The Impact of Waterfowl on Water Quality
- Literature Review -

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1.0 Introduction

In Canada, migrating bird formations are as symbolic of the approaching winter as the changing colours of autumn leaves. As these creatures stop to rest for a period of time, they do not leave the landscape unscathed. Potentially large numbers of birds busily feed on any available vegetation or wildlife in order to build energy stores for their future journey, but that which they do not need, is excreted and left behind.

The potential for migratory or resident bird populations to impact water quality with nutrients or pathogens has been touched upon by various scientists over the years. Nutrient and pathogen content in feces can vary between different bird species, populations of the same species, as well as feeding and nesting patterns (Dobrowolski et al. 1976). However, by examining past studies and the characteristics of the study, one can assess the general potential for water quality contamination. The objective of this literature review is:

- to review studies completed to date and draw conclusions about the impact of waterfowl on water quality.

2.0 Manure Production

Table 1 shows examples of mean values of various manure constituents based on the amount of fresh manure produced by 1000 kg live animal mass per day (ASAE 1999). From the table, one can get a sense of how bird feces production compares to other animals. The authors of the table had access to very limited data on waste production from waterfowl.

Table 1 – Fresh manure production and characteristics per 1000 kg live animal mass per day (standard deviation in brackets). (from ASAE 1999)

		Animal Type			
Parameter	Units	dairy	swine	turkey	duck
total manure	kg	86 (17)	84 (24)	47 (13)	110 (n/a)
Total Kjeldahl N	kg	0.45 (0.096)	0.52 (0.21)	0.62 (0.13)	1.5 (0.54)
Total P	kg	0.094 (0.024)	0.18 (0.10)	0.23 (0.093)	0.54 (0.21)
Fecal coliform bacteria	colonies $x10^{10}$	16 (28)	18 (12)	1.4 (n/a)	180 (180)

3.0 Bacteria and other pathogens

As with feces from other animals, bird feces can contain potentially harmful bacteria or other pathogens.

3.1 Bacteria and pathogen content of bird feces

Gould and Fletcher (1978) examined the feces of five species of captive gulls, the great black-backed gull (*Larus marinus*), lesser black-backed gull (*L. fuscus*), herring gull (*L. argentatus*), common gull (*L. canus*), and the black-headed gull (*L. ridibundus*). Over a 24 hour period, the lesser black-backed gull excreted the highest amount of fecal coliforms per gram of feces excreted at $3.73x10^8$, whereas the lowest amount was excreted in the black-headed gull feces at $0.27x10^8$. These translate into fecal coliform loading rates of $16x10^6$ and $1.1x10^6$ organisms per hour per bird, respectively. The authors felt that large numbers of these birds frequenting an area regularly would be capable of adversely affecting water quality.

Damare et al. (1979) examined the intestinal tracts of Canada geese and Whistling swans in order to determine the kinds of flora inhabiting them. 64% of the 101 fermentative strains were classified as *E. coli*, and the remaining were associated with 13 other taxa, none of which were specific to waterfowl. It was not determined whether these bacteria present in healthy birds were pathogenic when excreted into the environment.

In a study by Graczyk et al. (1996), six previously uninfected Peking ducks were each inoculated with $2x10^6$ viable *Cryptosporidium* oocysts. Oocysts were detected in all inoculated ducks. The authors determined that, even after passing through the intestinal tract of the avian host, 73% of the oocysts shed in the feces were still viable. The authors concluded that waterfowl, like the Peking duck, could serve as a mechanical vector for the transport of viable *Cryptosporidium* oocysts.

Though gulls carry substantial amounts of salmonellae, Girdwood et al. (1985) suggest that when gull populations are low and the excretion period is limited, they do not pose a public health hazard. This conclusion was based on a two year study of fecal and intestinal infection of various gulls captured in different localities around Scotland.

