Controlled Tile Drainage in Ontario:

Producer costs and benefits

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The views expressed herein are solely those of the Ontario Soil and Crop Improvement Association.

I. Executive Summary

Over the last several decades, controlled tile drainage (CTD) has emerged as an on-farm beneficial management practice (BMP) that can help mitigate agricultural run-off via tile drains as well as provide agronomic and financial benefits to producers. CTD is considered a risk mitigation practice that can help protect producers from crop losses and can stabilize yields over the long term. Despite well-documented environmental and agronomic benefits resulting from adoption of CTD and a high level of awareness of the technology amongst producers, uptake of the practice has been relatively low with few Ontario producers to date having retrofitted their existing tile drainage systems with control structures.

The primary objective of this project was to analyze the on-farm costs and benefits of controlled tile drainage to better understand the impacts of CTD adoption. A secondary objective was to estimate the public benefits associated with CTD adoption on farms in Ontario. Current and accessible information regarding the on-farm costs and benefits of CTD is a gap that should be filled to aid in adoption of CTD.

This project considers three types of available CTD technology installed on farms growing corn and soy including:

- Manually Controlled;
- Basic Automatic; and
- Remote Controlled Automatic systems.

Documented agronomic benefits of CTD adoption on farms with existing tile drainage systems include 4% yield increases for corn and 3% yield increases for soybean crops. When all costs are taken into account, retrofitting existing tile drainage fields with CTD can provide up to $48.53 of net revenue per hectare annually on a farm growing equal amounts of corn and soybean crops over the lifetime of the structure (estimated at 20 years). The per hectare value of CTD varies depending on field size and system design. The results of this project show that CTD systems can provide a positive net return for many Ontario producers with an investment payback period of 3 to 11 years depending on the individual farm scenario.

Annualized benefit per hectare attributed to CTD retrofits

CTD System	Annualized Benefit per Hectare
Manual	$18.67 to $48.53
Basic Automatic	$(69.23) to $18.87
Remote Controlled Automatic	$(334.08) to $(63.57)

It is widely accepted that CTD mitigates losses of nitrate - Nitrogen ($N0_3^-$-N) and Phosphorus (P) from tile drained fields by reducing the amount of drainage discharge water from the tile drainage system during the growing season. Improvement in water quality is considered a public benefit attributed to CTD. A Cost-Benefit Analysis revealed that retrofitting an existing uncontrolled tile drainage (UCTD) system with CTD effectively reduced the abatement cost associated with nutrient export resulting from UCTD by $25.65/ha/growing season for Total N and Total P combined. The public benefits associated with CTD retrofits may justify public investment in the form of cost-share incentives to increase adoption of CTD amongst producers in Ontario.

II. Introduction

Ontario is home to over 50,000 farms on approximately 5 million hectares of land (OMAFRA, 2013). Approximately 1.6 million hectares of agricultural land is tile drained with another estimated 1.5 million hectares that may benefit from tile drainage in the future (Sunohara, et al., 2015; Crabbe, Lapen, Clark, Sunohara, & Liu, 2012). Tile drainage enhances farmland's productive capacity by draining spring melt water and precipitation more rapidly, allowing equipment to enter fields earlier in the season as well as optimizing soil conditions for early plant growth. While agricultural tile drainage is necessary for crop production in some parts of Ontario, conventional tile drainage systems can impact water quality by providing a rapid pathway for sediment, nutrients, pathogens and pesticides to enter surface waters (Sunohara, Craiovan, Topp, Gottschall, Drury, & Lapen, 2014; AAFC, 2010; Tan & Zhang, 2011).

Nutrients from agricultural non-point sources can contribute to harmful algal blooms and hypoxic conditions in water bodies. Current environmental regulatory directives for water quality in Canada and the US are focused on reducing nutrient pollution in the Great Lakes and Gulf of Mexico (Sunohara, et al., 2016; Frankenberger, et al., 2007). Over the last several decades, controlled tile drainage (CTD) has emerged as an on-farm beneficial management practice (BMP) that can help mitigate agricultural run-off via tile drains as well as provide agronomic and financial benefits to producers (Sunohara, et al., 2015; Skaggs, Fausey, & Evans, 2012; Crabbe, Lapen, Clark, Sunohara, & Liu, 2012; Wall, Coote, DeKimpe, Hamill, & Marks, 1994).

CTD helps to manage risks associated with flooding and periods of drought by allowing producers to control the depth of their water table during planting and crop growth. In a conventional tile drainage system, drainage outlets flow freely throughout the season and water in the soil will continue to drain away from crops that could benefit from moisture during the growth period. CTD systems manage the water table by installing a control structure in the tile drainage mainline, which restricts drainage when the control structure is closed. CTD systems are typically allowed to flow freely during the spring planting period and then closed to restrict drainage from fields after planting. After harvest, CTD systems are opened again and allowed to flow freely over the winter (AAFC, 2010). Research suggests that CTD decreases yield variability year-to-year and can buffer producers from risks associated with flooding and drought. As such, CTD is considered a risk mitigation practice that can help protect producers from crop losses and could potentially stabilize yields over the long term (The Nature Conservancy, 2015; Cicek, et al., 2010).

