THE NATURE CONSERVANCY

Real Time-Drainage Water Management in the Great Lakes

Final Report submitted to the Great Lakes Protection Fund

2/18/2015

Prepared by:

The Nature Conservancy

nicholas-h2o

Contents

EXECUTIVE SUMMARY

This report sets out to address two questions as posed by the Great Lakes Protection Fund: 1.) could Real Time-Drain Water Management (RT-DWM) provide meaningful nutrient load reduction to the Great Lakes, and 2.) what are the potential ecological and agronomic benefits associated with RT-DWM implementation. Our modeling, analysis, reviews of the literature, and consultation of experts indicate that RT-DWM can provide meaningful nutrient reductions while also producing agronomic, economic and environmental benefits to farmers and watershed communities. To understand the efficacy of RT-DWM we first examined the impacts and benefits of Drain Water Management (DWM).

Geographies best suited for Drain Water Management, due to the prevalence of flat topography and hydric soils, are located in the Lake Huron and Lake Erie basins. DWM implemented in these basins is estimated to reduce annual nutrient loads by 2.8% to 14.2% for Lake Huron and 2.9% to 15.1% for Lake Erie under the scenarios modeled in this report. Nutrient reductions from tile flow will likely play an important role in meeting nutrient reduction goals as previous studies have found that the increased implementation of practices that primarily address surface flow will not be sufficient. It is also estimated that nutrient reductions from DWM have the potential to improve ecological outcomes, as estimated across four watersheds in the Saginaw Bay watershed.

A strong economic argument can be made to individual farmers and landowners for DWM, with an anticipated payback period of 5 to 10 years under prevailing commodity prices. For a demonstrative field, the annual cost of DWM is estimated at $17.60 per acre over a ten year period at a 4% cost of capital. Under typical environments, DWM is estimated to provide a yield benefit of 2-3%. By allowing for more aggressive and precise in-field water levels, it would be anticipated that RT-DWM could augment yield performance even further. A 3% improved corn yield at an initial 175 bushels per acre and a corn price of $4.00 per bushel, while holding other production costs constant, would provide additional annual revenue of $21 per acre.

The additional equipment and management costs of RT-DWM do not make it an economical investment for individual operators at this point in time. Over a 10 year payback period, RT-DWM is estimated to cost $58.51 to $144.41 per acre per year. However, RT-DWM is estimated to provide cost-effective nutrient reductions when considered as part of a watershed scale nutrient reduction strategy, in the range of $69.81 to $826.22 per pound of P retained. These costs compare favorably to estimates of P reductions needed to meet Total Maximum Daily Loads established for watersheds in the Great Lakes and Chesapeake Bay.

An important advantage of RT-DWM is that it can help producers overcome perceived risks of DWM, further eliminating barriers of adoption, and scale the management of drainage water for coordinated environmental benefits at a watershed scale. Management and implementation strategies for RT-DWM will require a coordinated watershed approach, potentially creating new business opportunities for drainage, agriculture and conservation professionals. In order to realize these watershed level benefits, it is anticipated that some form of public investment in RT-DWM will be needed. Given the need to address nutrient loading from tile drain flows, and the relative cost-effectiveness of watershed scale nutrient reductions from RT-DWM, such a public investment may be justified. To further advance the feasibility of RT-DWM it will be important to better understand producer attitudes towards adoption of DWM and RT-DWM, and to better quantify the relative flow and nutrient reduction benefits of RT-DWM to DWM at a drainage or HUC 12 watershed scale.

INTRODUCTION

Drainage is necessary for agricultural production in many areas in the Great Lakes Basin. Without drainage some of the region's richest agricultural areas could not be farmed. Drainage typically consists of shallow perforated pipes linked into networks on farms with outlets into streams or drainage ditches. Some of the densest tile drainage in the U.S. is in the Saginaw Bay and western Lake Erie Watersheds.

While necessary for agriculture, drainage networks often are a major source of nutrient loadings to the Great Lakes. Nitrate (N) and soluble reactive phosphorus (SRP) are the leading nutrients of concern for eutrophication of streams, lakes, and parts of the Great Lakes, such as Green Bay, Saginaw Bay, and Maumee Bay. Both N and SRP are readily transmitted from farm to stream via drainage tile networks (see review papers by Skaggs et al. 2012 and King et al. 2014).

Drainage water management (DWM) uses control structures to reduce flow from tile drainage networks. DWM has been shown to significantly reduce flow from tiles, thereby reducing export of N and SRP (Skaggs et al. 2012 and Williams et al. 2015).Typically, for conventional DWM, the control structure shuts off or reduces flow from tiles during times when farm equipment does not need to be the field and during non-growing months, retaining the water in the tiles and fields. In the southern Great Lakes region, DWM is used to reduce flow from tiles typically during the months of November through March, though annual and local variability exists. During the growing season, control structures are opened to allow tiles to drain for agricultural production.

In contrast, active management of drainage water also can be done during the growing season, typically April through October in the southern Great Lakes region. During these months, if soils are too wet, control structures open to allow free drainage from tiles. When soils are too dry, control structures are closed to allow water to rise in soils. A properly operated system would allow enough water to remain in the soil to assist crop yield, but not enough to damage cops. The amount of water that can be actively managed may be substantial. For instance, about 45 percent of streamflow occurs during the growing season (April through October) in streams tributary to Saginaw Bay and Western Lake Erie.

The Nature Conservancy (TNC) led a group that proposed to the Great Lakes Protection Fund (GLPF) that DWM could be enhanced through real-time control of flow from tiles, especially during the growing season. The proposed real-time drainage water management system (RT-DWM) couples a communication network of automated sensors, drain control structures, and optimization programming that seeks to meet potentially conflicting goals of reducing nutrient export from tiles and maintaining or increasing crop yields; RT-DWM can provide a direct linkage between field and stream conditions. Central to our vision is that the use of RT-DWM for interconnected landscape-scale management of drainage water has the potential to hold more tile water back during the growing season, and assuming nutrient retention rates are similar to those observed for DWM, RT-DWM can therefore produce greater reductions in watershed nutrient loadings. The Great Lakes Ecosystem would benefit from such a reduction in nutrient loading to streams, and likely reduced sediment loading and flooding downstream, including the receiving body of water (for instance, Saginaw Bay or Western Lake Erie). RT-DWM can also be designed to benefit farmers through more precise management of soil moisture and nutrients during the growing season to augment crop yields.

The GLPF requested that, rather than developing and field testing RT-DWM technology, the project team conduct an initial 9-month phase of the project focused on answering two questions. First, if RT-DWM is implemented what would be the potential nutrient load reduction to the Great Lakes? Second, what are the ecological and agronomic goals and value propositions associated with RT-DWM implementation? This report summarizes our project and answers both of these questions.

Note that a significant assumption, in the original proposal and in this report, is that RT-DWM will outperform DWM in flow and nutrient management. Another assumption is that farmers will be motivated to implement RT-DWM. These assumptions have not been tested as a part of this project, but testing these assumptions is a logical next step in the second phase of this project.

A significant part of this project was a workshop held October23, 2014. The project team (Appendix A) presented preliminary findings to 8 experts in DWM and nutrient loading to the Great Lakes (Appendix B). Input from the workshop is incorporated into this project report and the experts were all invited to review a draft of the report.

POTENTIAL NUTRIENT LOAD REDUCTIONS FROM RT-DWM IMPLEMENTATION

Potential load reductions were estimated by answering two questions. Where in the Great Lakes Basin could RT-DWM be implemented? If RT-DWM were implemented at various scales and with various levels of success in reducing nutrient loads, what are potential ranges of nutrient load reductions?

The first question was addressed using GIS to map those areas of the Basin that have land use, soil type, and slope appropriate for DWM. The second question was addressed using information from scientific literature in conjunction with modeling. As with any modeling, assumptions are made that constrain conclusions. The assumptions and their impact are discussed in a separate section in this report.

Where could RT-DWM be implemented?

Three GIS coverages were used to answer this question. The 2006 NLCD (National Land Cover Database), on a 30m grid, was used to determine agricultural land-use areas (NLCD class 81/82) in the Great Lakes Basin (Figure 1). SSURGO data (Soil Survey Geographic database), on a 30m grid, were used to select soil types that are typically artificially drained (Figure 2). These correspond to SSURGO drainage classes 1, 2, and 3 (very poorly drained, poorly drained, and somewhat poorly drained). The intersection of the NLCD and SSURGO data provides a coverage of agricultural land that may be drained by tile. A third coverage, topographic slope, was used to determine which tile-drained land is suitable for DWM. This coverage was developed from a 30m DEM (digital elevation model) where slopes were computed from each point to the eight nearest points and then averaged. Note that land suitable for RT-DWM is assumed to be the same land that is suitable for DWM.

Figure 1 Percentage of each watershed with agricultural land classification.

