Impact of Intensive Livestock Operations on Water Quality

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■ Take Home Messages

- Estimates of manure production from 1992 census data showed that Alberta produced the largest quantity of cattle and hog manure, and British Columbia the largest amount of poultry manure in Canada. Updated estimates based on 1999 and 2000 census data revealed that Alberta still produced the highest quantity of cattle manure, but Manitoba produced the most hog manure, and British Columbia the largest amount of poultry (layers) manure.
- Nutrients, soluble salts, pathogens, heavy metals and organic chemicals in the manure have the potential to pose a threat to water quality if the soil is used as an infinite sink.
- Intensive livestock operations have a vested interest in protecting water quantity and quality, as large quantities of good quality water are needed for drinking by livestock.
- Nitrogen and phosphorus are the nutrients in livestock manure of most concern because they can cause eutrophication of surface water, and nitrate-N can leach into groundwater. Application of manure to cropland at rates that meet plant uptake and closely monitoring N and P levels in manure and soil is the best approach to manage these nutrients.
- Livestock manure contains a high amount of soluble salts. Research at the Lethbridge Research Centre has found that long-term application of beef cattle manure can leach soluble salts into the groundwater under irrigation but not dryland. The high salt content of compost is the main factor limiting its use as a peat substitute in the greenhouse industry.
- The main pathogens in livestock manure of concern are bacteria and protozoa (Giardia, Cryptosporidium). Composting of manure can kill-off most of these pathogens, so application of compost to cropland will minimize transport of pathogens into the environment.

- Heavy metals in manure may pose a threat to water quality. Researchers have documented a build-up of zinc in surface soils after 11 yr of application of beef cattle manure. Runoff from this manured land may transport zinc into surface water and possibly harm aquatic life.
- Many different organic chemicals are used in the livestock industry. Research has shown that certain ionophores and antibiotics may be excreted by cattle, which may pose a water quality concern if these chemicals are transported off-site.
- A review of the North American literature revealed little or no water quality problems associated with beef cattle feedlots and their catch basins. Insufficient research has been conducted on the potential impact of land application of beef cattle manure on surface water quality. The area of greatest concern appears to be potential deterioration in soil and groundwater quality from long-term land application of beef cattle manure.
- Little research has been conducted in Alberta on the impact of dairy cattle manure on water quality.

Intensive Livestock Operations in Western Canada

There are approximately 10.6 million cattle and calves in western Canada (Manitoba, Saskatchewan, Alberta, B.C.), 8.2 million poultry (layers), and 4.8 million pigs (Statistics Canada 2000). Alberta has the highest percentage of total cattle and calves (54%), followed by Saskatchewan (26%), Manitoba (13%) and B.C. (7%). Alberta has the largest number of steers (78%), followed by Saskatchewan (31%), Manitoba (14%) and B.C. (7%). Steers are the dominant cattle used in the feedlot industry in western Canada. There are approximately 4,500 feedlots in Alberta with a combined one-time feeding capacity of about one million head (AAFRD 2000a). Beef feedlots range in size from small operations with under 1,000 head capacity to large, specialized lots with the capacity to feed over 50,000 head. There are about 257,000 milk cows in western Canada and about 104,500 dairy heifers. Alberta has the highest percentage of milk cows and dairy heifers (∃38%), followed by B.C. (∃30%), Manitoba (∃16%), and Saskatchewan (12%). British Columbia has the highest percentage of poultry layers (34%), followed by Manitoba (29%), Alberta (24%) and Saskatchewan (12%).

Barnett (1987) estimated the amount of livestock waste produced by different livestock species for each province in Canada based on 1992 census data. Barnett reported that Alberta produced the largest quantity (wet wt.) of manure from total livestock (cattle, hogs, poultry, sheep, horses, goats, rabbits) and cattle, followed by Saskatchewan, Manitoba and B.C. Alberta produced the most dairy cattle manure, followed by B.C., Manitoba and Saskatchewan. Alberta also generated the largest quantity of manure from hogs, followed by

Manitoba, Saskatchewan and B.C. British Columbia produced the largest quantity of manure from poultry, followed by Alberta, Manitoba and Saskatchewan.

