Environmental Benefits of Tile Drainage
- Literature Review -

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1.0 Introduction

Agricultural land drainage has been practiced for millennia. Greek and Egyptian civilizations relied on surface drainage to preserve cropland from being damaged by flood waters. Since then, agricultural drainage has continued to change and develop throughout the years to now include subsurface drainage (Donnan 1976). England boasts to have laid the first cylindrical tile drains in 1810. 1844 marks the time when the first clay tile was reported to have been laid in Canada, near Bowmanville, Ontario (Irwin, 19__). In the United States, widespread use of concrete tiles occurred about 1900 (Donnan 1976). Subsurface drainage improved land for agricultural production, and was a way to control diseases carried by the mosquitoes and black flies living in wet areas. The USDA (1955) claims that **land drainage facilitated settlement in North America.**

A more recent look at land drainage reveals that, out the 170 million hectares (ha) of cropland in the U.S., 45 million ha have benefited from some form of improved drainage. 15.3 million ha (34%) of that has been tile drained (Skaggs et al. 1994). In Ontario, there are 3.5 million ha of land classified as cropland (OMAFRA 1996). It is estimated that 1.5 million ha (43%) has been tile drained, and that an additional 1.5 million could benefit from tile drainage within the next 30 years (Vanderveen 2001). Though tile drainage has been practiced for over 150 years in some of these areas, there is still much land that could benefit from tile drainage.

The term *tile drainage* refers to a subsurface conduit for removing excess water from the soil. This pipe can be made of fired clay, concrete, or more popularly, perforated corrugated plastic. The term *agricultural drainage* refers to both surface and subsurface drainage. The purpose of this report is to provide an overview of research conducted on tile drainage. It will also provide a thorough list of references to consult for further reading. The outline of the report is as follows:

- agronomic benefits
- economic benefits
- hydrology
- water quality
- innovative management
- conclusions/recommendations

2.0 Agronomic Benefits

The agronomic reasons for having tile drains installed into farm land are many. Tile drainage can affect the physical properties of the soil. The removal of excess water results in better aeration and corresponding microbial activity, improved soil porosity and tilth and overall better soil structure (Hill 1976; Gardner et al. 1994). Because dry soil warms up faster than wet soil, tile drainage also promotes warmer spring soil temperatures which can lead to earlier spring sowing and germination of seeds (Plamenac 1988; Liefers and Rothwell 1987).

By removing excess water from the upper layers of the soil more quickly than undrained soils, tile drainage can improve the trafficability of soil (Geohring and Steenhuis 1987; Madramootoo et al. 1997; and Bailey 1979). A study conducted in British Columbia on a naturally moderately poor to poorly drained silty-clay loam found that subsurface drainage could remarkably advance soil trafficability by more than 60 days (Chieng et al. 1986). A more modest advancement was seen by Aldahagh and Beer (1975), who found spring workability could be increased by 16 days on a poorly draining Webster silty-clay loam. A modeling study by Wendte et al. (1978) predicted similar results. Lengthened growing seasons are important, especially in climates where growing seasons are limited (Madramootoo et al. 1997). Heavy machinery use and tillage on wet soil can result in soil compaction, which damages the soil structure (Wind 1976). Tile drainage reduces the risk of this damage.

3.0 Economic Benefits of Tile Drainage

Tile drainage is economically beneficial to the farmer. It can allow higher value crops, such as fruits and vegetables, to be planted where they could not otherwise be profitably grown. Tiling can increase the yield for a variety of different crops, including: wheat, corn, soybeans, sugar beets, sunflowers, sugar cane, citrus and forages (Bolton et al. 1982; Warin et al. 1998; Geohring and Snyder 1983; Colwell 1978; Buscaglia et al. 1994; Geohring and Steenhuis 1987; Carter 1987; and Plamenac 1988). For example, Colwell (1978) reported yield increases of 35, 32, 48 , 47 and 27% for grain corn, soybeans, wheat, oats and hay (see Table 1). Finally, because machinery works more efficiently on drier soil, tile drainage reduces labour hours (Plamenac 1988) and helps to minimize fossil fuel consumption and associated costs (Madramootoo et al. 1997; Wind 1976).