Promotion of CTD in Ontario as a BMP dates back to the 1980s and the practice itself has been the subject of several research projects including a multi-year watershed level research project funded through the Watershed Beneficial Management Practices program (WEBs) (Wall, Coote, DeKimpe, Hamill, & Marks, 1994; Sunohara, et al., 2016; Drury, Tan, Reynolds, Welacky, Oloya, & Gaynor, 2009; Tan & Zhang, 2011; Jaynes, 2012). Despite well-documented environmental and agronomic benefits resulting from adoption of CTD and a high level of awareness of the technology amongst producers (approximately 70% awareness), uptake of the practice has been relatively low with few Ontario producers to date having retrofitted their existing tile drainage systems with control structures (Dring, et al., 2014). Documented reasons for a lag in adoption of CTD on farms include:

- Uncertainty about the return on investment;

- A perceived labour burden associated with the management of control structures (particularly accessing systems in poor weather conditions); and
- Concerns with the legitimacy of research on CTD to date (Dring, et al., 2014; Strock, Kleinman, King, & Delgado, 2010).

Researchers have noted the importance of providing current financial data to agricultural producers to aid in the decision about whether or not to adopt a practice. Tyndall & Roesch-McNally (2014) recommend that producers be provided with transparent financial data to help them weigh the costs and benefits of a technology while Dring, et al. (2014) indicated that producers are often financially motivated when choosing to adopt an environmental BMP. Current and accessible information regarding the on-farm costs and benefits of CTD is a gap that should be filled to aid in adoption of this BMP.

A. Project Description

The primary objective of this project was to analyze the on-farm costs and benefits of controlled tile drainage to better understand the impacts of CTD adoption. A secondary objective was to estimate the public benefits associated with CTD adoption on farms in Ontario. The methods used to conduct this project included:

- A literature review focusing on recent research in the field of CTD costs and benefits; and
- Economic analyses including:
    - Discounted Cash Flow (DCF) analyses to evaluate the value of CTD adoption on individual farms in Ontario; and
    - A Cost Benefit Analysis (CBA) to evaluate the value of CTD adoption to the broader public, taking into account the environmental benefits associated with water quality improvement in addition to the private costs and benefits.

Data for the economic analyses was obtained from two sources:

- Data reported in the literature; and
- Semi-structured phone interviews with four Ontario drainage contractors and one CTD structure manufacturer (see Appendix for list).

Specific data sources will be described in detail in the body of this report and in further detail in the Appendix.

In the winter of 2017, Ontario Soil and Crop Improvement Association (OSCIA) retained Amy and Patrick Kitchen from Yarrow Consulting to assist with this project. The literature review and financial analyses were part of a larger collaborative project taking place between January 2017 and March 2018 titled ‘Controlled Tile Drainage – Calculate Your Benefits’ where OSCIA and scientists at the University of Ottawa and Concordia University are researching the crop yield benefits of controlled tile drainage. Funding for this project was provided through Agriculture and Agri-Food Canada’s (AAFC) AgriRisk Initiatives (ARI) program.

OSCIA is a grassroots farm organization with a head office located in Guelph, Ontario. OSCIA has been a delivery agent for farm-based stewardship programs for many years, including the long-standing and successful Environmental Farm Plan (EFP) program since its inception in the early 1990s. Currently, OSCIA delivers multiple environmental cost-share programs for various federal departments, provincial ministries, and not-forprofit agencies across the province.

The remainder of this report is organized as follows:

- In section three, a brief overview of CTD technology is discussed;
- In section four, producer costs and benefits are described and the results of the DCF are presented;
- In section five, public benefits are described and the results of the CBA are presented;
- In section six, we discuss conclusions and offer some suggestions for future research topics; and
- The Appendix contains more details on the data used to conduct the financial analyses presented in this report.

III. Controlled Tile Drainage Technologies

Three types of CTD technologies were available on the market at the time of this project:

- Manually Controlled;
- Basic Automatic; and
- Remote Controlled Automatic systems.

All three types of CTD technologies and associated costs were considered in the economic analyses described in this report. A brief description of each technology is provided below (AgriDrainCorporation, 2017). The primary management difference between the systems is the amount of time it takes to operate the structure during the season.

1. Manual CTD Structure

A Manual CTD structure, installed in the mainline (or header) of a field, controls the flow of water through the mainline through the manual addition or removal of stoplogs (physical barriers) within the structure to raise or lower the level of the water table. The farm operator must physically visit the structure to change the water level setting. For the purposes of this project, *we assume the operator will visit the site two times throughout the year* (once in the spring after planting to bring water table up, and again in the fall pre- or post-harvest to allow the field to drain throughout the winter and spring) and to adjust the level and maintain the system (i.e. grease). The cost of a Manual CTD structure ranges from $1,466 to $2,121 CAD inclusive of installation costs, depending on the size of structure required.

2. Basic Automatic CTD System

A Basic Automatic System installed in the mainline (or header) of a field controls the flow of water through the mainline through two valves within the structure to increase or decrease the level of the water table. *The farm operator must physically visit the structure once per year to program the system with the timing and water levels they require through the year.* The system requires no additional maintenance (i.e. grease) and functions automatically throughout the season based on the prescribed program/schedule. *We assume the operator will visit the site one time throughout the year to program the system*.

The Basic Automatic System requires a larger structure than the manual CTD system. The system makes use of additional components that require more space necessitating a larger structure. For example, on a 4 ha field a 6” manually controlled CTD structure may be effective, whereas an 8” Basic Automatic CTD structure would be required for the same field. There is an associated cost increase due to the larger physical structure required. The cost of the additional components associated with the Basic Automatic System range from $3,625 to $4,028 CAD depending on the size of the structure. This cost is in addition to the cost of a Manual CTD structure.