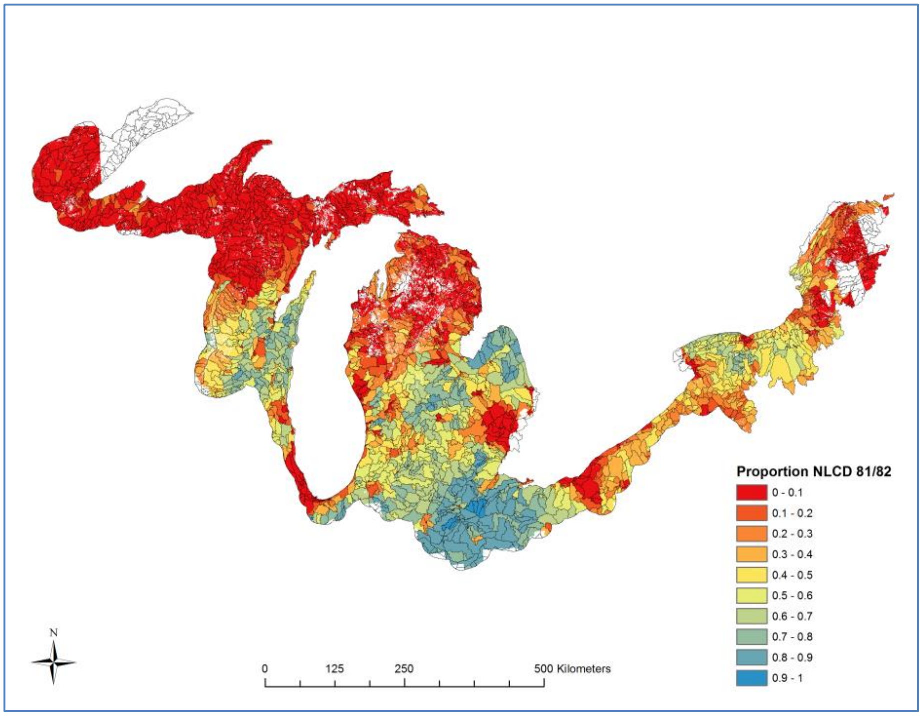


Figure 2 Distribution of SSURGO drainage classifications in the Great Lakes Region.

Drainage classes 1, 2, and 3 require drainage tiles for agricultural production, approximately 45 percent of the U.S. Great Lakes Basin

Typically, DWM is done on slopes of 1 percent or less. However, it can also be applied to slopes greater than 2 percent, although higher slopes have a greater cost due to more control structures. Three scenarios were developed using slopes of 1 (Figure 3), 1.5 (Figure 4), and 2 percent. Note that mapping is done using watersheds from the ERF-1 (Enhanced River Reach File), a USEPA database USGS has used for SPARROW modeling described later in this report. The scale is slightly coarser than HUC-12, approximately the same as a HUC-11.

Figure 3 Percentage of each watershed in the Great Lakes Basin with agricultural land, SSURGO drainage classes 1-3, and topographic slope less than or equal to 1 percent.

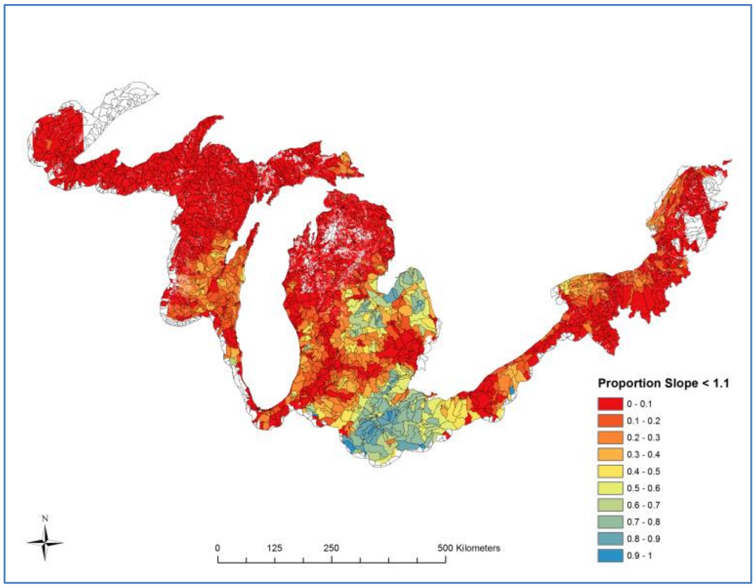
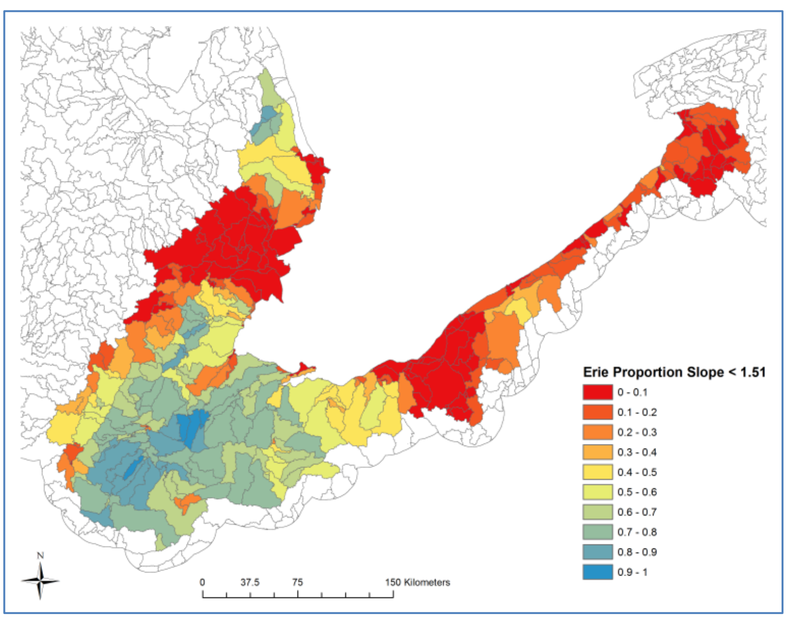


Figure 4 Percentage of each watershed in the Lake Erie Basin with agricultural land, SSURGO drainage classes 1-3, and topographic slope less than or equal to 1.5 percent.



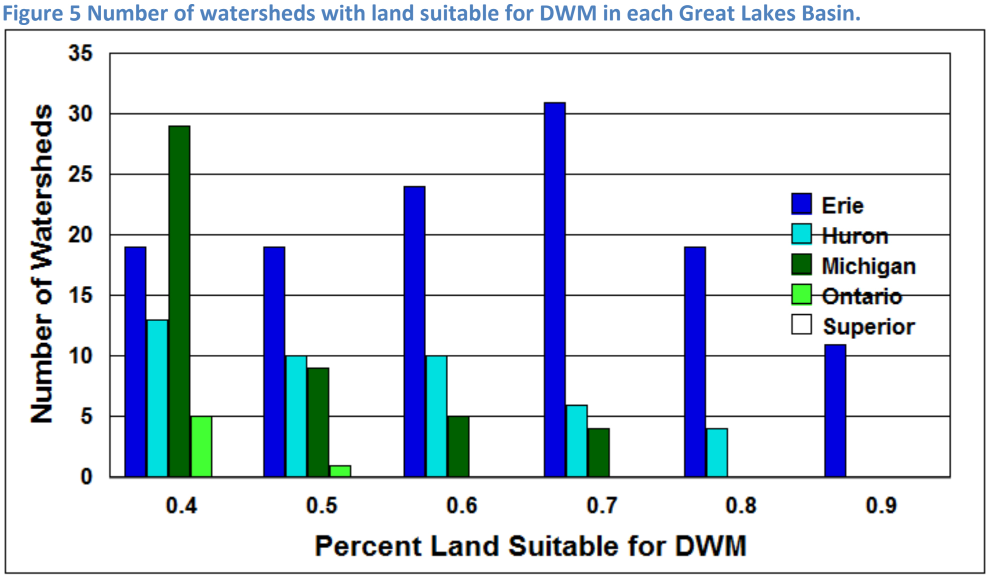
All of the coverages were obtained from USGS. The SSURGO and slope coverages were developed by USGS for another project. Although others have mapped areas that may be tile drained (Sugg, 2007) and land suitable for DWM (NRCS, 2012) for most of the Great Lakes Basin; they either used coarser coverages, did not use the same slope criteria, or did not specify the coverages that were used.

Two key findings emerged from the GIS analysis. First, the amount of land that met the land use, soil type, and slope criteria was essentially the same for all three slope scenarios. Consequently, further work described in this report used the coverage with a slope of 1.5 percent. Second, the areas that meet the criteria for DWM in the Great Lakes Basin are mostly in the Lake Huron and Lake Erie watersheds (Figure 3). ERF-1 watersheds with a high percentage of land suitable for DWM (greater than 50 percent) are almost entirely restricted to the Lake Huron and Lake Erie watersheds (Table 1and Figure 5). Consequently, further work described in this report is restricted to the Lake Huron and Lake Erie watersheds.

Table 1 Percentage of watershed suitable for DWM in each Great Lakes Basin.

