The Sustainability of Municipal Wastewater Irrigation in the Interlake Region of Manitoba as a Means of Nitrogen and Phosphorous Abatement for Lake Winnipeg

By

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We accept this thesis as conforming to the required standard

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Abstract

In Manitoba there are an estimated 200 small and 10 large wastewater treatment systems contributing nutrients to surface water when effluent is discharged. The objective of this study was to assess the sustainability and social acceptance of wastewater irrigation in the southeast Interlake region. It was concluded that sustainably irrigating forage crops would be challenging. The combination of soils with only ratings of fair for irrigability and the low quality of wastewater limits the long term sustainability of irrigation. Only one study site maintains a high potential to develop a wastewater irrigation program due to sufficient suitable land and appropriate wastewater quality. The social acceptance of wastewater irrigation is mixed with only about half the survey respondents favourable to irrigation or reuse of wastewater.

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1 Introduction

Water quality is an urgent environmental concern with water resources coming under increasing volume and quality demands. A symptom of impacted surface water quality is eutrophication, the stimulated growth of plants and algae due to increased additions of nutrients (nitrogen and phosphorous) which have adverse impacts on habitat and aquatic organism health and water potability.

In Canada, eutrophication is of increasing concern for many surface water bodies including Lake Winnipeg and other Manitoba lakes. Manitoba Water Stewardship estimates that all Manitoba wastewater sources (excluding the City of Winnipeg) contribute 8% of total phosphorous loading and 3% of total nitrogen loading to Lake Winnipeg (Lake Winnipeg Stewardship Board [LWSB], 2006). In the Manitoba drainage basin of Lake Winnipeg there are an estimated 200 small and 10 large wastewater treatment systems. All are contributing wastewater discharge to surface water within the Lake Winnipeg drainage basin (LWSB, 2006). Typically, wastewater from small treatment lagoon systems is discharged annually between June 15 and November 1. These effluents reach Lake Winnipeg, contributing to nutrient enrichment of the aquatic system.

A cost effective sustainable alternative to discharge, such as irrigation onto annual and forage crops which utilize nitrogen and phosphorous, is needed to prevent nutrient enrichment of surface waters. Within Canada and the United States there has been significant success with wastewater reuse for irrigation to important food crops and forage lands (Bouwer, 2000; Hogg, Weiterman and Tollefson, 1997; Lazarova and Bahri, 2005; Mohammad Rusan, Hinnawi, & Rousan, 2007). Sewage wastewater reuse is not a common practice in Manitoba with only three municipal wastewater irrigation projects currently established.

A well-managed wastewater irrigation system provides environmental, agronomic, and socially sustainable benefits without deleterious effects on soil and/or foodstuffs (Bouwer, 2000; Hogg et al. 1997, Lazarova et al., 2005 and Mohammad Rusan et al. 2007). Sustainable benefits to soil resources are: increased soil organic matter, nutrients, improved crop quality, and improved yields. Environmental benefits include less demand on fresh potable water resources for agricultural practices (Lazarova et al., 2005 and Toze, 2005) and mitigation of nutrient and contaminant loading to surface water bodies through open discharges (Toze, 2005). However, municipal wastewater is not a pristine water source and contains elevated concentrations of salts (sodium and chloride), heavy metals, pathogens, personal care products and pharmaceuticals (Canadian Council of Ministers of the Environment [CCME], 2006) that may affect the soil, groundwater and/or food quality. Sustainability of a wastewater irrigation program is realized through matching crop nutrient uptake to supply and crop water demand to water supply, suitable land, and suitable water quality. Additional requirements for a successful irrigation program include crop rotation, land rotation, irrigation management, and stakeholder ownership.

Irrigating municipal wastewater to the land may not be well received due to the perception and concern for public health, food safety (Lazarova et al., 2005), and odour. Public concern, either perceived or actual, is based upon the degree of reuse of the wastewater; for example, reuse of water at home versus reuse in an agricultural field (Toze, 2005 and Hartley 2006).

The research question for this Master of Science project is as follows:

Is wastewater irrigation, from municipal lagoons onto forages crops, a sustainable and socially acceptable practice to abate nutrient loading to the Lake Winnipeg watershed?

There were two separate objectives to study, firstly to assess the sustainability of wastewater irrigation and nitrogen and phosphorous abatement to surface water systems that directly leads to Lake Winnipeg. The second objective is to assess the social acceptance of effluent irrigation in rural communities. To achieve these two objectives; land suitability, lagoon wastewater suitability and social perception were assessed at eight study sites in the southeast Interlake region of Manitoba, including the towns of Stony Mountain, Stonewall, Balmoral, Teulon, Arborg, Winnipeg Beach, Dunnottar and Petersfield.

2 Literature Review

2.1 Regulatory Framework

In Canada, all levels of government, municipal, provincial/territorial and federal, are responsible for managing municipal wastewater effluent (CCME, 2006). Federally, there are no direct legislative Acts pertaining to municipal wastewater effluent. However, the Fisheries Act, 1985 (Minister of Justice, Canada, 1985) and the Canadian Environmental Protection Act, 1999 (Minister of Justice, Canada, 1999) are both effective in governing discharges from wastewater lagoons (CCME, 2006). Provincial governments are responsible for the regulation of the actual treatment and management of wastewaters. Appropriate regulatory departments licence/permit wastewater treatment systems. Municipalities through statutory mandate are responsible for the treatment and management of wastewater within their jurisdictions. Through municipal bylaws, there are restrictions as to acceptable substances that may be discharged to the sewer system (CCME, 2006).

In Manitoba, Manitoba Conservation and Manitoba Water Stewardship each manage and administer legislative acts and regulations for the operation of wastewater treatment systems, discharge of effluent and implementation of water quality guidelines. Manitoba Conservation administers The Environment Act (Manitoba, 2009); the Act is the guiding regulatory legislation to ensure protection of the environment, while aiding in social and economic developments for current and future generations. The Environment Act outlines that all new developments, including wastewater lagoons, require an Environmental Act Licence (EAL). The Environment Act and/or applicable provincial regulations do not contain water quality criteria for wastewater discharges. Canadian federal government guidelines developed/adopted by the provinces provides applicable environmental guidelines for wastewater effluents. In Manitoba, all public and private municipal sewage lagoons require an EAL. Typically, EALs for wastewater lagoons outline the design, operation, maintenance requirements, and effluent discharge criteria.

> "In 2010, Manitoba Water Stewardship intends to enshrine the Manitoba Water Quality Standards Objectives and Guidelines into a regulation under The Water Protection Act. Included in the regulation will be water quality standards for nitrogen and phosphorous in municipal wastewater effluent" (N. Armstrong, personal communication, January 11, 2010).

Federal guidelines are provided by the Canadian Council of Ministers of the Environment (CCME), Canadian Environmental Quality Guidelines (CEQG) to provide safe limits for contaminants in soil, sediment and water (CCME, 1999). The intent of the CEQG is to protect human health in regards to air, land, and water resources across Canada. The CEQG provide numerical values for the assessment and rating of soil, sediment, and water. They are subdivided into the Canadian Soil Quality Guidelines (CSQG), Canadian Sediment Quality Guidelines (CSedQG) and the Canadian Water Quality Guidelines (CWQG). The CWQG is further divided into Community Water Supplies (Health Canada, Drinking Water), Recreational Water, Protection of Aquatic Life and Protection of Agricultural Water Uses (Irrigation and Livestock) (CCME, 1999).

2.2 Land Suitability for Wastewater Irrigation

In Manitoba, an assessment of the suitability of land (soil) for irrigation is required prior to the establishment of an irrigation program. The chemical and physical characteristics of the soil are key parameters in determining the suitability and sustainability of land for irrigation (United States Environmental Protection Agency [USEPA], 2006).

In-field assessment of the soil's chemical and physical characteristics is prudent prior to establishing an irrigation program. For initial planning purposes, existing information on soil characteristics to determine suitability for irrigation should include a review of soil pedology, drainage, texture, salinity, and sodicity. Review and use of the Agriculture and Agri-Food Canada's publications 1) Irrigation Suitability Classification System for the Canadian Prairies (Agriculture and Agri-Food Canada [AAFC], 1987)) and 2) Canada Land Inventory Soil Capability Classification for Agriculture (Fraser, Cyr, Eilers, & Lelyk, 2001) is an acceptable starting perspective.

In Manitoba, the Water Protection Act (C.C.sMc W65, 2005), Nutrient Management Regulation (62/2008) outlines nutrient application restrictions for the application of nutrients in agriculture. These nutrient application restrictions are based upon Water Quality Management Zones (WQMZ) that is derived from the Canada Land Inventory Soil Capability Classification for Agriculture ratings (Manitoba Water Stewardship, 2008). Therefore, in addition to the resources of soils information outlined above, the requirements of the Nutrient Management Regulation and WQMZ are discussed.

2.2.1 Irrigation Suitability Classification System for the Canadian Prairies

Prior to the early 1980's there was numerous land suitability classification systems used for the purposes of regional land use planning (AAFC, 1987). In the early 1980s, the Prairie Farm Rehabilitation Association (PFRA) developed an irrigation suitability classification based on soil chemical and physical properties and landscape characteristics (AAFC, 1987).

The Irrigation Suitability Classification (ISC) (AAFC, 1987; Fraser, et al. 2001) system is a means of evaluating land with standard guidelines, pedological and topographical, to determine the degree of limitations to irrigation. Pedologically, a soil's irrigability is directly related to a soil's physical, morphological, and chemical properties. These properties are directly related to the ability of irrigation water to infiltrate the profile, drain through the profile and at the same time be retained within the profile (water holding capacity). Topographically, landscape criteria further relate to the irrigability of the field as it relates to landscape evaluation criteria such as degree of slope, slope position, stoniness, and flooding. Soil features affecting irrigation are outlined in Table 1 and landscape features limiting irrigation are outlined in Table 2.

Table 1 Soil Chemical and Physical Properties Affecting Irrigation

Soil Property (Symbol)		Degree of Limitation			
		None (1)	Slight (2)	Moderate (3)	Severe (4)
Structure (d)		Granular, Single grained, Prismatic, Blocky, Subangular Blocky	Columnar Platy	Massive	Massive
Ksat (d),	0-1.2m (mm/hr)	>50	50-15	15-1.5	<1.5
Drainage (x),	1.2-3m (mm/hr)	>15	5-15	0.5-5	<0.5
AWHC (m)	mm/hr, (%vol.)	Subhumid >120 (>10) Subarid >150 (>12)	Subhumid 120-100 (8-10) Subarid 120-150 (12-10)	Subhumid 100-75 (6-8) Subarid 100-120(10-8)	Subhumid <75 (<6) Subarid <100 (<8)

Soil Property (Symbol)		Degree of Limitation			
		None (1)	Slight (2)	Moderate (3)	Severe (4)
Intake Rate (q)	mm/hr	>15	1.5-15	1.5-15	<15
Salinity (s)	dS/m				
	0-0.6m	<2	2-4	4-8	>8
	0.6-1.2m	<4	4-8	8-16	>16
	1.2-3.0m	<8	8-16	>16	>16
Sodicity (n) SAR	0-1.2m	<6	6-9	9-12	>12
	1.2-3.0m	<6	6-9	9-12	>12
Geological Uniformity (g)	0-1.2m	1 texture	2 textures, coarse below	2 textures, finer below, 3 texture groups coarser below	3 texture groups finer below
	1.2-3.0m	2 textures	3 textures, coarse below	3 texture groups finer below	
Depth to Bedrock (r)		>3m	3-2m	2-1m	<1m
Depth to water table (h)		>2m	2-1.2m, if salinity is a problem		<1.2m

Soil Property (Symbol)		Degree of Limitation			
		None (1)	Slight (2)	Moderate (3)	Severe (4)
Drainage Class (w)		Well, moderately well, rapid, excessive	Imperfect	Imperfect	Poor, very poor
Texture	0-1.2m	Medium	Moderately fine, moderately coarse	Fine, coarse	Very fine, very coarse
		L, SiL, VFSL, FSL	CL, SiCL, FSCL, SL,VLFS	C, SC, SiC, VFS, LS, CoSL	HvC, GR, CoS, LCoS, S
Organic Matter	%	>2	1-2	1-2	<1
Surface Crusting Potential		Slight	Low	Low	Moderate

Note. AWHC: Available Water Holding Capacity, Ksat: Hydraulic Conductivity

(Source Fraser et al. 2001; reproduced with permission).

Table 2 Landscape Features Affecting Irrigation

Landscape Feature		Degree of Limitations			
		None (A)	Slight (B)	Moderate (C)	Severe (D)
Slope					
(t1) Simple	%	<2	2-10	10-20	>20
(t2) Complex		-	<5	5-15	>15
Average Local Relief (e)	m	<1	1-3	3-5	>5
Stoniness Class (p)		0, 1, 2	3	4	5
Inundation	Frequency (yrs)	1:10	1:5	1:1 annual spring	1:<1 seasonal

Note: (Source Fraser et al. 2001;reproduced with permission).

To appraise land suitability for irrigation, soil and landscape properties (Table 1 and 2) are evaluated for the potential effect to soil quality. Relative limitation rankings are applied (none, slight, moderate and sever) to both soil chemical and physical and landscape properties. These limitations are applied with respect to the affect of long-term irrigation management (AAFC, 1987) on soil quality. The irrigation suitability rating is determined by assessing parameters individual and then combining assessments in a 4 x 4 matrix and assigning an irrigation suitability rating of: excellent, good, fair and poor. The various classes are described below (Frazer et al. 2001).

Excellent Land assessed, as “Excellent” have no significant limitation for irrigation. These soils are medium textured, well drained and hold adequate available moisture. Topography is level to nearly level.

Good Land assessed, as “Good” have slight limitations due to limitations of soil or landscape or both. The range of crops that can be grown may be limited, higher development inputs and management skills are required.

Fair Land assessed, as “Fair” have moderate limitations due to limitations of soil or landscape or both. Limitations reduce the range of crops that may be grown and increase development and improvement costs. Management may include special conservation techniques to minimize soil erosion, limit salt movement, limit water table build-up or flooding of depressional areas.

Poor Land assessed, as “Poor” have severe limitations due to limitations of soil or landscape or both. Limititations generally result in a soil that is unsuitable for sustained irrigation. Some lands may have limited potential when special crops, irrigation systems, and water conservation techniques are used.

2.2.2 Canada Land Inventory – Soil Capability for Agriculture

The Water Protection Act (C.C.sMc W65, 2005) Nutrient Management Regulation (62/2008) outlines nutrient application restrictions based on the Canada Land Inventory Soil Capability Classification for agriculture ratings (Manitoba Water Stewardship, 2008). The Canada Land Inventory (CLI) is a dry-land agricultural capability inventory for rural Canada. Similar to the ISC, the CLI limitations are based on climate, geology, soil chemical and physical characteristics (salinity and structure), draughtiness, inundation, erosion, stoniness, and landscape topography of the soil. It is important to note that the CLI is a soil rating system for dry-land agricultural production and is not an assessment of suitability or sustainability (AAFC, 2008, Frazer et al. 2001).

The CLI groups mineral soils into seven classes with the same relative degree of limitation and then delineates subclasses within each class based on type of limitation (Frazer et al. 2001). Classes one to seven are based on increasing degree of limitation, the first three classes are capable of sustained cultivated crop production, class four is marginal for sustained arable cropping, class five is capable of pasture or hay, class six is capable of permanent pasture and class seven has no capability for arable crop or permanent pasture (Table 3). Thirteen different subclasses or limitations are considered (Table 4) (Frazer et al. 2001).

Table 3 Canada Land Inventory Soil Capability Class Description for Agriculture

Class Descriptions
Class 1 - Soils in this class have no significant limitations in use for crops. The soils are deep, are well to imperfectly drained, hold moisture well, and are well supplied with plant nutrients. They can be managed and cropped without difficulty. Under good management, they are moderately high to high in productivity for a wide range of field crops.
Class 2 - Soils in this class have moderate limitations that restrict the range of crops or require moderate conservation practices. The soils are deep and hold moisture well. The limitations are moderate and the soils can be managed and cropped with little difficulty. Under good management they are moderately high to high in productivity for a fairly wide range of crops.
Class 3 - Soils in this class have moderately severe limitations that restrict the range of crops or require special conservation practices. The limitations are more severe than for class 2 soils. They affect one or more of the following practices: timing and ease of tillage, planting and harvesting, choice of crops, and methods of conservation. Under good management, they are fair

Class Descriptions
to moderately high in productivity for a fair range of crops.
Class 4 - Soils in this class have severe limitations that restrict the range of crops or require special conservation practices, or both. The limitations seriously affect one or more of the following practices: timing and ease of tillage, planting and harvesting, choice of crops, and methods of conservation. The soils are low to fair in productivity for a fair range of crops but may have high productivity for a specially adapted crop.
Class 5 - Soils in this class have very severe limitations that restrict their capability to producing perennial forage crops, and improvement practices are feasible. The limitations are so severe that soils are not capable of use for sustained production of annual field crops. The soils are capable of producing native or tame species of perennial forage plants. The improvement practices may include clearing of bush, cultivation, seeding, fertilizing, or water control.
Class 6 - Soils in this class are capable only of producing perennial forage crops, and improvement practices are not feasible. The soils provide some sustained grazing for farm animals, but the limitations are so severe that improvements are impractical as terrain may be unsuitable, or soils may not respond to improvement, or the grazing season may be very short.
Class 7 - Soils in this class have no capability for arable culture or permanent pasture. This class also includes rock land, other non-soil areas, and bodies of water too small to show on the maps.
Class 0 - Organic soils (not placed in capability classes).

Note: (Source Frazer et al. 200; reproduced with permission).

Table 4 Canada Land Inventory Subclass Limitations for Agriculture

Subclass Descriptions
'c' - Adverse Climate - this subclass denotes a significant adverse climate for crop production as 'median' climate which is defined as one with sufficiently high growing-season temperatures to bring crops to maturity.
'd' - Undesirable soil structure and/or low permeability - this subclass indicates soils that are difficult to till or soils where water is absorbed very slowly or where the depth of rooting zone is restricted by conditions other than a high water table or consolidated bedrock.
'e' - Erosion - this subclass includes soils where damage from erosion is a limitation to agricultural use. Damage is assessed on loss of productivity and on the difficulties in farming land with gullies.
'f'' - Low Fertility - included are soils having low fertility that either is correctable with careful management in the use of fertilizers and soil amendments or is difficult to correct by any practical means. The limitations may be due to lack of plant nutrients, high acidity or alkalinity, low exchange capacity, high levels of carbonates or presence of toxic compounds.
'i' - Inundation by streams or lakes - this subclass includes soils subjected to inundation causing crop damage or restricting agricultural use.
'm' - Moisture Limitations - this consists of soils where crops are affected by drought owing to inherent soil characteristics. These soils usually have low water-holding capacity.
'n' - Salinity - soils of this subclass possess excessive soluble salts which adversely affect crop growth or restrict the range of crops that may be grown.
'p' - Stoniness - these soils are sufficiently stony to hinder tillage, planting and harvesting operations.

Subclass Descriptions
'r' - Consolidated Bedrock - this subclass includes soils where the presence of bedrock near the surface restricts their agricultural use. Consolidated bedrock at depths greater than 3 feet from the surface is not considered as a limitation except on irrigated lands where a greater depth of soil is desirable.
's' - There are two interpretations accorded to subclass s. In the case of maps generally produced before 1969, subclass s will be used in place of subclasses d, f, m or n. If two or more of subclasses d, f, m or n are applicable to the same area, then again subclass s will be substituted. On most of the maps subsequent to 1969, the applicable subclass d, f, m, or n will appear if an area is classified with a single subclass. For areas classified with two or more of d, f, m or n then subclass s will appear, denoting a combination of subclasses.
't' - Topography - this subclass is made up of soils where topography is a limitation. Both the percent of slope and the pattern or frequency of slopes in different directions affect the cost of farming and the uniformity of growth and maturity of crops as well as the hazard of erosion.
'w' - Excess Water - this subclass includes soils where excess water other than brought about by inundation is a limitation to agricultural use. Excess water may result from inadequate soil drainage, a high water table, seepage or from runoff from surrounding areas.
'x' - This subclass is comprised of soils having a limitation resulting from the cumulative effect of two or more adverse characteristics.