Table 1 B Effect of tile drainage on yields of five different crops

Crop	Average Yield before tile drainage	Average yield after tile drainage	Yield increase	
	tonne/ha	tonne/ha	tonne/ha	%
Grain corn	4.14	5.58	1.44	34.8
Soybeans	1.96	2.59	0.63	32.1
Wheat	1.77	2.61	0.84	47.5
Oats	1.60	2.35	0.75	46.9
Hay	4.10	5.20	1.10	26.8

(from Colwell 1978)

In Ontario, after analyzing 51 years of data on subsurface drainage, an after-tax analysis indicated that government benefited through increased tax revenue. Higher income farmers would invest profits, which added to the tax revenue as investment income (van Vuuren and Jojani 1986). Not all areas of land, however, will realize economic benefits from tile drainage installation (Found et al. 1976). An appropriate economic analysis should be completed prior to installation.

4.0 Environmental Benefits of Tile Drainage

At the turn of the 21st century, it is not enough for the farmer to ensure that agriculture is fulfilling its productivity and economic demands. It is important that the agricultural sector manages itself in an environmentally responsible manner. This section will address the various ways in which land with tile drainage can affect the environment.

4.1 Hydrology

Comparisons in this report will be made between tiled and untiled *agricultural* land. Natural, undrained land, behaves differently - for example, peak runoff rates as well as sediment and pollutant loading are lower in natural systems than agricultural systems (Skaggs et al. 1994). Bearing in mind that agricultural production is essential to society and the economy, this section will review water behavior in agricultural areas only.

a) Storage Space

The literature agrees that tile drained fields can offer more temporary storage space for water than their undrained equivalents (Van Vlack and Norton 1944; Mason and Rost 1951; Skaggs and Broadhead 1982; and Irwin and Whitely 1983;). Skaggs and Broadhead (1982) observed five different storm events. They noted that in these events, subsurface drainage increased storage capacity in the soil by continually removing excess, or "loose" water, from the soil profile. This Aloose@ water (also called gravitational water) is not available for use by plant roots. It fills the soil pores normally occupied by air and leads to drowning of crops. Plant roots use Acapillary@ water, which is held to soil particles by surface tension. Soils with tile drainage were found to have a greater storage capacity than naturally well-draining soils that did *not* have tile drainage. Irwin and Whitely (1983) reviewed literature from the US, UK, Europe and Canada. They found that under "drained" conditions, it should take the water table three to four days to fall to drainage depth. In contrast, undrained fields may take several weeks for evaporation alone to lower the water table to a similar depth. If there is an intervening rain, it will take longer.

Further, some soils drained with tiles may actually have a *higher* capacity to store water because tile drainage improves soil structure. Better soil structure means that the soil is more porous, and is therefore better able to store water (Gardner et al. 1994).

b) Infiltration vs surface runoff

Because tile drained soils can have a higher capacity to store added moisture, more water is able to infiltrate into the soil profile, thus reducing surface runoff volumes. Extensive review articles covering North American, European and British literature (Baker and Johnson 1976; Hill 1976; Irwin and Whitely 1983; Belcher and Fogiel 1991; and Thomas et al. 1995), as well as other individual studies (Van Vlack and Norton 1944; Mason and Rost, 1951; Watelet and Johnson 1999) have confirmed that tile drainage reduces surface runoff. For example, in western Oregon, Istok and Kling (1983) observed that when tile drainage was installed in a silt loam watershed with slopes ranging from 0-15%, watershed runoff yield was reduced by 65%.

Reduced surface runoff can result in decreased soil, chemical and nutrient losses from a field, though the losses are dependant on the timing of the runoff event with respect to the time of application and protective cover crop. It can also decrease peak flows and total volumes lost from the watershed, as well as increase the time between the beginning of a rain event and the peak flow ("lag time"). These topics will be discussed in later sections.

c) Peak flows reduced

Good subsurface drainage significantly reduces peak flow volumes. Peak flow refers to the greatest amount of flow resulting from the total of surface runoff and subsurface drainage. Because increased storage capacity allows more water to infiltrate, the soil acts as a buffer for rainfall and spreads the runoff over a longer period of time (Mason and Rost, 1951; Larson et al. 1980).