Percentage of Land Suitable for DWM					
			# of watersheds		
%	Erie	Huron	Michigan	Ontario	Superior
0-<10	107	155	454	181	296
10-<20	20	24	146	46	0
20-<30	24	11	84	22	1
30-<40	19	13	29	5	0
40-<50	19	10	9	1	0
50-<60	24	10	5	0	0
60-<70	31	6	4	0	0
70-<80	19	4	0	0	0
80-<90	11	0	0	0	0

Figure 5 Number of watersheds with land suitable for DWM in each Great Lakes Basin.



What is the potential nutrient load reduction?

To calculate a percentage reduction in agricultural nutrient load for each ERF-1 watershed, four different percentages need to be calculated.

(1) **DWMland:** The percentage of agricultural land that is suitable for DWM in each watershed (DWMland). DWMland was calculated using the GIS coverage described above and is different for each watershed. The distribution of these percentages for Lake Erie is shown in Table 2. Note that 50 percent of the ERF-1 watersheds in the Lake Erie Basin have 80 to 100 percent of the agricultural land suitable for DWM.

Table 2 Percentage of watershed with agricultural land suitable for DWM in the Lake Erie Basin.

Percent of AgLand suitable for DWM	Number of Watersheds	%
0-<20	27	9
20-<40	43	14
40-<60	41	13
60-<80	47	15
80-<100	159	50

(2) **DWMtile:** The percentage of the agricultural nutrient load that is delivered to a stream via tiles, rather than overland (DWMtile). DWMtile was estimated based upon scientific literature. For the scenarios, DWMtile was assumed to be the same in all watersheds.

(3) **DWMinstalled:** The percentage of DWMland where RT-DWM is implemented (DWMinstalled). RT-DWM will only be implemented in a percentage of all of the land on which it could be implemented, depending on the business case for RT-DWM. DWMinstalled was selected for a feasible range and, for the scenarios, was assumed to be the same in all watersheds.

(4) **DWMload:** The percent that the nutrient load will be reduced by implementing RT-DWM (DWMload). DWMload was estimated based upon scientific literature associated with DWM and was biased toward higher reductions, following the assumption that RT-DWM will outperform DWM. For the scenarios, DWMload was assumed to be the same in all watersheds.

Thus the percentage reduction in agricultural nutrient load for each ERF-1 watershed is:

DWMland x DWMtile x DWMinstalled x DWMload.

Again, in the scenarios, only DWMland differs among watersheds. So for a watershed where DWMland is 90 percent, DWMtile is 30 percent, DWMinstalled is 25 percent, and DWMload is 50 percent, the percent load reduction is:

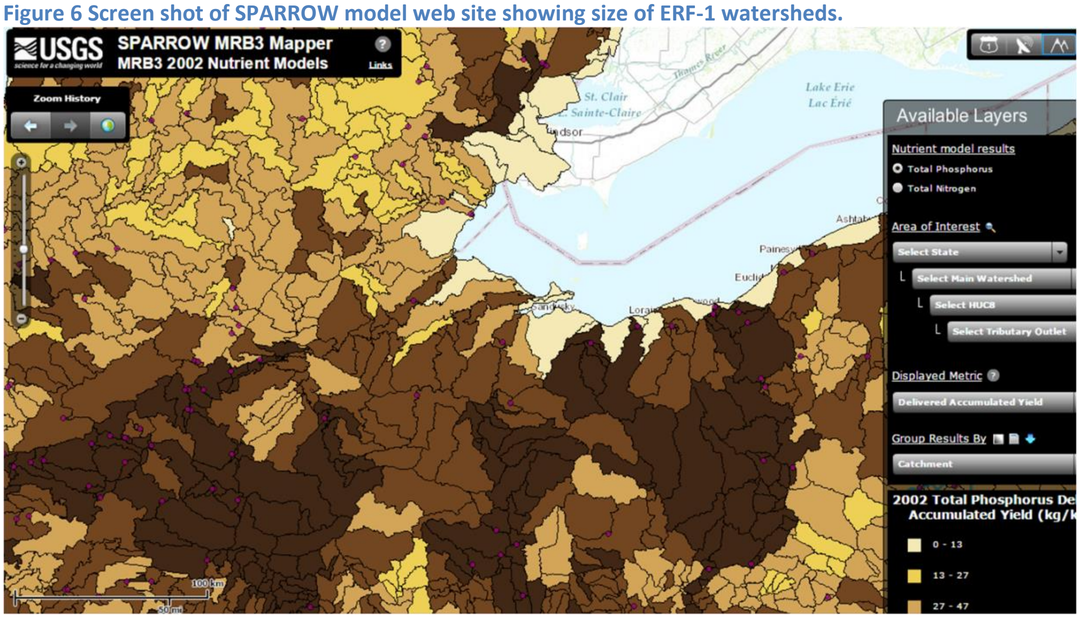
$0.9 \times 0.3 \times 0.25 \times 0.5 = 0.033$, or a 3.3 percent load reduction.

Baseline Loads and the SPARROW Model

To calculate the effect of RT-DWM on agricultural nutrient loads to the Great Lakes, one must have an estimate of nutrient loads (baseline loads) against which to apply a percent load reduction. Results from Robertson and Saad (2011) were used for baseline loads for each ERF-1 watershed. Robertson and Saad used the USGS SPARROW (SPAtially Reference Regression on Watershed attributes) model to calculate these loads. Nutrient inputs are described by Sadd et al. (2011). SPARROW was calibrated principally to data from USEPA STORET and USGS NWIS databases, using data from 1970-2006 and then annual loads were normalized to 2002 (Robertson and Saad 2011 and Saad et al. 2011).

In terms of spatial scale the SPARROW model is fairly detailed, providing nutrient loads to each stream in the ERF-1 (Figure 6). Furthermore, SPARROW tracks nutrient loading by input source. Thus, loadings from agricultural sources (manure and fertilizer) are distinguished from other loadings. In terms of temporal scale, the SPARROW model is less detailed, representing long-term average annual loadings. For the purposes of this project, the temporal scale is not limiting, if we assume that the spatial distribution of annual nutrient loading is not highly variable over time.

Figure 6 Screen shot of SPARROW model web site showing size of ERF-1 watersheds.



While SPARROW provides nutrient loading information at a scale that is needed by this project, there is a significant drawback to using SPARROW output as baseline loads. For Great Lakes nutrient issues, the primary concern is soluble reactive phosphorus (SRP), and the secondary concern is nitrate ($NO3^-$). SPARROW calculates loads for total phosphorus (P) and total nitrogen (N). Furthermore, this project is concerned with nutrient loading via tiles. SPARROW has calibrated coefficients associated with transport of P and N in tiled landscapes and they have opposite signs, meaning SPARROW calculates that tiles enhance N transport, but not P transport. Clearly this has significant implications regarding running and interpreting scenarios. These are discussed in the section on assumptions and limitations later in this report.

Load reduction scenarios

Spreadsheets containing SPARROW input and output were obtained from USGS (Robertson, written communication, 2014) and modified so as to easily run load reduction scenarios. There are 3 variables (DWMtile, DWMinstalled, and DWMload) that can be changed at user discretion and values for these are taken either from the literature (DWMtile and DWMload) or arbitrarily selected (DWMinstalled). Thus any number of scenarios could be run. We selected two. Scenario 1 should be considered optimistic with respect to load reductions and Scenario 2, less so. Scenarios were run only for N, since the transport mechanisms for the P model do not translate to SRP. However, the N model scenarios do have implications for SRP and these are discussed. Rationale for the values selected for both scenarios are discussed in the next section on assumptions and limitations.

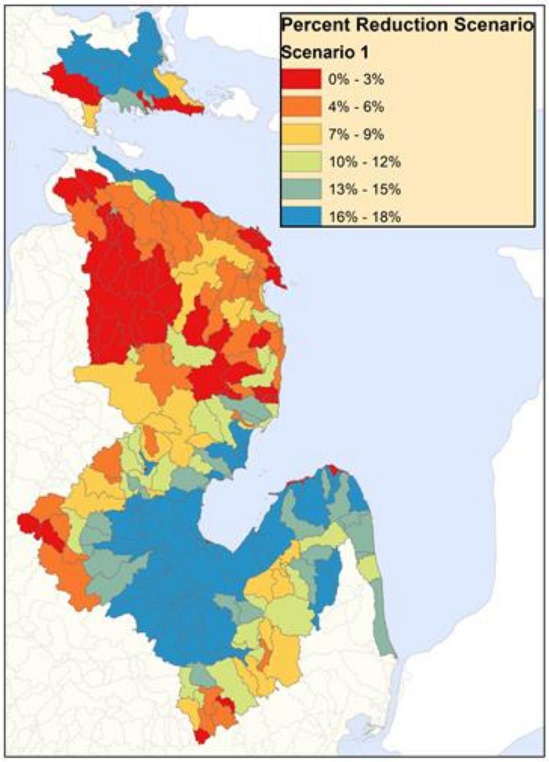
Scenario 1 assumes that: 50 percent of the N export from the watershed is via tile, as opposed to overland (DWMtile =0.5); 60 percent of the land suitable for DWM has RT-DWM implemented in it (DWMinstalled = 0.6); and RT-DWM implementation reduces N loads from tile by 60 percent (DWMload = 0.6). Thus in each watershed, the percent load reduction is DWMland x 0.18 (0.5 x 0.6 x 0.6). If all of the agricultural land in a watershed is suitable for DWM (DWMland = 1.0), then the load from that watershed is reduced by 18 percent in this scenario. If only half of the agricultural land in a watershed is suitable for DWM (DWMland = 0.5), then the load from that watershed is reduced by 9 percent in this scenario.

