Relationship of NMAN Output to Tile Drain Water Nutrient Levels - Field Study

Final Report

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1.0 Introduction

Researchers at Ridgetown College, University of Guelph, conducted a water quality study between 1995 and 1998, on twenty different farms in southwestern Ontario. They collected and analyzed weekly water samples from tile drain outlets. Farms selected had similar soil types (clay loam to sandy loam), and were in Chatham-Kent and Essex, so that climate and cropping practices were similar. Farm selection was also based on the accessibility of the main exit drain, and the location of potential surface water inlets or connections to the drainage system. Of the twenty farms selected, five farms applied liquid swine manure to fields, five farms had tomatoes as part of their crop rotation, five farms used moldboard plow, and the remaining five used some form of conservation tillage (no-till, ridge-till or reduced tillage). Farmers supplied information on crop planting dates, tillage practices, fertilizer and manure applications, harvest yields, soil characteristics and precipitation data.

A report was created a the end of the study (Fleming et al, 1998). However, a portion of the data gathered was not reported due to time constraints and the fact that it was not needed to satisfy the original study goals. This data addresses Nutrient Management issues and has a greater significance in Ontario today, with the recent implementation of Nutrient Management legislation.

For each site, tile water samples were collected from the main drain exiting the field. This represented a drainage area completely within the farm. The average drainage area was 15.9 ha, and usually only supported one crop (Fleming et al, 1998). Samples were taken weekly throughout the three year study period and analyzed for nitrate-N. Analysis of total P and total K took place from the start of the study until March 1997, when the Soil and Plant Analysis Lab at Ridgetown College closed. During farm visits to collect samples, water temperature was recorded as well as tile flow rate. Flow rates were calculated by timing the filling of a graduated container. Samples could not be collected when drains were submerged or covered in ice, or when flows were too small to collect. On average the tiles were dry about 1/3 of the year (Fleming et al, 1998).

Three piezometers were installed (i.e. one location, three depths) on each farm so that shallow groundwater samples could also be analyzed. Samples were collected monthly using a peristaltic pump. Piezometers were pumped dry, then allowed to recharge before a sample was taken. The average water table depth was 1.9 m below ground level (Fleming et al, 1998).

For farms that applied liquid swine manure, manure samples were taken occasionally and analyzed. Soil samples were collected for all farms in the spring of each year of the study, and occasionally in the fall.

Findings from the study showed that the mean tile water nitrate-N, total P and total K concentrations were 17.0, 0.48, and 3.8 mg/L, respectively. Different farming practices influenced the levels of N and P found in tile drains. Swine farming, growing corn and chisel plowing all corresponded to significantly higher levels of nitrate-N in tile water and in shallow groundwater. Swine farming and growing field corn or seed corn also showed significantly higher levels of P in tile water.

For the current report, the data collected from the three year study were analyzed again using NMAN, the nutrient management software program developed by the Ontario Ministry of Agriculture and Food (OMAF). All necessary information needed to run the NMAN program had been collected during the 1995-1998 study. The output data from NMAN were then compared against the tile drain concentrations to determine if a relationship existed.

2.0 Objective

The objective of the current study was to determine if a relationship existed between the NMAN program results and actual water quality data (N,P,K), collected from the Fleming et al. (1998) study.

3.0 Background

The addition of a subsurface drainage system (usually referred to as 'tile drains') to a field can provide many benefits to a farming operation. Among other benefits, tile drains cause soils to warm up quicker in the spring, (by drying out faster). They will also drain fields with sporadic wet spots more uniformly (Sands, 2001).

Tile drains are usually positioned about 0.75 to1.0 metre below the surface of the soil, and as water infiltrates through the soil it enters the porous tiles (Anon, 1998b). Tile water then flows to a main pipe that drains into either a stream or a ditch. Only excess soil moisture is removed by tile drains, not water needed for plant growth. The removal of excess water helps to lower the water table and promotes the growth of deep roots (Sands, 2001). Although the installation of tile drains can benefit farming operations greatly, there is much concern that soluble nutrients, such as nitrate-N, can enter tile drains and move quickly to surface water. A **drinking water** standard of 10 mg/L for nitrate-nitrogen exists (Peterson, 2003). In surface water, excess nitrogen and phosphorus can speed up eutrophication, which is the slow, natural nutrient enrichment of streams and lakes, leading to algae blooms (Baird, 1990). As algae decomposes, dissolved oxygen in the water is depleted, which is needed to support aquatic life.

Different farming practices and methods can minimize the loadings of nitrate-N and other nutrients into ground and surface water:

3.1 Cropping Practices

Planting cover crops during off-seasons can be viewed as a preventative cropping practice that minimizes nutrient leaching. Cover crops reduce the amount of nitrate-N that leaches into tile drains because they can effectively “trap” and “fix” nitrogen in plants (Creamer and Baldwin, 1999). Organic matter is added back to the soil after cover crops are plowed down. This improves the soil’s water infiltration ability, reduces soil crusting and increases nutrient retention in the root zone (Creamer and Baldwin, 1999). Cover crops also control nutrient leaching by providing a ground cover that minimizes the effects of erosion and runoff (Creamer and Baldwin, 1999). Therefore, nutrient losses to ground and surface water can be reduced by growing cover crops.

Crop rotation will influence the volume and the concentration of nutrients that leach from the soil. At Iowa State University, a study was performed to determine the effect that different cropping rotations had on nitrogen leaching. On average, larger subsurface drain flows and higher nitrate-N concentrations in tile drains were observed under a continuous corn rotation compared to fields under a corn-soybean rotation (Kanwar et al, 1994). For fields under a continuous corn rotation, 200 kg/ha of nitrogen was added every year. For the corn-soybean rotation, only 168 kg/ha of nitrogen was added during the corn years and none was added in the soybean years (Kanwar et al, 1994). Continuous corn rotations proved to be unfavorable for the environment as significantly higher nitrate-N losses were observed on continuous corn plots compared to corn-soybean plots (Kanwar et al, 1994).