Alderisio and DeLuca (1999) tested fecal samples from 249 ring-billed gulls and 236 Canada geese for fecal coliform bacteria. Over a two year period, fecal coliform levels in the gull samples averaged 3.68×10^8 g^{-1} of feces while the goose samples averaged 1.53×10^4 g^{-1}. This is equivalent to a loading of approximately 1.77×10^8 and 1.28×10^5 fecal coliforms per fecal deposit into the surface water, for gulls and geese, respectively. The study also found that sun-dried feces can contain viable fecal coliform. Fecal coliform in the dried samples ranged from 8.2×10^2 to 3.0×10^5 g^{-1}.

3.2 Bacterial and pathogen loading of bird feces on land and in water bodies

In a New Mexico watershed study, Brierley et al. (1975) found that the presence of large amounts of migratory birds did not appear to affect water quality. In most cases, the fecal colonies in the water samples remained the same, and in some cases decreased, when migratory birds visited. The decreasing levels occurred during November through February. This corresponded to both the time when migrating bird numbers were highest, and when bacteria– which was introduced with suspended sediment during the previous spring's flooding– began to settle and die. For example, concentrations of coliform colonies counted at an incubation temperature of 35°C ranged from 1.9×10^4 to 3.6×10^6 per 100 mL. Elevated levels of bacteria were mainly attributed to upstream contamination. Bird populations *averaged* 10 500 sandhill cranes, 2000 Canada geese, 8300 snow geese and 26 500 ducks during the months of October to early March.

Hussong et al. (1979) observed Canada geese and Whistling swans, two of the dominant migratory waterfowl populations present in the Chesapeake region. They aimed to determine the loading and fate of any bacterial flora contributed by these birds. To determine fecal loading rates, droppings were collected in the wild as well as from birds caged for between 4 to 24 hours. The numbers of fecal coliforms per gram of feces over a 24 hour period for both wild swan and Canada goose were estimated at 2.5×10^6 and 3.6×10^4, respectively. Captive and fasting birds had less fecal coliform per gram of feces. In a 24 hour period, a single swan can excrete up to 10^9 fecal coliforms and a goose can excrete up to 10^7 fecal coliforms. However, from a random selection of 75 *E. coli* isolates, there were only seven enterotoxin-producing *E. coli*. From 44 different samples, no *Salmonella* spp. were found. They concluded that only a minority of the birds, if any, were carrying *Salmonella* spp. "Bird hours" are the number of birds present multiplied by the number of hours they spent near the pond. Minimum and maximum bird hours ranged from 1 to 31,000 from the five ponds monitored. Fecal coliform levels from these ponds were both measured to be 1.0×10^0 per 100 mL of water. The highest fecal coliform level per 100