Scenario 2 assumes that: 35 percent of the N export from the watershed is via tile, as opposed to overland (DWMtile =0.35); 25 percent of the land suitable for DWM has RT-DWM implemented in it (DWMinstalled = 0.25); and RT-DWM implementation reduces N loads from tile by 40 percent (DWMload = 0.4). Thus in each watershed, the percent load reduction is DWMland x 0.035. If all of the agricultural land in a watershed is suitable for DWM (DWMland = 1.0), then the load from that watershed is reduced by 3.5 percent in this scenario. If only half of the agricultural land in a watershed is suitable for DWM (DWMland = 0.5), then the load from that watershed is reduced by 1.75 percent in this scenario.

Scenario 1 results for Lake Huron are shown in Figure 8 and for Lake Erie in Figure 8. The percent N load reduction for the watersheds tributary to Lake Huron is 14.2 percent and for Lake Erie 15.1 percent. These are relatively close to the maximum percent reduction that could occur under this scenario (18 percent), indicating that much of the agricultural land in these watershed is suitable for DWM, averaging out to about 84 percent for Lake Erie (18 x .84 = 15.1). Without DWM, annual agricultural N loading to Lake Huron is 12,670 tonnes. In scenario 1, the N loading to Lake Huron is reduced to 10,890 tonnes. Without DWM, annual agricultural N loading to Lake Erie is 66,270 tonnes. In scenario 1, the N loading to Lake Erie is reduced to 56,240 tonnes. Table 3 shows the distribution of load reductions for Lake Erie watersheds.

Table 3 Distribution of percent load reductions for N in the Lake Erie Basin.

Percent Reduction	Number of Watersheds
0-<3	63
3-<6	41
6-<9	36
9-<12	21
12-<15	58
15-18	144



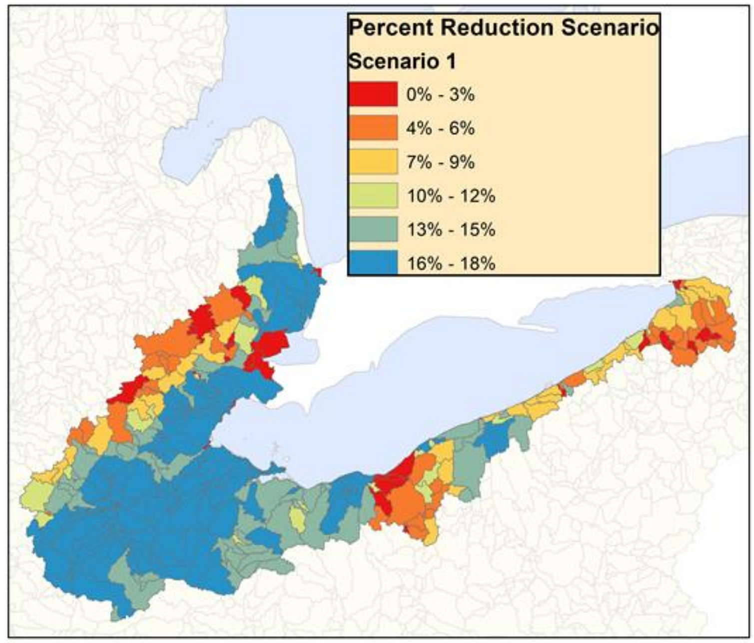
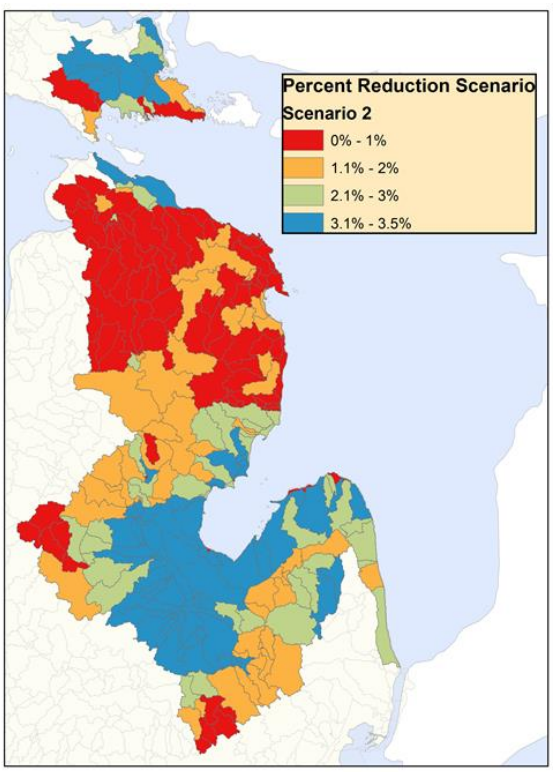


Figure 7 Distribution of percent load reductions in N for Scenario 1 in Lake Erie Basin. (above)

Figure 8 Distribution of percent load reductions in N for Scenario 1 in Lake Huron Basin. (left)

Scenario 2 results for Lake Huron are shown in Figure 9 and for Lake Erie in Figure 10. The percent N load reduction for the watersheds tributary to Lake Huron is 2.8 percent and for Lake Erie 2.9 percent. Without DWM, annual agricultural N loading to Lake Huron is 12,670 tonnes. In scenario 2, the N loading to Lake Huron is reduced to 12,350 tonnes. Without DWM, annual agricultural N loading to Lake Erie is 66,270 tonnes. In scenario 2, the N loading to Lake Erie is reduced to 64,320 tonnes.



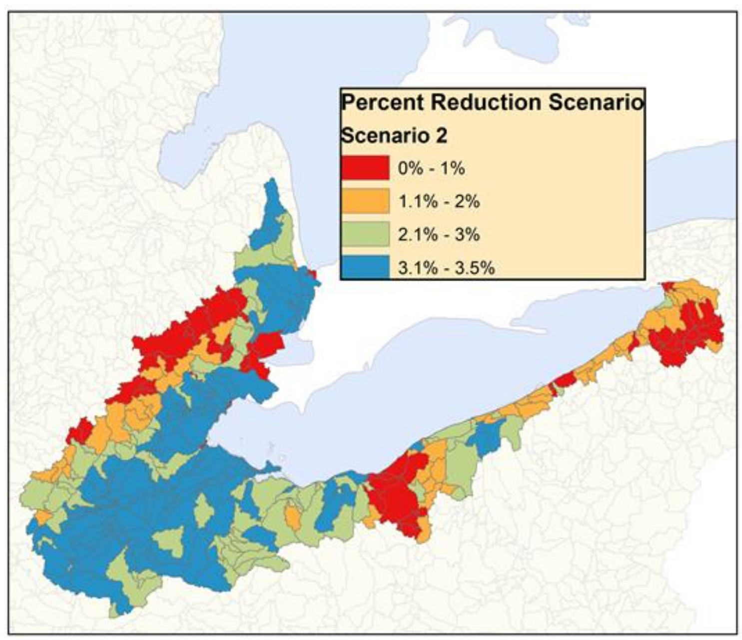


Figure 9 Distribution of percent load reductions in N for Scenario 2 in Lake Erie Basin. (above)

Figure 10 Distribution of percent load reductions in N for Scenario 2 in Lake Huron Basin. (left)

The scenarios above are for N, whereas this project focuses on NO3- and SRP. We assume that NO3- reductions from tiles are essentially the same as those for N. This is discussed in the next section. Although we do not have baseline loads for SRP, we assume that reductions in SRP scale similarly spatially to those for N. That is, watersheds with large N reductions also have large SRP reductions; watersheds with small N reductions also have small SRP reductions. Again, this assumption is discussed in the next section.

Assumptions and Limitations

Several assumptions are explicitly mentioned in the previous sections and there are others which are implicit. This section discusses each of these assumptions, in the order they appear earlier in the report, and their implications with respect to load reduction scenarios.

(1) Land suitable for RT-DWM is the same land that is suitable for DWM

Areas suitable for DWM management are also suitable for RT-DWM. However, land that is suitable for DWM is not necessarily tiled. Some may not be drained at all, or may be drained by other methods. Furthermore, tiles need to arranged and spaced in specific ways to accommodate DWM, so implementing RT-DWM may require retrofitting existing drainage. Thus, the amount of land calculated to be suitable for RT-DWM likely is overestimated.