Fleming et al. (1998) found that levels of nitrate-N and total P in tile water were significantly higher when field corn and seed corn were grown, compared to fields of soybeans, wheat and tomatoes. Tomato fields which received high inputs of K, showed relatively low levels of total K in tile water, compared to the seed corn and field corn fields which had significantly higher total K levels. Analysis of samples collected from the piezometers, showed that corn and soybean fields had significantly higher levels of nitrate-N in groundwater, compared to other crops (Fleming et al, 1998).

3.2 Tillage Methods

Tillage practices will influence the amount of nutrients that are found in tile drain water. Four different tillage practices were tested at Iowa State University, to study the effects that each had on tile drain concentrations. The tillage methods analyzed were moldboard plow, chisel plow, ridge-tillage and no-tillage. Moldboard plow plots had the highest nitrate-N concentrations in tile drainage water, compared to the other three tillage systems (Kanwar et al, 1994). However, no-tillage and chisel plow plots had the greatest nitrate-N losses through tile drainage water (Kanwar et al, 1994). No-tillage plots had the highest subsurface drain peak flows for most of the rainstorms (Kanwar et al, 1994). A study done by Kanwar and Bakhsh (2001) also found that, on average, no-till systems resulted in higher tile peak flows compared to other tillage systems. The increased tile flows and higher resultant nitrate-N losses (even though concentrations were lower) from the no-till plots could be attributed to the formation of macropores in the soil. Macropores, such as cracks, worm-holes and root-holes are beneficial for drainage and aeration in the soil. However, they can provide direct channels for water and nutrients to tile drains (Kanwar et al, 1994). In no-tilled fields, macropores persist compared to fields that are conventional tilled, as tillage breaks up and destroys macropores.

Fleming et al, (1998) reported that tile water nitrate-N and shallow groundwater nitrate-N levels were significantly higher on fields that had been chisel plowed. Total P levels were not influenced by different tillage methods (Fleming et al, 1998).

3.3 Soil Characteristics

The amount of nutrients that leach from a field will depend on the soil characteristics of the field. Soil properties determine relevant properties such as the drainage rate and ability of the ground to absorb water. Texture is one important soil property. Medium-to fine-textured soils that are rich in loam and silt have greater nutrient and water holding capabilities compared to coarse, sandy soils (Miner, 1995). Water moves slowly through clay soils because particles are very fine and are packed closely together. Clay soils have the tendency to waterlog after heavy rains due to their slow draining rate (Whiting et al, 2005). Sandy soils have larger soil particles and therefore, larger pore spaces, which will increase the rate at which water drains from the soil (Whiting et al, 2005). Runoff will be greater for soils that tend to have compacted surfaces, like clay soils, as water will not be able to penetrate the tough crust (Miner, 1995). Increased runoff can mean elevated levels of nutrients in surface water if manure or fertilizer were recently spread on the surface.

3.4 Water Partitioning in a Field

A study was done in Butlerville, Indiana, to determine what effect tile drain spacings would have on tile drain nitrate-N loadings. Tile drains were monitored during a 15 year period. The spaces were 5, 10 and 20 m. The study showed that for the 5, 10 and 20 m spacings, 20.6, 14.8 and 12.0% of annual rainfall was removed, by the tiles respectively (Kladivko, 2004). As well as removing more rain water, tiles positioned closer also had greater drain flow volumes and nitrate-N loadings compared to tiles that were placed farther apart (Kladivko, 2004). Tiles placed closer together will drain an area faster because the flow lines are much shorter than they are for an area where tiles are spaced far apart (Franzmeier et al, 2001). During the 15 year study period, nitrate-N loadings decreased because of lower fertilizer rates, changes in rotation and tillage, and the growth of a cover crop (wheat added to a corn-soybean rotation) (Kladivko, 2004).

3.5 Controlled Drainage

High nutrient levels in ground water can be controlled by using water table control structures. Controlled drainage and subirrigation are two water table control structures that can be added to the end of an existing tile drain system in fairly level fields. A controlled drainage system can be used as a tool to adjust water table levels, as well as an environmental protection system (Oertel, 2005). Water from field tiles enter a main drain where it can be stopped and held back by stoplogs (Oertel, 2005). When stoplogs are put in place any contaminated water can be prevented from entering surface waterways. By delaying the immediate release of water high in nutrients, surface water contamination can be reduced or prevented. Controlled drainage should be used during fall, winter and early spring months when drain flow is greatest and nitrogen losses are highest (Oertel, 2005).

Some controlled drainage systems come with automated control boxes that raise and lower the water table at various times of the year, based on crop needs (Oertel, 2005). Otherwise, the water level controller can be adjusted manually.

Controlled drainage can be thought of as a Best Management Practice (BMP) because of the benefits to both crop productivity and water quality (Anon, 1998). Controlled drainage holds nitrate-N in the soil, making it available for plant uptake. It increases soil moisture, which slows the nitrification process. Also, denitrification takes place before the nitrate leaches (Anon, 1998). Controlled drainage is so effective, that tile drain nitrate losses have been reduced by 50%, compared to the amount lost from conventional drainage (Anon, 1998). The University of Minnesota's Extension Service also reported that controlled drainage reduced tile drain nitrate-N losses by 60% (Oertel, 2005). What is less clear is the percentage lost through leaching versus denitrification and the possible environmental impacts of either of these losses.