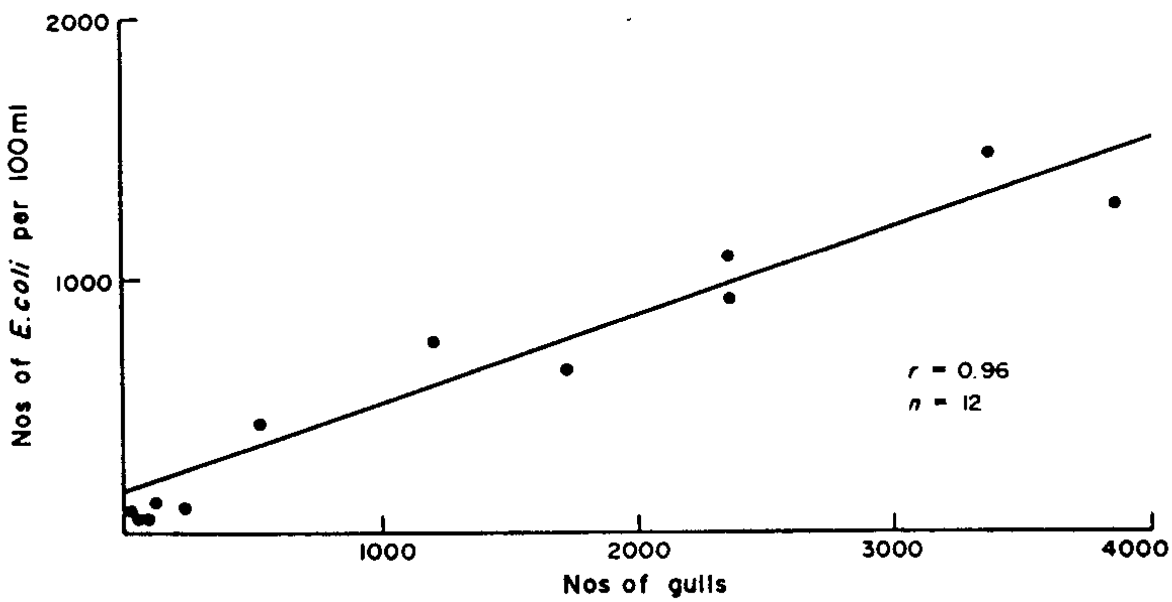

Figure 1 Correlation of mean monthly numbers of gulls roosting on a reservoir with mean monthly numbers of *E.coli* per 100 mL from August 1979 to July 1980 (from Benton et al. 1983).

mL of water was 2.4×10^3 which corresponded to a pond with only 220 bird hours. The authors concluded that fecal coliform densities vary with different species of waterfowl, pond size, diets and feeding habits.

High fecal coliform levels resulting in beach closures in Madison, Wisconsin, were attributed to a permanent mallard duck population of 100 to 200 in a study by Standridge et al. (1979). The local sewer system, a nearby zoo, visiting dogs and cats, and rodents were ruled out as sources of the elevated levels of fecal coliform. The study also indicated that conditions within the beach sand were suitable for fecal coliform growth and rapid multiplication during the first week after inoculation.

Benton et al. (1983) observed the relationship between the number of roosting gulls and number of *E. coli* per 100 mL of water from two reservoir lakes, north of Glasgow, Scotland. The relationship between the two parameters was found to be highly significant (see Figure 1). When the birds were present, fecal coliform levels were well above the target maximum concentration of 100 organisms per 100 mL of water, suitable for recreational use.

Valiela et al. (1991) studied the fecal coliform loadings and stocks from various sources in Buttermilk Bay, Massachusetts. Major sources of fecal coliform to the bay were waterfowl (ducks, geese, and swans), surface runoff, groundwater, and streams. From January to March, waterfowl contributed the most fecal coliform (an estimated fecal coliform level of 1.8×10^{11} day^{-1}; or 82% of total loading), but from July to September, they contributed comparatively little (5.7×10^9 day^{-1}; or 7%) (see Figure 2). Though some suggest eliminating the waterfowl as a means of reducing fecal coliform loading, the authors refute this idea. Firstly - eliminating one source still leaves several other sources of contamination (runoff, streams, etc.). Secondly - fecal coliform loading from the birds is highest in the winter (when roosting time is increased), whereas beach closures due to high levels of coliforms occur in the summer, when birds are sparse. They concluded that eliminating birds would not be an efficient means of reducing elevated fecal coliforms leading to beach closures.

Levesque et al. (1993) investigated the impact that the Ring-Billed Gull (*Larus*