Note. Reproduced with Permission (Frazer et al. 2001)

The Water Protection Act (C.C.sMc W65, 2005), Nutrient Management Regulation (62/2008) outlines criteria for the application of nutrients (nitrogen and phosphorous) to agricultural land. The purpose of the Nutrient Management Regulation is to protect water quality by encouraging responsible nutrient planning. The objective to regulate the application of substances containing nitrogen or phosphorus to land and the development of certain types of nutrient generating facilities in areas is a protective measure for sensitive water bodies and/or groundwater (Manitoba Water Stewardship, 2008).

Table 5 Water Quality Management Zones and Associated CLI Agricultural Capability

WQMZ	Zone Definition and Associated CLI Agricultural Capability
N1	CLI Classes 1, 2, 3, excluding 3M, 3ME, 3MI, 3MN, 3MP, 3MT, 3MW, and any other subclass of soil class 3 has an “M” subclass designation.
N2	CLI Classes 3M, 3ME, 3MI, 3MN, 3MP, 3MT, 3MW or any other subclass of 3 having an “M” subclass designation, soil Class 4, soil subclass 5M, if it is being irrigated.
N3	CLI Class 5 that is not included in zone N2.
N4	CLI Classes 6 and 7 and unimproved organic soils.
N5	Land in a city, town, local urban district a community defined in the Northern Affairs Act, a lot shown on a plan of a subdivision and having an area of 2 ha or less, land not described above that is in a built –up area.

Note. (Manitoba Water Stewardship, 2008)

2.3 Effluent Quality for Wastewater Irrigation

Municipal wastewater treatment lagoons generally receive wastewater from storm and septic sewers and from both residential and commercial properties (CCME, 2006). In rural Manitoba, treatment lagoons also receive waste from rural resident septic holding tanks.

Municipal wastewater typically contains human, organic, and inorganic waste. The waste is composed of nutrients, microorganisms, suspended solids, household and industrial chemicals (CCME, 2006), personal care products and pharmaceuticals (Kinney, Furlong, Werner, & Cahill, 2006; Ternes, Bonerz, Herrmann, Teiser, & Andersen, 2007; Kleywegt, et al., 2007). Regardless of the source of water (groundwater, fresh surface water or wastewater) the quality of that water needs to be suitable for irrigation. The several parameters considered necessary to assess wastewater quality include nutrients (nitrogen and phosphorous), salts (electrical conductivity, total dissolved solids), cations and anions (i.e. bicarbonate, chloride, calcium, and sodium), trace elements (i.e. Arsenic, Boron, Cadmium), pathogens (i.e. total and fecal coliform) and acidity/alkalinity (pH) (Lazarova et al., 2005).

2.3.1 Nutrient (Nitrogen and Phosphorous)

Total nitrogen in wastewater is a collective of ammonia (NH_3), ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), Organic N (proteins of algae and bacteria and urea), and nitrogen gas (N_2). About 40% of total nitrogen is mainly organic and depending on pH the remainder is either ammonia or ammonium (USEPA, 2006). Nitrogen provided through irrigation is a form of *fertigation* for crop nutrient requirements; however, mineralization of organic forms of nitrogen can produce excess nitrate. Nitrates can easily leach through the soil profile to groundwater and become a human health concern (Lazarova et al., 2005). Currently, there are no regulatory limiting criteria for nitrogen compounds (nitrate, ammonium) in irrigation water. However, the application of nitrogen-enriched water must be consistent with crop demand and annual removal rates to prevent accumulation of nitrate in soil and subsequent leaching to groundwater.

Phosphorous in municipal wastewater is composed of orthophosphate, polyphosphate and organic phosphate (USEPA, 2006). Sallanko & Sarpola (2007), found that approximately 50% of total phosphorous in municipal wastewater is dissolved and in the form of orthophosphates which are readily bioavailable in the soil ecosystem. The balance is particulate phosphorous (>0.45 microns when filtered) and consists of organic and inorganic forms. Organic waste matter, industrial and commercial chemicals and synthetic detergents and household cleaning products (laundry soaps) are the primary sources of phosphorous in municipal wastewater. Currently, there are no regulatory limiting criteria for total phosphorous in irrigation water. Application of phosphorous-enriched waters must be consistent with crop demand and annual removal rates of phosphorous to prevent excessive phosphorous accumulation in soil. Increase in phosphorous content of soil increases risk of transfer of phosphorous from soil to water.

To ensure a sustainable irrigation program without affecting groundwater or surface water quality, nitrogen and phosphorous input must balance with crop uptake and removal. BMPs, such as; selecting an appropriate crop with high nutrient removal and crop water use (Tzanakakis, Paranychianakis, & Angelakis, 2009), harvest timing, irrigation management and monitoring soil nutrient levels will ensure a sustainable system. Early work has determined that wastewater-irrigated crops, specifically perennial grass such as Reed Canary grass (*Phalaris arundinacea*), remove significant amounts of nitrogen, (Geber, 2000; Linden, Clapp, & Gilley, 1981).

2.3.2 Salts & Salinity

Wastewaters are typically elevated in salt content when compared to the parent source of drinking water due to water treatment and domestic and industrial use. The salt within the wastewater poses two separate risks to the plant/soil system. First, salts in soil increase a plant's osmotic stress for water and nutrient uptake and have direct toxicity effects. Second, various cations affect dispersion of soil aggregates and alters soil structure (Hillel, 2000; Lazarova et al., 2005). To evaluate the degree of wastewater salinity the following parameters are assessed; total dissolved solids (TDS), electrical conductivity (E.C.), sodium adsorption ratio and specific cations (sodium, potassium, calcium and magnesium) and anions (chloride, sulphate, nitrate, and bicarbonate).

2.3.2.1 Total Dissolved Solids

TDS are the total minerals or cations (Ca^{2+}, Mg^{2+}, and Na^{+}) and anions (Cl^{-}, SO_4, and HCO_3) dissolved in a given volume of water. TDS is an indicator of the degree of water salinity and is expressed as milligrams per litre (Hillel, 2000). TDS is easily reported as electrical conductivity since there is a relationship between the two measurements (Lazarova et al., 2005). This relationship is expressed as: TDS (mg L^{-1}) = ECw (dS m^{-1}) x 640

The CCME (1999) Canadian water quality guidelines (CWQG) for the protection of water for agricultural use have developed TDS guidelines based on maximum limits for specific crops (Table 6).

Table 6 Irrigation Water Quality Guidelines for Total Dissolved Solids

TDS (mg L^{-1})	Crop
500	Strawberries, raspberries, beans and carrots
500-800	Boysenberries, currants, blackberries, gooseberries, plums, grapes, apricots, peaches, pears, cherries, apples, onion, parsnips, radishes, peas, pumpkins, lettuce, peppers, muskmelons, sweet potatoes, sweet corn, potatoes, celery, cabbage, kohlrabi, cauliflower, cowpeas, broad beans, flax, sunflowers and corn
800-1500	Spinach, cantaloupe, cucumbers, tomatoes, squash, Brussels sprouts, broccoli, turnips, smooth brome, alfalfa, big trefoil, beardless wild rye, vetch, timothy and crested wheat grass
1500-2500	Beets, zucchini, rape, sorghum, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, reed canary grass, birds foot trefoil and perennial ryegrass
>3500	Asparagus, soybeans, safflower, oats, rye, wheat, sugar beets, barley hay, and tall wheat grass

(Source CCME, 1999)

The Government of Saskatchewan has established municipal wastewater irrigation guidelines for TDS whereas Manitoba and Alberta use CCME CWQG for assessment.

Table 7 Saskatchewan Municipal Wastewater Guidelines for TDS

Total Dissolved Solids (mg L^{-1})		
<450	450-2000	>2000
No restrictions	Slight to moderate restrictions	Severe restrictions

(Source Saskatchewan Environment, 2004)

2.3.2.2 Electrical Conductivity

E.C. of wastewater is an effective infield or laboratory measure that correlates well to the potential impact of salts in soil on plants and relates well to total dissolved solids (salt) content of water. Significant work to categorize water's E.C. value and its irrigation quality has been conducted (Richards, 1954; Lazarova et al., 2005; Hillel, 2000; Alberta Agriculture, Food and Rural Development [AAFRD], 2003). The Alberta and Saskatchewan governments have each developed guidelines for assessing quality of municipal wastewater for irrigation in cluding quidelines for E.C. (Table 8).

Table 8 E.C. Suitability of Irrigation Water for Saskatchewan and Alberta

	E.C. Classification (dS m^{-1})		
Saskatchewan	<0.7 No restrictions	0.7-3.0 Slight to moderate restrictions	>3.0 Severe restrictions
Alberta	<1.0 Safe	1.0-2.5 Possibly Safe	>2.5 Hazardous

(Source Alberta Environment, 2000; Saskatchewan Environment, 2004)

The Manitoba Water Quality Standards, Objectives and Guidelines (Manitoba Conservation, 2002-11), Tier II conductivity criteria is 1500 uS cm^{-1} (1.5 dS m^{-1}) for waters for field crop irrigation.

2.3.2.3 Sodium & Sodium Adsorption Ratio

High concentrations of sodium (Na) in irrigation water can have several deleterious effects on plants and soil. An accumulation of Na in plants creates an osmotic imbalance and inhibits bioavailability of other essential cations such as calcium and magnesium. In the soil, the Na ion at high concentrations (>15% Exchangeable Sodium Percentage) results in a dispersion of soil particles and consequently reduces water infiltration into the soil (McBride, 1994).

A quantitative index of sodium risk for soil and water is the Sodium Adsorption Ratio (SAR). The SAR is defined as follows: $SAR = (0.043\,[Na\,]) \div \sqrt{0.025\,[Ca\,] + 0.04\,[Mg]}$, where concentrations are expressed in mg L^{-1}

The Alberta and Saskatchewan governments have each developed guidelines for municipal wastewater irrigation including criteria for SAR (Table 9).

Table 9 SAR Irrigation Water Quality Guidelines for Saskatchewan and Alberta

	SAR		
Saskatchewan	<3 No restrictions	3 - 9 Slight to moderate restrictions	>9 Severe restrictions
Alberta	<4 Safe	4.0-9.0 Possibly Safe	>9 Hazardous

(Alberta Environment, 2000; Saskatchewan Environment, 2004)

The Manitoba Water Quality Standards, Objectives and Guidelines (Manitoba Conservation, 2002-11), Tier II SAR criteria is 6 for waters for field crop irrigation.

2.3.2.4 Chloride

Similar to sodium, chloride has an osmotic affect on plant uptake of water and nutrients. In soil, the Cl ion is highly soluble and mobile is soil solution (except in acidic soils). Due to the movement of Cl with soil water, it collects where there is restricted internal drainage and shallow groundwater. Cl can also migrate to the soil surface through capillary action resulting in deposition on the surface after evapotranspiration (Havlin, Beaton, Tisdale, & Nelson, 1999). The primary effect of Cl is the increase in osmotic pressure of the soil water lowering the availability of water to plants.

In plants, the chloride ion can be absorbed by either the roots or leaves and is considered a micro-nutrient. The uptake of Cl varies for plant species and cultivars thus crops vary widely in their tolerance of excess conditions of Cl (Fitzgerald, Flaten, Racz, Eilers, Bulley, & Sri Ranjan, 1994; Havlin et al., 1999). Crop removal is generally considered minor for an ion balance. It is reported that alfalfa can remove 50 kg Cl per hectare based on a yield of 11.3 tonne ha^{-1}, whereas potatoes and corn remove at harvest 25 to 40 kg Cl and 1 to 3 kg Cl ha^{-1}, respectively (Fitzgerald et al., 1994).

An assessment was conducted by Fitzgerald et al. (1994) on the sustainability of irrigation with lagoon effluent high in Cl and groundwater with high concentrations of Cl for a site near Carberry, Manitoba. They concluded that the water would need to be diluted ten times to limit concentrations to less than 30 mg L^{-1} of Cl prior to irrigation of potato crops.

The CCME (1999) CWQG for the protection of agricultural water use have chloride guidelines based on specific crops as reported by Eaton (1942) and Ayers and Westcot (1985) (Fitzgerald et al., 1994).

Ayers and Westcot (1985) determined that most annual crops are not sensitive to Cl and therefore recommend that it is more suitable to use salinity tolerance as a guide to irrigation water quality. Sprinkler irrigation of sensitive crops with Na and Cl concentrations in irrigation water greater than 3 meq L^{-1} or 100 mg L^{-1} has resulted in excessive crop damage under certain climatic conditions and therefore the water quality guidelines for sensitive crops is set as 100 mg L^{-1}.

2.3.2.5 Boron

Boron (B) has an essential role in higher plants in the development and growth of new plant cells, pollination and seed set, translocation of N and P, synthesis of amino acids, proteins, nodule formation and the regulation of plant metabolism (Havlin et al., 1999). Plants require low soil concentrations of B (<1 mg L^{-1}) and toxicity occurs in sensitive plants (alfalfa and canola) at concentrations greater than 2 mg L^{-1} (Lazarova et al., 2005).

In wastewater the predominant sources of B is perborate, which is used as a bleaching agent in laundry detergents and cleaning products (Lazarova et al., 2005). Boron concentration in wastewater ranges between 0.3-2.5 ug L^{-1} with a typical concentration of 5.0 ug L^{-1} (National Research Council [NRC], 1996).

The CCME (1999) CWQG for the protection of agricultural water uses have guidelines for B (Table 11) for specific crops similar to guidelines reported by Ayers and Westcot (1985).

Table 10 Irrigation Water Quality Guidelines for Chloride

Chloride (mg L^{-1})	Crops
Foliar Damage	
100-178	Almonds, apricots and plums
178-355	Grapes, peppers, potatoes, and tomatoes
355-710	Alfalfa, Barley, corn and cucumbers
>710	Cauliflower, cotton, safflower, sesame, sorghum, sugar beets and sunflower
Rootstocks	
180-600	Stone fruit (peaches, plums etc.)
710-900	Grapes
Cultivars	
110-180	Strawberries
230-460	Grapes
250	Boysenberries, blackberries and raspberries

(Source CCME, 1999)

Table 11 Irrigation Water Quality Guidelines for Boron

Boron ($\mu g\ L^{-1}$)	Crop
500	Blackberries
500-1000	Peaches, cherries, plums, grapes, cowpeas, onions, garlic, sweet potatoes, wheat, barley, sunflowers, mungbeans, sesame, lupines, strawberries, Jerusalem artichokes, kidney beans and lima beans
1000-2000	Red peppers, peas, carrots, radishes, potatoes and cucumbers
2000-4000	Lettuce, cabbage, celery, turnips, Kentucky bluegrass, oats, corn, artichokes, mustard, clover, squash and muskmelons
4000-6000	Sorghum, tomatoes, alfalfa, purple vetch, parsley, red beets and sugar beets
6000	Asparagus

(Source CCME, 1999)

2.3.2.6 Total Suspended Solids

Total suspended solids (TSS) are a measure of inorganic and organic particles such as clay, silt, plant matter, algae and bacteria in water. Suspended solids can be removed by filtration (if required) and generally are not restrictive to use of water for irrigation except for drip irrigation equipment (USEPA, 2006). Saskatchewan Environment (2008), reports that typical values for TSS range from 50-110 mg L^{-1} for primary anaerobic lagoons and from 20-60 mg L^{-1}(spring) and from 10-40 mg L^{-1} (fall) for faculative lagoons. Alberta Environment (2000) states that values less than 100 mg L^{-1} are not restrictive to irrigation.

2.3.3 Management of Salts in Irrigation

The development of excessive salinity within the crop root zone is a result of the interactions of two or more of the following factors (Havlin et al., 1999; Fitzgerald et al., 1994):

- Considerable amounts of sodium and chloride salts in the irrigation water,

- Failure to apply sufficient water to leach the Na and Cl ions adequately from the root zone,
- Unsuitable soil physical properties and drainage,
- High water table.

While it is important to have guidelines and loading limits for effluent application, establishment of a multifaceted monitoring program to examine water, soil and crop quality (Hillel, 2000; USEPA, 2006) improves integrity and sustainability of an irrigation program. Water quality monitoring on a periodic basis prior to the establishment of an irrigation program will allow for the establishment of a water quality baseline and identify fluctuations in quality parameters throughout the growing season (USEPA, 2006). Lazarova et al., (2005) recommend monthly monitoring of nutrients (nitrogen & phosphorous), salinity indicators (EC, TDS, cations and ions) and pathogens (total and fecal coliform) and annual measurements for trace elements or metals in irrigation wastewater. Crop growth and quality also has to be assessed, visual inspections for toxicity stresses, collecting of plant tissues for analysis and crop yield are important observations. An inventive monitoring program is the planting of salt sensitive plants to assess growing conditions not observable using salt tolerant species (Hillel, 2000).

Monitoring of soil quality for salinity, pH, trace elements, and nutrients is to assess changes and risk to soil quality and sustainability. Soil monitoring starts with a comprehensive baseline evaluation. Soil sampling to depth (120 cm) in representative soil types of the field receiving irrigation wastewater will establish a baseline for the crop-rooting zone. Salinity assessment parameters should include SAR, E.C., and a cation and ion balance. An assessment of these parameters will aid in the determination of exchangeable sodium percentage (ESP) of the soil profile (Hillel, 2000). The ESP is an evaluation of sodium ions that occupies exchange sites on colloids in relation to that of calcium, magnesium, and potassium. Irrigated soils that are in danger of becoming sodic have an ESP approaching 15 (McBride, 1994).

2.3.4 Trace Elements – Metals

Some trace elements (As, Cr, Fl, Pb, Hg, Mo, and Se) are of environmental and human health concerns because they are taken up by plants in amounts potentially harmful if consumed. Elements such as B, Cd, Cu, Cr, Ni, Zn, and Se are of concern due to toxicity to plants thus affecting yield potential (Lazarova et al., 2005) . Bioaccumulation of these elements in plants is dependent on the supply to the plant root and this is largely dependent upon the soil pH (McBride, 1994; Lazarova et al., 2005).

In sewage lagoon systems, trace elements or metals are strongly adsorbed to negatively charged organic and clay minerals and hence are concentrated in the sludge material (Hamilton, Stagnitti, Xiong, Kreidl, Benke, & Maher, 2007). Studies presented by Lazarova et al. (2005) and Hamilton et al., (2007) indicate that long-term irrigation projects in Israel (>20 years) and Australia (>107 years), indicate minimal environmental impact due to metals such as copper, chromium, nickel, zinc and cadmium.

The CCME (1999) CWQG for the protection of agricultural water uses and guidelines outlined by Lazarova et al. (2005) for metals (trace elements) are shown below.

Table 12 Trace Element Guidelines for Irrigation Wastewater

Element	CCME CWQG	Permanent Irrigation [a]	< 20yrs Irrigation [a]	Comments [a]
		(mg L^{-1})		
Al	5.0	5.0	20	Soil pH <5.5 & >7 can cause non-productivity and toxicity.
As	0.1	0.1	2.0	Toxicity to plants varies widely.
Be	0.1	0.1	0.5	Toxicity to plants varies widely.
Cd	0.0051	0.01	0.05	Toxic to beans, beets and turnips at 0.1 mg L^{-1}. CCME indicates four grain crop species are very sensitive.
Cr	0.0049 Cr III 0.008 Cr VI	0.1	1.0	Not an essential growth element. Conservative limits due to lack of knowledge on plant toxicity.
Co	0.05	0.05	5.0	Toxic to tomato plants at 0.1 mg L^{-1} Inactive in neutral to alkaline soils.
Cu	0.2 - 1.0	0.2	5.0	Toxic to a number of plants at 0.1-1.0 mg L^{-1}. CCME 0.2 mg L-1 for cereals, 1.0 mg L-1 for tolerant crops
Fe	5.0	5.0	20	Not toxic to plants in aerated soils, can contribute to soil acidification and loss of availability of essential P an Mo.
Pb	0.2	5.0	10	Can inhibit plant cell growth at very high concentrations
Li	2.5	2.5	-	Tolerated by most crops up to 5 mg L^{-1}, mobile in soil.
Mn	0.2	0.2	10	Toxic to a variety of crops in acid soils.
Mo	0.01 0.05 – short term use on	0.01	0.05	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage with high

Element	CCME CWQG	Permanent Irrigation [a]	< 20yrs Irrigation [a]	Comments [a]
		(mg L^{-1})		
	acidic soils			concentrations of available Mo.
Ni	0.2	0.2	2.0 – acid soils only	Toxic to a number of plants at 0.5-1.0 mg L-1; reduced toxicity at neutral or alkaline pH.
Se	0.02-continuous 0.05	0.02	0.02	Toxic to plants at concentrations as low as 0.025 mg L^{-1} and toxic to livestock if forage with relatively high levels Se.
V	0.1	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zn	1-soil pH<6.5 5-soil pH>6.5	2.0	10	Toxic to many plants at varying concentrations at pH>6.0 and in fine-textured or organic soils.