Skaggs and Broadhead (1982) found that conditions prior to precipitation affected how well tile drained soil buffered peak flows. By monitoring five different storm events, they found that good subsurface drainage significantly reduced peak flows. Subsurface drainage increases storage capacity in the soil by continually removing water from the soil profile. If the soil was very wet prior to precipitation, peak flow was reduced by 20%, but when prior conditions were dry, a reduction of up to 87% was observed. It was also emphasized that there is an interaction between subsurface and surface drainage. When subsurface drainage was good, improvements to the surface drainage system made little difference to peak flow rates. However, when subsurface drainage was poor, improving the surface drainage increased the peak flows.

Natho-Jina et al. (1986) found that peak flows were significantly influenced by the **soil moisture condition**. When soil was dry before a rain event, there was a relatively small amount of tile flow. The water table had been lowered by the subsurface drainage system, so there was more space in the soil profile available for storage. They also found that the subsurface flow hydrograph was flatter and longer compared to the surface runoff hydrograph. However, most of the water removed from the field was from the tile drainage. The Quebec study was completed on a silt-loam soil having a slope of 2%.

Larson et al. (1980) also found that soil moisture conditions affected peak flow. When soil moisture levels were low, subsurface drainage produced only small increases (if any) in storm runoff volumes, compared to a surface inlet. However, when soil moisture conditions were high, significant increases in storm runoff volume occurred from subsurface drainage but the discharges were maintained over a longer period of time. The researchers found that the presence of subsurface drainage produced a significant increase in the annual total flow volume (total of surface runoff and subsurface flow), compared to surface drainage only.

Konyha et al. (1992) also found that total outflow from the field increased, by 40 mm (10%) when compared to surface drainage only. However, the peak runoff rate was reduced from 101 to 28 mm/day. The volume of surface runoff from the field decreased by 192 mm (66%). This modeling study was conducted on well- to poorly-drained Wadasa muck soil in North Carolina. When McLean and Schwab (1982) modeled total runoff at a *watershed* scale, peak flow runoff rate reductions of up to 18% during the growing season and 11% in the non-growing season were seen. The study gathered long term data from 0.2 ha plots under four different drainage regimes. On average, peak flow rates from the field were reduced by an average of 32%, ranging from 7 to 77%, compared to undrained plots. For storms that produced high rates of surface runoff, peak flow rates were reduced by 50% with tile drainage.

Istok and Kling (1983) observed that when tile drainage was installed in a silt loam watershed with slopes ranging from 0-15%, watershed runoff was reduced by 65% and sediment yield was reduced by 55%. The hydrology of this western Oregon watershed also changed so that the lag time increased - drainage water moved through the watershed more gradually, which is generally desirable.

Many of the studies mentioned in this review have been conducted on relatively flat surfaces. Parkinson and Reid (1986) determined that **slope** plays a large role in the efficiency of tile drainage. The site was a heavy clay soil with slopes ranging from 3.6 to 5%. Drainage efficiency, peak drain discharge and flood lag time all decreased as slope increased - i.e. as more surface runoff occurred.

Soil type plays a major role in tile drainage volume and rate. After comparing the drainage from four sites with four different soil types, Clark et al. (1988) found that drainage response of heavy clays is slow initially but increases rapidly once a route-way has been established. Cracks which mainly form during dry periods make the route-ways. Other soil types have a more constant flow response. The land slope in this experiment was minimal, ranging from 1.5 to 2.0%.

Tile drainage spacing affects the quantity of tile discharge. Hoover and Schwab (1976) found that tile spacings of 9.1 m (30 feet) increased the tile flow discharge by 50% compared to spacings of 15.2 m (50 feet). Schwab et al. (1961) compared 9.1 m and 18.2 m spacing of tiles. Tile flow was considerably greater for the 9.1 m spacings. Plamenac (1988) plotted discharge rates of tiles at various spacings in a heavy clay soil. Though maximum discharge volumes were similar, tiles that were further apart took longer to drain. Tiles 20 m apart took about 40 hours to drain, whereas at 50 m spacing, drainage took about 125 hours.

d) Stream flow

Researchers at the University of Waterloo examined stream flows from the middle Thames River in Ontario from 1949-1980. Their results showed that drainage had little to no effect on the stream flow for the watershed for the period observed (Serrano et al. 1985). Eddie (1982) also failed to find any trend in stream flow characteristics that might be related to agricultural drainage. The study examined the annual mean, maximum and minimum stream flows of 10 rivers in western Ontario.

e) Groundwater

From a study that collected tile drainage data for 16 years from a site in central New York, Walter et al. (1977) found that only 7.5% of the average annual precipitation came out in the tile discharge. This study also found that most of the average annual tile flow (84%) occurred during the months from November to April. This is during periods of abundant moisture, where water would be lost in runoff anyway. The driest months were from July to September, during a time when very little tile flow would be occurring. Soil properties, especially hydraulic conductivity, can affect the extent to which land drainage can affect ground water levels (Hill 1976).