4.0 Procedure

Data collected during the period from June 1995 to June 1998 were analyzed in the summer of 2005, using the current version of the Nutrient Management software, NMAN 2004. A file was set up for each farm and the data collected during the three years were entered. Information that was required for NMAN included:

- cropping information
- tillage methods
- fertilizer applications
- manure applications
- soil sample analysis
- manure analysis
- soil characteristics
- farm background data

Information was entered for each farm, and for each cropping year of the study. NMAN then performed the necessary calculations to determine the agronomic nutrient balance, crop removal balance, P-Index and the N-Index (described later) for each year, and for each farm. Consecutive years for each farm are linked together in NMAN so that nitrogen credits from the previous crop carry over to the current crop.

Tile drain data were also reexamined so that they could be compared to the outputs from NMAN. Tile drain data were re-sorted so that tile water samples were organized into cropping years instead of calendar years. Cropping years were organized so that the beginning of a cropping year started when the crop was planted and ended when the next crop was planted. If the planting date was not known, a default date was used from NMAN. For example, for corn and tomatoes, May 1st was used as the planting date; for soybeans, May 15th; and for wheat, October 1st was used.

5.0 NMAN

5.1 Background

NMAN is a software program developed by the Ontario Ministry of Agriculture and Food (OMAF)[1] to aid in designing Nutrient Management strategies (NMS) and plans (NMP) for farms. NMAN can be used to assist farmers in predicting nutrient generation and determining the amount of land needed for effective use of the nutrients (OMAF, 2004). Features of NMAN allow it to track nutrient and manure application, identify risk factors of nitrogen movement to groundwater and identify minimum recommended separation distances from watercourses (OMAF, 2004).

5.2 Version

The latest version of NMAN, 'NMAN June 14, 2004', was used. Once NMAN December 10, 2003, was installed, the upgrades were downloaded from the OMAF website.

5.3 Manure/Prescribed Materials

NMAN allows the user to check off whether they are a manure/prescribed material generator or a receiver, both or neither. Once the "manure/P.Mat'l generator" box has been checked off on the "Farm Information" form, the "Manure/P.Mat'l" form becomes available. On this form the user can add, edit and delete different types of livestock manure. To add a manure, information regarding form (liquid, solid), type (beef, swine, etc.), yearly amount generated on the specific farm unit, days of storage on the specific farm unit, and N, P, K and dry matter percentages must all be entered. If a nutrient lab analysis had not been performed on the manure than values for N, P, K and dry matter may be obtained from the nutrient databank. For the current study, all manure analysis results were available.

The total nutrients applied depends on application date, method, rate and timing of manure incorporation. This information is entered in the "Field" form, in the "Edit Detailed Field Information" section, under the "Manure/P.Mat'l" tab.

The total nutrients available is different from the total nutrients applied. NMAN credits N from previous manure applications by assuming that 10%, 5% and 2% of the total organic N is available from manure applied 1, 2 and 3 years earlier, respectively (OMAF, 2004).

The program assumes that 40% of the total applied P_2O_5 found in manure, will be available to the growing crop. Another 40% will contribute to the available P_2O_5 in the soil. This amount of P can gradually build up in the soil. The final 20% will be unavailable for crop use. Ninety percent of the total K_2O applied will be available to the growing crop.

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[1]Now called the Ontario Ministry of Agriculture, Food and Rural Affairs

5.4 Field Form

The "Field Form" is a detailed form that consists of up to 8 tabs. If manure is applied then the tabs "Manure/P.Mat'l," "Economic" and "Heavy Metal" become available to the user. The 5 main tabs that are always available are "General," "Properties", "Cropping/Tillage", "Fertilizer" and "Balance".

5.41 General - The "General" tab can be used to write a detailed description about the farm location. Images of the location can be added to this section. The concession and lot number entered on the "Farm Information" screen show up as a default for farm location.

5.42 Properties - The required information under the "Properties" tab is: tillable area, area for manure/prescribed material, maximum slope of the field, soil series, soil texture and soil test values from an accredited lab analysis for nitrate-N, phosphorus, and potassium. All of this information was available for the 1995-1998 sites.

5.43 Cropping/Tillage - The information regarding what crop is grown in what year is entered here. The estimated yield must be entered as it influences the production recommendations and the nutrient removal, which in turn will affect the agronomic nutrient balance and the crop removal balance. For this study the actual yield supplied by the farmer was entered. The previous crop N credit can be entered in this section too. Tillage method, tillage practice, tillage time and length of slope are all used to calculate the estimated soil erosion in tonnes/ha.

5.44 Fertilizer - Fertilizer applications for the field can be entered in this tab. Fertilizer type must be specified, (i.e. liquid, dry or fertigation). The blend and application rate must also be entered. NMAN calculates the amount of nutrients applied. If a custom blend is chosen, then the user manually enters the amount of nutrients applied.