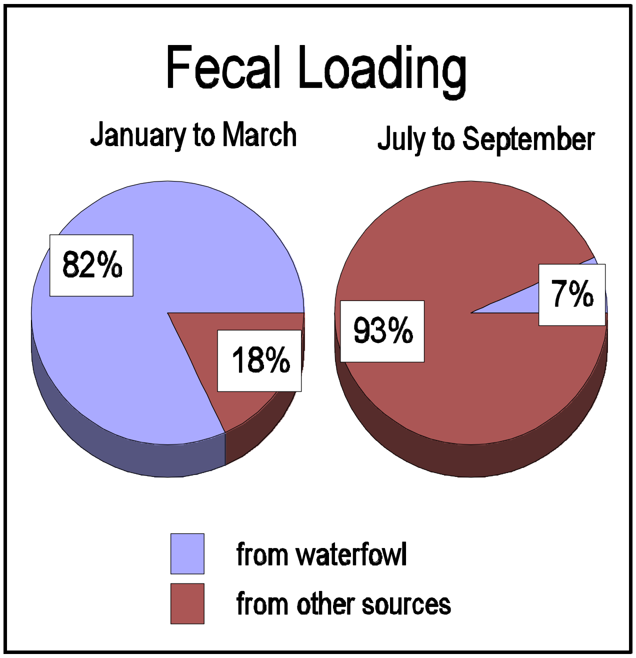

Figure 2 - Fecal coliform loadings in Buttermilk Bay, Massachusetts, during two time periods from waterfowl or other sources (from Valiela et al. 1991).

delawarensis) had on recreational water quality. By collecting fecal samples from the gulls, they determined that there was an average 7.1×10^7 bacteria per gram of gull feces. 99% of this bacteria consisted of strains of *E. coli*. Approximately 200 strains of *Salmonella spp* were isolated and 42 were serotyped. Only seven of these serotypes were potentially pathogenic to humans and animals. The previously excellent water quality of the 10 000 m^3 spring-fed lake in Quebec degraded with the presence of only 30 gulls. After only two days, the Canadian standard for recreational water quality (200 fecal coliforms per 100 mL) had already been exceeded (264 fecal coliform). After just seven days, with 103 birds, bacteria in the water reached levels of over 5000 fecal coliforms per 100 mL. This level of fecal coliform is unacceptable.

Levesque et al. (2000) studied three colonies of ring-billed ducks along the St. Lawrence River. Bacteria were present in large quantities in the feces (10^4-10^8 colony forming units/g). The measurements determined, however, that the recreational water quality standard of 200 FC/100 ml of water was not exceeded. Because of the risk of direct contact with gull feces, the authors advised that gull populations be minimized by limiting their food supply. Bacteria levels measured included *S. aureus*, *Aeromonas spp.*, *P. aeruginosa*, *Campylobacter spp.*, *Salmonella spp.*, and fecal coliform.

4.0 Nutrients

Fecally derived nutrients have the potential to enrich surface water and thus contribute to the process of eutrophication, the accelerated aging of lakes. Various authors have examined how nutrients from migratory bird populations can affect water quality.

4.1 Studies examining the nutrient content of bird feces

Both Kear (1963) and Manny et al. (1975) investigated the nutrient content of Canada geese feces. Table 2 displays the results of their studies.

Table 2 – Average fecal nutrient loading from individual Canada geese

Author(s)	avg dry weight (g)*	avg wet weight (g)*	avg. droppings/h/bird	%N	%P	%dry ash	% K	%C
Kear (1963)	1.6 to 1.9	8 to 9.5#	3.8	2.2	1.0	N/A	2.0	N/A
Manny et al. (1975)	1.17	5.56	1.2	4.38	1.34	24.14	N/A	75.86

* per dropping
\# the dry weight times a factor of five

Gould and Fletcher (1978) measured the nutrient content of feces from five species of gulls. The daily total production per bird of total Kjeldahl nitrogen ranged from 608 mg in black-headed gull feces to 1819 mg in Herring gull feces. Total phosphorus levels ranged from 38 mg in black-headed gulls to >115 mg in the Herring gull. The authors concluded that at this rate, gulls present in large numbers are capable of moderately affecting surface water quality.

Gere and Androkovics (1992) investigated the feeding patterns of a colony of 1500 pairs of Cormorants and their fledglings in Hungary. They estimated that the Comorants consumed 12.49 tonnes of N and 3.12 tonnes of P every year, yet they found that less than that was excreted. The authors estimated that only 2% of the total N and P loading to the lake came from the birds. However, they concluded that there is a potential for waterfowl to contribute to the process of eutrophication.