I used the 2000 census data for cattle and calves and hogs, the 1999 census data for poultry layers, Barnett's constant values for manure production from various livestock species, and updated the estimates for manure production. Alberta produced the most manure from all livestock, followed by Manitoba, Saskatchewan and B.C. Alberta also produced the highest amount of manure from cattle and calves, followed by Saskatchewan, Manitoba, and B.C. Alberta produced the most feedlot manure from steers, followed by Saskatchewan, Manitoba, and B.C. Alberta also produced the most dairy manure, followed by B.C., Manitoba, and Saskatchewan. Manitoba produced the most manure from hogs, followed by Alberta, Saskatchewan and B.C. British Columbia had the greatest amount of poultry (layers) manure, followed by Manitoba, Alberta and Saskatchewan. The major change from 1992 to 1999 and 200 was the shift in hog manure production from Alberta to Manitoba.

▪ Intensive Livestock Operations Need Water to Survive

Expansion of the intensive livestock industry in western Canada has raised environmental concerns related to surface water and groundwater quality. Clean water is vital for drinking water by humans and livestock, for irrigation of crops, recreational use by humans, and for protection of aquatic life (CCME 1987). In fact, the survival of feedlots depends on their ability to obtain large quantities of good quality water for their cattle. Dairy cows have the greatest water volume requirements (160 Liters/day), followed by beef cows (55 L/d), feeder pigs (7-10 L/d), ewes (2-7 L/d) and laying hens (0.25-0.3 L/d) (CCME 1987). Most livestock water in the western prairies is obtained from groundwater wells (Hess 1981). The exception is in irrigated areas of southern Alberta, where surface water from irrigation reservoirs is used. Livestock operations in British Columbia obtain most of their livestock water from surface water (60%), with lesser amounts from groundwater (Hess 1981). In addition to water quantity, the livestock industry needs good quality water. Poor quality water can result in economic loss to the producer, and an inferior product to the consumer (CCME 1987). In certain cases, contaminants in drinking water for livestock could be transferred from livestock to the consumer and might cause a public health concern. For example, Salmonella infection is occasionally transferred from livestock to man (CCME 1987).

Contaminants in Livestock Manure that May Affect Water Quality

Nutrients

Nitrogen (N) and phosphorus (P) are the two major nutrients in manure that can affect water quality. Nitrogen concentration is highest in hog manure (76.2 g N kg^{-1} dry wt.), followed by turkeys (59.6), poultry layers (49.0), sheep (44.4), poultry broilers (40.0), dairy cattle (39.6) and beef cattle (32.5) (Sharpley et al 1998). Phosphorus content is highest in poultry layers (20.8 g N kg^{-1} dry wt.), followed by hogs (17.6), turkeys (16.5), poultry broilers (16.9), sheep (10.3), beef (9.6) and dairy (6.7) (Sharpley et al. 1998). Phosphorus, and to a lesser extent nitrogen, are the major causes of eutrophication of surface water bodies such as lakes. Eutrophication is a process whereby enrichment of P and N cause excessive algae and weed growth, toxic algae blooms, low oxygen levels, and fish kills. In general, P tends to be more of a problem with surface water quality, whereas N tends to pose more of a threat to groundwater quality by nitrate leaching through soils. The provincial water quality guidelines in Alberta for the protection of aquatic life in surface waters are 1.00 mg L^{-1} for total N and 0.05 mg L^{-1} for total P (Alberta Environment 1999).

The five-year water quality study in Alberta funded by the Canada-Alberta Environmentally Sustainable Agriculture Agreement (CAESA 1998) found that N and P were significant contaminants in streams of areas of moderate and high agricultural intensity. Agricultural intensity was indicated by fertilizer or herbicide inputs, or by animal unit density. Phosphorus was a significant contaminant in small lakes in high intensity agricultural areas, and in irrigation canals. Nitrate concentrations in groundwater exceeded Canadian drinking water quality guidelines (10 mg L^{-1}) only occasionally. However, specific research projects indicated that excessive manure and fertilizer applications are likely to result in unacceptable levels of nitrates in shallow groundwater over time. At high risk are areas with shallow, unconfined aquifers.