3. Remote Controlled Automatic System

A Remote Controlled Automatic System installed in the mainline (or header) of a field controls the flow of water through the mainline through two valves within the structure to increase or decrease the level of the water table. Once installed, the structure can be maintained remotely in real time*. No visits are required*. The operator can set the schedule for the structure, change it in real time, program set points, etc. The system requires a larger structure than the manual CTD system for the same size mainline. The Remote Controlled Automatic CTD system consists of additional components that require more space in the structure necessitating a larger structure. There is an associated cost increase due to the larger physical structure required. Required components associated with the Remote Controlled Automatic system range from $6,713 to $8,056 CAD depending on the size of the structure.[1] This cost is in addition to the cost of a Manual CTD structure. The system also requires a cellular connection (i.e. a cellular plan) with a monthly fee of approximately $73.85 CAD.

IV. Financial Analysis of Controlled Tile Drainage

This section explores the private benefits and costs associated with CTD and presents the results of the DCF analysis.

A. On-Farm Benefits of CTD Adoption

Several studies indicate that over several years both corn and soybean yields are improved by CTD (Sunohara, et al., 2016; Jaynes, 2012; Poole, Skaggs, Cheschier, Youssef, & Crozier, 2013). In Ontario, Sunohara et al. (2016) reported a significant boost in yields as a result of CTD adoption in the South Nation watershed in eastern Ontario. Furthermore, during the study period, adoption of CTD in the watershed increased abruptly largely as a result of producers observing taller, healthier looking crops in fields where CTD was installed and communication of CTD benefits via peer networks (Sunohara, et al., 2015). The results of the WEBs research indicated that CTD increased yields by 4% in corn and 3% in soybean crops due to increased N uptake by plants (Sunohara, Craiovan, Topp, Gottschall, Drury, & Lapen, 2014). It is possible that in a drought stress year, CTD could increase yields by considerably higher amounts (CVision Corporation, 2006). However, in an extremely dry year, CTD may have no impact on yield.

[1] We assume that a basic sensor package is used for the system. Additional sensors will change the price of the system.

Table 1, adapted from Skaggs, Fausey & Evans (2012) summarizes the measured effects of CTD on crop yields reported in the literature.

Table 1.Summary of measured effects of CTD on crop yields reported in the literature

Reference	Location	Years Observed	Number of Sites	Crop	Effects of CTD on crop yield
(Tan, et al., 1998)	Ontario	2	1	Soybean	No effect
(Drury, Tan, Reynolds, Welacky, Oloya, & Gaynor, 2009)	Ontario	2	1	Corn	No effect
		2	1	Soybean	No effect
(Sunohara, et al., 2016)	Ontario	9	**7**	Corn	4% increase
		9	**7**	Soybean	3% increase
(Fausey, 2005)	Ohio	5	1	Corn	No effect
		5	1	Soybean	No effect
(Poole, Skaggs, Cheschier, Youssef, & Crozier, 2013)	North Carolina	6	2	Corn	11% increase
		5	2	Wheat	No effect
		6	2	Soybean	10% increase
(Delbecq, Brown, Florax, Kladivko, Nestor, & Lowenberg-DeBoer, 2012)	Indiana	5	2	Corn	5.8% - 9.8% increase
(Jaynes, 2012)	Iowa	2	1	Corn	No effect
		2	1	Soybean	8% increase
(Helmers, Christianson, Brenneman, Lockett, & Pederson, 2012)	Iowa	4	1	Corn	Reduced yield
		4	1	Soybean	No effect
(Cooke & Verma, 2012)	Illinois	2	4	Corn	No effect
		2	3	Soybean	No effect
(Ghane, Fausey, Shedekar, Piepho, Shang, & Brown, 2012)	Ohio	1 to 2	7	Corn	1 to 19% increase
		1 to 2	7	Soybean	1 to 7 % increase

Research suggests that CTD decreases yield variability year-to-year and can buffer producers from risks associated with flooding and below average precipitation. As such, CTD should be considered a risk mitigation practice that can help protect producers from crop losses and could potentially stabilize yields over the long term (The Nature Conservancy, 2015; Cicek, et al., 2010).

B. Discounted Cash Flow Scenarios, Parameters and Assumptions

CTD system design, costs and on-farm benefits may vary widely depending on initial site conditions, hydrology, soils, crop, and management (Tyndall & Roesch-McNally, 2014). It is important to understand that the financial assessments presented in this report are meant to be informative and not prescriptive at the individual farm level. For the purposes of this project, it was necessary to develop scenarios in order to analyze costs and benefits that are likely relevant to Ontario producers. Three scenarios were developed based on study parameters and system design reported by Crabbé et al. (2012), which, in consultation with OSCIA, was considered to be the study that is most applicable to Ontario producers. Crabbé et al. (2012) conducted a financial analysis of CTD based on parameters and data collected in the WEBs study in the South Nation Watershed in eastern Ontario between 2005-2009. Results of Crabbé et al.'s (2012) analyses were reported in real 2006 Canadian dollars and consider only the manually controlled CTD system. This project builds on the research presented by Crabbé et al., (2012) by including current (2016) CTD system installation and maintenance costs and crop market data as well as including automated CTD technology in the analyses.

For the purposes of this project we consider three field sizes for the DCF analysis. The range in field sizes reflects the variability in farmland and the fact that in more hilly regions, 4 ha (or less) may be the limit for one CTD system to be effective, whereas in more flat regions (for example 0.1% slope), one CTD structure could be installed on a larger field and remain effective. We assume that on all field sizes, the land is relatively flat (<1.0% slope) and thus the CTD structure can effectively control the water table for the entire field.[2] The scenarios were crosschecked for applicability during consultations with drainage contractors. The specific field sizes and associated number of structures considered in the scenarios were as follows[3]:

- 4 ha fields on 111 ha farms requiring 28 CTD systems total;
- 9 ha fields on 111 ha farms requiring 13 CTD systems total; and
- 14 ha fields on 111 ha farms requiring 8 CTD systems total.[4]

All scenarios involve retrofitting an existing uncontrolled tile drainage (UCTD) system on a 111 ha farm with CTD structures to control flow through the existing tile drains. Three separate CTD systems are considered in the analysis:

- Manually controlled;
- Basic Automatic; and
- Remote Controlled Automatic systems.