(2) DWMtile—Percentage of agricultural nutrient load in tile vs runoff (and same in all watersheds)

In a recent review paper, King et al. (2014a) state that "discharge from tile drains constitutes the majority of stream flow in many agricultural watersheds across the midwestern United States and Canada" and cite studies where tile flow was 42, 51, 60 and 86 percent of annual streamflow. Numerous field studies show that P and N in tiles can be equal to or greater than the amount in runoff, including two recent studies in the Lake Erie Basin showing that P export in tiles was nearly half the P export for the watershed (King et al. 2014b and Smith et al. 2014). Thus, assuming that DWMtile is 50 percent and 35 percent in the two scenarios is reasonable.

There are many factors, however, that affect the percentage of watershed flow and nutrient load coming from tiles, including: climate (including seasonality), soil type and characteristics, watershed hydrology, cropping practices, tile spacing and depth, and P sorption capacity of the soil. Thus, the assumption that DWMtile is the same for all watersheds in the two scenarios is weak. Given the scope of the project, however, accounting for the factors that cause spatial variability in DWMtile was not possible.

An additional issue is that DWM may change the ratio of tile flow to runoff. Specifically, DWM could result in an increase in surface runoff and a smaller percentage of nutrient transport via tiles, thus leading to a smaller DWMtile.

(3) DWMinstalled—Same in every watershed

An even distribution of RT-DWM installation across the Lake Erie and Lake Huron watersheds is unrealistic, but was assumed for simplicity in running scenarios and because there is no information to suggest how else to distribute RT-DWM.

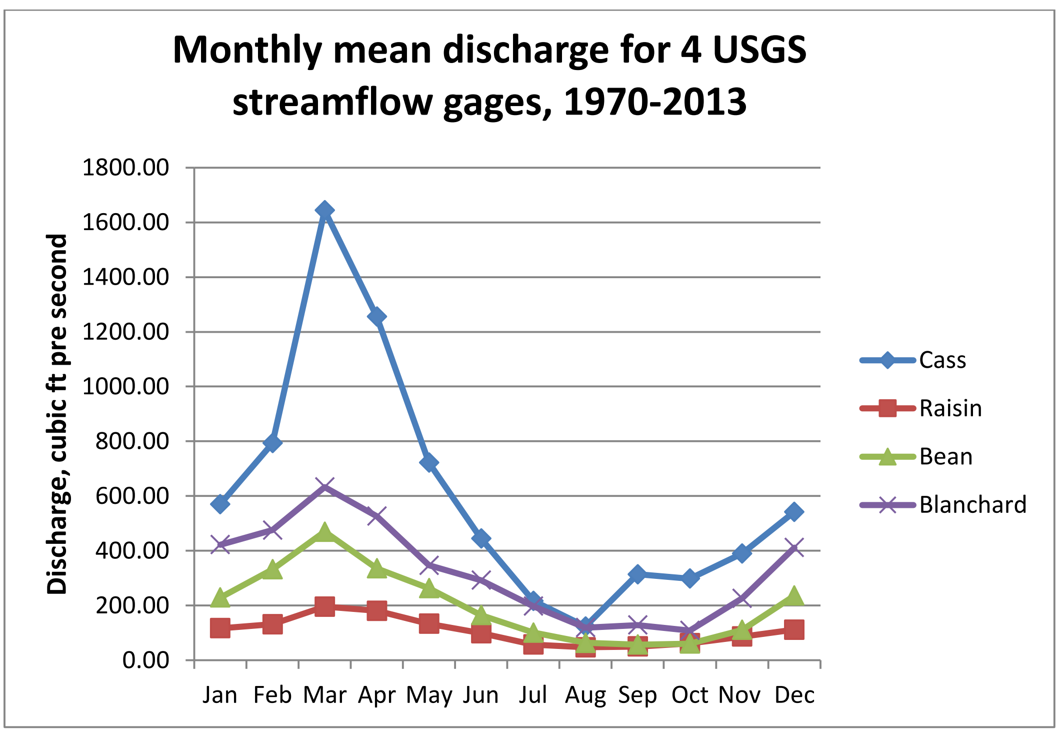
(4) DWMload—Percent load reduction due to RT-DWM implementation (and same in all watersheds)

There is a fair amount of literature regarding the effects of DWM on NO3- export from tiles and watersheds. A recent review paper (Skaggs et al. 2012) summarized about 20 field experiments. NO3- tile load reductions due to DWM ranged from 18-80 percent, with an average of 49 percent and a median of 50 percent. NO3- tile load reductions were essentially due to tile flow reductions (flow reductions in these studies ranged from 16 to 89 percent). Our study assumes that RT-DWM outperforms DWM, so the assumptions of a 40 percent and 60 percent reduction in NO3- load in the two scenarios is reasonable.

There is little literature regarding the effects of DWM on SRP export from tiles and watersheds. Several studies (as cited in King et al. 2014a) found that SRP concentrations in tiles increase with DWM (although some of these also used subirrigation), and/or the fraction of P that is DRP in tile drainage increased. P concentration increases, however, did not necessarily result in higher loads, due to flow reductions using DWM. There is limited information on how biogeochemical reactions and other factors affect the concentration of DRP in DWM systems. King et al. (2014a) concluded that "in general, dissolved P concentrations from DWM are greater than dissolved concentrations from FD [free drainage]; however, due to the reduction in discharge resulting from DWM, P loads are less when compared with FD." The Ohio Lake Erie Phosphorus Task Force (2013), the section on drainage management stated "Management and structural practices designed to reduce or minimize the drainage water volume from the outlet will likewise reduce the DRP [SRP] load in the tile flow proportionally."

RT-DWM would provide load reductions greater than those associated with DWM. RT-DWM would be controlling flow and nutrient loadings during the growing season, when conventional DWM typically allows free drainage. About 45 percent of the annual streamflow in Saginaw Bay and western Lake Erie watersheds occurs during the growing season (Figure 11). Thus there is significant potential for RT-DWM to manage tile drainage during the growing season, both to reduce nutrient loading and improve crop yield.

Figure 11 Monthly mean discharge for 4 USGS streamflow gages, 1970-2013



(5) Spatial distribution and magnitude of annual nutrient loading is represented by SPARROW loads
In addition to issues identified earlier with the use of SPARROW output for baseline loads, there are two additional potential issues. The first issue is that SPARROW uses annual loads that are normalized to 2002. As noted in figure 3-8 of the Ohio Lake Erie Phosphorus Task Force Phase II report (2013), DRP concentrations from the Maumee River have an increasing trend since the late 1990s, roughly tripling since that time. The second issue, identified by Richards et al. (2012) in a discussion of the SPARROW model for the Great Lakes, is potential underestimation of agricultural inputs for P and a low bias in P loads, in particular for highly monitored streams in the western Lake Erie Basin.

Both of these issues could be significant. Both, however, would indicate that load reductions due to DWM would be higher in western Lake Erie than those in our scenarios, because the baseline loads would be higher.

(6) NO3- reductions from DWM are the same as N reductions
Skaggs and others (2012), in their review of the field studies mentioned above, noted that N losses in the studies were almost entirely NO3-.

(7) Reductions in SRP scale similarly to those for N
As noted in the discussion of scenarios, SPARROW does not provide baseline loads for DRP, but we assumed that reductions in SRP loads would scale similarly to reductions in N loads. This is really two assumptions: (1) that percentage load reductions for SRP and NO3- due to DWM are similar (see assumption 4); and (2) that loadings of SRP and NO3- scale similarly spatially. To address the second assumption, we compared ranked SPARROW agricultural P and N inputs and loads for Lake Erie HUC-8 watersheds (Figure 12 and 12). The results indicate that the assumption of similar scaling for DRP and NO3- is reasonable.

Figure 12 Ranked agricultural inputs of N vs P for Lake Erie HUC-8 watersheds.

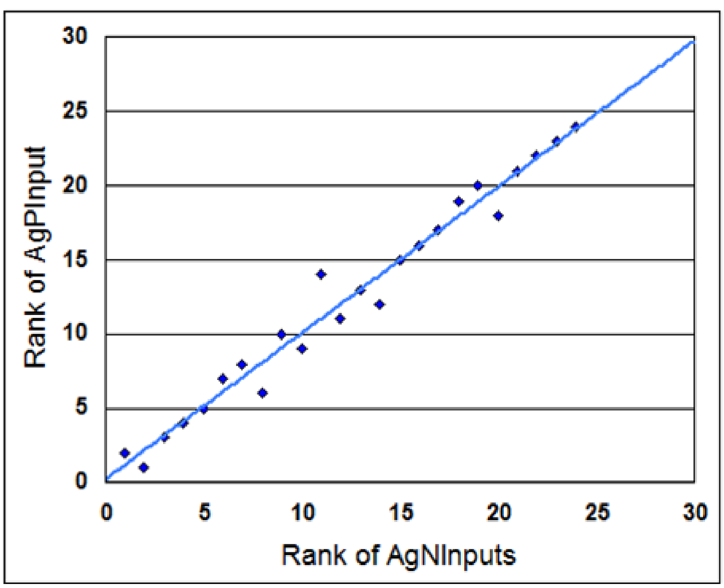
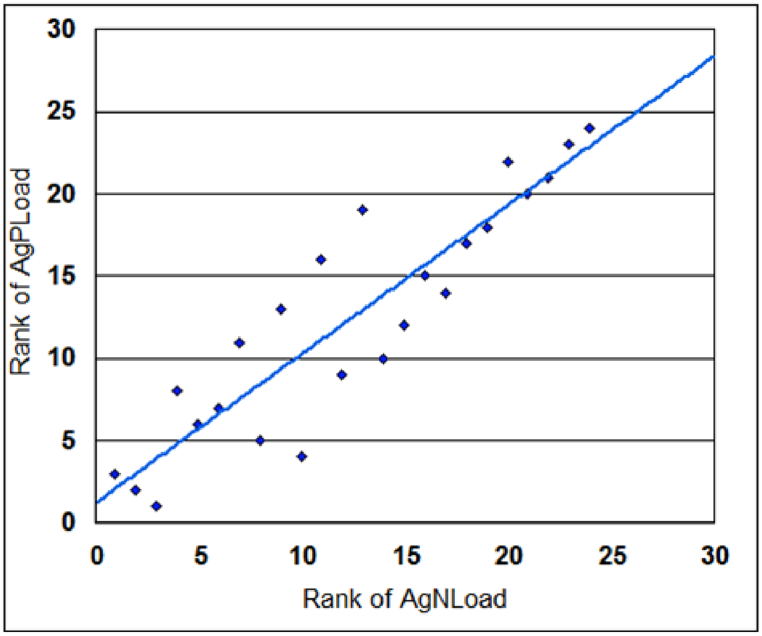