5.45 Balance

a) Agronomic Nutrient Balance

The agronomic balance can be used to determine if there is an abundance or a lack of nutrients in the soil. It is calculated by subtracting the crop production requirements from the total field inputs (Jamieson and Mabon, 2004). Field inputs are nutrients supplied by commercial fertilizers, current manure applications and the nitrogen credit from the previous crop and the previous manure/p.mat'l applications. The crop production requirement is the required nutrient level for a crop to obtain the desired yield (Jamieson and Mabon, 2004). The agronomic nutrient balance is based on the nutrient levels required to achieve the desired yield for the crop (Jamieson and Mabon, 2004). A positive number indicates that there will be a surplus of nutrients, and a negative number indicates a deficiency of nutrients in the soil (Jamieson and Mabon, 2004). Numbers that are highlighted yellow indicate that the agronomic balance has exceeded 17 kg/ha or is less than 0 kg/ha, and has been flagged as a "caution."

b) Crop Removal Balance

The crop removal balance displays the mass balance of nutrients for the crop. It is calculated by subtracting the crop removal numbers from the total field inputs (Jamieson and Mabon, 2004). Field inputs may include commercial fertilizer applications, the current year's manure application and the nitrogen credit. Crop removal can be described as the nutrient removal abilities of the crop, and is based on crop type and yield (Jamieson and Mabon, 2004). A positive number indicates that field inputs of nutrients exceed nutrient removal by the current crop. A negative number indicates that the current crop is removing more nutrients than what will be available (Jamieson and Mabon, 2004). A positive nitrogen balance suggests that nitrogen may be available after crop harvest. The N crop removal balance will be red-flagged if the total amount of N is greater than 224 kg/ha (Jamieson and Mabon, 2004). This represents a high potential for N leaching after the growing season ends.

c) N-Index

The Nitrogen Index is a tool for limiting nitrate-N movement below the root zone in agricultural fields (Jamieson and Mabon, 2004). It is based on nutrient management practices and characteristics of the soil. The N-Index is only triggered when the agronomic nutrient N balance exceeds 17 kg/ha (Jamieson and Mabon, 2004). The N-Index will be flagged green, red, or yellow. If the number is flagged yellow this signals missing information. A green flag means that the N-index is below the maximum allowable limit. A red flag is a warning that the maximum allowable value for the nitrogen index has been exceeded. The maximum N-Index value is dependent on soil characteristics (refer to Table 1).

Table 1 - Maximum N-Index Value Related to Soil/Site Risk

Hydrological Soil Group	Leaching Risk	Maximum N-Index Value
AA	Very High	1
A	High	3
B	Medium	4
C	Low	6
D	Very Low	9

(Jamieson and Mabon, 2004)

d) P-Index

The Phosphorus Index is calculated in all cases. It determines the setback distance requirements for phosphorus application from surface water (Jamieson and Mabon, 2004). The P-Index is a tool for limiting phosphorus movement into surface water from agricultural fields (Jamieson and Mabon, 2004). The summary of the P-Index shows the detailed breakdown of how the P-Index is calculated and what factors are involved, such as: soil erosion, water runoff class, phosphorus soil test, etc. A value is assigned to each P-Index factor, which is then multiplied by the weight to produce the rating. The P-Index is the total of the summed ratings. The P-Index can then be used to determine the separation distance from waterways using Table 2.

Table 2 - Separation Distances and Application Rates for Various P-Index Values

	Separation Distance			
P-Index	<3m	3 - 30.5 m	30.6 - 61 m	>61 m
< 30	STOP - No Application	CAUTION - Only apply P_2O_5 up to crop removal (Line M)	No additional restriction due to P-Index	No additional restriction due to P-Index
30 - 50	STOP - No Application	CAUTION - Only apply P_2O_5 up to crop removal (Line M)	CAUTION - Only apply P_2O_5 up to crop removal (Line M)	No additional restriction due to P-Index
> 50	STOP - No Application	STOP - No Application	CAUTION - Only apply P_2O_5 up to crop removal (Line M)	CAUTION - Only apply P_2O_5 up to crop removal (Line M)

(Jamieson and Mabon, 2004)

6.0 Results and Discussion

As mentioned earlier, not all of the tile drains had measurable flows for every week of the study - most had no flow for up to half of the year. Precipitation events in the growing season did not appear to contribute greatly to the total annual flow. P and K analyses were only carried out for the first half of the study.

6.1 Tile Drainage Systems

The drainage systems at the 20 sites represented a range of drained areas. The mean size of drainage area was 15.2 ha (SD = 12.3), and the sizes ranged from 1.8 to 59.8 ha. This range was not expected to affect the interpretation of results, however, as it was the concentrations of nutrients that were of greatest concern.

There was no mechanism in place to record flows constantly, only manually at the time of the weekly sampling. As a result, a total loading of nutrients to surface water could not be calculated. This posed a problem. One explanation for low concentrations of a nutrient at one site might be that the tile flow rate is very high. This could, for example, be caused by a high water table at the site (e.g. draining a spring). This would result in greater dilution, even though the total loading of the nutrient to surface water may be very similar to a field having less drain flow. There was a need to find the average tile flow rates for each site to ensure they were all within a reasonable range. Average flow rates for each of the sites ranged from 0.86 to 5.5 L/min per ha. The mean value was 2.11 L/min per ha (SD = 1.2). No values stood out as being unusually low or high.

As mentioned earlier, variations in flows can be caused by differences in tile spacings. Unfortunately, tile spacings were not known for most sites.

A check was done to see if a relationship existed between flow rate and the concentration of N and P in tile water. One might expect that as flow rates increased on a farm, concentrations would drop due to dilution. This did not appear to be the case. While there was a statistically significant relationship between flow rate and concentration of N ($P = 0.01$), the linear model had an R^2 value of only 0.005, representing a very weak fit. A comparison of alternate models did not find any useful relationship. For P, there was no statistically significant relationship between flow rate and concentration. When the analysis was carried out for individual farm sites, the relationships did not improve - at some sites, the concentrations were generally lower for higher flow rates while at other sites, the opposite was true.

As a result of these tests, it seemed reasonable to expect that tile water concentrations of the nutrients being studied should give a fairly accurate indication of losses of those nutrients through the subsurface drainage system.