Note: Sources: (CCME, 1999; Lazarova et al., 2005)

[a] Maximum concentration level (MCL) based on water application rate consistent with good irrigation practices (10,000 m^3 ha^{-1} $year^{-1}$).

2.3.5 pH

The acceptable pH range for wastewater irrigation is between 6.5 and 8.4, the optimum range for crop growth. Wastewater with pH values outside of this normal range can create nutritional imbalance affecting crop growth and development (Lazarova et al., 2005). Continuous use of irrigation water with pH outside of the acceptable range may alter soil pH levels in surface soils and thus mobilize or immobilize trace elements depending upon the element's characteristics (Alberta Environment, 2000; McBride, 1994).

2.3.6 Pathogens

There are four main categories of microorganisms as potential risk to human health from wastewater irrigation. Pathogens of concern include bacteria, protozoa, viruses, and heminthic worms (Toze, 2006; Hamilton et al., 2007 and Lazarova et al., 2005).

There are three necessary components to produce an infectious disease transmission in a population; these are: (i) prescence of a disease; (ii) present in sufficient concentrations, and (iii) susceptible individuals, must have contact. Three primary risk exposure routes are ingestion, respiratory inhalation, and ocular contact for sprinkler wastewater irrigation. All three pathways can occur if an individual is directly exposed in an irrigation event. However, the general population's exposure is more likely from the eating of raw food crops irrigated with wastewater (NRC, 1996; Lazarova et al., 2005).

Actual risk exposure to pathogens from wastewater irrigation is low and is more directly related to the use of untreated sewage or low quality wastewater (NRC, 1996; Lazarova et al., 2005; Hamilton et al., 2007). Peasey, Blumenthal, Mara, and Ruiz-Palacios (2000) found that eating raw vegetables (carrots, cauliflower, lettuce and cucumbers) irrigated with partially treated wastewater did not increase the risk exposure to infections for the general population. Lazarova et al., (2005) also report that there is no strong evidence to suggest that people residing near wastewater irrigation sites are subject to increased risk from pathogens. Schaub, Bausum, & Taylor (1982) found that in sandy loam and silt loam soils there was good removal of wastewater borne viruses as the water moved down through the profile and that within 7.5 weeks after treatment nearly all viruses were absent.

The standard test to assess for the presence of microorganism pathogens in water is to measure total and/or fecal coliform bacteria. The CCME (1999) CWQG for the protection of agricultural water use criteria for fecal coliforms is 100 per 100 mL and for total coliforms is 1000 per 100 mL. The Manitoba Water Quality Standards, Objectives and Guidelines (Manitoba Conservation, 2002-11), Tier II for fecal coliform bacteria or *Escherichia coli* (*E.coli*) is 200 colony forming units per 100 ml during the irrigation season (May 1-September30) when workers or the public may come in contact with irrigation water.

2.3.7 Pharmaceutical and Personal Care Products

Pharmaceutical and personal care products are anthropogenic chemicals such as painkillers, antibiotics, antidiabetics, contraceptives, antidepressants, antieoplatics, hormone supplements, skin care products, shampoos, musks, etc. Recently, pharmaceutical and personal care products (PPCP) have become a concern in the discharge effluent from wastewater treatment systems and are considered an environmental risk (Kleywegt, et al., 2007). PPCPs in wastewater treatment systems are sourced from industries, medical care facilities, households (unused medications flushed down toilets and human excretion) and veterinary clinics. Miege, Choubert, Ribeiro, Eusebe, & Coquery, (2009), in a literature review identified more than 100 PPCPs from wastewater treatment plants. The PPCP identified include analgesics, anti-inflammatory drugs, antibiotics, bacteriostatics, anti-epileptics, betablockers, blood lipid regulators, contrast media, cytostatics, hormones, antidepressants, anxiolitics, musk fragrances, disinfectants and antiseptics.

Oppel et al., (2004) investigated the leaching behaviour of six pharmaceuticals in three different soils. They determined that carbamazepin, diazepam, ibuprofen and ivermectin were immobile in the soils assessed. However, they also observed that there was a discrepancy between their results and the behaviour of carbamazepin in the environment since it is found in groundwater samples. Oppel et al., (2004) also observed that clofibric acid and iopromide were mobile in the soil columns and thus a potential risk for groundwater impacts.

Lishman et al. (2006) assessed wastewater from 12 municipal treatment plants (3 lagoon systems) in southern Ontario for the presence of PPCPs, specifically selected acidic drugs, triclosan, polycyclic musks and estrogens. Their data showed that there were detectable levels of PPCPs being discharged, and that only some compounds are reduced significantly during sewage treatment. Several processes that influence reduction of PPCPs include sorption and de-sorption from the primary sludge and biosolids, biodegradation (complete or partial) and decomposition through deconjugation of human metabolites and photo-degradation in lagoon systems (Lishman, et al., 2006).

Kinney et al., (2006) assessed 19 PPCPs in soil irrigated with treated urban wastewater in Colorado, USA. It was observed that typical concentrations of individual PPCPs were low (0.02-15 ug kg-1 dry soil) and that some PPCPs accumulated in the surface soil and persisted for months. They found some of the PPCPs interacted with the soil organic matter, whereas nine of the PPCPs demonstrated vertical distribution within the top 30 cm of the soil demonstrating a potential for leaching of these compounds in soil. However, no confirmation sampling was completed below 30 cm nor in the vadose zone.

Ternes et al. (2007) conducted a study of the vadose zone and groundwater that assessed 52 PPCPs on a site with 45 years of wastewater irrigation in Germany. Measurable concentrations (micrograms per litre) of diatrizoate, iopamidol, iothalamic acid, carbamazepin, and sulfamethoxazole where identified in vadose zone lysimeters placed 0.4-1.2 metres below grade. In addition, measurable concentrations of diatrizoate, iopamidol, carbamazepin, and sulfamethoxazole were detected in the groundwater, 12 to15metres below grade. None of the other 47 PPCPs were detected in groundwater or aqueous vadose zone samples. Therefore, Ternes et al. (2007) concluded that the remaining 47 PPCP including acidic pharmaceuticals, musk fragrances, estrogens and betablockers were sequestered by sorption to clay and/or soil organic matter or transformed by degradation including biodegradation. In conclusion, they recognized that land treatment of wastewater through irrigation is an effective means to remove PPCPs.

Oppel et al., (2004); Kinney et al., (2006) and Ternes et al. (2007) all stated that further research is needed to assess the risk to human and environment health from PPCPs in wastewater irrigation and the potential for groundwater impacts. Toze (2006) states that, PPCPs are of little health risk since the concentrations of PPCPs in treated effluent are lower than the initial human exposure. However, the larger concern may be antibiotic resistance in microorganisms due to the discharge of antibiotics into the soil and water environment.

2.4 Social Perception

Social or public perception can limit, delay, or prevent particular practices with respect to wastewater reuse. Use of wastewater effluent irrigation is of concern to various stakeholders including nearby residents, communities (towns or special interest groups), and institutions (public and private) who can be affected directly or indirectly (Lazarova et al., 2005). Lazarova et al. (2005) assessed elements of perceived risk to include risk to human health, environmental quality impacts, and economics. Very little information on the public's perception to wastewater reuse and irrigation was found (Po, Kaercher, & Nancarrow, 2003; Friedler, Lahav, Jizhaki, & Lahav, 2006; Hartley, 2006; Hamilton et al., 2007).

Po et al. (2003) in a literature review assessed the factors that limit the acceptance of water reuse in Australia. Ten categories of public acceptance or perception of wastewater reuse was identified. Including: a disgust or yuck factor that is a psychological barrier to wastewater reuse, the public's perceived risk to using wastewater, and the source of wastewater (i.e. to reuse one's own wastewater versus their neighbours). They also found the public acceptance to wastewater reuse was generally lower when the contact potential was higher. Various studies reviewed by Po et al. (2003) found public opposition to domestic wastewater reuse for drinking water ranged from 44-74%, reuse for cooking at home ranged from 38-62%, reuse for bathing at home ranged from 22-52%, reuse for home toilet flushing ranged from 3-23% and home lawn/garden irrigation ranged from 1-6%. Po et al. (2003) also found that public opposition to agricultural reuse of wastewater for irrigation onto vegetable crops ranged from 7-21%, onto hay/alfalfa was 9%; onto dairy pastures was 15% and irrigation on to vineyard or orchards ranged from 10-15%.

Hartley's (2006) work on public perception and participation in water reuse consisted of a literature review. It was determined that public acceptance of wastewater reuse is higher when the degree of human contact is minimal, protection of public health and environment is clear, the community is aware of water supply limitations and the niche role of reclaimed water, and when the public has confidence in the costs and local management. Hartley's (2006) study on public perception and participation in water reuse also consisted of review of case studies that identified five related themes and broader social principles to improve the public's perception of wastewater reuse. Hartley (2006) found managing information, knowledge, local context, and education was all important in shaping public perception. If information appears to be incomplete, uncertain or have a "black-box" affect it will create a negative public sentiment. Hartley also found that sustaining commitment from individuals and organizations was essential to ensuring the success of water reuse projects. Institutions must demonstrate genuine commitment to projects to continue to build trust with project managers. Effective communication and quality dialog was found to further develop relationship with the public and acceptance of proposed projects. It was also found that fair and sound decision-making processes, based on technically and scientifically sound criteria are needed. Hartley (2006) concluded that the cumulative effect of the above four themes developed trust, public confidence, and success in each stakeholder.

Friedler et al., (2006) surveyed 256 participants in Haifa, Israel on public support on 21 wastewater reuse options that were categorized as low, medium, and high contact potential levels. Friedler et al. anticipated greater support for low contact reuse options. However, they found 86% support for field crop irrigation, 62% support for aquifer recharge for agricultural irrigation and only 49% support for orchard irrigation. This limited level of support was surprising, they stated, since these three low contact options are practiced on a large scale in Israel.

2.5 Wastewater Irrigation in Other Regions

Wastewater irrigation is a common means of irrigating crops. Globally, in 2001 an estimated 20 million hectares of land was irrigated with either treated or untreated wastewater (Hamilton et al., 2007). The World Health Organization (WHO) in 2006 estimated that global wastewater irrigation was about 3 to 3.5 million hectares (Water Policy Briefs, 2009). Friedler et al., (2006) report that Israel reclaims 65% of its sewage effluent with reuse projects varying in size from small and local to large and regional. In North America, Mexico irrigates in excess of 350,000 hectares of farmland in 40 irrigation districts. Wastewater from Mexico City is transported 65 km north to irrigate 90,000 hectares. In the United States, California (548 to 730-million m^3 yr^{-1}) and Florida (803-million m^3 yr^{-1}) are leaders in reuse of wastewater for irrigation (Hamilton et al., 2007).

Hogg et al. (1997) reported that in Canada there were 65 wastewater irrigation projects across Alberta (3050 ha), Saskatchewan (2620 ha) and Manitoba (53ha). Today, there are a 96 wastewater irrigation projects in Alberta alone (Aidun, B. Personal Communication, January 27, 2010). Clifton Associates reported in 2008 that there were three major irrigation projects in Saskatchewan located at Swift Current, Moose Jaw and Lloydminster (~690 ha) and 28 small community effluent irrigation projects. Hogg et al. (1997) had reported similar values for number of wastewater irrigation projects in Saskatchewan.

Irrigation at Moose Jaw has been conducted for over 25 years primarily onto forages, cereals, and oil seed crops and is approximately 1,200 ha in size. A review of groundwater and soil monitoring data completed in 2006, indicate that groundwater levels at the site are generally rising and that EC and SAR values in the soils under effluent irrigation are approaching guideline values (Pokhrel, 2009). The City of Swift Current effluent irrigation program was established in 1979 with approximately 335 ha (830 acres) under irrigation. Personal communication with the superintendant of wastewater treatment for the City of Swift Current determined that recent treatment plant improvements have reduced the need to irrigate and that only 100-120 ha (250-300 acres) of land was required in 2009. It was reported that the previous effluent irrigation program disposed of nearly 1,818,000 cubic meters of wastewater annually. However, today the program is based on crop requirements and only 681,913 cubic meters of wastewater is irrigated in a growing season (Cox, T., Personal Communication, January 25, 2010).

Currently, there are three municipal wastewater effluent irrigation projects in Manitoba, Town of Roblin, Town of Carberry, and the R.M of Lac du Bonnet (Webb, B. Personal Communication, and January 14, 2010). Irrigation at Roblin was started in 1993 using a pivot irrigation system (~53ha) to limit wastewater discharge to the Shell River and to utilize the nutrients on forages (Bereza, 2005). The irrigation program was greatly reduced in 2000 due to concerns of excess soil salinity and only limited irrigation has occurred in recent years (Bulbuck, L. and Todorovich, D., Personal Communication, January 14, 2010). The Town of Carberry irrigates approximately 137 ha each year with approximately 181,843 cubic meters of effluent. The operating licence requires that the effluent water has to be sampled twice during the growing season and the groundwater has to be sampled semi-annually. However, no soil sampling is required (McMillan, B., Personal Communication, January 22, 2010). Currently, the Rural Municipality of Lac du Bonnet operates a 14 ha irrigation program, applying approximately 25, 000 cubic meters of wastewater. However, the municipality plans to discontinue irrigation and develop a wetland treatment system instead (Strong, K. Personal Communication, January 20, 2010).

In western Manitoba, there are two private industry wastewater irrigation programs that reuse industrial effluent. In one instance, 181,000-273,000 m^3 of effluent is irrigated onto 480-550 ha of land primarily on forages (Sveistrup, R., personal communication, January 14, 2010). At the second location approximately 514,500 m^3 of effluent from a food processing plant is irrigated onto 378-450 ha of land, onto potatoes, forages, and cereals. This project is established on 604 ha of rotational land and will be expanding to 1,000 ha in size. Irrigation is based upon crop water demand and nutrient uptake and removal as the effluent is enriched with nitrogen, phosphorous and potassium (Hyra, B., personal communication, January 26, 2010)

Although there is no specific information provided for wastewater irrigation projects in western Canada, the information obtained for Moose Jaw and Roblin indicates a risk of environmental impacts. However, due to insufficient monitoring and reporting of data, it cannot be determined if these problems are inherent in all sewage effluent irrigation programs or a problem only for some programs and whether or not the adverse environmental impacts were due to inadequate planning (i.e. assessment of suitability of soils, quality of water and crop requirements) and/or subsequent management.

3 Methods

3.1 Study Sites

Eight sites, located at Arborg, Balmoral, Dunnottar, Petersfield, Stonewall, Stony Mountain, Teulon, and Winnipeg Beach, were selected for study (Figure 1). Each town or site had a sewage lagoon. The size of lagoons varies among sites and two of the sites have additional water polishing treatments systems. The Village of Dunnottar has added an enzyme and a filter bed treatment system to the wastewater lagoons and the R.M. of St. Andrews (Petersfield) has added a constructed wetland cell for treatment of wastewater prior to discharge. Sewage lagoons are a common biological treatment system for numerous small towns in Canada.

Discharge of wastewater from sewage lagoons is practised to increase holding capacity of lagoons to allow for inflow of wastewater from town sewers. The effluent is discharged directly to the adjacent surface drainage system (roadside ditch, secondary drain, or creek). Wastewater at Stony Mountain, Stonewall, Balmoral, and Teulon are discharged to second order drains, which enter creeks that flow to Lake Winnipeg. Wastewater at Arborg is discharged to a roadside ditch leading to the Icelandic River, which flows to Lake Winnipeg. Wastewater from Winnipeg Beach and Petersfield lagoons are discharged directly to Lake Winnipeg marshland. Wastewater from Dunnottar is discharged to a roadside ditch leading to Tuglea Creek, which drains to Lake Winnipeg (Table 13). Discharge volumes vary among sites and from year to year, due to differences in population, lagoon size, and annual precipitation.

3.2 Regional Study Area

The study was conducted within the south-eastern portion of the Interlake region of Manitoba (Figure 1). The eight study sites are located in two sub-district drainage basins to the Lake Winnipeg drainage basin. The Arborg site is in the Icelandic River and Willow Creek sub-district drainage system whereas the Stony Mountain, Stonewall, Balmoral, Teulon, Petersfield, Dunnottar, and Winnipeg Beach sites are located in the Netley and Wavey Creek sub-district. (East Interlake Conservation District [EICD], 2007, EICD, 2009). These two sub-districts lie within two Terrestrial Ecozones of Canada. The southern portion of the Netley and Wavey Creek sub-district is within the Prairies Ecozone and consists of the Lake Manitoba Plain Ecoregion. The northern portion of the district and the Icelandic River and Willow Creek sub-district lie within the Boreal Plains Ecozone and consists of the Interlake Plain Ecoregion (EICD, 2009). Surface elevation is highest in the west at 283 metres above sea level (ASL) sloping gently eastward to a low of 212 m ASL at the shore of Lake Winnipeg.

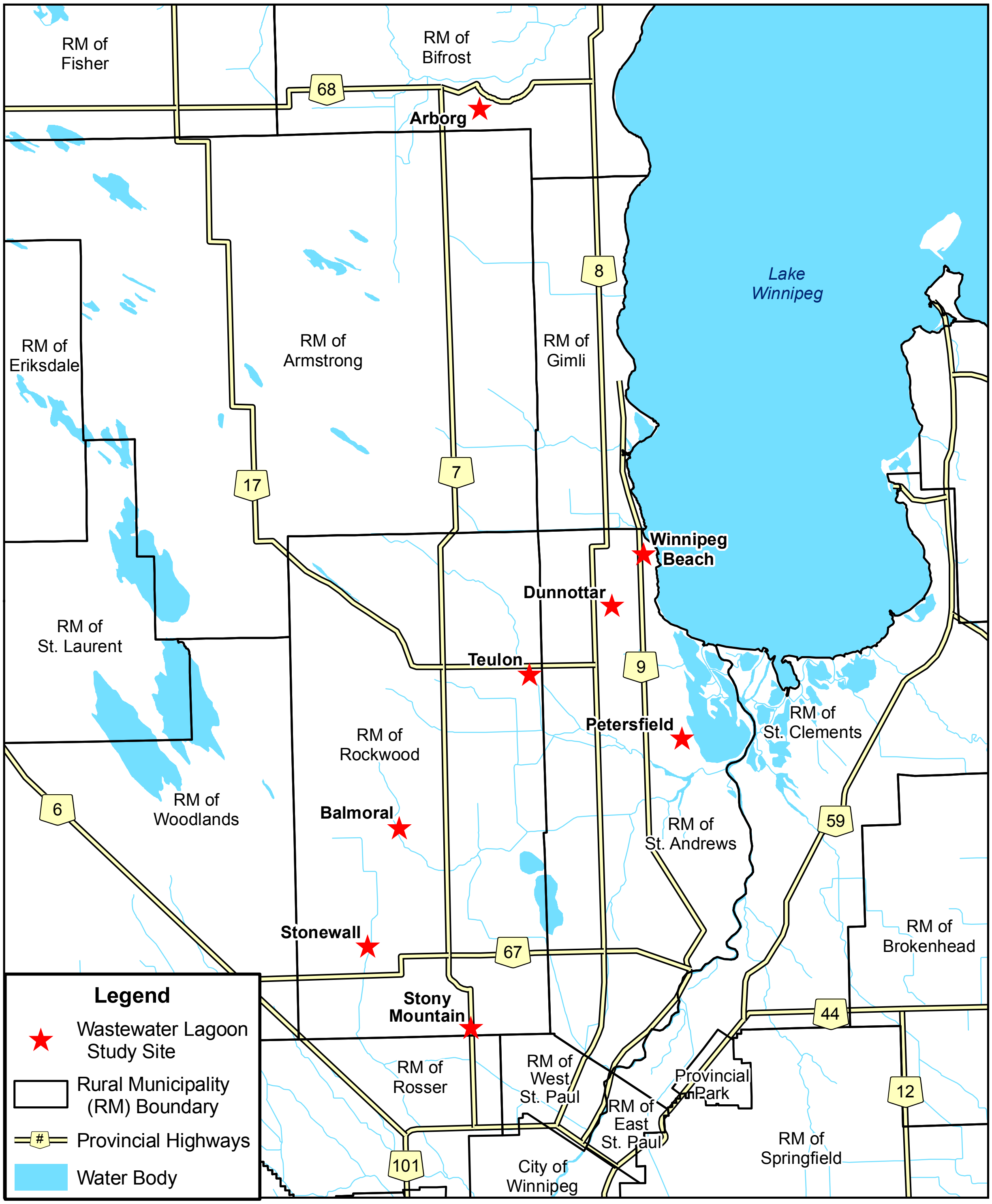
3.2.1 Geology and Surface Deposits

The regional study area is underlain by four distinct limestone, dolomite, and dolomite shale bedrock formations, they are: the East Arm Formation, the Stonewall Formation, Stony Mountain formation, and the Red River formation. The depth to bedrock ranges from less than a metre to greater than 25 metres below grade (EICD, 2009, Podolsky, 1986).