Assumptions and parameters applied to the analyses were as follows:

- The existing UCTD system specifics reported by Crabbé et al. (2012) and developed in consultation with drainage contractors include:
    - 16.8 meter (55 foot) spacing between lateral drain tiles[5];
    - 10.2 cm (4 inch) diameter lateral drainage at 1 meter depth;
    - 15.2 cm (6 inch) mainlines on 4 ha fields;
    - 25.4 cm (10 inch) mainlines on 9 ha fields; and
    - 30.5 cm (12 inch) mainlines on 14 ha fields.
- One CTD structure was installed per field.
- The 111 ha farm is planted in a 50% corn and 50% soybean rotation.
- We assumed that the CTD system has a 20-year life span (AgriDrainCorporation, 2017). The estimate of system lifespan is consistent with the more conservative estimates of CTD lifespan reported in other studies (Crabbe, Lapen, Clark, Sunohara, & Liu, 2012; Tyndall & Roesch-McNally, 2014).

[2] Research indicates that CTD systems are most suitable for fields with slope <1.0% (CVision Corporation, 2006; Frankenberger, et al., 2007; Hein, 2014).
[3] Note that the field sizes and farm size were based on parameters set in Crabbé et al. (2012) and in consultation with contractors and consultants.
[4] Note that the number of systems was rounded up to the nearest whole number.
[5] Note that several drainage contractors indicated that newly installed drainage systems are typically spaced between 20'-26'; however, to be consistent with parameters set in the WEBs study, we consider 55' tile spacing in this project.

- The status quo scenario, which we compare to CTD scenarios, is assumed to be an existing UCTD system. Costs and benefits resulting from a UCTD system are assumed to be $0, or no change.
- All scenarios are changes to the status quo.
- We assumed that the system was not financed.
- Depreciation costs were not considered in the analyses.
- All costs and benefits were adjusted to real 2016 Canadian Dollars (average 2016 exchange rate $1.00 US : $1.33 CAN) (Bank of Canada, 2016).
- Net present value (NPV) and annualized benefit amounts were calculated using an 8% discount rate, which is the rate recommended by the Treasury Board of Canada Secretariat (2007) and is more conservative than the discount rates found in the literature reviewed for this project. For example, Tyndall & Roesch-McNally (2014) recommend a discount rate of 3.75% when analyzing water quality BMPs.

Discussion of CTD System Costs

CTD system costs can be separated into one time installation costs and ongoing maintenance costs. The initial investment costs vary depending on the size and type of CTD system (i.e. Manual, Basic Automatic or Remote Controlled Automatic). CTD system and installation cost data was collected through consultation with drainage contractors and one CTD system supplier.

Annual maintenance costs are costs that will be experienced by producers each year over the lifetime of the CTD structure. These costs include system maintenance, operation and in the case of the remote controlled automatic system, the cost of a cellular plan necessary for the CTD structure (Table 2).

Table 2. Breakdown of infrastructure and annual maintenance costs per structure

System	Height (ft)	Diameter (in)	Structure Cost[a]	Additional Infra-structure Costs[b]	Instal-lation Cost[c]	Float Fee[d]	Annual Mainten-ance Costs[e]
Manual	6	6	$904.60	$0.00	$524.96	$36.06	$52.63
	6	10	$1216.34	$0.00	$524.96	$77.66	$52.63
	6	12	$1469.36	$0.00	$524.96	$126.19	$52.63
Basic Automatic	6	8	$1045.04	$3625.27	$524.96	$36.06	$20.19
	6	12	$1469.36	$3826.67	$524.96	$77.66	$20.19
	6	15	$1837.42	$4028.07	$524.96	$126.19	$20.19
Remote Controlled Automatic	6	8	$1045.04	$6713.45	$524.96	$36.06	$886.18
	6	12	$1469.36	$7384.80	$524.96	$77.66	$886.18
	6	15	$1837.42	$8056.15	$524.96	$126.19	$886.18

a. Structure costs (AgriDrainCorporation, 2017): Structure costs vary depending on the height and diameter of the structure.
b. Additional costs (AgriDrainCorporation, 2017): Additional components to modify manual system to automatic. Components include valves, solar power, basic sensors, etc.
c. Installation costs: Based on 2 hours of labour plus materials to connect structure. Developed in consultation with Ontario drainage contractors.
d. Float fee: The float fee (i.e. heavy equipment transport fee) is $1,009.54/project. The per structure float fee varies based on the number of structures per project and not the actual size of the structure itself. Developed in consultation with Ontario drainage contractors.
e. Maintenance costs (AgriDrainCorporation, 2017): Manual system costs are based on two 1-hour visits to maintain and adjust stoplogs at $20.19/hr and 1 tube of grease at $12.41. Basic automatic system costs based on 1 visit to program schedule for the year (1 hour at $20.19/hr). Remote controlled automatic has no standard maintenance costs. However, there is a monthly cellular plan fee of $73.85.

Table 3 outlines the CTD infrastructure and maintenance costs per hectare. See the Appendix for the total system costs for each scenario.