Manure application to cropland has traditionally been based on N rather than P uptake of crops. However, because N and P are in manure, soil and crops at specified and different ratios, application rates based on N have resulted in a build-up of P in the soil over time. As soils are not infinite sinks for P, this can threaten water quality by increased eutrophication. Researchers in North America have proprosed two concepts to deal with the soil P issue. The first concept utilizes a maximum P limit in soils based on the agronomic concept that plant uptake will eventually level-off at some value of soil test P. Alberta proposed to adopt a limit of 200 ppm (mg kg^{-1}) soil test P, which was used in Texas (Daniel et al. 1998), but this concept was rejected in Alberta. The second concept is the P index (Sims and Sharpley 1981). The P index estimates the potential for P loss from soils to surface water by considering many different factors. These factors include soil and irrigation erosion, soil runoff class, soil test P, phosphorus fertilizer rate and method, and organic P source application rate and method. The new code of practice in Alberta has not officially adopted either concept, but does mention that "In some situations, P may be considered a more limiting nutrient than N over time. Therefore, manure application adjustments may be required to address soil P levels." (AAFRD 2000b).

Soluble Salts

Manure contains large quantities of soluble salts, including potassium, sodium and chloride. The average total salt content or electrical conductivity (EC) of beef cattle manure from six feedlots in southern Alberta was around 20.0 dS m^{-1} (Chang 1987). Soils in Alberta are considered saline if the EC is greater than 4 dS m^{-1}. Chang et al. (1991) reported that significant leaching of soluble salts occurred under irrigation but not dryland, which suggests a potential for salinization of groundwater under irrigation. Assuming potassium is the dominant soluble salt in manure, the highest soluble salt content in livestock manure is in dairy cattle (31.6 g potassium kg^{-1} dry wt.), followed by sheep (30.5), hogs (26.2), beef cattle and poultry layers (20.8), turkeys (19.4), and poultry broilers (19.0) (Sharpley et al. 1998). There is a linear relationship between salt concentrations in manure and the salt level in cattle ration (Sweeten and Mathers 1985). Therefore, there is an opportunity to reduce salt levels in manure by reducing the salt in the ration. For example, cattle are fed salt to furnish sodium, while most rations supply adequate chlorine. Experiments have shown that salt levels in rations could be limited to 0.25% to minimize salt levels in manure without harming beef cattle production (Sweeten 1985).

Pathogens

The main pathogens of concern in livestock manure that can affect water quality for humans are bacteria and protozoa (Giardia, Cryptosporidium). No water sample for drinking by humans should contain more than 10 total coliform organisms per 100 ml, none of which should be fecal coliforms (CCME 1999). There are no proposed guidelines for protozoa or viruses at this time; but it is recommended that none of these organisms be detected in water samples. Various categories of bacteria have been used to indicate water quality. These have included total coliforms, fecal coliforms, total enterococci, and more recently, *Eschericia coli* (*E. coli*). Some microbiologists believe that *E. coli* gives the best indication of fecal contamination of water (Edberg et al. 2000), and it is being increasingly used as an indicator for public health protection in water. Although most strains of *E. coli* are harmless and live in the intestines of healthy humans and animals, some strains produce powerful toxins than can cause severe illness and even death. One example is *E. coli 0157:H7*, which can cause hemorrhagic colitis and hemolytic uremic syndrome in humans

(Kudva et al. 1998). Healthy cattle and sheep sporadically have *E. coli 0157:H7* in their gastrointestinal tracts and shed the bacteria in their feces (Kudva et al. 1998).

The protozoa Giarida and Cryptosporidium, which can be found in most livestock manure, have become major health concerns in water supplies (Fayer 1997; Thompson et al. 1994). These protozoa can make people seriously ill, and those persons who are young, old or immune-compromised are especially susceptible. For example, a massive waterborne outbreak of Cryptosporidium occurred in Milwaukee, WI, and involved 403,000 persons. The cysts of these protozoa are extremely resistant to chlorination, and filtration is often used to trap the tiny cysts.

We conducted two years of field experiments on windrow composting of beef cattle manure containing both straw and wood bedding materials. Preliminary results from our study indicate that *E. coli* was generally killed-off after only two to four weeks of composting, and there was no differences between persistence in piles of the different bedding materials. Dr. T.A. McAllister (2000, pers. comm.) also found that composting killed-off most of the Giardia and Cryptosporidium. Therefore, application of compost to cropland should result in no pathogens being added to soil. In contrast, our preliminary results indicate that *E. coli* bacteria persist in soil under fresh manure application for up to eight months. If these pathogens persist and are transported off-site, they may pose a threat to surface water or groundwater quality.