Figure 13 Ranked loads of N vs P from agricultural sources for Lake Erie HUC-8 watersheds.



Goals

Real Time Drain Water Management is a new, and yet unproven, technology. Before additional investments in this technology are made, it's important to understand how RT-DWM can address water quality and agronomic objectives. The goal for RT-DWM is to move the needle, both for water quality and for farm performance, while not producing any negative or unintended impacts. In order to provide context for the estimated nutrient reductions from DWM or RT-DWM implementation presented in the previous section, we explore how such reductions would contribute to watershed nutrient and aquatic ecosystem targets in Lake Erie and Lake Huron watersheds as well as contribute to agronomic performance objectives.

Environmental Goals

The primary environmental goals for RT-DWM considered in this report are those relating to water quality. Specifically, the role that RT-DWM and other drainage practices can contribute to the 40 percent reduction of nutrient loading target set for Lake Erie by the Ohio Lake Erie Phosphorus task force (2013) and aquatic ecosystem targets established for the Saginaw Bay watershed. In both watersheds, and towards both targets, RT-DWM can provide meaningful nutrient reductions towards the achievement of these environmental goals.

Water Quality Goals for Western Lake Erie

Conservation practices that only address surface flow will not be sufficient to meet nutrient reduction targets. In intensively-tiled watersheds of the Great Lakes region, 47% of streamflow and similar levels of P transport have been attributed to flow from tile drainage (Smith et al. 2014, King et al. 2014b). There is growing recognition that prevailing Best Management Practices (BMP) and/or levels of conservation funding are insufficient to significantly reduce nutrient loads (Bosch et al. 2013; Kim et al. 2014; Lemke et al. 2011; Smith et al. 2014). Modelling the effect of prevailing BMPs (No-till, cover crops, filter strips) in six Lake Erie watersheds, Bosch et al. (2013) found that even when BMPs were implemented jointly and at high concentrations, reductions of nutrient loads were not significant. Focusing on the Maumee Watershed, implementing No-Till, cover crops and filter strips on 100% of agricultural land, P and SRP loads were estimated to be reduced by 29.6% and 25.8%, respectively. At a more realistic 25% BMP implementation scenario, P and SRP loads were estimated to be reduced by a more modest 2.3% and 6.2%, with targeting BMPs to highest sources providing an overall reduction in SRP of 10% in the Maumee. Employing an econometric statistical model to the Maumee and Sandusky watersheds, Kim et al. (2014) similarly found that prevailing BMPs and funding levels were incapable of producing nutrient loading reductions on the order of 40%. A sizable 25% tax on P inputs was estimated to contribute an 8% reduction in SRP loading in the two modeled watersheds, the Maumee and Sandusky (Kim et al. 2014). By looking at watershed loading from 1975 to 2011, previously installed DWM would be captured in these estimates, although the implementation levels are very limited and are assumed to play a very minor role in the resulting loading estimates. The dataset would not capture the potential effect of DWM relative to more prevalent practices, e.g. reduced till, cover crops, CRP and filter strips.

The role of DWM to help meet watershed goals was underscored in a paired watershed study in Illinois' Mackinaw River watershed, where after achieving BMP implementation targets in the treatment watershed, no significant differences of suspended solids, P, SRP, or NO3- concentrations were observed after 7 years of stream monitoring (Lemke et al. 2011). The BMPs promoted and implemented in the treatment watershed targeted surface flow (stream buffers and reduced tillage practices), only later determining that NO3- loads were primarily occurring through subsurface flow from tile drainage (Lemke et al. 2011). The authors called for additional conservation practices that intercept and retain tile-drained runoff such as DWM and constructed wetlands.

Aquatic Ecosystem Goals for Saginaw Bay Watershed

To provide perspective on how drain water management may contribute to ecological outcomes, we evaluated improvements in biological integrity (Index of Biotic Integrity or IBI) potential of stream fish communities, as a result of DWM, in four watersheds in Saginaw Bay. We used the spatially explicit proportional reductions in N and P loadings due to DWM implementation, and applied those to SWAT modeled water quality results for the four watersheds (Nejadhashemi et al. 2011; Sowa et al. 2013). We then applied the changes in water quality to relationships between water quality and fish community potential (as established in Sowa et al. 2011, 2013) to evaluate improvements due to DWM. Note that potential improvement in IBI are specifically related to the contribution of nutrients as limiting factors (Sowa et al. 2012, 2013), but other factors (e.g. instream habitat) may also be limiting IBI potential and will need to be addressed through other conservation measures.

For these evaluations we compared fish biological integrity potential for three scenarios; current conditions and with DWM implemented in 25% and 50% of the row crop acres that are feasible for the practice. Improvements in fish IBI potential as a result of DWM are a function of reductions in P and N. Analyses were performed at subwatershed scales for improved information for implementation.

We found that many subwatersheds within the four watersheds experienced fish IBI improvements (Figure 14 and Figure 15). Several subwatersheds become no longer limiting to IBI (most limiting water quality or flow variable no longer constrains IBI) as a result of 25% or 50% DWM implementation (Figure 14). The greatest amount of improvement was generally seen in the Pigeon-Pinnebog Watershed, however some Shiawassee and Cass subwatersheds experienced substantial improvements (Figure 15).