4.2 Water Quality

Water quality, as it relates to agricultural practices, is an important issue. This section will examine how potential water contaminants are affected by tile drainage.

a) Sediment

Wall et al. (1982) determined that 0 to 30% of suspended sediment in streams comes from bank erosion, and 70 to 100% comes from cropland sheet erosion. These numbers were determined by studying 11 small (<6 000 ha) agricultural watersheds over a two year period. Because of the additional storage volume that tile drainage can create within the soil profile, tile drainage greatly reduces the amount of destructive overland flow from a field, and thus the amount of sediments lost. Baker and Johnson (1976); Hill (1976); Loudon et al. (1986); Belcher and Fogiel (1991); Skaggs et al. (1994); and Thomas et al. (1995) all reported that tile drainage can reduce the amount of sediment lost from an agricultural watershed.

Some chemicals and nutrients, such as pesticides (mostly herbicides) and phosphorus (a constituent of phosphate), are strongly adsorbed to soil constituents. By reducing the amount of sediments lost from a watershed, associated chemical and nutrient losses can also be reduced (Gaynor et al. 1995). Loudon et al. (1986) found that tile drainage is an effective method of reducing non-point source pollution in areas where sediment and phosphorus are the major concerns. Skaggs et al. (1982) also determined that tile drainage should be considered a best management practice for reducing erosion on relatively flat land. This recommendation was made after it was found that **tile drainage could reduce the amount of soil lost to erosion by a factor of ten** on a Goldsboro sandy loam, with a 2% slope in North Carolina.

Soil erosion from tile drained fields is further reduced by tile drainage because a) tile drainage improves soil structure, and therefore makes soil more stable and less likely to erode (McLean and Schwab 1982; Hundle et al. 1976); and b) spring planting can be done earlier. Plant growth can sooner provide protection from wind erosion (Colwell 1978).

b) Pesticides

Though tile drainage can act as a conduit for pesticides, it may actually reduce the amount of pesticides that arrive to the surface water by reducing runoff volumes. A study conducted in the Yamaska river basin in Quebec determined that, of the total amount of the herbicide, atrazine, lost to runoff, 51 to 62% was removed from the field through surface runoff compared to16 to 24% through tile drainage (Muir and Baker, 1976). Bastien et al. (1990) also found pesticide loading to be far higher in surface runoff than in subsurface flow. Loadings in the tile drains were up to 3.47 ìg/L, compared to as much as 47 ìg/L in surface runoff.

Various studies have been done to examine the importance of a variety of factors in the movement of pesticides through the soil:

- climate and season (Bastien et al. 1990; Traub-Eberhard et al. 1995)
- pesticide sorption coefficient (Kladivko et al. 1991; Traub-Eberhard et al. 1995)
- soil type (Traub-Eberhard et al. 1995; Novak et al. 2001)
- preferential flow through soil macropores (Kladivko et al. 1991; Kladivko et al. 1999)
- tillage practices (Elliot et al.2000)

After reviewing the literature, Gaynor et al. (1995) summarized that the highest concentrations of pesticide in surface runoff or tile discharge typically occur in events soon after herbicide application. The risk of contamination is greatest: a) if there is precipitation shortly after application, or b) on fields with slopes greater than 3%, and c) where pesticide application rates are high. On level ground, more pesticides were lost from surface drainage than from tile drainage.