Table 3. CTD infrastructure and annual maintenance costs reported in dollars per hectare

System	Field Size (ha)	Farm Size (ha)	Number of Systems (per farm)	Structure Cost (per ha)	Installation Cost (per ha)	Total Structure + Installation Cost (per ha)	Annual Maintenance Cost (per ha)
Manual	4	111	28	$226.15	$140.25	$366.40	$13.16
	9	111	13	$135.15	$66.96	$202.11	$5.85
	14	111	8	$104.95	$46.51	$151.47	$3.76
Basic Automatic	4	111	28	$1167.58	$140.25	$1307.83	$5.05
	9	111	13	$588.45	$66.96	$655.41	$2.24
	14	111	8	$418.96	$46.51	$465.47	$1.44
Remote Controlled Automatic	4	111	28	$1939.62	$140.25	$2079.88	$221.54
	9	111	13	$983.80	$66.96	$1050.75	$98.46
	14	111	8	$706.68	$46.51	$753.19	$63.30

Discussion of Benefits

Retrofitting an UCTD system with CTD can result in increased yields of 4% for corn and 3% for soybean per hectare (Sunohara, et al., 2016). Assuming a cropping ratio of 50%

corn and 50% soybean, the average yield increase for corn and soybean combined is $67.08 per hectare. Prices for corn and soybean were calculated as 2011-2016 averages reported by Grain Farmers of Ontario (2017).

For the DCF we analyzed the benefits of CTD under three different conditions through a sensitivity analysis (Table 4):

- Average prices for corn and soybean (2011-2016) remain constant for the 20-year lifespan of the CTD structure;
- Average prices for corn and soybean (2011-2016) are 10% higher for the 20-year lifespan of the CTD structure; and
- Average prices for corn and soybean (2011-2016) are 10% lower for the 20-year lifespan of the CTD structure.

Table 4. Yield increase benefits resulting from CTD in corn and soybean crops reported in dollars per hectare

Parameter	Benefit per ha
Corn Yield Increase	$ 83.60
Soybean Yield Increase	$ 50.56
Average Yield Increase (Corn and Soybean combined)	$ 67.08
Sensitivity Analysis - 10% increase in price of corn and soy	$ 73.79
Sensitivity Analysis - 10% decrease in price of corn and soy	$ 60.37

More detail regarding benefit calculations and data sources are provided in the Appendix.

C. Results of the DCF Analyses

DCF analyses were conducted for the three farm scenarios described above and a sensitivity analysis was included for each to account for variation in corn/soybean prices. The net present value (NPV) of the systems is the current value of CTD if a producer were to install a system on their land today, accounting for all benefits and costs accrued over 20 years (using an 8% discount rate). The annualized benefit per ha indicates the value of the CTD system per hectare per year.

Results of the analyses show that in all scenarios where a Manual CTD system is installed, benefits of CTD outweigh the costs. Assuming that corn and soybean prices remain constant over the next 20 years, the annualized benefit of a manual CTD system ranges between $18.67 and $48.53 per hectare (Table 5). In some cases it may make financial sense for producers to adopt automated CTD systems, for example if fewer structures are required over a large area such as in the 14 ha field size scenario, a Basic Automatic system would provide a return of $18.87 per hectare per year assuming corn and soybean prices remain stable. It should be noted that given advancements in remote controlled technology, the cost of these systems may reduce considerably over time and could become financially viable in the future. Tables 6 and 7 outline the results of the sensitivity analysis.

Table 5. Discounted Cash Flow of CTD reported per hectare (average prices 2011 - 2016)

System	Field Size (ha)	Number of Systems (per farm)	NPV per ha (8% d.r.)	Annualized Benefit per ha
Manual	4	28	$183.28	$18.67
	9	13	$408.46	$41.60
	14	8	$476.46	$48.53
Basic Automatic	4	28	$(679.67)	$(69.23)
	9	13	$(9.63)	$(0.98)
	14	8	$185.30	$18.87
Remote Controlled Automatic	4	28	$(3,280.00)	$(334.08)
	9	13	$(1,217.06)	$(123.96)
	14	8	$(624.16)	$(63.57)

Table 6. Discounted Cash Flow of CTD reported per hectare (10% *increase* in average prices 2011 - 2016)

System	Field Size (ha)	Number of Systems (per farm)	NPV per ha (8% d.r.)	Annualized Benefit per ha
Manual	4	28	$249.14	$25.38
	9	13	$474.32	$48.31
	14	8	$542.32	$55.24
Basic Automatic	4	28	$(613.81)	$(62.52)
	9	13	$56.23	$5.73
	14	8	$251.16	$25.58
Remote Controlled Automatic	4	28	$(3,214.14)	$(327.37)
	9	13	$(1,151.20)	$(117.25)
	14	8	$(558.30)	$(56.86)

Table 7. Discounted Cash Flow of CTD reported per hectare (10% *decrease* in average prices 2011 - 2016)

System	Field Size (ha)	Number of Systems (per farm)	NPV per ha (8% d.r.)	Annualized Benefit per ha
Manual	4	28	$117.42	$11.96
	9	13	$342.60	$34.89
	14	8	$410.60	$41.82
Basic Automatic	4	28	$(745.53)	$(75.93)
	9	13	$(75.49)	$(7.69)
	14	8	$119.44	$12.16
Remote Controlled Automatic	4	28	$(3,345.86)	$(340.78)
	9	13	$(1,282.92)	$(130.67)
	14	8	$(690.02)	$(70.28)

A breakeven analysis was conducted for each scenario. Depending on system parameters, a manual CTD system pays for itself between 3 to 11 years after installation (Table 8).