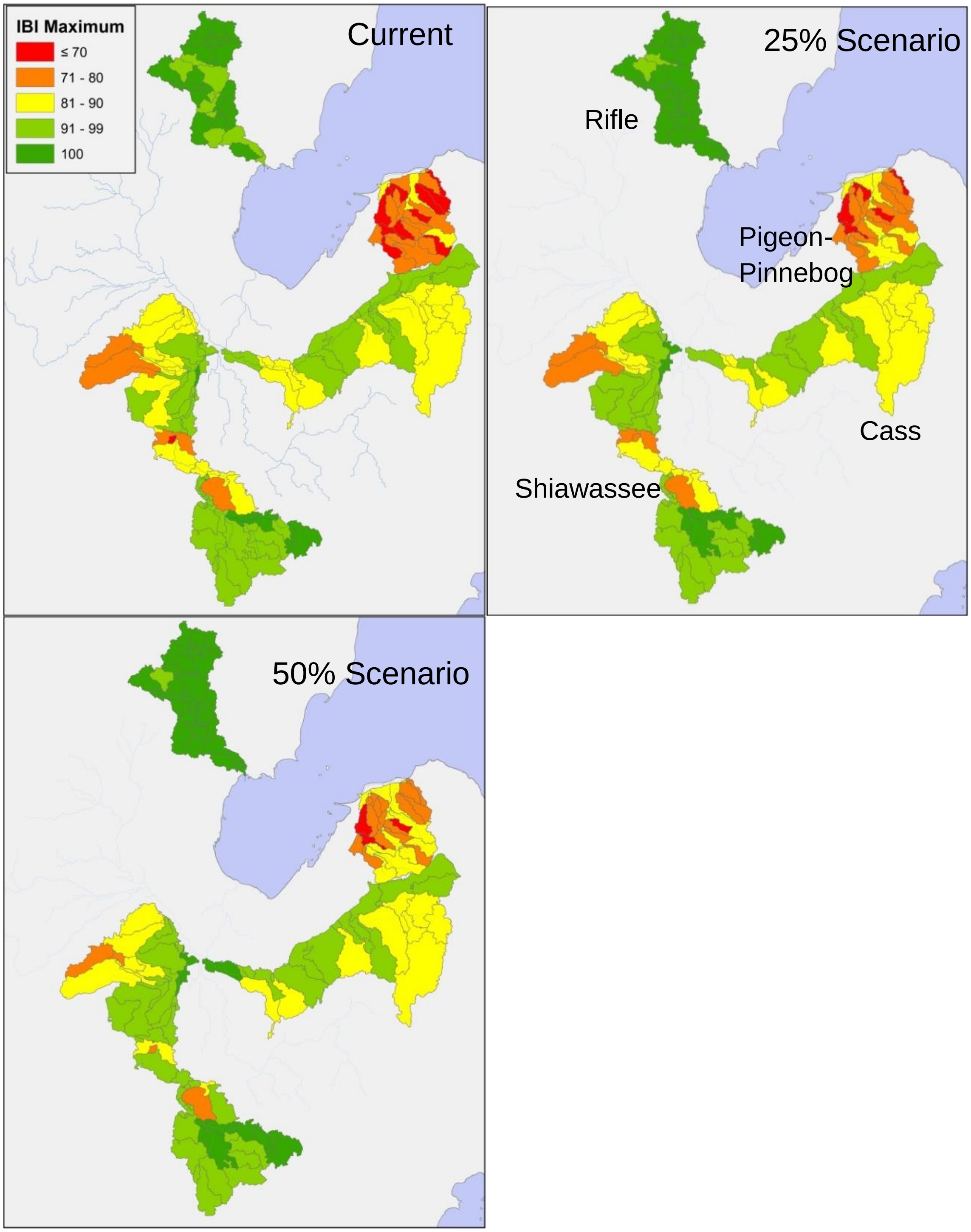


Figure 14. Percent maximum attainable fish Index of Biotic Integrity (IBI) score based on the most limiting water quality or flow variable for each subbasin across the four priority watersheds for current conditions, and with drain water management implemented in 25% and 50% of the row crop acres that are feasible for the practice. Subbasins in dark green are not limited by water quality or flow variables, while subbasins in orange or red are extremely limited.

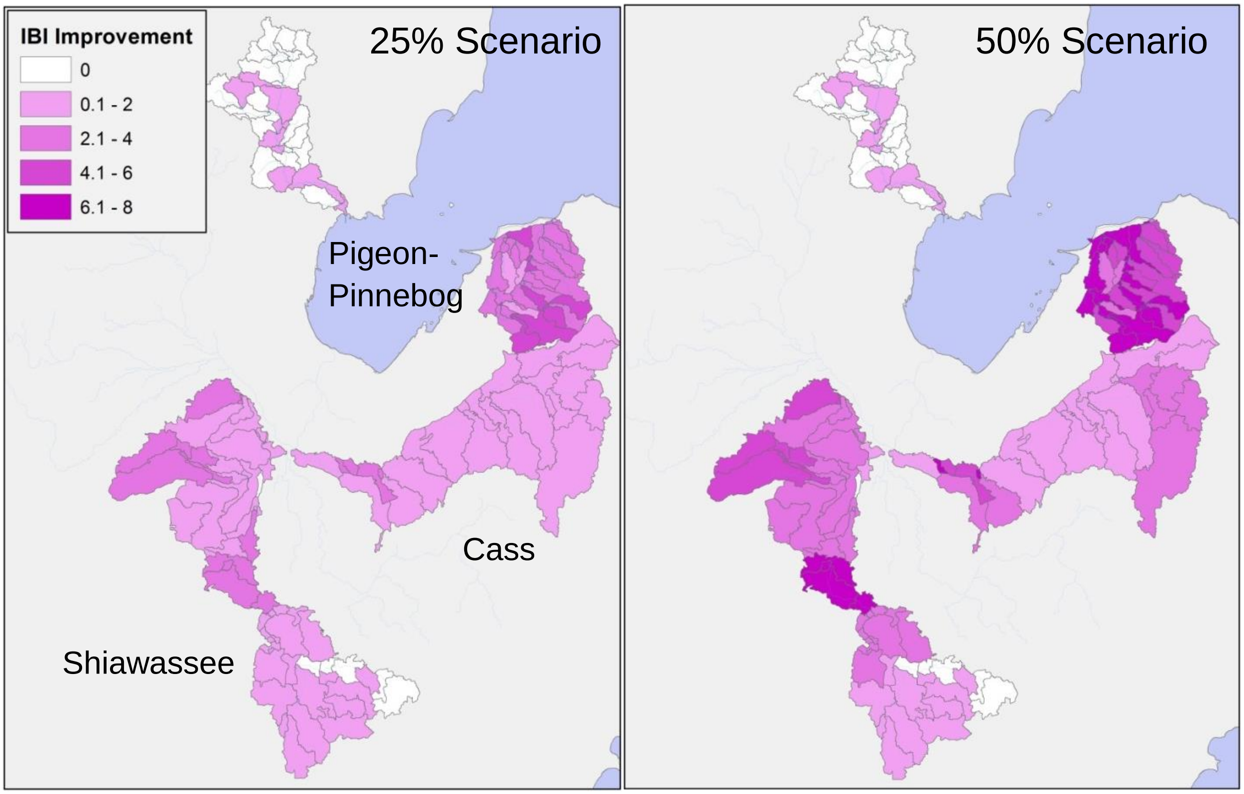


Figure 15 Change (increase) in the percent maximum attainable IBI score based on the most limiting water quality or flow variable for each subbasin across the four priority watersheds for A) 25% and B) 50% of the feasible row crop acres in drain water management. Subbasins with darker purple colors experienced greater improvement in IBI scores.

We also evaluated how well these improvements contributed toward target subwatershed goals for fish IBIs that TNC and partners recently established for three of these four watersheds (Figure 16). These goals are based on achieving IBI potential of 90 in the Shiawassee and Cass Watersheds and 80 in the Pigeon-Pinnebog Watershed and are the basis for a multi-partner, $10M USDA Regional Conservation Partnership Program project that TNC is co-leading with the Michigan Agri-Business Association. The DWM scenarios would result in goal attainment for numerous subwatersheds throughout the study area, and the vast majority of subwatersheds attain progress toward the goal of at least 25% (Figure 16). It should be noted that the water quality improvements needed to attain goals may be modest and that attainment of 80 and 90% IBI goals does not mean attainment of non-limiting conditions (100% IBI). Nonetheless, DWM can produce required water quality improvements for goal attainment. At similar implementation rates, RT-DWM should, at a minimum provide equal IBI improvement and goal attainment benefits, if not greater assuming additional nutrient reduction benefits from RT-DWM.

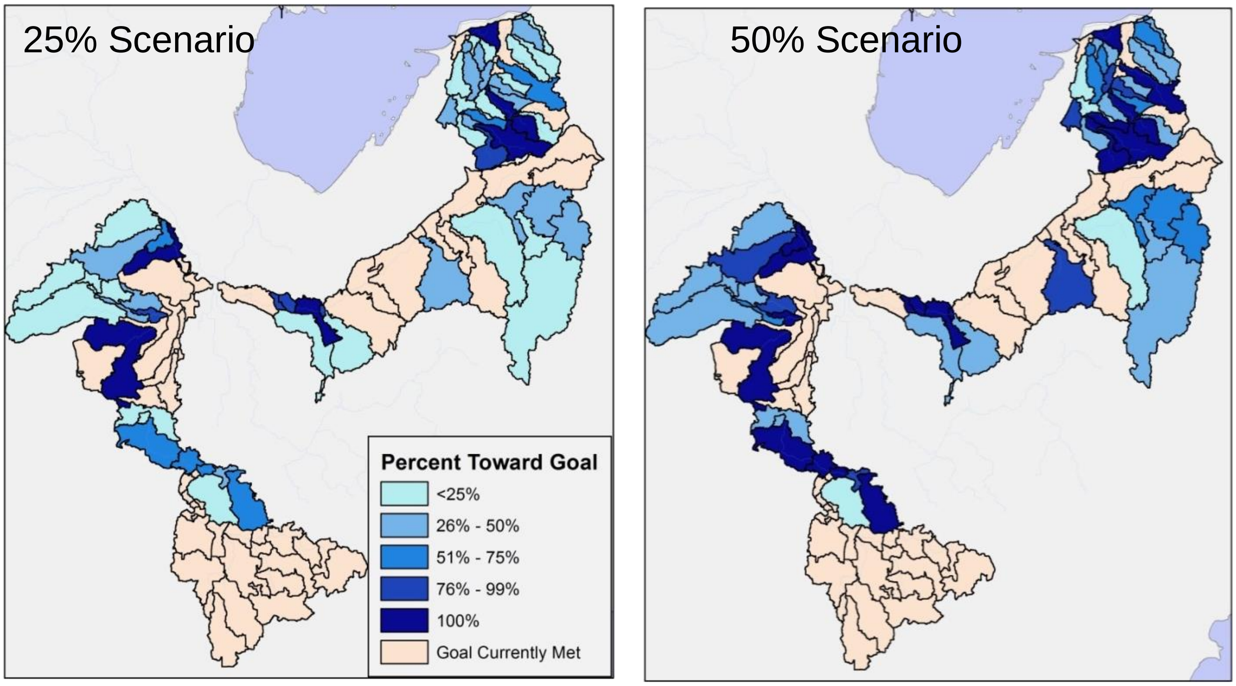


Figure 16. Progress toward target goals established based on relationships between water quality and fish IBI potential drain water management implemented in 25% and 50% of the row crop acres that are feasible for the practice. Goals were based on achieving IBI potential of 90 in the Shiawassee and Cass Watersheds and 80 in the Pigeon-Pinnebog Watershed.

