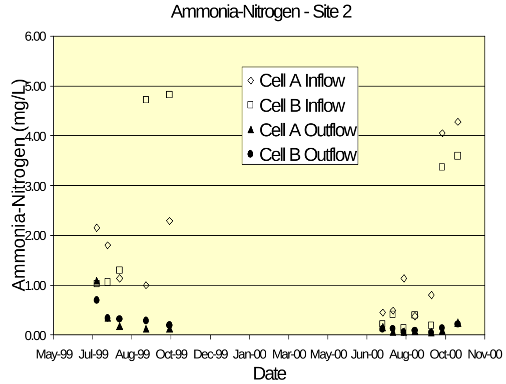
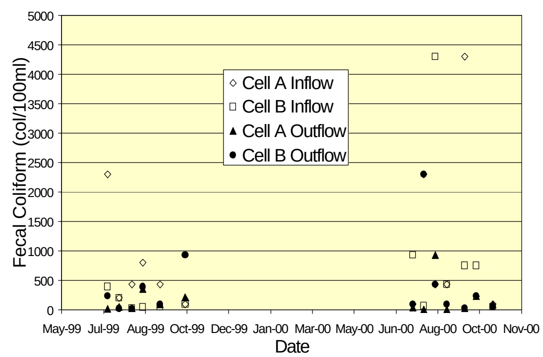


Figure 16
Fecal Coliform - Site 2



There was little water flow through the system in 1999 due to low runoff volumes from the feedlot. The long hydraulic retention time of the system, including the holding pond, is again evident as some of the data shows very low concentrations of contaminants in the wetland inflow. Comments on selected parameters is presented below.

- With inflow ammonia concentrations reaching a high of 4.8 mg/L, the effluent ammonia-nitrogen was consistently less than 0.5 mg/L with one exception. Here again the wetland produced an effluent that met the Canadian Water Quality Guidelines for unionized ammonia concentration.
- The combined wetland effluent BOD_5 was 15 mg/L or less throughout both years that the system has been in operation with one minor excursion.
- Unlike Site 1, the phosphorus reduction was consistent each year with lower concentrations in the effluent than was measured in the influent.
- With the exception of two sample points, the TSS concentration in the wetland effluent was consistently less than 15 mg/L. The elevated TSS levels reported for the July 26, 2000 sample may have been due to large concentrations of aquatic organisms, wetland vegetation debris picked up during sampling, or some other anomaly. The somewhat elevated concentration on August 23, 2000 may reflect the elevated wetland inflow concentration.

Wetland discharge concentrations of many of the parameters at Site 2 were also close to typical wetland background levels, below most environmental guidelines, and at low enough concentrations to be safe for fish and aquatic life.

DESIGN CONSIDERATIONS

There are lessons that have been learned over the past three years of operation. They include:

***Pre-Treatment and storage*:** A primary treatment lagoon or settling pond is required upstream of the treatment wetland. A lagoon or pond allows initial removal of settleable contaminants, particularly suspended solids that typically are high in phosphorus and BOD_5, and provides storage where the contaminated stormwater can accumulate during the winter months and be discharged at a controlled rate to the wetland for maximum removal efficiency. This also prevents solids build up in the wetland cell that will reduce the hydraulic retention time and decrease performance.

Set reasonable targets for pollutant reduction: Setting reasonable effluent targets is an important task in developing a treatment wetland that meets producer and regulator expectations and is economically feasible for widespread adoption of the technology. Targets should be set based on average strength of feedlot runoff and empirical performance data from cold climate livestock wetlands.

Configuration and size: The wetland system must be designed in such a way that it will not negatively impact the normal farming practices. It is difficult to sacrifice productive land and so the wetland footprint must be minimized. While channelized systems are attractive and have potential for landscape features, they also take up two or three times the land area of a rectangular system. During the design stage, consideration can be given to reducing the amount of overcapacity designed into the system and locating it such that extra treatment cells can be constructed if increased capacity is required in the future.

Pumping requirements: This passive treatment option has the advantage of not requiring pumping as long as the relief of the land allows for gravity flow throughout the system. This is another siting consideration that can reduce the construction, operations, and maintenance costs. In relatively flat areas, however, pumping may be required to move the water through the system. This is especially true for seasonal systems where the holding pond must be emptied by the end of the treatment season as is the case in the Manitoba systems.

Siting and setback restrictions: Manitoba Livestock regulations were followed for setbacks from property lines, residences and wells

Cost Considerations: For the farming community, the cost of any treatment option will be a major factor that will determine whether it will be considered. The construction costs associated with a treatment wetland depend on the topography, site soil conditions, and infrastructure requirements.

Liners: Wetland and storage pond lining is required in permeable soils to prevent vertical movement of contaminated water. Synthetic or clay liners add significant cost to a wetland project especially when clay is not readily available. Since the Manitoba wetlands were both built in areas that had high clay content in the soils, this cost was not incurred.

Land Costs: Land purchase can drive up the cost of a farm treatment wetland considerably. For most on-farm systems landowners may donate the land to the project. Whether purchased or donated the value of the land does represent a cost of development. As such wetland sizing is the main determinant and will vary with feedlot size and livestock numbers. The footprint of the two Manitoba projects excluding feedlot drainage area was approximately 1.5-2 hectares.

Muskrat Control: Muskrat colonization of the constructed wetland can be devastating to the integrity of the wetland dikes and the vigour of wetland vegetation. The repair of muskrat damage at Site 1 cost approximately $2500 after the first year of operation. Burrowing into the surrounding dikes was the principle damage that caused collapse and a near breach of the dike. To prevent further occupation and damage a muskrat exclusion fence was designed and built around the wetland cell.

SUMMARY

The agricultural industry in Manitoba and across the rest of Canada has expressed considerable interest and acceptance of wetland technology for the polishing of high- and low-strength agricultural wastewater and stormwater. The systems in Manitoba have a demonstrated capability to reduce contaminant loadings to the water environment and have the potential for operation on a much wider scale. Continued data collection is required to provide the long-term data that will help determine the future of constructed treatment wetland technology in Manitoba and other cold climate locations.