4.2 Studies examining the effects of bird-derived nutrients

Kear (1963) determined the implications of wild goose droppings on agriculture. To reach the 54 kg per ha N required to produce 1 ton of wheat grain and straw, it would require 1000 geese to defecate on the same acre of grass for three weeks straight – a scenario which would never occur in nature. Kear also noted that, because food passes quickly through a goose, most of the manure is produced on the land from which it was feeding. This means that feces generally provides no new nutrients to the system, but, because the droppings contain partly digested nutrients, the nutrients may be in a more readily available form. Feces deposited on land could pose a threat to water quality if the land is in a flood plain or subject to runoff.

Manny et al. (1975) were interested in how Canada geese would affect a productive 15 ha lake. They calculated that the population of 2100 Canada geese contributed a total of 4404 kg dry weight of feces, 3341 kg of carbon, 193 kg nitrogen, and 59 kg phosphorus each year. At this loading rate, they thought it reasonable to assume that the geese were a significant contributor of nutrients. A summary of this study as well as several others in this section is found in Table 3.

Brandvold et al. (1976) conducted a three year study of the Bosque del Apache National Wildlife Refuge area in New Mexico. Water quality was monitored at various locations throughout the watershed. Comparisons were made at locations up- and downstream from the refuge to determine the effects of the birds on water quality. The mean values of total Kjeldahl nitrogen, total phosphorus, and chemical oxygen demand were found to increase downstream from where the birds were roosting (see Table 4). This suggests the potential for the birds to contribute to eutrophication-related problems. The excreted uric acid was insoluble in this pond and thus settled on the pond-floor. In the spring, most of the water from this pond was drained away. The plants that subsequently grew in this area were able to absorb these nutrients and thus prevent migration of nutrients downstream. The authors warn that not all uric acid may be insoluble.

Kitchell et al. (1999) studied the same wildlife refuge. A model indicated that nutrient loading in the wetlands could get as high as 40% for total nitrogen and 75% for total phosphorous. These estimates apply a) during the winter when bird populations are at their highest, 45 000 birds comprised mostly of lesser snow geese; and b) at a time when the birds feed mostly on food high in nitrogen. Birds were found to substantially increase phosphorous and nitrogen levels. However, the wetland was efficient at retaining the nutrients so that little to no net export occurred.

Bazely and Jefferies (1985) conducted a study of the effects of lesser snow geese (*Anser caerulescens caerulescens*) on plant growth in a salt marsh in northeastern Manitoba. Most years find more than 5000 pairs of geese arriving in the second half of May and departing in mid-August. Temporary grasslands form during this time where the water from Hudson Bay is low. The main vegetation on this site were two types of sedges: *Puccinellia phryganodes* and *Carex subspathacea*. This study showed that the addition of nitrogen in the form of goose feces resulted in a significant increase in standing crop and higher N content in shoots of the forage species. Where goose droppings were present, approximately 200 g m^{-2} of standing crop was produced compared to 125 g m^{-2} in an untreated plot. Most (60%) of the nitrogen was initially soluble, but after 48 h, the soluble N concentration was much lower.

Table 3– Summary of studies examining the impact of nutrient loading from large bird populations on water quality.

	Manny et al. (1975)	Brand-vold et al. (1976)	Manny et al. (1994)	Marion et al. (1994)[#]	Scherer et al. (1995)*	Pettigrew et al. (1998)	Post et al. (1998)
Size of lake (ha)	15		15	6300	105		
total bird population	2100		10 700	1 021 600 - 2 435 000			40 000
type of bird	Canada goose	various	Canada goose and mallard	various	various	Canada goose	lesser snow and Ross' geese
dry weight feces	4404 kg						
Nutrient content in feces							
P (% of total loading in lake)	59 kg		88 kg (70%)	2000-2530 kg (2.4-6.6%)	159-167 kg (25-34%)		
N (% of total loading in lake)	193 kg		280 kg (27%)	5800-7640 kg (0.4-0.7%)			
C (% of total loading in lake)	3341 kg		4462 kg (69%)				
mean nutrient content in water when birds were present							
P		2.1 mg/L				1.3 mg/L	
N		7.4 mg/L				1.1 mg/L	
Nutrient Loading rate							
N						660	3150
P					0.419-0.438	1600	450
units					$mg/m^2/day$	$mg/m^2/day$	mg/day/bird
impact of bird-derived nutrients on water quality	significant	minimal	significant	minimal	minimal	minimal	minimal