It is important to note that tile drainage can improve crop quality (Colwell 1978). Higher quality crops are better able to withstand disease, which could result in a reduced need for pesticides.

c) Manure application

In Ontario, Best Management Practices (BMPs) have been produced that address the environmental impacts of the agricultural sector. The following are some recommendations for minimizing the risk of tile drainage contamination from manure (or fertilizers):

- consider risks to water resources before application - make sure crops can use manures or fertilizers at time of application;
- consider cultivation to break up preferential flow paths on the soil surface and within the soil before applying liquid fertilizer or liquid manure;
- monitor irrigation and tile systems carefully, especially if applying fertilizers or manures
- avoid winter manure application, especially on sloping land; and
- do not apply manure on saturated soils. (Ag Can and OMAF 1994)

Fleming and Bradshaw (1992) found that working the soil prior to spreading of manure minimizes the amount of contamination from the manure. They also recommended that farmers should monitor tile drainage outlets during and after manure application. Tile water contamination was easily detected as it would run darker and have a noticeable odour. Geohring et al. (1998) found that spreading liquid manure when the soil was dry reduced the risk of macropore flow.

d) Nutrients

Studies examining the nutrient losses from tile drain effluent are many. The general consensus in the literature, is that tile drainage reduces P, potassium (K), organic nitrogen and ammonium (NH_4) losses (Baker and Johnson 1976; Hill 1976; Bengtson et al. 1982; Belcher and Fogiel 1991; Konyha et al. 1992; Skaggs et al. 1994; and Thomas et al. 1995). The studies show that this is largely because sediment-associated nutrients, such as P and K, do not move easily through the soil profile. With tile drainage reducing runoff volumes, less of these nutrients are transported to surface waters. Nitrates (NO_3), on the other hand, are highly mobile in the soil because they easily dissolve in water. Various reviews show elevated losses of nitrogen from tile drained fields compared to undrained fields (Baker and Johnson 1976; Hill 1976; Bengtson et al. 1992; Belcher and Fogiel 1991; Skaggs et al. 1994; and Thomas et al. 1995).

A study by Bengtson et al. (1982) compared water quality from four plots. Two had tile drainage and two did not. In the tile drained plots, surface runoff and soil losses were both lower by 17%. Total P and K losses were lower by 48% and 22%, respectively. Only total N values were higher - by 3.2%. Further study of this site was conducted by Bengtson et al. (1992). After an additional 10 years, average runoff volume, soil, P and K losses were lower by 35, 31, 31 and 27%, respectively. These reductions occurred despite a 27% increase in water leaving the site. The site was a 4.4 ha Commerce clay loam on a 0.1% slope, near Baton Rouge, Louisiana.

Rooting systems of crops can affect nutrient losses from tile drains. Shallow rooted crops, like the potato, often have high leachate losses in tile water (Milburn et al.1990; Madramootoo et al. 1992b). This is because shallow roots are unable to remove nitrates from greater depths in the soil, leaving them to be leached away. Because tile drainage removes excess water from the upper layers of the soil more quickly than undrained soils, plants in drained fields often develop deeper rooting systems. As well, drainage promotes beneficial soil bacteria activity and improves soil tilth (Van Vlack and Norton 1944). This also allow the roots to penetrate deeper into the soil. Deeper roots means more nutrients and water can be accessed for plant use. Improved soil tilth also increases soil aeration which allows for increased nutrient availability through bacterial activity. If nutrients are available to plants and bacteria, they are less apt to leach downward through the soil profile.

Timing of when drainage occurs can affect the amount of nutrients lost. During dry conditions, total phosphorus in the soil can accumulate as microbes break down organic phosphorus. If there is a heavy rainfall, some of this P will be essentially "flushed" out of the soil profile. According to Simard et al. (2000), this can happen to a greater degree with permanent grasslands, partly due to increased preferential flow. A study by Hooda et al. (1999) with intensively managed tile drained pastures supported this finding.

Soil type has an influence on the risk of phosphorus leaching. More P has been shown to leach from organic soils compared to mineral soils, largely dependant on the amount of adsorbed cations in the soil, particularly aluminum, as well as the pH of the system (Miller 1979).

Yearly precipitation patterns can have an impact on long-term nutrient loadings in tile drains. High levels of residual nitrate-N can accumulate in the upper layers of the soil during dry years when drainage does not occur. This nitrate will be released during subsequent years. Randall (1998) investigated 5 different tile drainage sites over a 20 year period in southern Minnesota. Following a dry year, levels of nitrate-N in tile outflow were two to four times higher than normal levels. Elevated levels persisted for four years after the dry year. Randall urges that scientists and citizens and farmers should understand these types of cycles and manage crop and nutrient inputs accordingly.