Heavy Metals

Heavy metals in livestock manure may pose a threat to water quality. Since most of these metals are positively charged cations, they tend to become adsorbed to organic matter and clay particles, and are therefore more susceptible to off-site transport by surface runoff. The metals that might be added to livestock rations may include arsenic, cobalt, copper, iron, manganese, selenium and zinc. Many of the metals are toxic to aquatic life at very low concentrations. For example, copper is toxic at 2-4 $\mu g\ L^{-1}$ and zinc at 30 $\mu g\ L^{-1}$ (CCME 1999). Chang et al. (1991) found an accumulation of zinc (but not copper) in the top 30 cm of soil after 11 yr of annual beef cattle manure application. This suggests that if runoff occurs from these soils, water quality problems for aquatic life may arise. Selenium is a negatively charged anion and is likely to be transported off-site by leaching.

Organic Chemicals

The livestock industry uses many different organic chemicals. These may include vaccines to treat viruses and bacteria, anthelmintics to treat intestinal worms, parasiticides to treat worms and coccodia (cell parasites), ionophores, insecticides, and feed medication and miscellaneous chemicals (Crandall and

Van Donkersgoed 1996). The water quality concern about organic chemical use in the livestock industry is excretion of these products in the manure and urine, and potential transport into surface water or groundwater. Ionophores and antibiotics are commonly used in the livestock industry. Ionophores often mimic hormones. The environmental concern with hormones is potential effects on crops and possible endocrine disruption in non-target animals such as humans. Endocrine disruptors are chemicals that interfere with normal function of hormones and the way hormones control growth, metabolism and body functions. Ionophores are used in feedlots as ear implants in steers and heifers, or as feed additives in heifers. They increase weight gain, and result in leaner meat and less fat.

The study by Estergreen et al. (1977) indicates that ionophores can be excreted by cattle. They reported that 50% of progesterone was excreted in the feces and 2% in the urine of cows; and that 12% and 1.2%, respectively, were excreted in the feces and urine of steers. Overall, ionophores have a low water pollution potential because they are generally fat-soluble and not water-soluble compounds; however exceptions do occur. For example, Shore et al. (1993) found that testosterone was readily leached from soil, but estradiol and estrone were not. Water in streams of Chesapeake Bay in the eastern U.S.A. had 0.8-2.9 0g L^{-1} of testosterone and 1.2-4.1 0g L^{-1} of estrogen; and runoff from land amended with poultry manure containing these chemicals may be a source of these compounds (Shore et al. 1995). Nichols et al. (1997) found 17∃-estradiol in runoff from pasture land amended with poultry manure. They concluded that poultry manure could contribute to this chemical in runoff, it persisted at least seven days, and amending poultry litter with alum (aluminum sulfate) reduced runoff losses of the chemical.

Antibiotics are organic chemicals produced by microbes that have the ability at low concentrations to inhibit growth or destroy another microbe. They are used in the livestock industry to improve growth and feed efficiency, disease prevention and therapy of cattle. The environmental concern is possible alteration of microbial flora, which could cause disease and development of resistant strains of micro-organisms. A headline in the Lethbridge Herald on April 11, 1997 was “Threat of the superbugs-livestock operations could be home to strains of new antibiotic-resistant bacteria.” Research indicates that antibiotics can be excreted in the manure or urine of cattle. Elmund et al. (1971) reported that 75% of dietary chlortetracycline was excreted in the manure. They also noted that 38% more organic matter was oxidized in control steers than treated steers, which may make the organic matter less biodegradable.

Various insecticides are used in the feedlot industry. Environmental concerns from their use are impairment or kill of non-target organisms, possible carcinogens, and endocrine disruption. Ivermectin is commonly used to treat various nematodes and arthropods in beef cattle. It has been detected in cattle feces for up to ten days post-treatment (Floate et al. 1997; Floate 1998). Other studies (Nessel et al. 1989) have reported that ivermectin is tightly bound to soil, is not lost by runoff or leaching, and is degraded to a metabolite that is nontoxic to Daphnia (freshwater crustacea). We are unaware of any studies in western Canada that have examined the potential impact of organic chemicals used in livestock industry on water quality.

▪ Impact of Intensive Livestock Operations on Water Quality in Western Canada

A literature review on the impact of beef cattle feedlots on water quality in North America (Miller 2000) revealed little or no surface water or groundwater quality problems associated with feedlots and their catch basins. Insufficient research has been conducted on the potential impact of land application of manure on surface water quality. The area of greatest concern appears to be potential deterioration in soil and groundwater quality from long-term land application of manure.