[#] data from two year range

* data from three year range

Table 4– Selected mean concentrations of chemical parameters upstream and downstream of roosting birds in the Bosque del Apache National Wildlife Refuge. (from: Brandvold et al. 1976)

	Upstream	Downstream
total Kjeldahl-N (mg/L)	2.59 +/- 2.62	7.37 +/- 17.74
total phosphorous (mg/L)	1.12 +/- 1.35	2.08 +/- 2.56
COD (mg/L)	22.2 +/- 50.1	31 +/- 37.0

Manny et al. (1994) observed migratory bird populations at Wintergreen Lake in Michigan. An estimated 6500 Canada geese and 4200 ducks (mostly mallards) visited this 15 ha lake. Mean defecation rates of the Canada geese in both day and night were estimated at 1.96 and 0.37 droppings per goose per hour, respectively. Daily nutrient loading, per migrant Canada goose, averaged: 24.9 g of carbon; 1.6 g of nitrogen; and 0.49 g of phosphorus. Loading rates from the ducks was assumed to be similar. A model was developed to determine the percent nutrient loading into the small lake from the birds in relation to other nutrient sources. They estimated that the birds added 4462 kg of C (69% of total C-loading); 280 kg of N (27% of the total); and 88 kg P (70% of the total). Other nutrient sources that were monitored were: watershed runoff, fertilizer runoff, feedlot effluent, septic leachate, and precipitation. This modeling technique showed that waterfowl presence led to degraded water quality.

Marion et al. (1994) found that birds contributed relatively low amounts of N and P to a 6300 ha lake in France. During 1981-82 and 1990-91, they estimated that 1 021 600 and 2 435 000 birds contributed 0.7 and 0.4% (7640 and 5800 kg) of the total N and 2.4 and 6.6% (2000 and 2530 kg) of the total P inputs into the lake. They found the level of P contributed by the birds rose during the plant growing season (April to September) to 37%. This resulted from low water flow rates in the lake from the rivers. Both human sewage and agricultural inputs were larger contributors of nutrients to this fairly polluted lake. Overall, birds played a generally small role in the eutrophication of this lake.

Scherer et al. (1995) monitored P loading by bird droppings in a shallow, 150 ha urban lake between January 1992 and December 1994. Bird days (the number of birds multiplied by the number of days present) for each year were: 528 355, 530 318, and 546 943. Though various birds were present, the most abundant waterbirds were American coots (36% of all water birds), mallards (17%), gadwalls (12%) and various species of gulls (12%). Even though geese were not as numerous (only 6% of the waterbird population), they were noted as significant contributors of feces. Water birds contributed 87% of the total feces from birds. The authors estimated in 1992 that 160 kg (27%) of the total P loading came from water birds. In 1993, bird droppings contributed 159 kg (25%), and in 1994 approximately 167 kg (34%) was added. These are equivalent to a P loading rate of 0.422, 0.419, and 0.428 mg $m^{-2}yr^{-1}$, for 1992, 1993, and 1994, respectively. 99% of the P loading was from water birds. The authors noted that P loading varied with the seasons (ie. with migration patterns). The highest loading occurred in Jan 1994 with 34kg, while the lowest loading rate occurred in May 1994 with 3kg. 87% of the P in the droppings appeared to be from nutrients derived from the lake itself, thus representing nutrient cycling. Correlation tests suggested that P from droppings did not remain in the water column or stimulate algae production in the short term. Rather, it appeared to enrich sediments. Under the right conditions (low dissolved oxygen concentrations or high pH) this P could be released and reduce water quality. The authors emphasized how nutrient cycling and sediment enrichment depend on conditions specific to an individual ecosystem.