Surface deposits in the study area are thin veneers of clayey textured lacustrine sediment over thick, highly calcareous, loam to clay glacial till, over sand and gravel deposits (Michalyna & Podolsky, 1980; Podolsky, 1986)

3.2.2 Climate and Agrometerology

The climate for the Interlake region, is similar to the rest of southern Manitoba, and considered as subhumid, cool continental with large temperature differences seasonally (winter to summer) and daily (Shaykewich, 1997). Generally, in Manitoba approximately 60% of the annual precipitation occurs during the active growing season providing a significant portion of annual crop water demand (Shaykewich, 1997). Environment Canada maintaines 110 weather stations in Manitoba (Environment Canada, 2009). Three stations, Stony Mountain, Gimli, and Arborg were assessed, representing 30 years of climate normals in the southeast Interlake region (Table 14).



MUNICIPAL WASTEWATER IRRIGATION STUDY IN THE INTERLAKE REGION OF MANITOBA

Location of Study Sites

NORTH

Data provided by: Manitoba Land Initiative (MLI) Data Warehouse (2009). Retrieved December 21, 2009 from https://mli2.gov.mb.ca.

0 2.5 5 10 15 20

Kilometres

MAP SCALE 1:600,000

DATE December 21, 2009

FIGURE NO. 1

Table 13 Sample Site Characteristics, Drainage Network and Estimated Discharge Volumes

Study Site and Legal Land Location	Number of Residences & Businesses	Type of Treatment System	Discharge Drainage Network	Estimated Volume Discharged (m^3)			Mean Volume Discharged (m^3)
				2006	2007	2008	
Arborg NW14-22-2E	1345 Res. 182 Bus. [e]	Sewage Lagoons (1 Primary, 2 Secondary)	Ditch, Icelandic River, Lake Winnipeg	235,000	235,000	240,000	236,666
Balmoral SE06-15-2E	326 Res. 6 Bus. [c]	Sewage Lagoons (1 Primary, 1 Secondary)	Ditch, Jackfish Creek, Wavey Creek, Netley Creek, Red River, Lake Winnipeg	19,031	29,181	20,843	23,018
Dunnottar NW8-17-4E	381 Res. 16 Bus. [g]	Sewage Lagoons (1 Primary, 2 Secondary)	Ditch, Tuglea Creek, Lake Winnipeg	17,733	10,581	22,196	16,836
Petersfield SW36-15-4E	823Res. 38 Bus. [h]	Sewage Lagoons (1 Primary, 1 Secondary, 1 Wetland)	Lake Winnipeg marsh	-	None	None	-
Stonewall SE02-13-2E	2,515 Res. 160 Bus. [b]	Sewage Lagoons (1 Primary, 1 Secondary)	Centre Branch Grassmere Creek Drain, Grassmere Creek Drain,	416,500	416,500	397,500	410,167

Study Site and Legal Land Location	Number of Residences & Businesses	Type of Treatment System	Discharge Drainage Network	Estimated Volume Discharged (m^3)			Mean Volume Discharged (m^3)
				2006	2007	2008	
			Red River, Lake Winnipeg				
Stony Mountain SW35-13-1E	698 Res. 23 Bus. [a]	Sewage Lagoons (1 Primary, 3 Secondary)	East Branch Grassmere Creek Drain, Grassmere Creek Drain, Red River, Lake Winnipeg	121,672	124,992	148,519	131,728
Teulon SW21-16-3E	1092 Res. 86 Bus. [d]	Sewage Lagoons (2 Primary, 5 Secondary)	Netley Creek, Red River, Lake Winnipeg	306,000	311,000	271,000	296,000
Winnipeg Beach NW27-17-4E	750 Res. 55 Bus. [f]	Sewage Lagoons (2 Primary, 3 Secondary)	Lake Winnipeg Marsh	19,822	58,106	54,272	44,066

Note. - Discharge volume unknown.

[a] Canada Post Corporation Total Points of Call (January 7, 2010) within Postal Code: R0C 3A0, Stony Mountain Institute is not included. (Canada Post, 2010)

[b] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 2Z0, (Canada Post, 2010)

[c] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 0H0, (Canada Post, 2010)

[d] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 3B0, (Canada Post, 2010)

[e] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 3B0, (Canada Post, 2010)

[f] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 3B0, (Canada Post, 2010), does not include seasonal residents at summer cottages.

[g] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 2B0 (MatLock), (Canada Post, 2010), Does not include seasonal residents at summer cottages.

[h] Canada Post Total Points of Call (January 7, 2010) within Postal Code: R0C 2L0, (Canada Post, 2010), Does not include seasonal residents at summer cottages.

[i] Secondary treatment cells with enzyme treatment and a filter bed.

Table 14 Climate Normals for Southeast Interlake Region, May to September and Year

	May	June	July	Aug	Sept.	Year
Stony Mountain						
	Temperature (^oC)					
Daily Avg.	12.1	16.9	19.5	18.4	12.3	2.5
Std Dev.	2.3	1.7	1.4	1.9	1.6	1.5
	Precipitation (mm)					
Rainfall	54.5	88.9	71.5	68.6	52.9	407.7
Precipitation	54.8	88.9	71.5	68.6	53.1	510.4
Gimli[a]						
	May	June	July	Aug	Sept.	Year
	Temperature (^oC)					
Daily Avg.	10.6	16.1	19.2	17.5	11.6	1.8
Std Dev.	2.6	1.7	1.3	1.9	1.3	1.4
	Precipitation (mm)					
Rainfall	47.6	94.1	69.7	64.2	65.6	407.8
Precipitation	49.8	94.1	69.7	64.2	66.7	532.5
Arborg						
	May	June	July	Aug	Sept.	Year
	Temperature (^oC)					
Daily Avg.	10.5	15.7	18.3	17.1	11	1.1
Std Dev.	2.4	1.7	1.5	1.7	1.4	1.4
	Precipitation (mm)					
Rainfall	47.6	76.9	70.9	79.7	55.2	402.5
Precipitation	48.4	76.9	70.9	79.7	55.8	506.1

Note. Snowfall is the difference between Rainfall and Precipitation.

Gimli is not a Study Site but is located within the study region along the Lake Winnipeg shore.

Source: Environment Canada (2009)

3.3 Suitability of Land for Wastewater Irrigation

Land suitability for wastewater irrigation was determined from existing soil information for the eight sections of land surrounding each study site and the section of land occupied by the lagoon. Soil Agricultural Interpretation Database (SoilAID) data was retrieved from the Manitoba Land Initiatives (2009) web site, a data warehouse for geo-spatial data in the province of Manitoba. Through a series of queries of the SoilAID database for the R.Ms of Rockwood, Rosser, St. Andrews, and Bifrost with ESRI ArcView, the dominant agricultural interpretation data was compiled for each study site. The compiled data included the study site, map scale, dominant agricultural capability, dominant irrigation classification, soil and landscape factors, general irrigation rating, and potential environmental impact rating. Within the SoilAID database, there are two basic scales of soil survey, detailed and reconnaissance. Both detailed and reconnaissance map scales combined to provide an aerial extent of each assessed property.

The information and background needed for evaluation of soils for suitability for irrigation and agricultural land capability was outlined in detail in the review of literature.

3.4 Wastewater Discharge Volumes

The lagoon characteristics, and volume of wastewater discharged from each lagoon system was determined through discussions with the respective wastewater lagoon managers or review of past records.

3.5 Wastewater Sampling

Wastewater samples were collected during the spring and fall release events from the retention cells near the discharge area at each site. Sampling in spring occurred on June 1 at Winnipeg Beach, June 2 at Stonewall and June 16 at all remaining sites. Sampling in fall at all sites was conducted on October 4, 2009.

Samples were obtained by gently lowering a clean, laboratory-supplied, one litre plastic bottle into the water column. The one litre plastic bottle was removed and the sample of water distributed to appropriate sample bottles containing preservative. Samples were not field filtered. Containers were labelled, placed in a cooler and maintained at approximately $4^{o}C$. Samples were then delivered to EXOVA (formally Bodycote Testing Group) laboratory in Edmonton, Alberta within 24 hours of collection. EXOVA is an ISO/IEC 17025, SCC, and CAEAL accredited testing laboratory. Standard chain-of-custody procedures were followed during sample handling and delivery.

Duplicate and trip blank sample sets for Quality Control (QC) were taken for each sampling event. Duplicate wastewater samples were taken from the Stonewall and Arborg Sites in spring and at the Balmoral and Winnipeg Beach Sites in fall. A spring and fall trip blank was opened at the Arborg Site, preservative added if required, and submitted. The analytical results of the wastewater samples and the respective duplicates and blanks generally showed that sampling procedures and protocols maintained integrity of samples.

Laboratory methods of analysis, references, comments, and QA/QC reports are in Appendix C. Analytical parameters for evaluation of wastewater are outlined in Table 15.

Table 15 Nutrients, Salts, and Trace Elements Selected for Analysis

	Specific Analytic Parameter	
Nutrients	Total Nitrogen	Total Phosphorous
	Nitrate-nitrogen	Organic Phosphorous
	Ammonium-nitrogen	Dissolved Phosphorous
	Organic nitrogen	
Salts	Chlorides	Sulfate
	Calcium	Electrical Conductivity (E.C.)
	Magnesium	Sodium Adsorption Ratio (SAR)
	Potassium	Total Dissolved Solids (TDS)
	Sodium	
Trace Elements (metals)	Aluminum	Lead
	Arsenic	Mercury
	Boron	Nickel
	Cadmium	Selenium
	Chromium	Vanadium
	Copper	Zinc
Other Parameters	Total Suspended Solids	pH
	Total and Fecal Coliform	

3.6 Wastewater Irrigation Criteria

The following regulatory criterion was utilized to assess the quality of the wastewater for irrigation:

1) Canadian Council of Ministers of the Environment (CCME), Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses, (CCME 1999).
2) Manitoba Water Quality Standards, Objectives, and Guidelines, Final Draft. Manitoba Conservation Report 2002-11, (Water Quality Management, 2002)
3) Guidelines for Municipal Wastewater Irrigation. (2000). Alberta Environment, (Alberta Environment, 2001)
4) Surface Water Quality Objectives (EPB 356, July 2006). Saskatchewan Environment, (Saskatchewan Environment, 2006).

3.7 Social Perception

Three assessments of the social perception of wastewater irrigation were conducted;

1) Municipal and Town focus group discussions – the governing bodies who would initiate municipal lagoon water reuse;
2) Survey of residents living directly around the area where irrigation may be conducted;
3) Odour perception survey – Odour intensity was assessed by volunteers during a field demonstration of wastewater irrigation.

3.7.1 Municipal/Town Council Group Discussions

The objective of the council group discussion was to gauge municipal and town leaders' perception of wastewater irrigation on agricultural land and to identify the goals and objectives of these communities regarding wastewater and nutrient management and abatement. Group discussions took place during regularly scheduled council meetings. Discussions, typically scheduled for 15-20 minutes, were prompt and direct, allowing little time to explore alternative questions. A few discussions extended beyond 15 minutes. The survey, shown in Appendix B, included a neutral introduction followed by six questions and open discussion. Discussion included council's perception of wastewater irrigation, their current programs, and limits to moving forward with alternative programs such as irrigation, and financial and regulatory limitations to proceeding with a reuse program. An ethical review was submitted to Royal Roads University on February 18, 2008 and approval shortly thereafter.

Seven council group discussions were planned. However, due to council time constraints only five were conducted. Councils to the Villages of Winnipeg Beach and Dunnottar were not interviewed.

3.7.2 Resident Survey

A survey targeting residents who live, own and rent residences up to a 1.8-2.0 km perimeter around each lagoon was conducted for each site. The intent was to target residents and landowners who are neighbours of the lagoons. The objective of the survey was to gauge the public perception of wastewater irrigation on agricultural land and the acceptance of alternative wastewater reuses. The target audience was one resident member of the household, sixteen years of age or older. The minimum age of 16 was selected since these people will be setting goals and initiatives for these communities.

The survey was distributed in two manners: a door-to-door survey was conducted for Stony Mountain, Stonewall, Balmoral, Teulon, and the Dunnottar sites during September 2009. A survey by mail was conducted for the towns of Arborg and Winnipeg Beach since these towns were adjacent to the lagoon sites. The residents of the town of Stonewall were also included in the mail survey since only the rural residents were surveyed in the door-to-door campaign. An ethical review was submitted to Royal Roads University on February 18, 2008 and approval shortly thereafter. The survey questionnaire included a consent form, neutral introductory paragraph, 23 research questions, and 6 demographic questions (Appendix B).

3.7.3 Odour Perception Survey

The third method of assessing the public perception of effluent irrigation was through a field demonstration of effluent irrigation. The objective was to assess odour intensity during an irrigation event by obtaining neighbours's opinions. Three Sites were selected, Stony Mountain, Stonewall, and Balmoral. Neighbours to the three sites were invited to attend one of the demonstrations of irrigation scheduled for September 26 and 27, 2009.

With permission from the wastewater lagoon managers a mini-gun irrigation system was setup adjacent to the discharge cell of the three lagoons. A sucker hose was weighted and placed into the lagoon water of the discharge cell approximately 1.2 to 1.5 metres from the cell berm. The sucker hose and an oscillating sprinkler head from a mini- OCMIS irrigator were attached to a 2 inch, 5 horsepower Honda water pump. Lagoon water was pumped through the system and the oscillating sprinkler head was adjusted so that discharge was focused in an appropriate direction and distance (20-25 m) on to a grassed surface or back into the lagoon cell to minimize exposure to assessors.

During the irrigation event, the participants were asked to stand at determined distances from the irrigation event (25 m, 50 m, 100 m, and 200 m) generally down wind and parallel to the irrigation event. To assess odour intensity, the odour assessors were asked to don a 3M 8247 Particulate Respirator R95 carbon filtered mask (suitable for nuisance level organic vapour relief) (Appendix A, Photos). Each odour assessor wore the carbon filtered mask for about two minutes to clear their nose. The assessors then removed the mask and breathed normally to evaluate and assign an intensity level to the odour. Assessments of odour were conducted prior to irrigation to assess odours naturally occurring in the area. The sprinkler head was then run for approximately 10 minutes prior to assessing for odour due to irrigation. Assessor opinions on the degree of odouriferousness was determined on a scale of 0 to 5 (0 = no odour, 5 = extremely annoying) as used by Zhang (2002). For each event, climatic conditions were recorded (wind speed and direction, temperature and cloud cover).

Inquires to Manitoba Conservation (Director of Environmental Assessment and Licencing Branch, November 3, 2008) indicated that no regulatory guidelines were breeched for such a study and that the local Environment Officer was contacted prior to the demonstration event. A safety assessment was completed prior to each event and was explained to the participants at the time of the demonstration. Clean water, soap, and hand towels were provided for the assessors.

4 Results

4.1 Crop Water Demand

Crop water demand (CWD) is the amount of water that a crop would use given an unlimited supply. The difference between CWD and the growing season precipitation plus the amount of available soil moisture is crop water stress (CWS). Forage crops have one of the longest growing periods and therefore one of the highest water demands and hence the potential for the most CWS (Nadler, 2007). Nadler (2007) completed an agroclimatic risk assessment for agricultural production across western Canada for frost, heat, and moisture. The risk assessment was based on 30 years of daily climate data from 77 weather stations in Manitoba, Saskatchewan, and Alberta. Nadler (2007) reports the mean CWD for forages is 678 mm, 596 mm, and 635 mm for Stony Mountain, Gimli, and Arborg, respectively, with a mean growing season precipitation of 376 mm, 378 mm, and 363 mm, respectively. Nadler also modelled the probability that a forage crop would be limited by water for limitations of 50 mm, 100 mm, 150 mm, 200 mm, and 250 mm of water stress at each weather station. The probability of crop water stress occurring means that in any given growing season there is a likelihood that there will be a given amount (50 mm, 100mm, 150 mm, 200 mm and 250 mm) of crop water stress and that irrigation would aid in alleviating CWD and hence increase yield. For Stony Mountain and Arborg, there is a high probability (0.97-0.99) that forage crops will have a crop water stress of at least 100 mm and a good probability (0.58-0.65) that a forage crop will have a CWS of 150 mm (Table 16). Therefore, Nadler's assessment of climatic data in the Interlake region indicates that CWD and CWS of forage crops is high enough to consider use of wastewater for irrigation since there is a need for additional water in virtually all years to maximize forage yield. For example, there is a virtual certainty that 100 mm of irrigation water could be applied each year.

Table 16 Growing Season Rainfall, Crop Water Demand and Probability of Moisture Stress for Forages in the South-Eastern Interlake Region

		Station		
Forage Crop Water Normals		Stony Mountain	Gimli	Arborg
Growing Season Rainfall (mm) [a]	Mean	376	378	363
	10%	253	252	248
	25%	311	312	302
	50%	376	378	363
Crop Water Demand (mm) [b]	Mean	678	596	635
	10%	747	657	699
	25%	714	628	669
	50%	678	596	635
Probability of Moisture Stress [c]	50 mm	0.99	0.88	0.99
	100 mm	0.99	0.52	0.97
	150 mm	0.65	0.31	0.58
	200 mm	0.43	0.18	0.35
	250 mm	0.28	0.11	0.21

Note. Source: Nadler (2007).

[a] Risk level: 10% (1 out of 10 years), 25% (1 out of 4 years), and 50% (1 out of 2) means that the amount of growing season rainfall will be limited to the predicted value or less.

[b] 10% (1 out of 10 years), 25% (1 out of 4 years), and 50% (1 out of 2) means that the amount of crop water demand would be expected to be higher than the values provide.

[c] A high probability value indicates a high likelihood of receiving the given amount of stress over a growing season.

4.2 Wastewater Discharge Volumes and Required Land Area

Discharge of wastewater at Stony Mountain, Stonewall, Balmoral, Teulon, Arborg, Dunnottar, and Winnipeg Beach is conducted each spring and fall. Discharge of wastewater at Petersfield occurs approximately once in three years. Stonewall had the largest discharges during the 2006, 2007, and 2008 seasons (average: 410,170 m^3). Discharges at Teulon, Arborg, Stony Mountain, and Winnipeg Beach were 296,000 m^3, 236,666 m^3, 131,728 m^3, and 44,066 m^3, respectively for 2006-2008 and discharges of wastewater at Balmoral was only 23,018 m^3 (Table 17).

The land area required annually at each site to utilize the wastewater, based on a CWS demand of 50 mm, 100 mm, and 150 mm are outlined in Table 17. A very high probability of CWS of at least 100 mm each year exists across the east Interlake region, except at Gimli. If a CWS of 100 mm is selected as a value to assess annual land requirements, the land area requirements vary from 17 to 410 ha for the various sites.

Table 17 Land Area Required for Wastewater Irrigation at Each Site

Study Site	Average Discharge Volume (m^3)	Crop Water Stress		
		50 mm	100 mm	150 mm
		Land Area Required (ha)		
Arborg	236,666	473	237	158
Balmoral	23,018	46	23	15
Dunnottar	16,836	34	17	11
Stonewall	410,167	820	410	273
Stony Mountain	131,728	263	132	88
Teulon	296,000	592	296	197
Winnipeg Beach	44,066	88	44	29

Note: Land Area Required = Discharge Volume (L) ÷ Crop Water Stress (L ha^{-1})

Three sites, Dunnottar, Winnipeg Beach, and Balmoral have very small land area requirements; whereas Stonewall, Stony Mountain, and Arborg need a relatively large land area each year to utilize wastewater. Land areas needed would be considerably less in drier years than in average years. However, for sustainability, it would be prudent to plan on annual land requirements based on a high probability of a lower crop water stress to ensure appropriate sustainable management.