6.2 Nitrogen

Table 3 gives a summary of the results relating to Nitrogen in the study - including soil N, NMAN Agronomic Balance, NMAN Crop Removal Balance, NMAN N-Index, and the average of the annual tile water nitrate-N concentrations. To find this latter quantity, an average was calculated for each farm for each year. The mean was then calculated using these values. It is only slightly different from the mean using all 1295 (for nitrate-N) water sample results (reported in Fleming et al, 1998).

Table 3 - Summary of N results for the study

	units	Mean	Standard Deviation	Min./Max.	Count
Soil N	ppm	20.5	15.6	2.0/64.0	67
NMAN Agronomic Balance	kg/ha	58.2	80.8	-161/240	80
NMAN Crop Removal Balance	kg/ha	-33.9	125	-237/187	80
NMAN N-Index		2.52	2.48	0/7	80
Tile drain Nitrate-N	mg/L	16.8	8.3	3.8/42.8	76

From Table 3 we can see that, based on the NMAN Agronomic Balance, the crops grown received, on average, 58.2 kg N per ha more than what was needed to reach the target yield. Remember that for these analyses, the target yield was not known and the "actual yield" was substituted. NMAN checks the target yield against a database of average yields for the municipality. If a yield was entered that exceeded the municipality average, it would be yellow flagged. In all cases the actual yield was close to this municipality average, and rarely exceeded it.

The table also shows the wide range of values for this Agronomic Balance (from a deficit of 161 kg/ha to a surplus of 240 kg/ha). As mentioned earlier, the NMAN program uses colour to highlight values outside of the desired range. Of the 80 values considered (i.e. 20 farms and at least a portion of four crop years), 8 (10%) represented an N balance that was predicted to be too low (i.e. < 0 kg/ha). Twenty-five values (31.25%) were in the desired range (between 0 and 16 kg/ha), and 47 (58.75%) were deemed to be high. There was also a wide range of values for the NMAN Crop Removal Balance, where the average value represented a deficit of 33.9 kg/ha.

The N-index is used to highlight situations where the greatest potential exists to lose N from the root zone. From Table 3, the average value is 2.52 (a dimensionless number). However red flags are used in the program to denote those situations that pose the greatest environmental threat. In some situations, a value of "4" triggered a red flag, while for others, a value of "7" did not (refer to Table 1). Of the 80 situations, there were 13 red flags, including six different farms.

The average tile drain nitrate-N concentration was 16.8 mg/L (based on the mean annual values for each site). While there is no N standard for surface water in Ontario, the drinking water standard is 10 mg/L and there is close link between surface water and drinking water (i.e. many Ontario residents rely on surface water as their source of drinking water). For the protection of freshwater aquatic life, Alberta has a guideline of 1.0 mg/L total N in surface water (Alberta Environment, 1999). Similarly, Environment Canada reports a guideline of 2.94 mg/L nitrate-N for surface water (Environment Canada, 2003). In most cases, there is a considerable potential for dilution in the receiving watercourses - however, many would consider these tile drain nitrate-N levels to be higher than desired.

Fleming et al (1998) found that the mean tile water nitrate-N concentration was nearly twice as high for the five livestock farms compared to the 15 non-livestock farms. One theory to explain this was that the livestock farms were in a soil nutrient excess situation. This could have resulted from failure to account for all of the nutrients in the manure. It could also be reasoned that by creating and following a nutrient management plan, the drainage water from these farms would return to nitrate-N concentrations similar to the other farms.

To test this, a number of ANOVA Tables were created to determine the influence of farm type on various N values. These are summarized in Table 4. The final column gives the tile water mean nitrate-N concentrations, based on the crop year (i.e. from the planting date for one crop to the planting date for the following crop). These numbers confirm that the average tile water nitrate-N concentrations for the 5 livestock farms were significantly higher than the levels for the remaining 15 farms. In addition, the N soil test results are significantly higher for the livestock farms than for the general crop farms - but not necessarily higher than the tomato farms. However, there was no statistically significant difference in either the NMAN Agronomic or Crop Removal Balances. There were significant differences in the N-index between farms, but in this case the tomato farms scored the highest average, and the livestock farms were not different from the general crop farms.

Table 4 - Summary of N information based on type of farm (5 livestock farms, 5 crop farms with tomatoes, 10 crop farms - general)

Farm Type	Soil N Test (ppm)	NMAN Agronomic Balance (kg/ha)	NMAN Crop Removal (kg/ha)	NMAN N-Index	Tile Water (Crop Year Avg) (mg/L)
Livestock	27.5 (b)	77.3 (a)	-45.7 (a)	2.9 (a,b)	29.7 (b)
Crop - Tomato	21.5 (a,b)	65.3 (a)	-43.9 (a)	3.3 (b)	16.0 (a)
Crop - General	17.0 (a)	45.1 (a)	-2.3 (a)	2.0 (a)	13.7 (a)

Values in the same column sharing the same letter are not significantly different - Fisher's LSD at 95.0% level

Manure was not applied every year on the drainage areas monitored on the livestock farms. Typically, manure was spread twice on each site (in the portions of the four crop years that made up the study). There were a total of 11 manure spreading times (out of a possible 20 opportunities). Limiting the analysis to the livestock farms, in the crop years when manure was spread, the average NMAN Agronomic Balance was 115 kg/ha. In the crop years when no manure was spread this average was 30.7 kg/ha, which was significantly lower ($P < 0.05$). Looking at the tile water nitrate-N concentration in this way resulted in a mean of 31.7 mg/l in the years when manure was applied. For years when no manure was applied (on the livestock farms) the tile water nitrate-N concentration averaged 27.2 mg/L, which was not significantly different. This analysis suggests that the NMAN program is responsive to over-application of manure N, but that the impact on tile drainage water is not immediate. One explanation for this latter point is that the N is moving downward through the soil profile and takes more than one season to reach the subsurface drains. Another possibility is that the NMAN program is under-estimating the amount of mineralized N (available to crops and available for leaching) in the years following manure application on livestock farms. Perhaps there is a larger pool of organic-N in the soil and more is being mineralized than what NMAN is assuming.