Table 8. Payback period of CTD

System	Field Size (ha)	Payback Period (Years)	Payback Year (installed in fall 2017)
Manual	4	11	2028
	9	4	2021
	14	3	2020
Basic Automatic	4	Investment not recovered	-
	9	Investment not recovered	-
	14	11	2028
Remote Controlled Automatic	4	Investment not recovered	-
	9	Investment not recovered	-
	14	Investment not recovered	-

At this time the costs of the Remote Controlled Automatic system appear to outweigh the benefits. However, The Nature Conservancy (2015) noted that yield increases may increase considerably beyond levels indicated in the current CTD literature if real-time management of drainage water is put into practice on farms. A further increase in yields resulting from Remote Controlled Automatic CTD could make the system viable on some farms.

It is challenging to compare the results of this analysis with other research as parameters can vary widely across locations and system designs. However it is worth noting that several other studies have indicated that CTD systems have increased profitability on the farm (CVision Corporation, 2006; AAFC, 2010; Wossink & Osmond, 2002; Nistor & Lowenberg-DeBoer, 2006). Crabbé et al. (2012) report a benefit cost ratio (BCR) of 2.6 for corn crops and 1.6 for soybean crops as a result of adoption of CTD. Based on parameters described above, we calculated BCRs using an 8% discount rate of:

- 1.4 for a Manual CTD structure installed on 4 ha fields;
- 2.6 for a Manual CTD structure installed on 9 ha fields; and
- 3.6 for a Manual CTD structure installed on 14 ha fields.

V. Public Benefits Resulting from Controlled Tile Drainage

Much of the literature on CTD is focused on the impact of CTD on nutrient and pathogen losses via drainage tiles on fields with CTD systems. It is widely accepted that CTD mitigates losses of nitrate - Nitrogen ($N0_3^-$) and Phosphorus (P) from tile drained fields by reducing the amount of drainage discharge water that exits the tile drainage system during the growing season (Sunohara, Craiovan, Topp, Gottschall, Drury, & Lapen, 2014; Lalonde, Madramootoo, Trenholm, & Broughton, 1996; Skaggs, Fausey, & Evans, 2012; Jaynes, 2012; Frankenberger, et al., 2007). In light of the current regulatory directives to reduce nutrient loads in the Great Lakes and Gulf of Mexico, CTD offers a realistic solution to non-point source nutrient losses resulting from UCTD on farms in Ontario and in the Midwestern United States (Sunohara, et al., 2016; Hein, 2014).

The results of the nine-season CTD study conducted through the WEBs program in eastern Ontario indicated an approximate net reduction in nitrogen losses of 51% nitrate – N and 58% ammonium – N (NH_4^+) in CTD fields compared to UCTD fields. A 66% reduction in total P losses was also observed on CTD fields relative to UCTD fields. The mitigation of nutrient losses was due a change in drainage water flux, which was reduced by an average of 60% in CTD fields (Sunohara, et al., 2016).

A number of studies based in Ontario have researched the impact of CTD on pathogen movement from agricultural fields via tile drains (Wilkes, et al., 2014; Frey, et al., 2013). Results show that CTD can effectively reduce the movement of fecal pathogenic bacteria via drainage water (for example *E. coli* and Enterococci) relative to UCTD (Sunohara, et al., 2016).

Improvement in water quality is considered a public benefit attributed to CTD (Crabbe, Lapen, Clark, Sunohara, & Liu, 2012; CVision Corporation, 2006). Some reports advocate that the public water quality improvement benefits attributed to CTD may justify cost-share incentives to assist producers with the costs of CTD implementation (The Nature Conservancy, 2015).

A. Cost Benefit Analysis Parameters and Assumptions

The purpose of a Cost Benefit Analysis is to understand the true costs and benefits of a project by including:

- The private costs and benefits of a project (i.e. producer financial costs and benefits) as presented in the DCF; and
- The public costs and benefits of a project, which can include environmental costs and benefits.

Environmental costs and benefits are assigned monetary values through a variety of techniques including stated preferences, revealed preferences, and abatement costs and are included in the analysis to present a more comprehensive picture of the true costs and benefits of the project.

In UCTD fields, nutrient export from the field occurs via drainage tiles and ultimately ends up in watercourses. Nutrients, specifically nitrogen (N) and phosphorus (P), can have deleterious impacts on the environment and one technique to value the impact is valuing the cost to remove (i.e. abate) N and P from water through wastewater treatment. When UTCD is retrofitted with CTD, there is an associated reduction in nutrient export via tile drains (Sunohara, et al., 2016) and thus an avoided abatement cost. For the purposes of this project, we consider the abatement costs associated with nutrient export via drainage water associated with UCTD. We calculated change (reduction) in nutrient export via drainage water (kg/ha/growing season) as a result of

CTD retrofits. The change in nutrient export was given a monetary value to include this avoided environmental cost in the CBA.[6]

We used benefit transfer to assign a monetary value to the reduction in nutrient export via drainage water. Olewiler (2004) estimates costs of removing N and P from water at Vancouver's (British Columbia) primary and secondary water treatment plants. We used these figures to estimate the benefits of CTD compared to UCTD (Table 9). The benefits are described as the avoided water treatment costs resulting from the reduction in nutrient export via drainage water associated with CTD retrofits.

Table 9. Cost of nutrient removal from water[a]

	Low ($ per kg)	High ($ per kg)	Average ($ per kg)	Source
Cost of Nitrogen Removal via Wastewater Treatment	$3.73	$10.44	$7.09	(Olewiler, 2004)
Cost of Phosphorus Removal via Wastewater Treatment	$26.83	$75.15	$50.99	(Olewiler, 2004)

a. All values have been adjusted for inflation (2016 CAN $).

The average cost of phosphorus removal used for this project is comparable, but more conservative than the $65.65/kg value used in Belcher et al. (2001), which looked at the municipal wastewater treatment of phosphorus in the Grand River Watershed in Ontario. However, the range of values presented by Belcher et al. (2001) is significantly larger ($6.57/kg to $656.51/kg)[7].