4.3 Land Suitability for Wastewater Irrigation

4.3.1 Agricultural Capability

Land used for wastewater irrigation must meet acceptable agricultural capability to ensure good yield of crops and sustainable land use. Aerial extent of various CLI soil classes at each site are presented in Table 18. The total land area with agricultural capabilities that allow for good forage production (class 1 to 5) ranged from 675 to 2,398 ha at the various study sites. Most of the land area is classed as CLI classes 2 to 4, with very small area of class 1 land. As noted in the previous section, the annual land requirements for irrigation based on water usage ranged from 17 to 410 ha if 100 mm of water is applied. Thus agricultural land base (CLI classes 1 to 5) near each site is much larger than that required for irrigation.

4.3.2 Water Quality Management Zones

The area of land adjacent to each site is virtually all within WQMZ N1 and N2. Nutrient application within these zones needs to match crop demand and/or uptake and removal but are not overly restrictive. Hence, WQMZ regulation will not limit nutrient application to levels such that irrigation with wastewater would not be permitted. Normal fertilization practices could be followed.

4.3.3 Irrigation Suitability

The area of land in each irrigation class at each site is summarized in Table 19. The majority of land at all sites is classed as fair to poor for general irrigation suitability. The major limitations to irrigation are drainage or excess soil wetness. Two of the sites, Balmoral and Stonewall have relatively large area of land assessed as excellent and/or good. The Balmoral Site has 166 ha of land classed as excellent and 722 ha of land classed as good. Stonewall, has 343 ha of land classed as good with the remaining land assessed as fair and poor.

Table 18 Aerial Extent (ha) of various CLI Agricultural Capability Classes for Study Sites

Study Sites	Agricultural Capability Class Land Area (ha) and (subclass Limitations)					
	1	2	3	4	5	Total Area
Arborg	0	0	230 (W)	400 (DP)	45 (M)	675
Balmoral	1	1443 (D, M, W, and X)	677 (D, W, M)	187 (DP, M)	99 (M,W)	2,407
Dunnottar	0	471 (D, W, WP)	294 (D, W, P)	1073 (DP)	529 (M,P,W)	2,367
Petersfield	0	499 (D, W)	386 (D, W)	0	0	885
Stony Mountain	12	396 (D, M, W)	1641 (D,W,N, NW)	197 (N, R)	117 (M,P,W)	2,363
Stonewall	13	1761 (D, M, W)	395 (W, NW)	198 (M,R)	25 (M)	2,392
Teulon	0	278 (W)	2120 (D, W)	0	0	2,398
Winnipeg Beach	0	611 (D, DP, W, WP)	633 (D, W)	0	123 (W)	1,367

Note. Data provided by: Manitoba Land Initiative (2009)

Table 19 Aerial Extent of Suitability of Land for Irrigation

Study Site	General Irrigation Suitability Rating (ha)			
	Excellent	Good	Fair	Poor
Arborg			400	1347
Balmoral	166	722	1288	239
Dunnottar			1257	1132
Petersfield			402	1066
Stonewall		343	255	1793
Stony Mountain		21	1543	799
Teulon			278	2120
Winnipeg Beach			139	1304

Note. Data provided by: Manitoba Land Initiative (2009)

Only the Balmoral site has sufficient land within the excellent to good class for irrigation to meet annual land requirements. Irrigation at all other sites would need to be extended onto land classed only as fair. Irrigation on soils rated as fair is sustainable if irrigation water is good or excellent in quality and under good management. Hence, sustainability of irrigation at seven of eight sites is highly dependent on quality of the irrigation wastewater and management.

4.4 Water Suitability for Wastewater Irrigation

4.4.1 Nutrients (Nitrogen and Phosphorous)

Total nitrogen (TN), ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) contents of wastewater were determined for each site. Organic nitrogen was obtained by calculating the difference between total N and ammonium N (Table 20). Analytical results obtained for the

Petersfield second treatment cell will not be included in the discussion of results as this is only a settling cell and water is not discharged from it. Total nitrogen in wastewater ranged from 1.63 to 13.80 mg L^{-1} in June and from 1.87 to 14.3 mg L^{-1} in October for the various sites. Wastewater at Teulon had a low amount of TN in June (1.63 mg L^{-1}) and October (1.87 mg L^{-1}). Nitrogen contents of wastewaters in June at Stony Mountain, Balmoral, Winnipeg Beach, and Dunnottar sites were quite different for water collected than October. Wastewater at Stony Mountain and Winnipeg Beach had higher total nitrogen and ammonium-nitrogen contents in June than in October whereas the Balmoral and Dunnottar sites had higher total nitrogen and ammonium-nitrogen contents in October than in June. Nitrate-nitrogen concentrations were relatively low (<0.05-0.59 mg L^{-1}) for all sites and sample times, except for the Winnipeg Beach site in June (2.90 mg L^{-1}). Organic nitrogen content of the wastewater samples was determined by subtracting the ammonium-nitrogen content from the total nitrogen content. Organic nitrogen ranged from 1.58 to 6.82 mg L^{-1} for the seven sites. Duplicate samples collected at Stonewall and Arborg in June and Balmoral and Winnipeg Beach in October were in good agreement.

Total, organic, dissolved, and percent dissolved phosphorous (P) values for wastewater at the various sites are outlined in (Table 21). Total P concentration for the various wastewaters ranged from 0.63 to 3.67 mg L^{-1} in June and from 1.72 to 5.14 mg L^{-1} in October. Total P was similar for samples taken in June and October at all sites, except at Balmoral, which varied considerably between sample times (0.63 mg L^{-1} in June and 4.26 mg L^{-1} in October). Total P content of waters at all sites except for Balmoral in June was greater than the anticipated regulatory discharge criteria of 1.0 mg L^{-1} to be set by Manitoba Water Stewardship.

Organic P concentrations ranged from 0.16 to 1.53 mg L^{-1} in June for the various sites. In October, the detection limit was raised due to matrix interference and therefore phosphorous contents for a number of samples were less than the detection limit (<0.09). Duplicate samples for organic P taken at the Winnipeg Beach site in October were not in good agreement, indicating that some of the values recorded may be in error (Table 21). Dissolved P in June ranged from 0.4 to 3.08 mg L^{-1} at the various sites and constituted between 50 and 94% of total P. In October, dissolved P ranged from 1.34 to 5.03 mg L^{-1} and constituted between 71 and 100 % of the total P (Table 21). The high portion of dissolved P in the waters indicates that the phosphorous is discharged waters would be highly available to plants or organisms.

Duplicate samples taken at Stonewall and Arborg in June, and Balmoral and Winnipeg Beach in October, showed good agreement for total and dissolved phosphorous contents.

Total amounts of nitrogen and phosphorous applied with 100 mm of wastewater to a hectare of land was calculated (Table 22). Potential total nitrogen loadings ranged from 1.8 kg ha^{-1} to 10.6 kg $ha^{-1}$and total phosphorous loadings ranged from 1.4 kg ha^{-1} to 3.0 hg ha^{-1}. Approximately 115 kg ha^{-1} of nitrogen and 15 kg ha^{-1} of P is removed with an average forage hay yield of 6.7 tonnes ha^{-1} (Manitoba Agriculture, Food and Rural Initiatives[MAFRI], 2009). Therefore, at 100 mm of wastewater irrigated, the amounts of nitrogen and phosphorous applied per hectare is much less than crop removal and hence commercial fertilizer would need to be added to correct nutritional deficiencies. Soil tests would need to be taken periodically to ensure adequate fertility for good crop growth.

4.4.2 Nutrient Discharge

The mass of nitrogen and phosphorous discharged from each site was calculated based on the concentrations of nutrients and mean volume discharged (Table 23). The mass of nitrogen varied from 96 kg to 2,562 kg and the mass of phosphorous varied from 26 to 753 kg. Stonewall discharged the largest amount, approximately 2,562 kg of total nitrogen and 753 kg of total phosphorous annually and Dunnottar, with a filter bed treatment system, annually discharged approximately 96 and 26 kg of total nitrogen and phosphorous. Cumulatively, discharged effluent results in 5,815 kg of total nitrogen and 2,332 kg of total phosphorous entering surface water bodies annually (Table 23).

Table 20 Nitrogen Content of Wastewaters

Study Sites	Parameters	TN	NH_4-N	NO_3-N	Organic-N
	Date	mg L^{-1}			
Arborg	June	3.36	1.00	0.13	2.36
	June [a]	3.45	1.02	0.11	2.43
	Oct.	3.63	1.62	0.16	2.01
Balmoral	June	2.98	<0.05	0.01	2.93
	Oct.	14.30	11.00	0.01	3.3
	Oct. [a]	14.40	11.6	0.01	2.8
Dunnottar	June	2.90	0.39	0.07	2.51
	Oct.	8.520	4.75	0.01	3.77
Petersfield	June	56.20	40.10	<0.05	16.10
2nd cell	Oct.	41.00	25.50	1.18	15.5
3rd cell	Oct.	6.52	3.35	0.05	3.17
Stony Mountain	June	13.80	9.90	0.08	3.90
	Oct.	7.26	0.44	0.37	6.82
Stonewall	June	7.00	0.71	0.59	6.29
	Oct. [a]	6.71	0.69	0.59	6.02
	Oct.	5.03	1.08	0.08	3.95
Teulon	June	1.63	<0.05	0.01	1.58
	Oct.	1.87	0.16	0.02	1.71
Winnipeg Beach	June	6.43	0.33	2.90	6.10
	Oct.	3.28	1.20	0.16	2.08
	Oct. [a]	3.00	1.23	0.16	1.77
QA Trip Blank	June	0.41	<0.05	<0.01	-
	Oct.	0.07	<0.5	<0.01	-
NDL	-	0.06	0.05	0.01	-

Note. [a] Duplicate sample, NDL = Nominal Detection Limit, < = Less than NDL

Organic Nitrogen = Total Nitrogen – Ammonium Nitrogen

Table 21 Dissolved, Total and Organic Phosphorous Content of Wastewaters

Study Site	Parameters	Total P	Total Organic P [b]	Total Dissolved P	Dissolved P
	Date		mg L^{-1}		(%)
Arborg	June	1.91	0.96	1.76	92.15
	June [a]	1.88	1.02	1.77	94.15
	Oct.	3.36	<0.09	3.34	99.40
Balmoral	June	0.63	0.102	0.40	63.49
	Oct.	4.26	<0.09	4.10	96.24
	Oct. [a]	4.26	<0.09	4.13	96.95
Dunnottar	June	1.16	0.657	1.09	93.97
	Oct.	1.88	<0.09	1.34	71.28
Petersfield	June	9.64	2.60	5.46	56.64
2^{nd} cell	Oct.	10.2	2.70	5.78	56.67
3^{rd} cell	Oct.	5.14	<0.09	5.03	97.86
Stony Mountain	June	3.51	1.53	3.08	87.75
	Oct.	2.24	<0.09	1.63	72.77
Stonewall	June	1.73	0.75	0.90	52.02
	June [a]	1.79	0.752	0.90	50.28
	Oct.	1.99	<0.09	1.69	84.92
Teulon	June	1.08	0.557	1.02	94.44
	Oct.	1.72	<0.09	1.72	100.00
Winnipeg Beach	June	3.67	1.03	2.53	68.94
	Oct.	2.49	0.33	2.10	84.34
	Oct. [a]	2.49	0.16	2.38	95.58
QA Trip Blank	June	<0.05	<0.003	<0.05	
	Oct.	0.006	<0.004	<0.05	
NDL		0.003	0.003	0.05	

Note. [a] Duplicate sample, NDL = Nominal Detection Limit, [b] Detection limit for organic P is 30x higher than NDL due to matrix interference.

Table 22 Total N and P Applied per 100 mm Wastewater

Study Site	Mean Total Nitrogen (mg L^{-1})	Total Nitrogen Applied (kg ha^{-1})	Mean Total Phosphorous (mg L^{-1})	Total Phosphorous Applied (kg ha^{-1})
Arborg (n=3)	3.48	3.0	2.38	2.0
Balmoral (n=3)	10.56	11.0	3.05	3.0
Dunnottar (n=2)	5.71	6.0	1.52	1.0
Stony Mountain (n=2)	10.53	10.0	2.88	3.0
Stonewall (n=3)	6.25	6.0	1.84	2.0
Teulon (n=2)	1.75	2.0	1.40	1.0
Winnipeg Beach (n=3)	4.23	4.0	2.88	3.0

Note. TN Applied (kg ha^{-1}) = (TN mg L^{-1} × 1,000,000 L ha^{-1}) ÷ (1,000,000 mg kg^{-1}), same for P.

n = number of samples

Table 23 Total Nitrogen and Phosphorous Discharged in Wastewater

Study Site	Average Volume Discharge (m^3)	Mean Total Nitrogen Concentration (mg L^{-1})	Mean Total Nitrogen Released (kg)	Mean Total Phosphorous Concentration (mg L^{-1})	Mean Total Phosphorous Released (kg)
Stony Mountain (n=2)	131,728	10.53	1,387	2.88	378
Stonewall (n=3)	410,167	6.25	2,562	1.84	753
Balmoral (n=3)	23,018	10.56	243	3.05	70
Teulon (n=2)	296,000	1.75	518	1.40	414
Arborg	236,666	3.48	823	2.38	564

Study Site	Average Volume Discharge (m^3)	Mean Total Nitrogen Concentration (mg L^{-1})	Mean Total Nitrogen Released (kg)	Mean Total Phosphorous Concentration (mg L^{-1})	Mean Total Phosphorous Released (kg)
Stony Mountain (n=2)	131,728	10.53	1,387	2.88	378
(n=3)					
Winnipeg Beach (n=3)	44,066	4.23	186	2.88	127
Dunnottar (n=2)	16,836	5.71	96	1.52	26

Note. Petersfield not included since no discharge volume reported. n = number of samples

4.4.3 Salt

4.4.3.1 Electrical Conductivity

E.C. of wastewater ranged from 0.729 dS m^{-1} (Balmoral) to 2.33 dS m^{-1} (Stony Mountain) in June and between 1.06 dS m^{-1} (Balmoral) to 2.7 dS m^{-1} (Petersfield & Stonewall) in October. E.C. of wastewater exceeded the Tier II Manitoba Water Quality Standards, Objectives, and Guidelines (2002) of 1.5 dS m^{-1} for irrigation at the Winnipeg Beach, Stonewall, and Stony Mountain sites in June. Wastewater at Dunnottar, Stonewall, Stony Mountain, and Petersfield exceeded the Manitoba guidelines in October (Table 24). Wastewater at Balmoral, Arborg, and Teulon had E.C values in both June and October that were consistently below allowable limits for Manitoba (Table 24). E.C values of duplicate samples were in good agreement.

E.C. of wastewater at all sites, except Balmoral in June, exceeded the Saskatchewan Environment minimum requirement (<0.7 dS m^{-1}) and the Alberta Environment guideline (<1.0 dS m^{-1}) for municipal wastewater irrigation for no restrictions on irrigation water. E.C. of wastewater at all sites were within the Saskatchewan Environment slight to moderate restrictions class (0.7-3.0 dS m^{-1}) and the Alberta Environment "possibly safe" guideline limit (1.0-2.5 dS m^{-1}) in June. However E.C. of wastewater at Stony Mountain, Stonewall, and Petersfield exceeded the Alberta guideline in October. In general, E.C. of wastewaters except at Balmoral was higher than limits considered being safe for most soils.

4.4.3.2 Sodium Adsorption Ratio

Sodium Adsorption Ratios (SAR) of wastewater ranged from 1.2 (Balmoral) to 7.3 (Stonewall) in June and from 0.9 (Balmoral) to 7.6 (Stonewall) in October. The SAR values for all sites except Stonewall were below the Tier II Manitoba Water Quality Standards, Objectives, and Guidelines for irrigation (2002) of 6.0 mg L^{-1} (Table 24). SAR values were similar for samples collected in June and October and values of duplicates were in good agreement.

SAR in wastewater at Arborg, Balmoral, Teulon, and Winnipeg Beach were below the Saskatchewan Environment (<3) and Alberta Environment (<4) guideline limits for safe irrigation. Water at Dunnottar, Petersfield, Stonewall, and Stony Mountain would be classed as possibly safe or slight to moderate restrictions for wastewater irrigation in Alberta and Saskatchewan.

4.4.3.3 Chloride

Chloride concentrations (Cl) in wastewater ranged from 54.5 mg L^{-1} (Balmoral) to 570 mg L^{-1} (Stonewall) in June and from 51.2 to 648 mg L^{-1} (Stonewall) in October. The CCME (1999) CWQG for foliar application of irrigation water for chloride and applicable crops (alfalfa or barley) is 355 – 710 mg L^{-1}. Cl concentration of wastewater at Stony Mountain, Stonewall, and Petersfield exceeded this criteria (Table 24). Cl concentrations of duplicates were in good agreement in June and October.

Amounts of Cl applied with 100 mm of wastewater to a hectare of land varied among the sites (Table 25). Cl application ranged from 53 kg ha^{-1} to 593 kg ha^{-1}. Crop removal of chloride by an average yielding crop of alfalfa hay is approximately 75 kg ha^{-1} (Fitzgerald et al., 1994). Therefore, there would be an accumulation of chloride in the soil at all sites except Balmoral. Cl content of soils at Dunnottar, Petersfield, Stony Mountain, and Stonewall would increase above normal levels. Leaching of Cl from surface soils to subsoil and to the water table would most likely occur over an extended period of time.

4.4.3.1 Sodium

Sodium (Na) concentrations in wastewater ranged from 48.9 mg L^{-1} (Balmoral) to 330 mg L^{-1} (Stonewall) in June and between 42.5 mg L^{-1} (Balmoral) and 395 mg L^{-1} (Stonewall) in October. The CCME (1999) CWQG for the protection of agricultural water use have no criteria for sodium in irrigation water.

Amount of sodium applied with 100 mm of wastewater to a hectare of land varied amongst the sites (Table 25). Na application ranged from 46 kg ha^{-1} to 350 kg ha^{-1}. Crop removal of sodium by an average yielding crop of alfalfa hay is approximately 2.0 kg ha^{-1} (Fitzgerald et al., 1994). Therefore, there would be an accumulation of sodium in the soil at all sites and leaching of Na from surface soil to subsoil or to water table would occur over an extended period of time.

4.4.3.2 Total Dissolved Solids

Total Dissolved Solids (TDS) ranged from 478 mg L^{-1} (Balmoral) to 1390 mg L^{-1} (Stony Mountain) in June and from 638 mg L^{-1} (Balmoral) to1, 810 mg L^{-1} (Stonewall) in October. TDS at Arborg, Balmoral, Teulon, and Winnipeg Beach were similar for wastewaters collected in June and October. TDS concentrations at Stony Mountain, Stonewall, and Dunnottar were somewhat different from June to the October sampling (Table 24). The CCME (1999) CWQG for the protection of irrigation water use for TDS and applicable crops (smooth brome, alfalfa, big trefoil, beardless wildry, vetch, timothy and crested wheatgrass) is 800-1,500 mg L^{-1}. TDS in wastewater at Stony Mountain, Stonewall, Teulon, Winnipeg Beach, Dunnottar and Petersfield exceeded guidelines in both June and October. TDS at Arborg slightly exceeded the criteria in October. TDS at Balmoral was below the 800 mg L^{-1} for both sample times. Difference between duplicate wastewater samples for values for TDS were small in both June and October (Table 24).

4.4.3.3 Total Suspended Solids

Total Suspended Solids (TSS) ranged between <2 mg L^{-1} (Dunnottar) and 250 mg L^{-1} (Stonewall) in June and between 4 mg L^{-1} (Teulon) and 174 mg L^{-1} (Dunnottar) in October (Table 24). There are no guidelines for TSS in the CCME CWQG (1999) for irrigation water. However, Alberta Environment (2000) has a guideline value for TSS of <100 mg L^{-1} as posing no restriction to irrigation use. The TSS of wastewater at Stonewall in June and Dunnottar in October exceeded 100 mg L^{-1}. Although values of duplicate samples for Stonewall in June were not in good agreement, both values exceed guidelines limits.