Considerable research has been conducted on leaching of nutrients and soluble salts (but not pathogens) under manured land in Alberta (Chang et al. 1991; Riddell and Rodvang 1992; Chang and Entz 1996; Olson et al. 1997, 1998). The major concern has been with nitrate leaching to groundwater. Considerable research has been conducted on leaching at long-term (since 1973) manure plots at the Lethbridge Research Centre. Beef cattle manure was annually applied to dryland plots at 0, 30, 60 and 90 Mg ha^{-1}, and to irrigated plots at 0, 60, 120 and 180 Mg ha^{-1}.

Chang et al. (1991) reported that the accumulation of organic matter, total nitrogen, nitrate-N, total phosphorus, available P, soluble sodium, calcium and magnesium, chloride, sulfate, bicarbonate, and zinc in the soil increased with increasing rates of manure applied. Chang and Entz (1996) found that under dryland conditions, beef cattle manure applied at rates from 30 to 90 Mg ha^{-1} resulted in a significant accumulation of nitrate-N in the root zone. Minimal leaching loss was observed below 1.5 m depth except for a year with unusually high precipitation, but nitrate-N in the soil profile continuously increased at all rates of manure application. On irrigated land, manure applied at rates from 60 to 180 Mg ha^{-1} resulted in leaching losses of nitrate-N as high as 341 kg N ha^{-1}, which can cause soil and groundwater pollution. They estimated that application rates of 14 Mg ha^{-1} would be required on irrigated land to have no nitrate-N leaching. They also concluded that rates ∃30 Mg ha^{-1} under dryland and ∃ 60 Mg ha^{-1} under irrigation are too high for annual application because of the potential soil and water contamination problems.

Riddell and Rodvang (1992) examined soil and groundwater chemistry beneath irrigated land (four sites) receiving manure applications in southern Alberta. They reported that producers were applying manure at variable rates (60-155 Mg ha^{-1}) that significantly increased the frequency of detection for groundwater nitrate-N above the drinking water limits for humans and livestock consumption. The magnitude of the increase in groundwater nitrate-N under fields was extremely variable (10-300 mg L^{-1}).

Olson et al. (1997) reported on the impact of beef cattle manure application on soil and groundwater quality at two sites (irrigated silage barley) in central Alberta. One site was located on a silt-loam to silty clay loam soil near Lacombe, the other on a loam soil near Ponoka. Manure was applied at rates from 20 to 120 Mg ha^{-1} wet weight. Two annual applications of manure (1994-95) did not affect the groundwater nitrate-N and chloride content at each site. However, soil extractable sodium, potassium, and chloride were increased. They concluded that additional time (3-5 yr) would be required to confirm the initial trends found.

Olson et al. (1998) also examined beef cattle manure application on soil and groundwater quality at two irrigated sites (silage barley) in southern Alberta. One site was located on a sandy loam soil, the other on a loam to clay loam soil. Manure was applied for four consecutive years (1994-98) at rates from 20 to 120 Mg ha^{-1}. Manure application significantly increased soil nitrate-N, sodium, potassium, chloride and bicarbonate at both sites. Groundwater nitrate-N was not affected by manure application at the medium textured site. However, significant amounts of excess nitrate-N from the 120 Mg ha^{-1} treatment reached the water table in 1995 at the coarse-textured site after only two applications, and this effect intensified in 1996 and 1997.

■ Current Research

We are currently conducting a three year (1998-2001) study on “managing feedlot manure to protect water quality and human health” that is funded by the Canada-Alberta Beef Industry Development Fund (CABIDF). The objectives of the study are to determine if feedlots and land application of manure are impacting water quality (bacteria, nutrients, soluble salts), and to develop beneficial management practices to protect and enhance the quality of our surface water and groundwater resources. The project is being conducted at the Lethbridge Research Centre (LRC) Feedlot. The impact of feedlots on water quality is being examined by the following studies. We are determining the quality (bacteria, nutrients and soluble salts) of pen manure throughout the year; the quality of soil and groundwater below, adjacent and away from the LRC feedlot; the quantity and quality of runoff from the entire feedlot into the catch basin; the quality of the catch basin effluent; the quantity and quality of runoff in pens bedded with straw and wood chips; and the effect of composting on bacteria survival. The impact of manure application to cropland on soil, crop and water quality is also being examined. Treatments include type of manure (fresh manure versus compost), rate of application, and bedding material (straw versus wood chips). We are determining the persistence and leaching of bacteria in the soil; the persistence of bacteria on silage barley irrigated with catch basin effluent; crop production; leaching; and the quantity and quality of surface runoff.

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