Tests of various relationships were examined to see if there was a way to use NMAN results to predict average yearly N concentrations in the tile drains. There was a statistically significant relationship between the NMAN Agronomic Balance for N and the average annual nitrate-N tile water concentrations (based on the crop year) ($P=0.02$). The equation of the fitted linear model is:

TN = 15.25 + 0.03 * AB

where: TN = Tile water nitrate-N concentration (mg/L)
AB = NMAN Agronomic Balance (kg/ha)

This relationship is shown in Figure 1. The R^2 value is only 0.078, however, so the relationship is very weak. The relationship between N-index and tile water nitrate-N was similar, also with a low R^2 value. A significant relationship did not exist between the NMAN Crop Removal Balance and tile water nitrate-N levels (P=0.51). Soil N levels were related to tile water nitrate-N levels, but once again, the linear relationship was weak (R^2= 0.13).

The final set of relationships considered was based on one overall average at each site for the NMAN Agronomic Balance and the tile water nitrate-N concentration. This was done to take into account that high levels of N applied in one year may not immediately impact tile water, but rather have more of a long-lasting impact. Neither the NMAN Agronomic Balance nor the NMAN N-index values had significant relationships with the tile water nitrate-N levels at the 95% confidence level. The relationship between the soil N content and tile water content was stronger, however (P = 0.018). The graph of this relationship is shown in Figure 2.

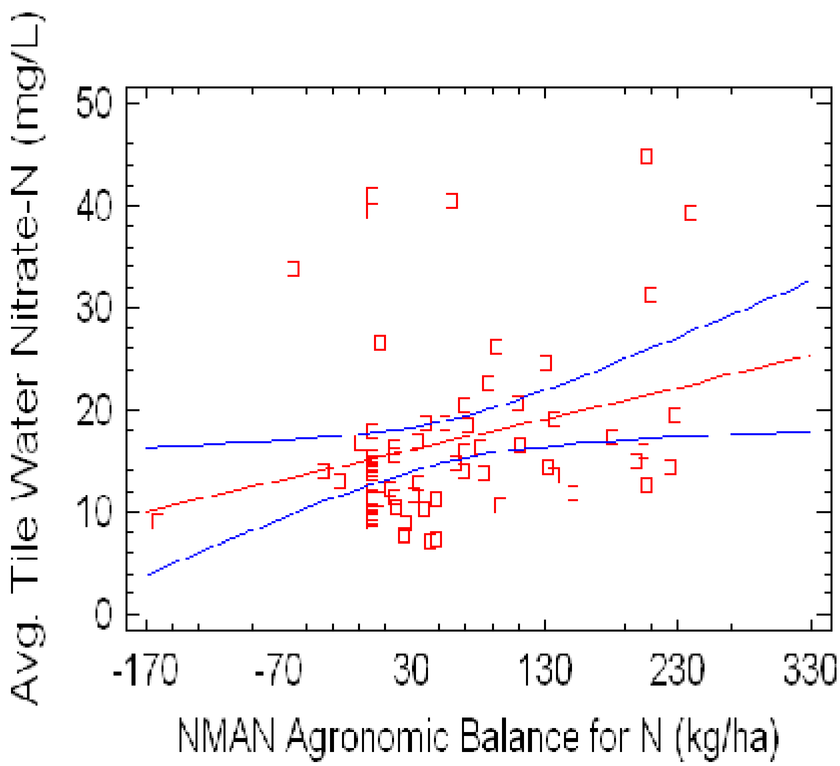

Figure 1- Best fitted regression line (and 95% Confidence Interval) for the relationship between the NMAN Agronomic Balance for N and the concentration of average nitrate-N in tile water for each crop year and at each site (R^2 = 0.078)

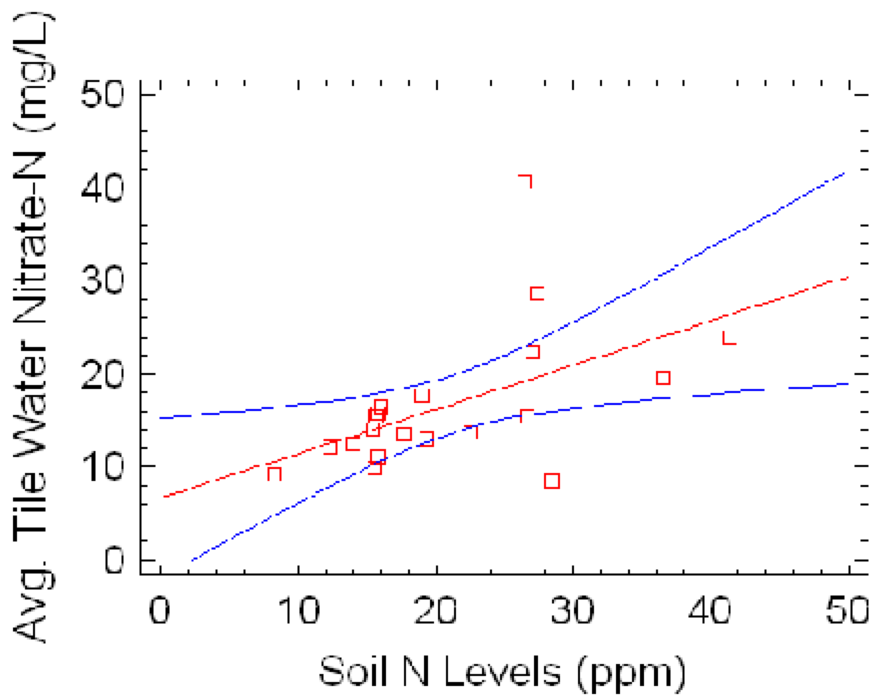

Figure 2 - Best Fitted Line and 95% Confidence Interval for overall averages for each farm for Soil N and Tile water Nitrate-N (R^2=0.275)