Table 24 Salinity Parameters for Wastewater

Study Site	Parameter	E.C [b]	SAR [c]	Ca	Mg	Na	K	Cl [d]	Fl	SO_4-S	TDS [e]	TSS [g]
		dS m^{-1}	mg L^{-1}									
Arborg	June	1.1	1.6	42.4	81.9	78.6	13.1	83.7	0.39	28.5	710	10
	June [a]	1.1	1.6	39.8	82.9	78	12.8	84.2	0.37	29.9	720	12
	Oct.	1.24	1.4	69.5	90.7	74.9	11.6	84.7	0.44	34.6	816	5
Balmoral	June	0.729	1.2	31.6	60.6	48.9	10.9	54.5	0.28	12.2	478	28
	Oct.	1.06	0.9	73	59	42.5	11.7	55.6	<0.2	11.5	648	22
	Oct. [a]	1.08	1	79.8	64.8	48	13.4	51.2	0.26	12.4	638	24
Dunnottar	June	1.41	4.1	43.5	50.3	167	27.8	251	0.42	7.6	850	<2
	Oct.	1.85	4.1	76.1	63.9	202	31.3	318	0.46	16.2	1080	174
Petersfield	June	3.23	6.7	78.8	90.9	371	84.9	605	<0.2	15	1830	57
2nd cell	Oct.	3.46	6.6	113	112	416	98.6	668	<0.02	18	1980	74
3rd cell	Oct.	2.7	5.6	84	96.7	315	70.8	493	0.05	5	1560	6
Stony Mountain	June	2.33	4.8	71.8	98.5	267	26.2	371	<0.2	59.5	1390	6
	Oct.	2.76	5.3	87.8	139	342	31.6	462	<0.2	102	1810	53
Stonewall	June	2.25	7.3	34.6	73.5	330	20.1	570	<0.2	19.5	1320	250
	June [a]	2.25	7.1	35.6	73.1	325	19.7	561	<0.2	19.7	1310	122
	Oct.	2.74	7.6	54.8	91.8	395	25.2	648	<0.2	24.8	1620	50
Teulon	June	1.34	3.1	46	72.9	144	6.8	203	0.28	10.4	822	4
	Oct.	1.47	3	53	77.6	146	16.9	187	0.24	10.9	872	4

Study Site	Parameter	E.C [b]	SAR [c]	Ca	Mg	Na	K	Cl [d]	Fl	SO_4-S	TDS [e]	TSS [g]
		dS m^{-1}	mg L^{-1}									
Winnipeg Beach	June	1.51	2.6	80.2	83.2	141	17.7	196	0.25	33.9	992	74
	Oct.	1.41	2.4	73.4	78.8	123	13.8	165	0.39	33.2	900	4
	Oct. [a]	1.41	2.4	73.7	79.1	124	14.1	171	0.39	32.6	902	4
QA Trip Blank	June	0.002	<0.1	<0.2	<0.2	<0.4	<0.4	<0.4	<0.05	<0.3	8	<2
	Oct.	0.002	<0.1	<0.2	<0.2	<0.4	<0.4	<0.4	<0.05	<0.3	<7	<2
	NDL	0.001		0.2	0.2	0.4	0.4	0.4	0.05	0.3	7	1
Irrigation Water Quality Guidelines		1.5	6					800 - 1500	1		500 - 3500	100

Notes. [a] Duplicate Sample

[b] E.C. Manitoba Water Quality Standards, Objectives, and Guidelines, Manitoba Conservation 2002-11, Tier II, 1500 uS cm^{-1} = 1.5 dS m^{-1} Alberta Environment, April 2000, Guidelines for Municipal Wastewater Irrigation, E.C. <1.0 dS m^{-1} for unrestricted use, 1.0-2.5 dS m^{-1} restricted use, >2.5 dS m^{-1} unacceptable

[c] SAR Sodium Adsorption Ratio = 6.0 for all periods when field, park and garden irrigation is likely to occur.

Alberta Environment, April 2000, Guidelines for Municipal Wastewater Irrigation, SAR <4 for unrestricted use, 4-9 for restricted use when EC >1.0 dS m^{-1}, >9 unacceptable.

[d] Chloride	100 - 178 mg L^{-1} for almond, apricots and plums
foliar damage	178 - 355 mg L^{-1} for grapes, peppers, potatoes and tomatoes
	355 - 710 mg L^{-1} for alfalfa, barley, corn and cucumbers
	>710 mg L^{-1} for cauliflower, cotton, safflower, sesame, sorghum, sugar beets and sunflowers
[d] Chloride	180 - 600 mg L^{-1} for stone fruit (peaches, plums, etc)
Rootstocks	710 - 910 mg L^{-1} for grapes
[d] Chloride	110 - 180 mg L^{-1} for strawberries
Cultivars	230-460 mg L^{-1} for grapes
	250 mg L^{-1} for boysenberries, blackberries, and raspberries
[e] Total	500 mg L^{-1} for strawberries, raspberries, beans and carrots
Dissolved Solids	500 - 800 mg L^{-1} for boysenberries, currants, blackberries, gooseberries, plums, grapes, apricots, peaches, pears, cherries, apples, onions, parsnips, radishes, peas, pumpkins, lettuce, peppers, muskmelons, sweet potatoes, sweet corn, potatoes, celery, cabbage, kohlrabi, cauliflower, cowpeas, broadbeans, flax, sunflowers, and corn
	800 - 1500 mg L^{-1} for spinach, cantaloupe, cucumbers, tomatoes, squash, brussels sprouts, broccoli, turnips, smooth brome, alfalfa, big trefoil, beardless wild rye, vetch, timothy, and crested wheat grass
	1500 - 2500 mg L^{-1} for beets, zucchini, rape, sorghum, oat hay, wheat hay, mountain brome, tall fescue, sweet clover, reed canary grass, birds foot trefoil, perennial ryegrass
	3500 mg L^{-1} for asparagus, soybeans, safflower, oats, rye, wheat, sugar beets, barley, barley hay, and tall wheat grass

[g] Total Suspended Solids	Alberta Environment, April 2000, Guidelines for Municipal Wastewater Irrigation, Values below 100 mg L^{-1} pose no restriction to irrigation use.

Table 25 Chloride and Sodium Application at 100 mm of Wastewater Irrigation

Study Site	Mean Cl Concentration (mg L^{-1})	Cl Mass per 100 mm Application (kg ha^{-1})	Mean Na Concentration (mg L^{-1})	Na Mass per 100 mm Application (kg ha^{-1})
Arborg (n=3)	84.2	84	77.1	77
Balmoral (n=3)	53.8	54	46.5	46
Dunnottar (n=2)	391.3	391	246.7	247
Petersfield (n=1)	493	493	315.0	315
Stony Mountain (n=2)	416.5	417	304.5	304
Stonewall (n=3)	593	593	350.0	350
Teulon (n=2)	157.9	158	122.9	122
Winnipeg Beach (n=3)	177.3	177	129.3	129

Note. n = number of samples

4.4.4 pH

The acceptable pH range for irrigation water is between 6.5 and 8.5 (Alberta Environment, 2000), the optimum range for crop growth. The wastewater pH level ranged from 8.63 to 9.86 in June and from 7.75 to 8.96 in October for the various sites (Table 26). pH of wastewater in June exceeded the optimum pH range for irrigation and optimum crop growth. In October only wastewater from Stony Mountain, Winnipeg Beach, Teulon, and Stonewall exceeded the optimum pH range. At each site, the pH value between June and October were similar, but values in October were less than in June. Values for duplicates were in good agreement.

4.4.5 Metals

In general, concentrations of Be, Cd, Hg, Mo, and Se in wastewater were less than or just greater than the laboratory nominal detection limits for these metals (Table 26). However, when these metals were above detection limits the concentrations were significantly less than CCME CWQG (1999) limits for of irrigation water.

The concentrations of Al and Cr in the wastewater from Dunnottar in October exceeded CCME CWQG (1999) criteria. These elevated concentrations of trace elements were likely due to the presence of some solids in the sample during collection from the lagoon after discharge of liquids in fall.

Concentrations of B, Co, Cu, Fe, and Ni in the wastewater samples (Table 26) did not exceed CCME CWQG (1999) limits for irrigation water. Concentrations of trace elements were reasonably similar for June and October. Little differences were noted in field duplicates. The manganese (Mn) concentration ranged from 0.007 mg L^{-1} to 0.36 mg L^{-1} in June and from 0.007 to 1.54 mg L^{-1} in October at the various sites (Table 26). The CCME (1999) CWQG for the protection of irrigation water is 0.2 mg L^{-1}. Water at Stony Mountain in June and at Petersfield in October exceeded the criteria. The Mn concentrations at some sites were different in June than in October, whereas, at some sites concentrations of Mn were similar for both sampling times. The reason for this variation is unknown. Values for duplicates were in good agreement.

Zinc (Zn) concentration in wastewater ranged from 0.002 mg L^{-1} to 0.01 mg L^{-1} in June and from 0.004 mg L^{-1} to 0.13 mg L^{-1} in October among all sites (Table 26). The CCME CWQG (1999) limits for irrigation water use is 1.0 mg L^{-1} when soil pH <6.5 and 5.0 mg L^{-1} when soil pH is >6.5. Soils in the east Interlake region are considered highly carbonated and have a pH value >6.5 and hence the Zn criteria of 5.0 mg $L^{-1}$is applicable. Zn concentrations were very low and did not exceed the criteria at any site in either June or October. At each site, the Zn concentrations were similar in both June and October. Values for duplicate samples were in good agreement.

Concentrations of As, Pb, Li, U, and V in the wastewater (Table 26) did not exceed CCME (1999) CWQG limits for irrigation water. At each site, these trace elements concentrations were similar in both June and October and values for duplicate samples were in good agreement.

Table 26 pH and Metal Contents of Wastewater

Study Site	Parameter	pH[c]	Hg	Fe	Mn	Al	As[d]	Be	B[e]	Cd[f]	Cr[g]
	Date					mg L^{-1}					
Arborg	June	9.19	<0.0001	0.34	0.035	0.417	0.0019	<0.0001	0.261	0.00003	0.0013
	June[a]	9.19	<0.0001	0.31	0.035	0.449	0.0020	<0.0001	0.257	0.00004	0.0018
	Oct.	8.48	<0.0001	0.17	0.016	0.233	0.0027	<0.0001	0.258	<0.00001	<0.0005
Balmoral	June	9.86	<0.0001	<0.05	0.01	0.020	0.0043	<0.0001	0.227	0.00002	0.0007
	Oct.	7.92	<0.0001	0.59	0.175	0.593	0.0091	<0.0001	0.222	0.00001	0.0014
	Oct.[a]	7.94	<0.0001	0.72	0.180	0.910	0.0092	<0.0001	0.243	<0.00001	0.0018
Dunnottar	June	9.55	<0.0001	0.08	0.018	0.100	0.0027	<0.0001	0.226	<0.00001	0.0008
	Oct.[b]	8.36	<0.0001	4.10	0.170	5.440	0.0130	0.0002	0.261	0.00004	0.0088
Petersfield	June	8.50	<0.0001	0.20	0.070	0.088	0.0035	<0.0002	0.401	0.00002	0.002
2nd cell	Oct.	8.11	0.0002	0.10	0.097	0.110	0.0046	<0.0002	0.443	<0.00002	0.002
3rd cell	Oct.	7.75	<0.0001	0.32	1.540	0.100	0.0048	<0.0002	0.283	<0.00002	0.002
Stony Mountain	June	8.81	<0.0001	<0.1	0.360	0.055	0.0023	<0.0002	0.36	<0.00002	<0.001
	Oct.	8.66	<0.0001	0.20	0.061	0.293	0.0035	<0.0002	0.459	0.00005	<0.001
Stonewall	June	9.22	<0.0001	0.76	0.053	1.040	0.0021	<0.0002	0.329	0.00007	0.001
	June[a]	9.27	<0.0001	0.95	0.054	1.350	0.0021	<0.0002	0.341	0.00006	0.002
	Oct.	8.96	<0.0001	1.2	0.030	1.640	0.0022	<0.0002	0.346	<0.00002	0.002
Teulon	June	9.6	<0.0001	<0.05	0.007	0.068	0.0037	<0.0001	0.165	<0.00001	0.0009
	Oct.	8.93	<0.0001	0.07	0.009	0.105	0.0047	<0.0001	0.266	<0.00001	<0.0005

Study Site	Parameter	pH [c]	Hg	Fe	Mn	Al	As [d]	Be	B [e]	Cd [f]	Cr [g]
	Date	mg L^{-1}									
Winnipeg Beach	June	8.63	<0.0001	<0.05	0.065	0.014	0.0009	<0.0001	0.13	<0.00001	<0.0005
	Oct.	8.70	<0.0001	0.08	0.022	0.141	0.0019	<0.0001	0.21	<0.00011	<0.0005
	Oct. [a]	8.70	<0.0001	0.08	0.022	0.149	0.0020	<0.0001	0.225	<0.00011	<0.0005
QA Trip Blank	June	6.47	<0.0001	<0.05	<0.005	0.008	<0.0002	<0.0001	0.005	0.00011	0.0006
	Oct.	6.48	<0.0001	<0.05	<0.005	0.008	<0.0002	<0.0001	0.003	<0.00011	<0.0005
NDL			0.0001	0.05	0.005	0.005	0.0002	0.0001	0.002	0.00001	0.0005
Irrigation Water Quality Guidelines		6.5-8.5	-	5	0.2	5	0.1	0.1	0.5-1	0.0051	0.0049-0.008

Study Site	Parameter	Co	Cu [h]	Pb	Li	Mo [i]	Ni	Se [j]	Ur	V	Zn [k]
	Date	mg L^{-1}									
Arborg	June	0.0004	0.002	0.0001	0.05	<0.001	0.0022	<0.0002	0.0039	0.004	0.004
	June [a]	0.0004	0.002	0.0002	0.05	<0.001	0.0021	<0.0002	0.0038	0.004	0.004
	Oct.	0.0003	0.001	0.0003	0.055	0.001	0.0015	0.0005	0.0041	0.0042	0.004
Balmoral	June	0.0005	0.001	<0.0001	0.022	<0.001	0.0025	0.0007	0.0019	0.003	0.003
	Oct.	0.001	0.002	0.0006	0.022	<0.001	0.0041	0.0006	0.0006	0.0043	0.004
	Oct. [a]	0.0011	0.002	0.0006	0.025	<0.001	0.0047	<0.0002	0.0006	0.0052	0.007
Dunnottar	June	0.0003	<0.001	<0.0001	0.025	<0.001	0.0018	<0.0002	0.0015	0.0033	0.002
	Oct. [b]	0.0031	0.006	0.0023	0.034	0.002	0.0115	<0.0002	0.0025	0.0256	0.030
Petersfield	June	0.001	0.005	<0.0002	0.097	<0.002	0.0061	<0.0004	0.002	0.0031	0.010
2nd cell	Oct.	0.001	0.003	0.0005	0.11	<0.002	0.005	<0.0004	0.001	0.0022	0.010
3rd cell	Oct.	0.0009	0.023	0.0045	0.092	<0.002	0.0033	<0.0004	<0.001	0.002	0.130
Stony Mountain	June	0.0004	0.003	<0.0002	0.067	<0.002	0.0034	<0.0004	0.0034	0.001	0.004
	Oct.	0.0006	0.005	0.0006	0.1	0.002	0.0038	0.0004	0.0061	0.006	0.009
Stonewall	June	0.001	0.006	0.001	0.05	0.002	0.0032	0.0005	0.0024	0.0077	0.010
	June [a]	0.001	0.006	0.001	0.052	0.002	0.0035	<0.0004	0.0026	0.0085	0.009
	Oct.	0.001	0.002	0.0009	0.058	0.003	0.0034	<0.0004	0.0029	0.0075	0.008
Teulon	June	0.0003	0.001	<0.0001	0.03	<0.001	0.0015	<0.0002	0.0016	0.0047	0.003
	Oct.	0.0002	<0.001	0.0005	0.036	<0.001	0.0008	<0.0002	0.0019	0.0045	0.004

Study Site	Parameter	Co	Cu [h]	Pb	Li	Mo [i]	Ni	Se [j]	Ur	V	Zn [k]
	Date	mg L^{-1}									
Winnipeg Beach	June	0.0002	<0.001	<0.0001	0.028	<0.001	<0.0005	<0.0002	0.0016	0.0009	0.003
	Oct.	0.0002	<0.001	0.0002	0.053	<0.001	0.0011	0.0002	0.0052	0.0027	0.004
	Oct. [a]	0.0002	<0.001	0.0003	0.055	<0.001	0.0013	<0.0002	0.0054	0.0029	0.005
QA Trip Blank	June	<0.0001	<0.001	0.0002	<0.001	<0.001	<0.0005	<0.0002	<0.0005	<0.0001	0.008
	Oct.	<0.0001	<0.001	0.0002	<0.001	<0.001	<0.0005	<0.0002	<0.0005	<0.0001	0.002
NDL		0.0001	0.001	0.0001	0.001	0.001	0.0005	0.0002	0.0005	0.0001	0.001
Irrigation Water Quality Guidelines		0.05	0.2-1	0.2	2.5	0.01-0.05	0.2	0.02-0.05	0.01	0.1	1-5

Note: All Metal concentrations are total concentrations, except Mercury which is dissolved.

Source: Canadian Council of Ministers of the Environment (1999), Canadian Water Quality Guidelines for the Protection of Agricultural Water Uses.

NDL Nominal Detection Limit

[a] Duplicate Samples

[b] Sample obtained after cell was fall discharged

[c] pH - Alberta Environment, April 2000, Guidelines for Municipal Wastewater Irrigation, Continued long-term use of waters outside this pH range could eventually alter naturally occurring pH levels in surface soils to which they are applied and therefore could possibly lead to micro nutrient imbalances and potential future crop production and fertility problems.

[d] Arsenic Interim Guideline

[e] 500 ug L^{-1} for blackberries

500-1000 ug L^{-1} for peaches, cherries, plums, grapes, cowpeas, onions, garlic, sweet potatoes, wheat, barley, sunflowers, mung beans, sesame, lupines, strawberries. Jerusalem artichokes, kidney beans and lima beans

1000-2000 ug L^{-1} for red peppers, peas, carrots, radishes, potatoes and cucumbers

2000-4000 ug L^{-1} for lettuce, cabbage, celery, turnips, Kentucky bluegrass, oats, corn, artichokes, tobacco, mustard, clover, squash and muskmelons.

4000-6000 ug L^{-1} for sorghum, tomatoes, alfalfa, purple vetch, parsley, red beets and sugar beets

6000 ug L^{-1} for asparagus

[f] Cadmium – crop specific based on sensitivity

[g] 4.9 ug L^{-1} for Trivalent chromium (Cr (III)) interim guideline

8.0 ug L^{-1} for Hexavalent chromium (Cr (Vi))

[h] 50 ug L^{-1} for short term use on acidic soils

[i] 20 ug L^{-1} for continuous use

50 ug L^{-1} for intermittent use

[j] 1000 ug L^{-1} when soil pH<6.5

5000 ug L^{-1} when soil pH>6.5

4.4.6 Pathogens (Biological)

The total number of colony forming total coliform and *Escherichia Coli* pathogens were determined for wastewater. In June total coliform and *E. Coli* counts ranged from <1 to 66 CFU 100 ml^{-1} (Table 27), The counts were all below the Tier II Manitoba Water Quality Standards, Objectives and Guidelines (2002) of 200 CFU 100 ml^{-1} total coliform and *E. Coli* in June. At Stony Mountain, Balmoral, and Dunnottar total coliform and *E. Coli* counts were higher in October than in June and above guideline limits. Personal communication with the lagoon managers indicated that in late fall water quality samples are often elevated in total coliform and *E. Coli* counts as a result of the presence of flocks of geese and ducks rafting on the lagoon water.

More data during the summer period is needed to confirm whether or not the pathogen levels are below tolerable levels when irrigation may be practiced.

Table 27 Pathogen Counts for Wastewater

Study Site	Parameter	Total Coliform	*Escherichia coli*
	Sample Date	CFU 100 mg^{-1} [b]	
Arborg	June	3	<1
	June [a]	6	<1
	Oct.	18	16
Balmoral	June	<1	<1
	Oct.	300	200
	Oct. [a]	400	200
Dunnottar	June	60	2
	Oct.	1,000	226
Petersfield	June	680	310
2nd cell	Oct.	6,900	1,900
3rd cell	Oct.	45	35
Stony Mountain	June	57	52
	Oct.	21,000	15,000
Stonewall	June	39	39
	June [a]	31	31
	Oct.	100	56
Teulon	June	<1	<1
	Oct.	3	1
Winnipeg Beach	June	66	3
	Oct.	60	25
	Oct. [a]	28	28
QA Trip Blank	June	<1	<1
	Oct.	<1	<1
NDL		1	1
Irrigation Water Quality Guidelines [c]		200	200

Note. Upon receipt of samples in June, one sample exceeded recommended holding time for microbiological analysis. Upon receipt of October samples, all samples exceeded recommended holding time for microbiological analysis, this may have affected coliform counts were values were low.