Pettigrew et al. (1998) calculated that the natural N and P loading rate from feces for migrating Canada geese was 1.84×10^{-5} mg $m^{-2} day^{-1}$ and 4.58×10^{-4}mg $m^{-2} day^{-1}$, respectively. This loading rate is based on a density of one bird per ha. The focus of their study was to monitor how the micro-invertebrate population was affected by the addition of bird feces. However, of interest for this report is how these additions affected N and P levels within the freshwater wetland of the shore of Lake Manitoba. There were two loading rates of feces: low, 11.5 g m^{-2} feces; and high, 115 g m^{-2} feces. The high loading rate is equivalent to 660 mg m^{-2} day^{-1} and 1600 mg $m^{-2} day^{-1}$, N and P respectively, a very high loading rate. The control levels of NO_3-N and soluble P were 0.050 and 0.058 mg/L, respectively. In the low treatment, NO_3-N increased to a maximum of 0.331 mg/L, while the soluble P levels increased to 0.094 mg/L. In the high application treatment, NO_3-N increased to a maximum of 1.067 mg/L, and P levels increased to a maximum of 1.314 mg/L. Despite these elevated levels, levels returned to the control level after 3 to 7 days. The authors suggested that migratory birds defecating in a marsh appeared not to affect water quality substantially, even under the unrealistically high application rates of this study.

Post et al. (1998) attempted to estimate the nutrient inputs from geese into the wetlands of a National Wildlife Refuge (NWR) in New Mexico near the Rio Grande. Field observations and model simulations determined that about 40 000 Lesser Snow Geese and Ross' Geese excreted a total of more than 15 000 kg N and nearly 1800 kg P in the NWR during the period of November to mid March, 1995/1996. Peak loading rates occurred in mid-November at 331.0 kg/day of N and 31.8 kg/day of P. Median rates were 38.6 kg/day N and 5.9 kg/day P. On average, individual geese excreted 3.15 g/day N and 0.45 g/day P. One section of the wetland, called unit 18d, was monitored more closely. In this unit, geese loaded 8780 kg N and 1090 kg P, while surface water flow into the same area contributed 13 000 kg N and 350 kg P. Because of differing metabolisms, a diet of alfalfa produces 5.0 times more N and 2.6 times more P per day than a diet of corn. The birds served to redistribute and aggregate nutrients: they dispersed themselves while at feeding time, consuming nutrients from a larger area, then they congregated to roost, thereby excreting the nutrients into a more confined area. Overall, under the aforementioned loading rates, unit 18d did not suffer from poor water quality.

5.0 Conclusions and Summary

After reviewing the literature, the following conclusions can be made:

1) Bird feces can contain viable bacteria and pathogens; some that are zoonotic;

2) The impact of fecally-derived bacteria and nutrient loadings in water from birds appears to vary with:

- bird species;
- bird population density;

- feeding habits;
- dilution capacity of the water body;
- time of year

3) Nutrients from migratory bird populations have the potential to contribute to the process of eutrophication. The degree of contribution depends on the factors listed above; generally it was found that migratory birds did not greatly affect nutrient levels in water.

4) Areas at high risk of contamination include:
- where birds are densely populated;
- on smaller bodies of water where the dilution capacity is minimal (ie. shallow lakes, shorelines, etc.);
- where prolonged residency occurs;
- when the bird population has a high rate of infection; and
- when larger birds have populated the area.

5) The relative significance that migratory birds have on nutrient and pathogen loading must be compared to other sources of contamination when creating a watershed management plan.

6) The number of studies relating directly to the effects of water fowl feces on water quality is limited. Further study is warranted (see recommendations).

6.0 Recommendations

The following studies could lead to a better understanding in the area of water quality in relation to bird populations:
- More long term studies, similar to the Scherer et al. (1995) study, would help to identify seasonal fluctuations in nutrient and pathogen levels caused by bird populations. Information gained from this type of study could be useful to water managers devising management schemes.
- Further examination of the extent that fecal nutrients are introduced versus recycled in a lake system.
- Finally, most of the available studies are very site specific. A larger scale study, which compares and contrasts how bird populations affect different bodies of water during the same time period, might aid in determining how the impact of bird populations is influenced by water body characteristics.

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