6.3 Phosphorus

Table 5 is similar to Table 3. It gives the corresponding values for Phosphorus (P). The mean soil P level was 29.5 ppm. On average, the Agronomic Balance suggests that P was over-applied by 16.5 kg/ha for the study sites. However, once again, the Crop Removal Balance is a negative number. The P-index values ranged from 5 to 46 (mean = 13.7). There were no Red Flags for these P-index values. Based on the Agronomic Balance, 19 (23.75%) cases had P nutrient levels deemed too low, 32 (40%) cases were in the desired range and 29 (36.25%) were deemed to be high.

There were many instances where Ontario's surface water guideline of 0.03 mg/L total P were exceeded. The mean value was 0.355 and the maximum concentration was 8.4 mg/L.

Table 5 - Summary of P results for the study

	units	Mean	Standard Deviation	Min./Max.	Count
Soil P	ppm	29.5	19.4	5.0/104	80
NMAN Agronomic P_2O_5 Balance	kg/ha	16.5	49.8	-170/160	80
NMAN Crop Removal P_2O_5 Balance	kg/ha	-11.1	43.1	-79/142	80
NMAN P-Index		13.7	7.2	5.0/46	80
Tile drain P	mg/L	0.355	1.29	0.0/8.4	56

Similar to the N analysis described earlier, a number of ANOVA Tables were created to determine the influence of farm type on various P values. These are summarized in Table 6. The final column shows that the average tile water P concentrations for the 5 livestock farms were not significantly different from the levels for the remaining 15 farms. However, the P soil test results are significantly higher for the livestock farms than for the other farms. The NMAN Crop Removal Balances were not significantly different for the three farm types. The NMAN Agronomic Balance is higher for the livestock farms than the tomato farms and the NMAN P-index for the livestock farms is significantly higher than that for the other two farm types (P=0.006).

Table 6 - Summary of P information based on type of farm (5 livestock farms, 5 crop farms with tomatoes, 10 crop farms - general)

Farm Type	Soil Test (ppm)	NMAN Agronomic Balance (kg/ha)	NMAN Crop Removal (kg/ha)	NMAN P-Index	Tile Water (Crop Year Avg) (mg/L)
Livestock	44.5 (b)	32.9 (b)	-11.2 (a)	18.0 (b)	0.206 (a)
Crop - Tomato	27.6 (a)	-0.25 (a)	-7.8 (a)	12.3 (a)	0.745 (a)
Crop - General	23.0 (a)	16.8 (a,b)	-12.8 (a)	12.2 (a)	0.106 (a)

Values in the same column sharing the same letter are not significantly different - Fisher's LSD at 95.0% level

When the analysis was limited to the livestock farms, in the crop years when manure was spread, the NMAN Agronomic P_2O_5 Balance was 57.9 kg/ha. In the crop years when no manure was spread this average was 2.33 kg/ha, which was significantly lower (P = 0.0007). Looking at the tile water P concentration in this way resulted in no significant difference between years of manure application and years with no manure applied. Once again, it suggests that P entry to tile drainage systems is more of a long-term process that is not well predicted by application rates in any one year.

There was no statistically significant relationship between the NMAN Agronomic Balance for P and the average annual tile water P concentrations (based on the crop year).

Similarly, there was no relationship between either the NMAN Crop Removal P Balance or the P-index and average tile P concentrations ($P > 0.10$). Not even the soil test P levels were correlated with tile water P concentrations.

One overall average at each site was considered for both the NMAN Agronomic P Balance and the tile water P concentration. There still was no significant relationship ($P=0.12$) between these values. Nor was there a relationship between the soil P levels and the tile water P levels. Note that the soil test for P is a shallower test than that used for N and neither test samples at or near the typical depths of tile drains (e.g. about 0.7 m).

6.4 Potassium

Table 7 gives the summary values for Potassium (K). It is partly because so little attention had been given to K that it was specifically measured in the study. Most people do not consider K to be a threat to water quality in Ontario. The soil and water concentrations are reported here, as well as the NMAN results. The mean Agronomic Balance for K was 59.7 kg/ha, suggesting over-application. Of the 80 situations, 46 (57.5%) were flagged as having higher than necessary levels of K in the soil. The Crop Removal Balance also suggests that more is applied than is removed by the crop.

Table 7 - Summary of K results for the study

	units	Mean	Standard Deviation	Min./Max.	Count
Soil K	ppm	141.6	48.6	50/261	80
NMAN Agronomic K_2O Balance	kg/ha	59.7	80.1	-114/310	80
NMAN Crop Removal K_2O Balance	kg/ha	35.1	88.0	-80/289	80
Tile drain K	mg/L	3.44	5.10	0.2/33.1	56

Table 8 summarizes the influence of farm type on various K values. The average tile water K concentrations for the 5 livestock farms were not significantly different from the levels for the remaining 15 farms. The K soil test results were significantly higher for the tomato farms than for the other farms. The NMAN Agronomic Balances were not significantly different for the three farm types. The NMAN Crop Removal Balance was higher for the tomato farms than the livestock farms.