[a] Duplicate sample

[b] CFU = Colony Forming Units per 100 mL

[c] Manitoba Water Quality Standards, Objectives, and Guidelines, Manitoba Conservation 2002, Tier II for May 1 – September 30 and when workers or the public may come in contact with irrigation water.

4.5 Social Perception

4.5.1 Council Group Discussions

Community group discussions were held with elected officials for five town or R.M councils; Stonewall, Teulon, Arborg, and the R.M of Rockwood (Stonewall, Balmoral) and St. Andrews (Petersfield). Two council groups of the five councils interviewed reported that they were aware of wastewater or effluent irrigation as a practice. One member of council had knowledge of wastewater irrigation at a larger center in Saskatchewan. The second council stated that they had briefly discussed wastewater irrigation during a previous council session. Although discussions of wastewater irrigation have occurred in some councils, none of the municipal councils have plans with respect to changes in present methods of wastewater discharge management. However, a variety of water and wastewater discussions have occurred in council chambers, including discussions on means and incentives for reduction of quantity of wastewater, water recycling projects, water discharge quality and sewage treatment.

Council members listed the following perceived benefits of wastewater irrigation; extending the life of their current lagoon system, providing benefits to local farm producers with a cheap source of water and nutrients, providing the ability to enable crop diversification, diverting pollution away from Lake Winnipeg, and improving downstream water quality for neighbours. Recently a large sinkhole was exposed in one of the drainage pathways. It was suggested by a council member that irrigation would divert water away from direct flow into groundwater for that community.

All council members had concerns regarding wastewater irrigation. Concerns included introduction of human waste and pathogens into the food chain, adverse groundwater and aquifer impacts, and pathogen and salt additions to the land, odour, economic costs to the community and system setup requirements, and long-term management.

Council members were then asked to comment on factors that would encourage them to consider a wastewater irrigation program. Councillors addressed economic, social, and environmental issues. Economic issues included financial support from provincial or federal agencies, a positive cost-benefit analysis for the community and economic benefit to producers receiving the wastewater. Issues within the social category included; a survey of residents to assess acceptance, landowner buy-in, need for pilot demonstration project, clear social demands from the public and regulatory limitations on current practices. Responses to environmental issues included; a requirement for clear demonstration of benefits to Lake Winnipeg. All council members expressed a need for further education and research in their communities.

Councillors' responses varied in regards to inquiries as to the implication of changes in provincial regulation for wastewater management to reduce nutrient discharge. Most councils responded that provincial regulations would highly influence their interest in wastewater irrigation while other councils felt that due to their current infrastructure, regulatory change would not influence their current methods of effluent management. The majority of council members felt that social/political pressure from their constituents would be an influencing factor to either acceptance or rejection of wastewater irrigation potential in their communities.

4.5.2 Survey of Residents

A total of 304 survey forms were delivered to residents. The number of surveys returned and distributed were as follows: Stony Mountain 6 of 21 (29% returned), Stonewall 17 of 60 (28% returned), Balmoral 14 of 43 (32.5% returned), Teulon 4 of 11 (36% returned), Dunnottar

4 of 8 (50% returned), Petersfield 6 of 12 (50% returned), Winnipeg Beach 19 of 49 (18% returned), and Arborg 21 of 100 (21% returned). A total of 81 surveys were returned.

Fifty nine percent of respondents were male and 41% were female, 62 %, 32%, and 6% of respondents were over 50 years of age, between 30 and 50 years of age, and between 20 and 30 years of age, respectively (Table 28). The majority of respondents both lived and worked in the community (82%) and 60% of respondents have lived at their current residence for more than 15 years. Of the 81 respondents 16 (20%) were farm producers (farm respondents) and 65 (80%) were classed as non-farm respondents (Table 28).

The first objective was to establish respondents' level of awareness regarding lagoon effluent management in the community and awareness of environmental concerns with respect to Lake Winnipeg (Table 29). The majority of respondents (65%) were aware that lagoon effluent was discharged to municipal ditches each season (three respondents did not answer the question and three were unsure). The degree of concern regarding the practice of effluent discharge to ditches varied and was equally distributed with 35% very concerned, 30 % concerned, and 35% somewhat concerned, and 1% not at all concerned. Respondents' degree of concern regarding nutrients entering Lake Winnipeg in general was varied with 48% very concerned, 30% concerned, 21 % somewhat concerned, and only 1% was not at all concerned. When respondents were asked which nutrient: nitrogen, phosphorous, or nitrogen and phosphorous equally, was of concern, the majority (77%) of respondents were concerned about nitrogen and phosphorous equally, 17% were concerned about nitrogen only, and 1% was concerned about phosphorous only (four respondents did not answer). Respondents were also very concerned (44%) about metals, personal care products (i.e. non-prescription drugs), and pharmaceuticals (i.e. prescription medication) entering into Lake Winnipeg from wastewater.

Table 28 Demographics of Survey Respondents

	Respondents	
	Count	Percent
Gender		
Male	48	59
Female	33	41
Age (years)		
15-20	0	0
20-30	5	6
30-50	26	32
50+	50	62
Live and work in the community		
No Response	1	1
Yes	67	83
No	13	16
Years living at current residence		
<1- 5	13	16
6-10	13	16
11-15	7	9
15+	48	59

Table 29 Survey of Residents on Lake Winnipeg Awareness and Concern

Question	Answers	Respondents	
		Number	Percent
Are you aware that most municipal wastewater lagoons release wastewater to the municipal ditches and drainage pathways each spring and fall?	No Response	3	4
	Yes	53	65
	No	22	27
	Unsure	3	4
How concerned are you about the release of wastewater into the municipal ditches and drainage pathways?	Very Concerned	28	35
	Concerned	24	30
	Somewhat Concerned	28	35
	Not at all Concerned	1	1
Are you concerned about nutrients (i.e. Phosphorous & Nitrogen) entering into Lake Winnipeg?	Very Concerned	39	48
	Concerned	24	30
	Somewhat Concerned	17	21
	Not at all Concerned	1	1
Which nutrient are you concerned about entering into Lake Winnipeg? Nitrogen (N), Phosphorous (P), N & P Equally	No Response	4	5
	N	14	17
	P	1	1
	N & P equally	62	77
Are you concerned about metals (i.e. Arsenic, Barium, Copper) entering into Lake Winnipeg?	Very Concerned	39	44
	Concerned	24	31
	Somewhat Concerned	17	16
	Not at all Concerned	1	9

Question	Answers	Respondents	
		Number	Percent
Are you concerned about personal care products (i.e. non-prescription drugs) entering into Lake Winnipeg?	Very Concerned	29	36
	Concerned	28	35
	Somewhat Concerned	15	19
	Not at all Concerned	9	11
Are you concerned about pharmaceuticals (i.e. prescription medications) entering into Lake Winnipeg?	Very Concerned	34	42
	Concerned	25	31
	Somewhat Concerned	13	16
	Not at all Concerned	9	11

Note. NR = No Response, VC = Very Concerned, C = Concerned, SWC = Somewhat Concerned and NAC = Not at all Concerned

Residents were also asked about their level of concern regarding alternative wastewater reuses such as irrigation onto golf courses, landscaping in industrial developments, public parks, and woodlots. Respondent data was separated based on occupation (farm producer vs. non-farm resident). Farm producers were supportive of irrigating woodlots whereas they were mostly neutral in regards to irrigating golf courses, landscaping in industrial developments, and public parks. Non-farm respondents were generally supportive of wastewater reuse for all four situations (Table 30).

Table 30 Survey of Residents on Support for Wastewater Reuse Alternatives

Irrigation onto:	Golf courses	Landscape in business parks	Public parks	Woodlots
Farm Respondent (%)				
No Response	0	0	0	0
Very Supportive	31	25	19	19
Supportive	25	25	25	38
Neutral	44	44	38	31
Not Supportive	0	0	13	6
Not at all Supportive	0	6	6	6
Non-Farm Respondent (%)				
No Response	2	2	2	2
Very Supportive	17	15	12	15
Supportive	42	48	29	48
Neutral	18	22	25	22
Not Supportive	18	11	25	11
Not at all Supportive	3	3	8	3

Residents were also asked about their awareness and level of concern for wastewater irrigation in agricultural cropping systems. Collectively 48% of respondents were not aware that wastewater irrigation occurs onto agricultural crops in western Canada. When asked as to their level of concern regarding wastewater irrigation onto forage crops, the majority of farm producers were somewhat concerned (38%) or not at all concerned (31%) and 25% were very concerned. Concern among non-farm respondents was more evenly divided with 23% very concerned, 25% concerned, 30% somewhat concerned, and 20% not at all concerned (Table 31). Similarly, when asked as to their level of concern regarding wastewater irrigation onto cereal crops, the majority of farm producers were somewhat concerned (38%) or not at all concerned (31%) and 25% were very concerned. However, non-farm respondents were more concerned about irrigating cereal crops with wastewater with 29% very concerned, 28% concerned, 34% somewhat concerned, and 8% not at all concerned (Table 31). When asked about level of support regarding wastewater irrigation as a means of limiting the amount of nutrients entering Lake Winnipeg, 44% of farm respondents and 48% of non-farm respondents were either very supportive or supportive (Table 32).

A small component of the survey assessed the residents' preference regarding annual notification prior to the irrigation season. Thirty eight percent of farm respondents stated that notification was important and required, 25% stated that notification was important and appreciated, and 31% stated that it was not important but appreciated (Table 33). Thirty-five percent of non-farm respondents stated that notification was important and required, 42% of respondents stated notification was important and appreciated, and only 18% stated that notification was not important but appreciated (Table 33). Very few respondents, farm or non-farm respondents reported that notification was not important and not required (Table 33).

The time of day that wastewater irrigation should occur was also surveyed. Farm respondents were generally neutral with respect to time of day of irrigation whereas, non-farm respondents strongly preferred that wastewater irrigation occur during the night (Table 34).

Respondents were then surveyed regarding their level of concern regarding odour emissions, the distance between their yard or home and the irrigated land, colour of the water, and cattle pastured on irrigated land. The majority of farm respondents (38%) were not at all concerned about odour due to wastewater irrigation whereas 48% of non-farm respondents were largely very concerned about odour (Table 35). Colour of the wastewater was not a concern for many respondents (Table 35). Collectively, 46% of respondents were very concerned with the proximity of irrigation to their homes or yards (Table 35). However, the majority of respondents were somewhat or not at all concerned about cattle grazing on land irrigated with wastewater (Table 35).

Municipalities are financially responsible for management of wastewater. As such, a primary concern of town and municipal councils are the costs of management and disposal or utilization of wastewaters. A limited number of questions were posed in the survey to assess residents' opinions as to who should be financially responsible for establishing wastewater irrigation. Fifty percent of farm respondents and 63 % of non-farm respondents stated that funding should be shared among the rural municipality, the provincial government, and the farm producer receiving the water (Table 36). Rural municipalities primarily receive their funds from property taxes. Thus, the survey assessed residents' reaction to a tax increase of 0.1-0.5%, 0.6-1.0%, 1.0-1.5%, 1.6-2.0%, and >2.0%. Consistently, respondents selected the lowest percentage of tax increase (63% farm respondents, 49% non-farm respondents). Seventeen percent did not respond to the question or stated 0% increases even though it was not a choice. However, it is noteworthy that one-third (31%) of respondents would be willing to pay more than the minimum amount (>0.5%) on their property taxes (Table 37) for the establishment of a wastewater irrigation program.

Farm respondents were specifically asked for their interest to irrigate crops with wastewater. Fifty six percent of farm respondents (9 of 16) were not interested, 31% (5 of 16) were interested, and 6% (1 of 16) of farm respondents were very interested. Farmers also stated that they might be more willing to consider wastewater irrigation after further communication and discussion on the advantages and disadvantages of wastewater as an irrigation source.

Table 31 Survey of Residents Level of Concern with Wastewater Irrigation

Question: If wastewater irrigation on to agricultural crops (forage or grain) was to occur in your community, how concerned would you be?

	Farm Respondents (%)		Non-Farm Respondents (%)		All Respondents (%)	
	Forage	Grain	Forage	Grain	Forage	Grain
No Response	0	0	1	1	1	1
Very Concerned	25	25	23	29	24	28
Concerned	6	6	25	28	21	23
Somewhat Concerned	38	38	30	34	31	35
Not at all Concerned	31	31	20	8	23	12

Table 32 Survey of Residents on Support for Wastewater Irrigation to Protect Lake Winnipeg

Question: How supportive are you of wastewater irrigation onto agricultural crops as a method of limiting the amount of nutrients and other contaminants from entering Lake Winnipeg?

	Farm Respondents (%)		Non-Farm Respondents (%)		All Respondents (%)	
	Nutrients	Contaminants	Nutrients	Contaminants	Nutrients	Contaminants
No Response	0	0	0	0	0	0
Very Supportive	13	13	17	15	16	15
Supportive	31	31	31	28	31	28
Neutral	31	38	32	32	32	33
Not Supportive	25	19	20	25	21	23
Not at all Supportive	0	0	0	0	0	0

Table 33 Survey of Residents on the Importance to Provide Notification Prior to Irrigation

Question: How important is it to provide advance notice each year, when wastewater irrigation is going to occur in your community?			
	Farm Respondents (%)	Non-Farm Respondents (%)	All Respondents (%)
No Response	0	2	1
Not important and not required	6	3	4
Not important but appreciated	31	18	21
Important and appreciated	25	42	38
Important and required	38	35	36

Table 34 Survey Residents on the Time of Day for Wastewater Irrigation

Question: Of the following three parts of the day (day, evening, night) would you prefer wastewater irrigation to occur?			
	8am–4pm (daytime)	4pm–12am (evening)	12am–8am (night)
		Farm Producer (%)	
No Response	13	19	19
Preferred	25	13	25
Not Preferred	31	31	13
Neutral	31	38	44
		Non-Farm Producer (%)	
No Response	22	23	8
Preferred	15	3	57
Not Preferred	32	42	12
Neutral	31	32	23
		Collective (%)	
No Response	20	22	10
Preferred	17	5	51
Not Preferred	32	40	12
Neutral	31	33	27

Table 35 Survey of Residents Level of Concerns for Different Aspects of Wastewater Irrigation

Question: Rate your level of concern with the following:

	Odour	Proximity to Property	Colour	Cattle Grazing
	Farm Respondent (%)			
No Response	0	0	0	0
Very Concerned	25	31	25	25
Concerned	13	31	13	19
Somewhat Concerned	25	19	19	31
Not at all Concerned	38	19	44	25
	Non-Farm Respondent (%)			
No Response	0	0	2	0
Very Concerned	48	49	9	32
Concerned	20	20	14	20
Somewhat Concerned	23	23	32	34
Not at all Concerned	9	8	43	14
	All Respondents (%)			
No Response	0	0	1	0
Very Concerned	43	46	12	31
Concerned	19	22	14	20
Somewhat Concerned	23	22	30	33
Not at all Concerned	15	10	43	16

Table 36 Survey of Residents on Funding Sources

Question: The cost of establishing a wastewater irrigation program includes consulting fees, labour, piping, irrigation equipment, and monitoring. Who should pay?				
	R.M funding only	Provincial funding only	Farm producer receiving the water, only	Rural Municipality, Province and Farm Producer jointly
Farm Respondents (%)				
No Response	25	19	19	6
Yes	19	38	19	50
No	31	19	38	19
Unsure	25	25	25	25
Non-Farm Respondents (%)				
No Response	38	34	37	11
Yes	18	35	31	63
No	23	15	18	17
Unsure	20	15	14	9
All Respondents (%)				
No Response	36	31	33	10
Yes	19	36	28	60
No	25	16	22	17
Unsure	21	17	16	12

Table 37 Survey of Residents on Willingness to Pay

Question: What rate of a property tax increase would you support to ensure wastewater irrigation was a successful, sustainable program at the municipal level?

	Farm Respondents (%)	Non-Farm Respondents (%)	All Respondents (%)
No Response or Zero [a]	19	17	17
0.1-0.5%	63	49	52
0.6-1.0	0	12	10
1.1-1.5%	6	11	10
1.6-2.0%	13	5	6
>2%	0	6	5

Note. [a] Zero was written in on surveys by respondents.

4.5.3 Assessment of Odour during Irrigation

Despite personal invitations, residents from the Stony Mountain, Stonewall, and Balmoral Sites did not attend the demonstration events scheduled for September 26 and 27, 2009. Therefore, on October 3, 2009 a demonstration was held using eleven colleagues and/or family members to assess odour intensity at the Stony Mountain site.

Prior to initiating irrigation a baseline assessment was conducted in which the assessors rated the degree of odour as “no odour” to “slight odour” at all distances (25 m, 50 m, 100 m, and 200 m) from the irrigation unit (Table 38). Assessors recorded odour values from a rating 0, no odour, to a rating of 2, slight odour after initiation of irrigation (Table 38). Some assessors whose initial rating prior to irrigation was 0 or 1 rated odours as 1 or 2, indicating a slight change in degree odour intensity. In general, odour intensity during irrigation was only slightly higher than prior to irrigation.

Odour assessors provided some general comments during the irrigation demonstration. They stated that the odour in the area was grassy or earthy and that there was no sewer odour. Specifically one assessor stated, “The smell is so faint you don’t even realize it is there until you are using the mask.”

Table 38 Assessment of Wastewater Irrigation Odour

	Distance From Irrigator	Assessor and Degree of Odour (1 to 5)										
		1	2	3	4	5	6	7	8	9	10	11
Irrigator Off	25 m	0	0	0	0	1	2	0	0	0	0	2
	50 m	0	0	2	1	1	2	0	0	1	0	1
	100 m	0	0	2	1	1	2	0	0	0	0	1
	200 m	0	0	2	1	1	2	0	0	1	0	1
Irrigator On	25 m	0	0	1	1	1	2	0	0	0	1	1
	50 m	0	0	2	1	1	2	0	0	1	0	1
	100 m	0	0	2	1	1	2	0	0	1	0	1
	200 m	0	0	2	1	1	2	0	1	1	0	1

5 Discussion

The objective of the study herein was to assess the sustainability and social acceptance of wastewater irrigation as a means to abate nutrient loading to surface water in the Lake Winnipeg watershed. To ascertain whether or not wastewater irrigation is environmentally sustainable, it is important to define sustainability of irrigation with wastewater. A definition of environmental sustainability as provided by Goodland & Daly (1996) is; "…holding waste emissions within the assimilative capacity of the environment without impairing it. It also means keeping harvest rates of renewables to within regenerations rates." Hu (1997) specifically addresses sustainability of effluent irrigation and that sustainability of effluent irrigation development is defined by environmental impacts that are caused by pollutants exported from the irrigated land/site or accumulated in the soil profile or rooting zone. Based on these two definitions, wastewater irrigation sustainability is the acceptable practice of irrigating crops with municipal wastewater without affecting crop yield and/or quality due to pollutant accumulation (i.e. salts, metals and PPCPs) in the crop-rooting zone and without affecting other systems (i.e. surface or groundwater quality).

In order to achieve sustainability four major requirements must be satisfied. The probability of crop water stress and the amount of crop water demand needs to be sufficient to justify irrigation, land must be suitable for irrigation, water used must meet requirements for irrigation and irrigation with wastewater must be socially acceptable.

5.1 Land Suitability for Sustainable Wastewater Irrigation

The area studied has a high probability of crop water stress of at least 100 mm when forage crops are grown. Thus, a demand for water above that obtained as rainfall is virtually certain in most years in the south-east region of the Interlake and use of wastewaters to alleviate water stress would be of benefit to producers. Yield of forage in most years would be increased.

The land area required at each of the various sites, to utilize 100 mm of wastewater annually, varies from 17 to 410 ha. All sites had sufficient land area with agricultural capability to grow forages. In contrast, the land area with soils suitable for irrigation, particularly with wastewater, was very limiting for all sites except the Balmoral site. Seven of the eight study sites would need to utilize soil rated only as fair to meet land area requirements for irrigation. The major limitation of the soils for irrigability was internal drainage and/or wetness. Soils rated as fair for irrigation suitability can be sustainably irrigated if water quality is good or excellent. However, sustainability of irrigation with water high in salts, such as municipal wastewater, on soils rated only as fair would be challenging. Hence, all sites except the Balmoral site have limited potential to establishing wastewater irrigation based on the aerial extent of suitable land. In this study, no in-field inspections were completed to confirm soil polygon data and no database quires excluded land with residential developments or non-agricultural land use. Therefore, on-site assessments would be required at most sites to confirm and/or adjust the findings noted above.