Cropping systems can also affect nutrient levels in tile drainage (Randall et al. 1997). A corn-soybean rotation resulted in lower nitrate losses than in plots grown under continuous corn (Kanwar et al. 1999). Neilsen et al. (1980) monitored eleven agricultural watersheds in the Great Lakes region from 1975 to 1977. Elevated levels of dissolved nitrogen (NO_3+ NH_4) were often highest in well-drained watersheds growing corn, with high fertilizer use. Bolton et al. (1970) found N, P, and K losses were greatest under corn and least under a bluegrass sod. After studying the tile discharge from 20 farms in southwestern Ontario, Fleming et al. (1998) found nitrate-N, total P, and K concentrations to be greater under field or seed corn crops (mean concentrations were 18.4, 1.6 and 7.6 mg/L, respectively) when compared to soybean, tomato or wheat crops. The Ontario Drinking Water Standard for nitrate-N is 10 mg/L (there is currently no standard for nitrate for surface water quality).

Various researchers have studied the **seasonal impact** on tile water nutrient levels. Bjorneberg et al. (1996) found that 45 to 85% of the annual nitrate-N losses through subsurface drainage occurred in the spring and fall, corresponding with times when crops were not growing, as well as with changes in rainfall and drainflow. This trend was seen below four different tillage systems: chisel plow and moldboard plow, ridge till and no-till. Nitrate losses were decreased under ridge till and no-till, compared to chisel plow and moldboard plow. They emphasized that the mineralization of inorganic nitrogen can occur throughout the year, not just when fertilizer is applied.

5.0 Management Systems

Management systems exist that can reduce the amount of contamination in tile drainage, when it does occur. This section will briefly outline some of the systems in use today.

5.1 Nutrient Management Planning

By applying nutrients and chemicals to the land on a needs-basis as well as at appropriate times, tile water contamination can be greatly minimized (Ritter and Chirnside 1987; Parkes et al. 1997). This is currently the subject of a major shift in management in Ontario.

5.2 Water table management

Two types of water table management, controlled drainage and sub-irrigation, seem to be quite promising methods of reducing nitrogen losses in tile water (Meek et al. 1970; Doty et al. 1986; Belcher and Fogiel 1991; Madramootoo et al. 1992a; Madramootoo 1994; Drury et al. 1996; Tan et al. 1998; Tan et al. 1999;). These have application where the land is fairly level. Controlled drainage contains a mechanism that keeps the water table at a set elevation, stopping drainage water from exiting the system. Sub-irrigation is similar but includes a method to introduce fresh water to the system in order to maintain the water table elevation. These systems increase denitrification rates in the root zone, which releases N to the air that otherwise would reach the groundwater or surface water.

Drury et al. (1996) found controlled drainage could reduce average annual nitrate losses by 43% from 25.8 to 14.6 kg/ha, compared to drainage treatments. In conjunction with conservation tillage, nitrate losses were reduced by 49% (11.6 kg/ha). Nitrate losses from surface flow increased in controlled drainage, but this amount was minimal (1.4 kg/ha). Eighty-eight to 95% of the NO_3 losses occurred during the non-crop period (Nov. to Apr.). This study was conducted on a Brookston clay loam.

Compared to free outlet tile drainage, Tan et al. (1999) found flow weighted mean nitrate outflow concentrations were reduced by 38% and total N losses were reduced by 37% with controlled drainage. On this sandy-loam soil, tomato and corn yields were shown to improve by 11 and 64%, respectively, on the site with controlled drainage. Improvements in crop yield due to controlled drainage were also reported by Doty et al. (1986); Nemon et al. (1987); and Madramootoo et al. (1992a).

Controlled water tables can also reduce concentrations of the herbicide atrazine in shallow groundwater. This is what Kalita et al. (1992) found from a Nicollet silt-loam with a 2.5% slope.

5.3 Constructed wetlands

Public perception of wetland "utility" in the past resulted in many natural wetlands being converted into agricultural land. Now, natural wetlands have been recognized for their ecological role in filtration, habitat and groundwater restoration. The Federal Wetlands Policy, enacted in Canada in 1991, classifies wetlands and protects them from conversion accordingly.