Table 8 - Summary of K information based on type of farm (5 livestock farms, 5 crop farms with tomatoes, 10 crop farms - general)

Farm Type	Soil Test (ppm)	NMAN Agronomic Balance (kg/ha)	NMAN Crop Removal (kg/ha)	Tile Water (Crop Year Avg) (mg/L)
Livestock	151 (b)	35.9 (a)	-0.75 (a)	5.13 (a)
Crop - Tomato	119 (a)	74.7 (a)	75.7 (b)	4.02 (a)
Crop - General	148 (b)	64.1 (a)	32.8 (a,b)	2.31 (a)

Values in the same column sharing the same letter are not significantly different - Fisher's LSD at 95.0% level

No significant linear relationship existed between any of the following: tile K levels and soil test K levels, tile K levels and NMAN Agronomic Balance K levels, or tile K levels and NMAN Crop Removal Balance K levels.

6.5 Loadings

As mentioned earlier, flow rates were only recorded at the time of sampling (i.e. at weekly intervals). Because of the potential for large flows to occur between sampling times, it was deemed inappropriate to estimate these flows, especially without the use of a sophisticated flow model. At this point in the analysis, however, there was a feeling that even a rough estimate of flows, and therefore nutrient loadings, might shed some light on the relationship between NMAN results and actual water quality measurements. The data for the second and third crop years were analyzed in this way. Estimates of tile flows were made for the days between site visits. Estimates were made to allow for those days when flow occurred but flow rates could not be measured. This happened at most sites for a few weeks every year, when either the outlet was covered with snow or the outlet was submerged in water.

For this period of time, the average number of weeks at each site with measurable flow was 33.5 (per crop year). Based on the rough assumptions listed above, the mean loading of nitrate-N for each of crop years #2 and #3 was estimated to be 29 kg/ha (SD = 34). For these crop years, the mean NMAN Agronomic N Balance was 58.2 kg/ha (SD = 83). The corresponding mean P loading for crop year #2 was 0.3 kg/ha and the NMAN Agronomic P Balance was -6.0 kg/ha.

While there was no difference in N loadings between crop years, the NMAN Agronomic N balance was significantly higher in Crop year #3. There was no significant relationship between the estimated N loadings and the Agronomic N balance. The same held true for P in crop year #2.

This analysis helped point out that, if the loadings of nutrients from tile drains must be known, there is no substitute for constant measurement. This measurement must account for variations in flow over time, so a “flow weighted” sampling scheme could be used. The tile drains had measurable flows approximately 2/3 of the year for the farms in this study. They were covered by snow and ice at times and at other times were submerged, thus posing challenges for constant monitoring.

One might argue that the Nutrient Management Act is designed to have a greater impact on the protection of “groundwater” quality when it comes to N movement. If groundwater is the main concern, then tile water “concentrations” may be exactly what should be measured, as they represent the N found in the soil water as it moves downward toward the water table. The total tile water loadings to surface water can be affected by several variables that have little impact on this general downward movement.

7.0 Summary

A study was conducted between 1995 and 1998 in which tile water samples were collected weekly from 20 farms within Chatham-Kent and Essex. The samples were analyzed for nitrate-N, Phosphorus and Potassium concentrations. Information regarding crop planting dates, tillage practices, fertilizer and manure applications, harvest yields and soil characteristics were all supplied by the farmers. A report was created at the end of the study (Fleming et al, 1998). However, in light of the recent implementation of the Nutrient Management legislation in Ontario, the data were analyzed again, using NMAN. NMAN is the Nutrient Management Program developed by the Ontario Ministry of Agriculture and Food. Features of NMAN allow it to track nutrient and manure application, identify risk factors of nitrogen movement to groundwater and identify minimum recommended separation distances from watercourses (OMAF, 2004). A separate file was created for each farm, and the data collected between 1995 and 1998 were entered into NMAN. Outputs from NMAN (i.e. Agronomic Nutrient Balance, Crop Removal Balance, N-Index, P-Index) were then compared to the tile water data to determine if any relationships existed. The main findings from the study are:

- The following average values were calculated for the study period: NMAN Agronomic N Balance = 58.2 kg/ha; Agronomic P_2O_5 Balance = 16.5 kg/ha; Crop Removal N Balance = -33.9 kg/ha; Crop Removal P_2O_5 Balance = -11.1 kg/ha; N-Index = 2.5; P-Index = 13.7; Soil Test N level = 20.5 ppm; Soil Test P_2O_5 level = 29.5 ppm; tile drain nitrate-N level = 16.8 mg/L; and tile drain P level = 0.355 mg/L
- There was only a very weak relationship between Agronomic Balance N values and tile water nitrate-N concentrations, and N-Index values and tile water nitrate-N levels.
- There was no relationship between tile water P levels and any of the following: NMAN Agronomic P_2O_5 Balance, P-Index, Crop Removal Balance and soil test P level.
- There was no relationship between the Crop Removal N and tile water N.
- Agronomic P Balances, Soil Test P values and NMAN P-Index values were all significantly higher for the 5 livestock farms.
- No significant linear relationships existed between any of the following: tile K levels and soil test K levels, tile K levels and NMAN Agronomic Balance K levels, or tile K levels and NMAN Crop Removal Balance K levels

- The NMAN program was responsive to over-applications of manure N and P, but the impact on tile drain water was not immediate. This suggests that nutrient entry to tile drainage systems is more of a long-term process that is not well predicted by application rates in any one year. Any prediction of tile drain concentrations of N and P would likely need to consider long term averages of the Agronomic Balances for N and P.

8.0 Acknowledgements

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