Using the abatement costs for N and P reported by Olewiler (2004) and the change in nutrient export between UCTD and CTD reported by Sunohara et al. (2016) we estimated the value of nutrient export reduction. The values are based on the growing season, which is defined as May to October, or 184 days. Note that any benefit associated with reduction in nutrient transport that falls outside of the growing season was not captured in this analysis.

We determined that the average economic value of nutrient export reduction associated with CTD for Total N is $24.32/ha/growing season and Total P is $1.32/ha/growing season. That is, retrofitting an existing UCTD system with CTD effectively reduced the abatement cost associated with UCTD by $25.65/ha/growing season for Total N and Total P combined (Table 10).

[6] Note that due to constraints this analysis does not value other non-market benefits such as recreation benefits due to improved water quality associated with CTD.
[7] Values have been adjusted for inflation (2016 CAN $).

Table 10. Environmental benefits associated with adoption of CTD

	Change in Nutrient Export associated with CTD (kg/ha/day)[a]	Change in Nutrient Export associated with CTD (kg/ha per growing season)[b]	Low Valuation of Reduction in Nutrient Export per Growing Season ($/ha)	High Valuation of Reduction in Nutrient Export per Growing Season ($/ha)	Average Valuation of Reduction in Nutrient Export per Growing Season ($/ha)
Change in Nitrate-N (NO_3^-)	-0.0185	-3.40	$12.70	$35.54	$24.12
Change in Ammonium N (NH_4^+)	-0.000158	-0.03	$0.11	$0.30	$0.21
Change in Total N	-0.018658	-3.43	$12.81	$35.84	**$24.32**
Change in Total P	-0.000141	-0.03	$0.70	$1.95	**$1.32**
Total Change in Nutrient Export over growing season	-0.018799	-3.46	$13.50	$37.79	**$25.65**

a. Note that negative values indicates a decrease.
b. Note that the growing season was defined as May to October (184 days).

B. Results of the Cost Benefit Analysis

We conducted a CBA to consider both the private and public costs and benefits of CTD. We used the avoided abatement cost figure of $25.65/ha/growing season as the public economic benefit associated with CTD as well as the private costs and benefits described above in the DCF analyses. All NPVs and annualized values increased as a result of the added benefit (Tables 11, 12 and 13). The Basic Automatic 9 ha field scenario NPV under average crop prices and 10% price decrease became positive as a result of the inclusion of this benefit. The NPV for the Remote Controlled Automatic 14 ha scenario is also close to $0 but remains negative.

Table 11. Cost benefit analysis of CTD reported per hectare (average prices 2011-2016)

System	Field Size (ha)	Number of Systems	NPV (8% d.r.)	Annualized Benefit
Manual	4	28	$431.40	$43.94
Manual	9	13	$658.27	$67.05
Manual	14	8	$726.79	$74.03
Basic Automatic	4	28	$(440.60)	$(44.88)
Basic Automatic	9	13	$235.83	$24.02
Basic Automatic	14	8	$432.62	$44.06
Remote Controlled Automatic	4	28	$(3065.74)	$(312.25)
Remote Controlled Automatic	9	13	$(983.12)	$(100.13)
Remote Controlled Automatic	14	8	$(384.56)	$(39.17)

Table 12. Cost benefit analysis of CTD reported per hectare (increase in average prices 2011-2016)

System	Field Size (ha)	Number of Systems	NPV (8% d.r.)	Annualized Benefit
Manual	4	28	$497.26	$50.65
Manual	9	13	$724.13	$73.75
Manual	14	8	$792.65	$80.73
Basic Automatic	4	28	$(374.74)	$(38.17)
Basic Automatic	9	13	$301.69	$30.73
Basic Automatic	14	8	$498.48	$50.77
Remote Controlled Automatic	4	28	$(2999.88)	$(305.54)
Remote Controlled Automatic	9	13	$(917.26)	$(93.42)
Remote Controlled Automatic	14	8	$(318.70)	$(32.46)

Table 13. Cost benefit analysis of CTD reported per hectare (decrease in average prices 2011-2016)

System	Field Size (ha)	Number of Systems	NPV (8% d.r.)	Annualized Benefit
Manual	4	28	$365.54	$37.23
Manual	9	13	$592.41	$60.34
Manual	14	8	$660.93	$67.32
Basic Automatic	4	28	$(506.46)	$(51.58)
Basic Automatic	9	13	$169.97	$17.31
Basic Automatic	14	8	$366.76	$37.35
Remote Controlled Automatic	4	28	$(3131.60)	$(318.96)
Remote Controlled Automatic	9	13	$(1048.98)	$(106.84)
Remote Controlled Automatic	14	8	$(450.42)	$(45.88)

Some non-market benefits associated with CTD were not valued in this analysis and these results should be considered with that in mind. If it were possible to include other non-market benefits in the analysis, such as recreational values associated with improved water quality, the results would likely show a greater public benefit as a result of CTD retrofits.

Results of this CBA were based on a specific set of parameters and therefore not easily comparable to other economic analyses reported the literature; however, it is worth noting that several reports consider CTD retrofits on farms to be an overall benefit to the public (Crabbe, Lapen, Clark, Sunohara, & Liu, 2012; CVision Corporation, 2006). For example, a report authored by CVision Corporation (2006) on behalf of the Agricultural Drainage Management Coalition based in the Midwestern United States found benefits of $7.57/acre ($18.70/ha) attributed to water quality improvements in the Gulf of Mexico due to CTD. Skaggs, Fausey & Evans (2012) indicated that when expenses, installation and management were considered, the cost per kilogram of removing nitrate-N was the lowest for CTD versus alternative practices and strategies.