AConstructed@ wetlands have similar benefits to the environment and are being explored as a mechanism to treat wastewater from livestock farms and agricultural drainage. Though long-term studies are still needed to establish the full impact of such wetlands (Woltemade 2000), current research indicates constructed wetlands are effective at removing nutrients, sediments and chemicals from agricultural wastewater. A simulation model based on data collected in field experiments predicted that wetlands can treat agricultural drainage water (Chescheir et al. 1992). It was predicted that the wetland buffer could remove 79% total Kjeldahl nitrogen (TKN), and 82, 81 and 92% of the NO_3 , total Phosphorous and sediment, respectively, over a 20 year period. Long narrow buffer areas were more effective than short wide wetlands because of higher residence times.

Brown et al. (1998) found that a constructed wetland can double as a treatment system and an irrigation reservoir. The benefits of the whole system were multiple: supply water to crops; eliminate drought stress; improve plant nutrient use; sustain yields; collect and recycle runoff and drainage; reduce off-site and downstream impacts; reduce amount of sediment and plant nutrients lost from cropland to surface waters; increase wetland acres, vegetation, and wildlife habitat.

5.4 Other

Other methods of management which can reduce the risk of tile drainage contamination include:

- marking outlets so they can be found at all times of the year;
- use of control valves to shut off the system if a manure leak is detected;
- use of inspection chambers on tile drains at farm lot lines to allow farmers to see and take samples of tile drain water;
- education about the hazards of illegally connecting milkhouse washwater treatment systems or household septic systems to field tile drainage systems;
- setting up a regular sampling schedule, complete with detailed records, of tile drain water quality, with tests for bacteria (especially if it is a livestock farm), nitrate, phosphorus and other potential contaminants; and
- creation of contingency plans - what to do if a problem arises, who to contact, etc.

6.0 Summary and Conclusions

Tile drainage is both agronomically and economically beneficial for reasons including better growing conditions, improved soil structure, better trafficability, reduced energy consumption, more timely planting and harvest, and improved yields for a variety of crops. Tile drainage can also impact the environment. After reviewing a large number of tile drainage research works, the following conclusions can be made:

- Rather than rely on evaporation alone to remove excess water from the soil, tile drainage can remove excess water within a matter of days rather than weeks. As a result, tile drained soil has increased water storage capacity.
- Soils with increased storage capacity, such as tile drained soils, have a higher infiltration capacity. Higher infiltration means a) the soil acts as a buffer to rainfall, decreasing stream peak flow volumes and extending watershed total runoff over a longer period of time; and b) surface runoff volumes can be reduced.
- The degree to which peak flows are affected by tile drainage depends on the moisture conditions in the soil. When soil is dry prior to rainfall, peak flows can be reduced by tile drainage by as much as 87%. Soil type, slope and drainage spacing also affect infiltration and peak flows.
- Tile drainage increases annual total runoff volumes compared to surface drainage only.
- Between 70 and 100% of suspended sediment in streams comes from cropland sheet erosion. Due to decreased surface runoff, tile drainage decreases sediment

loading in streams by as much as 40%. Because crops can be planted and thus provide protection to the soil earlier in the spring, tile drainage also reduces the magnitude of wind erosion on soil.

$ P and K do not move easily through the soil profile, so reduced surface runoff from tile drainage also reduces total P and K losses in mineral soils by as much as 48 and 29%, respectively.

$ Conditions which lead to the greatest nitrate losses in tile outflow are: a) when tile water flow is greatest; b) under corn-cropping systems; c) after an extended dry period; d) where fertilizer use is high (possibly as a result of poor nutrient management planning).

$ Because of a reduction in surface runoff, total pesticide losses from tile drained fields are also reduced compared to surface drained fields.

$ Nutrient management plans, water table management and constructed wetlands are management systems which can be used to correct problems with tile water quality, where they exist.

There are many environmental benefits of tile drainage systems on farms. In those cases where contaminated water exits from tile drainage systems, it is usually the result of a practice over which the farmer has control. If this happens, there are strategies that the farmer can use to either prevent contamination from entering the tile drains, or treating the water at the outlet. When used properly, tile drainage is an environmentally responsible practice.

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