Based on Canada land inventory for agricultural capability all sites have large areas of land classed as 1, 2 and 3. The area and class of land is be sufficient to satisfy the requirements of WQMZ N1 and N2 land with respect to management of nutrients in wastewater irrigation and nutrient management.

5.2 Water Suitability for Sustainable Wastewater Irrigation

Each study site contributes nitrogen and phosphorous to surface waters in the Lake Winnipeg drainage basin when discharged. If these wastewater sources were to be irrigated onto forage the waters used provide a small portion of the nitrogen and phosphorous required by a forage crop under irrigation. It is likely that synthetic fertilizers would be required to maximize yields.

A key criteria of sustainability, as defined previously, is the assimilative capacity of the environment (i.e. soil) without impairing it. The addition of salt from wastewater irrigation to the soil would eventually impair the ability of the land to produce a crop. A major limitation to sustainability of irrigation at seven of the eight sites studied is the quality of irrigation water with respect to salts and loadings of chloride and sodium. Most wastewater had salt contents above or just below guideline limits. The loadings of chloride exceeded the crop removal at all sites except at Balmoral, thus chloride would accumulate relatively quickly to levels much above background or normal soil levels. Some of the salts would move from surface soils to subsoil and/or the water table with time. However, due to the nature of the soils at most locations (limitations due to drainage and excessive wetness) accumulation of salts in the profile is likely, which would impair crop yields. Thus the combination of soil suitability and water quality limitations would make sustainability of irrigation at most sites challenging. Only the Balmoral site has a high probability of sustainability (suitable soils and good water).

As outlined in section 2.3.3, there are several means of salt monitoring. In addition to monitoring, there are active management techniques, which can be implemented to enhance sustainability. Agronomic management would include; land rotation (irrigation 1:3 years) to minimize loading and allow for natural leaching and creation of leaching fronts to move salts out of the rooting zone. Crop production may not be sustainable unless the transference of pollutants out of the rooting zone to deeper parent material and allow for potential impacts to groundwater;

The leaching of salts from surface to subsoil would only be suitable if associated receptors (i.e. groundwater) and hydrogeology are understood and the risk is acceptable.

The wastewater at seven of the eight sites would need to be improved to enhance the probability of sustainability. Improvements to the wastewater stream through the adoption of alternative treatment practices to drinking water, such as; changing the regenerant in water softeners (Fitzgerald et al., 1994), or pre-treatment (i.e. reverse osmosis) of a waste stream prior to discharge to municipal sewer systems.

The low concentrations of metals in the wastewater at most study sites would not impede crop yield or quality. Further sequestering of elements to soil and organic matter particles and crop uptake and removal would limit the environmental risk of metals from wastewater.

Pathogen counts for total coliform and *E. Coli* were all below irrigation water quality criteria in June. However, pathogen counts in fall were high and further monitoring of pathogen numbers is required to ensure that water quality meets acceptable standards at all time lines during irrigation. Wastewater irrigation onto forage land provides several degrees of separation between wastewater pathogens and food chain threat to human health. Direct exposure potential to pathogens in an irrigated wastewater stream would be to individual farm workers setting up the irrigation equipment.

5.3 Social Acceptance for Sustainable Wastewater Irrigation

Another vital component to sustainability is addressing social regard and social perception of wastewater irrigation with the local community. To evaluate social regard to wastewater irrigation, municipal and town council members for the study sites were interviewed. Council members were intrigued by the concept of wastewater irrigation as a means to management of their wastewater infrastructure. Council member expressed many legitimate concerns based on economics, social acceptance and perception and environmental implications. Council members anticipated the benefits would be; improved life span to current infrastructure, benefits to downstream water quality and contaminant abatement from Lake Winnipeg. However, most implied that a regulatory directive would be required before they would consider changes to current effluent discharge practices.

A survey of residents was a means to ascertain the social concern about Lake Winnipeg and their perception of wastewater reuse in an agricultural community. Respondents were generally concerned about the current practise of effluent discharge and contaminant loading into Lake Winnipeg. Acceptance and support towards various wastewater reuse alternatives was mixed with respondents generally supporting irrigation onto golf courses, landscapes in industrial parks, and woodlots. Similar results were observed by Po et al.,(2003); and Friedler et al., (2006). Wastewater irrigation on to either forage or wheat crops was of less concern for farm producers than for other respondents.

Respondents advised that notification prior to wastewater irrigation would be important, appreciated, and required. This would demonstrate respect to neighbours and community members, a vital requirement for social policy (Hartley, 2006). The time of day that wastewater irrigation would occur was preferred to be from 12am to 8am, likely because people would be indoors during that time, fortunately this is a preferred irrigation management practice.

Survey respondents were also highly concerned about the potential odour that would be produced during wastewater irrigation however based upon the odour assessment completed on October 3, 2009 this is not a concern, since eleven odour assessors determined that during irrigation odour was slight with an earthy odour.

6 Conclusion

In conclusion, sustainably irrigating forage crops with municipal wastewater at seven of eight sites studied would be challenging. The combination of soils with only ratings of fair for irrigability and the low quality of wastewater for irrigation, limits the long term sustainability of irrigation. Only the Balmoral site maintains a high potential to develop a wastewater irrigation program due to sufficient suitable land and appropriate wastewater quality.

The survey of residents to assess social acceptance and perception found that general respondents were mixed regarding their degree of concern for wastewater irrigation; respondents were generally favourable to irrigation or reuse of wastewater. It would be prudent to conduct public consultations on benefits and disadvantages of irrigation with wastewater to producers, the environment, and the general public prior to initiation of any program.

As outlined previously there are four key factors to the establishment of a sustainable irrigation system. The probability of crop water stress and the amount of crop water demand needs to be sufficient to justify irrigation, land must be suitable for irrigation, water used must meet suitable requirements, and irrigation with wastewater must be socially acceptable. A detailed assessment of these four aspects will satisfy economic, environmental, and social principles to the establishment of wastewater irrigation projects. Key lessons learned in regards to the establishment of a sustainable wastewater irrigation project include:

- Identify, involve and communicate with potential stakeholders,
- Plan, define goals, objectives, and environmental indicators,
- Execute, implement standards, and monitor indicators,
- Analyze, evaluate, and learn from all aspects of the project,
- Update, review, and adjust policy.

7 References

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8 Appendices

8.1 Appendix A - Pictures

Photo 1 Typical lagoon holding cell

Photo 2 Wastewater Discharged to 2nd Order Drain

Photo 3 Wastewater Sampling

Photo 4 Wastewater Sample

Photo 5 Wastewater Irrigation Demonstration

Photo 6 Odour Assessment

8.2 Appendix B – Council & Resident Survey Forms

Council Group Discussion

Approximately 30 communities are established along the shores of Lake Winnipeg; several communities have small lagoons for wastewater retention with no nutrient abatement infrastructure. In early summer to late fall these communities and others in the Lake Winnipeg drainage basin release the lagoon wastewater directly into ditches, streams and river systems which lead into Lake Winnipeg, contributing to nutrient (nitrogen and phosphorous) loading and impacting upon the health of the lake.

Wastewater irrigation onto agricultural crops can be an alternative to current practices in some of these small rural communities. Irrigating allows the crops to utilize the nutrients. Within Canada and the United States there is significant success with wastewater reuse for irrigation to important food crops such as; wheat, corn, potatoes and forages. However, municipal wastewater is not a pristine water source and contains elevated concentrations of salts, chlorides, heavy metals and pathogens that may impact on the soil, groundwater and food crops. Both Saskatchewan and Alberta currently allow wastewater irrigation onto agricultural crops and all governing bodies within the Lake Winnipeg drainage basin have established guidelines as to the quality of water that may be released from waste treatment ponds either directly or indirectly into water bodies within the Lake Winnipeg drainage basin.

In my study, the primary objective is to assess the sustainability of limiting nitrogen and phosphorous from entering Lake Winnipeg through irrigation onto crop land in the East Interlake region.

Discussion Questions

1) Have you heard about the potential use of wastewater for agricultural irrigation previously? What have you heard? After hearing about the potential to use wastewater for irrigation did you look for more information about the practice?
2) Has this council hosted a discussion about the potential of wastewater reuse? Was it a positive discussion? What did the council consider doing?
3) What do you see as the benefits to the community / environment in using wastewater for irrigation? What concerns do you have about the practice? What concerns do you think community members would have?
4) What would encourage the council to consider implementing a wastewater irrigation program?
5) How would the following factors impact the council's interest in establishing a wastewater irrigation program:
    a. Provincial regulation?
    b. Social /political pressure?
    c. Available financial resources or incentive programs?
    d. Others?
6) What risks do you think are associated with wastewater irrigation program?

Resident Survey Form

What is Wastewater irrigation?

Wastewater irrigation is the mechanical means of applying municipal wastewater (residential wastewater) to agricultural crops during the growing season. The irrigation would occur by pumping the water from municipal lagoons through pipes and applying by "Big Gun Sprinklers". Irrigation would only occur when crops require water to grow and produce the maximum potential of production. Many municipal lagoon wastewater projects across Canada, the United States and globally are to relieve water demand for food production and to improve landscape aesthetics in arid climates. The primary objective for water reuse in this study is to limit nutrient loading (along with other contaminants) to surface water that directly leads to Lake Winnipeg.

For each question, select only the most appropriate answer by marking the "O" with a ✔ or ✖.

1. Are you aware that most municipal wastewater lagoons release wastewater to the municipal ditches and drainage pathways each spring and fall?

   O Yes   O No   O Unsure

2. How concerned are you about the release of wastewater into the municipal ditches and drainage pathways?

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

3. Are you concerned about nutrients (I.e. Phosphorous & Nitrogen) entering into Lake Winnipeg?

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

4. Which nutrient are you concerned about entering into Lake Winnipeg?

Phosphorous	Nitrogen	Phosphorous & Nitrogen Equally
O	O	O

5. Are you concerned about metals (Arsenic, Barium, Copper) entering into Lake Winnipeg?

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

6. Are you concerned about personal care products (i.e. non-prescription drugs) entering into Lake Winnipeg?

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

7. Are you concerned about pharmaceuticals (i.e. prescription medications) entering into Lake Winnipeg?

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

8. Are you aware that wastewater irrigation occurs onto agricultural crops in Western Canada?

O Yes O No O Unsure

9. How supportive are you of the following wastewater reuse alternatives?

Check One for Each Row	Very Supportive	Supportive	Neutral	Not Supportive	Not at all Supportive
Irrigate golf courses	O	O	O	O	O
Irrigate landscape in business parks	O	O	O	O	O
Irrigate public parks	O	O	O	O	O
Irrigate on to wood lots	O	O	O	O	O

10. If wastewater irrigation on to agricultural forage crops (I.e. hay) was to occur in your community, how concerned would you be:

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

11. If wastewater irrigation on to agricultural grain crops (I.e. wheat) was to occur in your community, how concerned would you be:

Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
O	O	O	O

12. Are you a farm producer? Yes___ (go to 13) No__ (go to 15)

13. As a farm producer, how interested would you be in using wastewater irrigation on your crops?

a. Very interested O (go to Q15)

b. Interested O (go to Q15)

c. Not interested O (go to Q14)

14. As a farm producer, if you were not interested in using wastewater irrigation on your crops, would you reconsider it after?

a) Further information and or discussion with a professional O Yes O No O Unsure

b) Field demonstration on crops in your area O Yes O No O Unsure

c) Would not reconsider O Yes O No O Unsure

15. The cost of establishing a wastewater irrigation program includes consulting fees, labour, piping, irrigation equipment, and monitoring. Who should pay?
    a. Rural Municipal funding as a whole: O Yes O No O Unsure
    b. Provincial funding: O Yes O No O Unsure
    c. Farm Producer receiving the water: O Yes O No O Unsure
    d. Joint funding from Rural Municipality, Province and Farm Producer:
    O Yes O No O Unsure
16. What would be an acceptable method of determining a dollar value for wastewater irrigation?
    a. Value based on the nutrients in the water? O Yes O No O Unsure
    b. Value based on the volume of water? O Yes O No O Unsure
    c. Value based on open market purchase of wastewater? O Yes O No O Unsure
17. How important is it to provide advance notice each year, when wastewater irrigation is going to occur in your community?

Not important and not required	Not important but appreciated	Important and appreciated	Important and required
O	O	O	O

18. Of the following three parts of the day (day, evening, night) would you prefer wastewater irrigation to occur?

Check One for Each Row	Preferred	Not Preferred	Neutral
8am – 4pm (daytime)	O	O	O
4pm – 12am (evening)	O	O	O
12am – 8am (night)	O	O	O

19. Rate you level of concern with the following:

Check One for Each Row	Very Concerned	Concerned	Somewhat Concerned	Not at all Concerned
Are you concerned with odour from wastewater irrigation onto agricultural land?	O	O	O	O
Are you concerned with how close wastewater irrigation may occur to you yard and home?	O	O	O	O
Are you concerned with the colour of the wastewater irrigation onto agricultural land?	O	O	O	O
Are you concerned with domestic animals (I.e. Cattle) eating hay from irrigated land?	O	O	O	O

20. How supportive are you of wastewater irrigation onto agricultural crops as a method of limiting the amount of nutrients from entering Lake Winnipeg?

Very Supportive	Supportive	Somewhat Supportive	Not at all Supportive
O	O	O	O

21. How supportive are you of wastewater irrigation onto agricultural crops as a method of limiting the amount of other contaminants (metals) from entering Lake Winnipeg?

Very Supportive	Supportive	Somewhat Supportive	Not at all Supportive
O	O	O	O

22. What rate of a property tax increase would you support to ensure wastewater irrigation was a successful, sustainable program at the municipal level?

0.1-0.5%	0.6-1.0	1.1-1.5%	1.6-2.0%	>2%
O	O	O	O	O

23. When applying wastewater irrigation onto agricultural crops, how important is it to...?

Check One for Each Row	Very Important	Important	Somewhat Important	Not Important
Protect soil quality	O	O	O	O
Protect groundwater quality	O	O	O	O
Protect surface water quality	O	O	O	O
Protect human health	O	O	O	O

Demographic Questions

1. What is your gender? O Male O Female
2. What is your age range? O 15-20 O 20-30 O 30-50 O 50+
3. Are you a farm producer? O Yes O No
4. Do you live and work in the area? O Yes O No
5. Do you live in the area and work in another area? O Yes O No
6. How long have you been living at your current residents?
   O <1-5 years O 6-10years O 11-15years O more than 15 years

8.3 Appendix C Laboratory Methods

Exova
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Exova

Methodology and Notes

Bill To:	East Interlake Conservation	Project:		Lot ID:	**706355**
Report To:	Jacques Whitford AXYS Ltd.	ID:	DKMSC	Control Number:	A 129531
	103-611 Corydon	Name:		Date Received:	Oct 6, 2009
	Winnipeg, MB, Canada	Location:		Date Reported:	Oct 19, 2009
	R3M 0S1	LSD:		Report Number:	1256921
Attn:	Darren Keam	P.O.:			
Sampled By:	D. Keam	Acct code:			
Company:					

Method of Analysis

Method Name	Reference		Method	Date Analysis Started	Location
Alkalinity, pH, and EC in water	APHA	*	Conductivity, 2510	07-Oct-09	Exova Edmonton
Alkalinity, pH, and EC in water	APHA	*	Electrometric Method, 4500-H+ B	07-Oct-09	Exova Edmonton
Ammonium-N in Water	APHA	*	Automated Phenate Method, 4500-NH3 G	13-Oct-09	Exova Edmonton
Anions (Routine) by Ion Chromatography	APHA	*	Ion Chromatography with Chemical Suppression of Eluent Cond., 4110 B	06-Oct-09	Exova Edmonton
BOD in water (surrey)	APHA	*	5 Day, 5210 B	07-Oct-09	Exova Surrey
Chloride in Water	APHA	*	Automated Ferricyanide Method, 4500-Cl- E	06-Oct-09	Exova Edmonton
Coliforms - Membrane Filtration	APHA		E. Coli - MF Partition Procedures, 9222 G	06-Oct-09	Exova Calgary
Coliforms - Membrane Filtration	APHA		Standard Total Coliform Membrane Filter Procedure, 9222 B	06-Oct-09	Exova Calgary
Kjeldahl Nitrogen & Phosphorus (Dissolved) in Water	APHA	*	Automated Ascorbic Acid Reduction Method, 4500-P F	08-Oct-09	Exova Edmonton
Kjeldahl Nitrogen & Phosphorus (Total) in Water	APHA	*	Automated Ascorbic Acid Reduction Method, 4500-P F	08-Oct-09	Exova Edmonton
Mercury (Dissolved) in water	APHA	*	Cold Vapour Atomic Absorption Spectrometric Method, 3112 B	07-Oct-09	Exova Edmonton
Metals ICP-MS (Total) in water	US EPA	*	Determination of Trace Elements in Waters and Wastes by ICP-MS, 200.8	06-Oct-09	Exova Edmonton
Metals Trace (Dissolved) in water	APHA	*	Inductively Coupled Plasma (ICP) Method, 3120 B	06-Oct-09	Exova Edmonton
Metals Trace (Total) in water	APHA	*	Inductively Coupled Plasma (ICP) Method, 3120 B	06-Oct-09	Exova Edmonton
Odour in water	APHA	*	Threshold Odour Test, 2150 B	06-Oct-09	Exova Edmonton
pH in water (Surrey)	APHA	*	Electrometric Method, 4500-H+ B	07-Oct-09	Exova Surrey
Phosphorus - acid-hydrolyzable P (Surrey)	APHA	*	Preliminary Acid Hydrolysis, Ascorbic Acid Reduction Method, 4500-P B,E	15-Oct-09	Exova Surrey
Phosphorus - acid-hydrolyzable P (Surrey)	APHA	*	Preliminary Acid Hydrolysis, Ascorbic Acid Reduction Method, 4500-P B,E	19-Oct-09	Exova Surrey
Phosphorus - total (low level)	APHA	*	Preliminary Acid Hydrolysis, Ascorbic Acid Reduction Method, 4500-P B,E	08-Oct-09	Exova Surrey
Solids Dissolved (Total, Fixed and Volatile)	APHA	*	Total Dissolved Solids Dried at 180 C, 2540 C	06-Oct-09	Exova Edmonton
Solids Suspended (Total, Fixed and Volatile)	APHA	*	Total Suspended Solids Dried at 103-105'C, 2540 D	08-Oct-09	Exova Surrey
Solids Suspended (Total, Fixed and Volatile)	APHA	*	Total Suspended Solids Dried at 103-105'C, 2540 D	09-Oct-09	Exova Surrey
Total and Kjeldahl Nitrogen (Total) in Water	ISO	*	Water Quality - Determination of nitrogen, ISO/TR 11905-2	06-Oct-09	Exova Edmonton

** Laboratory method(s) based on reference method*

Exova
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Methodology and Notes

Bill To:	East Interlake Conservation	Project:		Lot ID:	**706355**
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	Winnipeg, MB, Canada	Location:		Date Reported:	Oct 19, 2009
	R3M 0S1	LSD:		Report Number:	1256921
Attn:	Darren Keam	P.O.:			
Sampled By:	D. Keam	Acct code:			
Company:					

References

APHA	Standard Methods for the Examination of Water and Wastewater
US EPA	US Environmental Protection Agency Test Methods
ISO	International Organization for Standardization

Comments:

- Upon receipt, all sampls had exceeded recommended holding time for microbiology analysis. Darren Keam with Jacques Whitford was contacted on Oct 6, 2009 and requested that we continue the service with the non-conformance.
- Lot 706355 was received in a plastic bottle which does not meet the sample requirements for odour as specified by the reference method.

- Reduction of analytical volume was necessary due to matrix effects in sample 706355-1,2,3,4,5,6,8,9,10. For Total Organic Phosphorus the reported detection limits are 30 times higher than the nominal detection limits.
- Sample 706355-7; 3162279 The ion balance was outside the range 90 - 110% for sample 706355-7. The ion balance can be variable in samples with TDS less than 100 mg/L.