The public benefits associated with CTD retrofits may justify public investment in the form of cost-share incentives to increase adoption of CTD amongst producers in Ontario. For example, if 50% cost-share funding were available to producers to support the initial investment costs of adopting CTD (structure cost and installation), Manual CTD retrofit projects would pay for themselves in 2-5 years versus 3-11 years without cost-share (depending on the individual farm scenario).

VI. Conclusions

Controlled tile drainage is a BMP that can help achieve regulatory water quality targets while also offering agronomic and financial benefits to producers. The level of benefits realized by individual farm operations depends on the CTD system design as well as environmental conditions and production practices. The analyses presented in this report show that for many producers, retrofitting an existing tile drainage system with manual or automatic CTD equipment may offer considerable benefits to corn and soybean growers in the form of yield improvements, stabilization of yields from year-to-year and risk management in drought and flooding situations over a 20 year time period. Public cost-share investments may help to increase adoption amongst producers in Ontario by reducing the payback time on the initial investment for the system for producers or to help make Basic Automatic and Remote Controlled Automatic systems financially viable on farms.

Recommendations for future research to assist in a better understanding of the potential impacts of CTD on farmland in Ontario are to investigate:

- The amount of land suitable for CTD systems in Ontario, given that the technology is best installed on land with a slope <1.0%;
- How yields are impacted by CTD given a variety of soil types, weather and management considerations; and
- The appropriate level of cost-share to incentivize adoption of CTD, given the considerable public benefits offered by the system.

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Appendix

A. Drainage Contractors/Manufacturers Consulted

- Benoit Drainage
- McCutcheon Farm Drainage Ltd.
- Agri-Drain Corporation
- Richmond Ditching Co. Ltd.

Note that one drainage contractor elected to have their name withheld from the report.

B. Description of Costs & Benefits Used in Discounted Cash Flow Analysis

- All costs and benefits were adjusted to real 2016 Canadian Dollars (average 2016 exchange rate $1.00US:$1.33CAN) (Bank of Canada, 2016).
- The number of structures per farm has been rounded up to a whole number since a fraction of the system is not feasible. All calculations were based on the whole numbers presented above. Actual numbers are 27.75 (4 ha design), 12.33 (9 ha design), and 7.93 (14 ha design)
- Installation Costs include:
    - $524.96 per structure including 2 hrs labour plus material
    - Floating fee to bring equipment to site ($1,009.54 per project)
    - Installation cost per structure varies by field size because set floating fee is fixed per project and spread over the number of structures. Thus, as more structures are installed at one project, the installation cost per structure is reduced
- Annual Maintenance costs for the Manual system include:
    - 2 one-hour- visits per year (at $20.19/hour to grease stoplogs and set water level)
    - 1 tube of grease ($12.64)
- Annual Maintenance costs for the Basic Automatic system include:
    - 1 visit per year to program system for the year
    - No maintenance (i.e. greasing of stoplogs required)
- Annual Maintenance costs for the Remote Controlled Automatic System include:
    - No visits for maintenance required
    - Monthly cellular plan fee of $73.85 per structure to enable communication with CTD structure in real time
- All cost parameters were set using information from Crabbé et al. (2012) and through consultation with a variety of drainage contractors

Table 14. Cost data per CTD structure

System	Height (ft)	Diameter (inches)	Number of Systems	Structure Cost	Installation Cost (per system)	Total Structure + Installation Cost (per system)	Annual Maintenance Cost (per system)
Manual	6	6	28	$904.60	$561.02	$1465.61	$52.63
	6	10	13	$1216.34	$602.62	$1818.96	$52.63
	6	12	8	$1469.36	$651.15	$2120.51	$52.63
Basic Automatic	6	8	28	$4670.31	$561.02	$5231.33	$20.19
	6	12	13	$5296.03	$602.62	$5898.65	$20.19
	6	15	8	$5865.49	$651.15	$6516.65	$20.19
Remote Controlled Automatic	6	8	28	$7758.50	$561.02	$8319.51	$886.18
	6	12	13	$8854.16	$602.62	$9456.78	$886.18
	6	15	8	$9893.56	$651.15	$10544.72	$886.18

- Updated corn and soybean prices were calculated using data from the Grain Farmers of Ontario (2017). An average 2011-2016 corn prices presented in real 2016 CAD, adjusted using the farm product price index (Statistics Canada, 2016).

Table 15. Benefit calculations source data

	Value (per ha)	Source
UCTD Corn Yield Average (tonnes per ha)	9.76	Crabbé et al., 2012
UCTD Soybean Yield Average (tonnes per ha)	3.47	Crabbé et al., 2012
Corn Price per tonne (Average 2011-2016 real dollars 2016)	$214.11	Grain Farmers of Ontario, 2017
Soybean Price per tonne (Average 2011-2016 real dollars 2016)	$485.97	Grain Farmers of Ontario, 2017
CTD Corn Yield Increase (%)	4%	Crabbé et al., 2012; Sunohara et al., 2014
CTD Soybean Yield Increase (%)	3%	Crabbé et al., 2012; Sunohara et al., 2014
CTD Corn Yield Increase (tonnes per ha)	10.15	Crabbé et al., 2012
CTD Soybean Yield Increase (tonnes per ha)	3.57	Crabbé et al., 2012
CTD Corn Yield Increase ($ per ha)	$83.60	Crabbé et al., 2012; Grain Farmers of Ontario, 2017
CTD Soybean Yield Increase ($ per ha)	$50.56	Crabbé et al., 2012; Grain Farmers of Ontario, 2017