No adverse ecological impacts- GHGs.

In addition to providing biological benefits, it should also be the goal of new conservation practices to not produce unintended negative ecological impacts. Potential negative ecological impacts that DWM and RT-DWM could produce are increased Greenhouse Gas emissions (GHG). The retention of water in-field has the potential to create anoxic conditions, transforming NO3 and NH4 to gaseous forms of N such as N_2O, a potent greenhouse gas. A field trial in eastern Ontario on silt loam soils with in-situ GHG measurements reported no treatment difference from DWM on N_2O emissions relative to free flow managed fields over four years of observations (Nangia et al. 2013). Measurements were only collected during the growing season and further empirical modeling did estimate higher N_2O emissions from DWM. Where increased emissions due to DWM do occur, emissions could be partially offset by increased biomass production, potentially making DWM a source for carbon sequestration (Nangia et al. 2013). The ultimate fate of nitrogen controlled in drains however may not be different than the same nitrogen transported into a waterway, where there is the potential for indirect N_2O emissions from nitrate leaching, the magnitude of which is uncertain (Blann et al. 2009). RT-DWM could theoretically reduce the likelihood of denitrification events that produce N_2O, as the system-wide control of drainage should optimize soil moisture, potentially reducing the chance of excess saturation that would facilitate denitrification.

Agronomic Goals

The overall agronomic goal of RT-DWM is to provide a positive return on investment for the installation of this technology within a reasonable time frame, i.e. 5 to 20 years. A positive return can be realized through increased yields, reduced costs (inputs, labor, etc.), and/or the creation of new revenue streams whereby the net return per acre is increased. Hedging instruments and buying and selling strategies can help producers manage price volatility of both inputs and crops sold, and although RT-DWM could potentially extend growing seasons or someday benefit contracting requirements, the benefits of RT-DWM are primarily realized through on-farm management actions that maximize yield relative to minimizing input costs. These benefits are described below with a full discussion of the economic returns discussed in the Value Proposition section.

Yield-Goal

Crop yield is a widely understood and tracked metric for on-farm agronomic performance. DWM is generally assumed to improve crop yields by the extension of the growing season and increasing soil moisture during periods of drought stress (King et al. 2014b, Frankenberger et al. 2006). The magnitude of yield benefits, as reported in the literature, is variable. Potential factors that could affect yield response to DWM include weather conditions and drainage system design and management intensity (Allerhand, Klang and Keiser 2013). Measuring and controlling for all potential variables and their interactions in field studies is difficult, so studies have reported a wide range of yield impacts from DWM. Precipitation and water management are obvious factors impacting crop yield. When precipitation levels meet plant needs, or do not occur after drain gates are raised, DWM likely has little to no impact on yield; whereas growing seasons with variable and prolonged wet and dry periods are likely to see maximal yield effects from DWM (Allerhand, Klang and Keiser 2013).

An extensive multi-year, multi-state, multi-location study led by the Agricultural Drain Management Coalition confirmed the difficulty of controlling for these factors. This study included four paired field evaluations in each of five states (MN, IA, IL, OH, IN), comparing controlled and uncontrolled drainage while holding other management variables constant for corn and soybeans from 2006 to 2009. Yield effects from DWM of an 11% decrease to a 13% increase were reported with the overall conclusion that not enough information or uniformly collected yield data were available to determine a yield impact (ADMC 2012). As reported by Ghane et al. (2012), numerous other studies have found no, or a non-statistically significant yield impact from Controlled Drain relative to Free Flow (NW Ohio Fausey et al. 2005, Ontario Drury et al. 2009). Delbecq et al. 2012 (Indiana) and Cicek et al.2010 (Ontario) reported a non-statistically significant yield benefit.

Studies that have systematically controlled for climate and other production factors have reported a statistically significant yield benefit for DWM (Ghane et al. 2012). In northwest Ohio, Ghane et al. (2012) observed a DWM yield effect of a 2-3% increase for corn and soybeans relative to Free Flow systems over multiple growing season environments. Yield improvements were observed in years both above and below mean regional precipitation levels (2008 to 2011). DWM on average provided a 3.3%, 3.1%, and 2.1% greater yield for corn, popcorn and soybean, respectively, relative to the Free Flow management (Ghane et al. 2012). Within the studied drainage areas, yield impacts were greater than the whole field averages, with localized yield effects greater than 6% for corn and 3.5% for Soybeans (Ghane et al. 2012). A study from Ontario using remotely sensed vegetation indexes similarly observed a non-statistically significant yield increase from DWM, averaging 2.3% for corn and 5.0% or better for soybeans over the extent of an experimental watershed (Cicek et al. 2010). Ultimately, given the variability of soils, climates, management practices and operating conditions, responses to DWM will be variable, requiring localized knowledge and management to optimally address resource and operation concerns.

What is a realistic yield goal for fields managed with RT-DWM? Based on expert opinion obtained during the October workshop, yield goals should be greater than dry land but perhaps less than irrigated yield goals. Based on the above reviewed literature, a realistic yield-goal for DWM should be in the order of

3% greater than Free Flow yield, although greater yield increases may be realized under certain conditions. A yield benefit of 2-4% has been identified as the threshold to provide a net positive economic return relative to Free Flow management (Nistor and Lowenberg-DeBoer 2007). Delbecq found that yield effects varied with intensity of drain management, with better yield requiring more intensive management (2010). RT-DWM, therefore, could be expected to provide optimal yield benefits from DWM and may provide average yields greater than 2-3%.

Ghane et al. (2012) did not find a statistically significant yield stabilization effect of DWM relative to Free Flow, although conclude that a larger sample size than that of the study would be needed to for a more accurate assessment of a yield stabilization effect. Cicek et al. did find a yield stabilizing effect from controlled drainage in Ontario as 89% of estimated yields had a lower standard deviation from controlled drainage relative to uncontrolled drainage (2010). Additional research is needed to determine whether DWM can provide a yield stabilization effect, and if so, to what extent.

Other Agronomic and Economic Goals

Yield alone does not determine the economic viability of an operation, as other production costs and revenue streams affect an operation's net return. A prominent goal of RT-DWM relative to DWM for the producer is the potential to lower management commitments for DWM by automating the management of water-levels. The full labor and management impacts of RT-DWM are further discussed under Value Proposition.

VALUE PROPOSITION

The potential of RT-DWM to address water quality and agronomic goals will never be realized unless it provides direct value to the potential users and beneficiaries of such technology. Broadly, there are two potential user groups of RT-DWM: the farmer or landowner (and potential investors) and collective downstream watershed users. Benefits to farmers from RT-DWM could be broadly classified as agronomic, characterized as providing a realized private economic benefit to the landowner or farmer. The benefits to the collective downstream users, or society at large, are characterized as ecosystem services, and although the private landowners and farmers also receive these benefits as well, these benefits are publically available. Potential downstream users include the County and public drain entities responsible for maintaining public drains in which in-field tiles flow, downstream communities and municipalities exposed to flooding or nutrient treatment costs, agribusinesses, land improvement companies, and broadly, regional economies.

Value Proposition to Farmers, Land Managers and Land Owners

The economic returns of DWM and RT-DWM are assessed in this section, looking at installation and management costs over 5, 10 and 20 year time periods, as well as potential for increased returns due to improved yields. Other potential benefits to farm operators and landowners are assessed, including implications on inputs, availability of cost-share for implementation of DWM, and the viability of novel revenue streams.

Economic Return

A primary value of RT-DWM to farmers, land managers and land owners would be the ability to generate a positive economic return from adoption of this management system. The economic return from DWM and RT-DWM will depend on numerous factors, importantly the size of the field benefiting from DWM (the larger the area, the more acres that fixed costs can be spread across). Not all tiled fields may be suitable for DWM or may require reinstalling or retrofitting existing tile to be compatible with effective DWM. These retrofitting costs (purchase of tile, installation and labor) can be significant.

Results from a partial budget analysis for DWM and RT-DWM are presented below in Table 4 (see **Error! Reference source not found.** for further budget details). The additional capabilities of RT-DWM require additional equipment and management, which result in higher overall costs relative to DWM. Additional costs for DWM relative to Free Flow are the equipment and installation costs as well as ongoing drain water management (estimated at the rate of Natural Resource Conservation Service cost share rate for drain water management). The equipment needed for DWM is the box unit, stop logs to control water levels, couplers to connect the box to tile lines, and a valve to prevent undesired backflow into field tile. Additional costs for RT-DWM considered in this analysis include equipment to source solar power, an actuator to provide motorized management of stop logs, a modem to send and receive management data, and remote control capabilities. Additional RT-DWM costs for communications services (wireless internet), data management, and sensors are also considered. Labor and installation costs are assumed to be similar for DWM and RT-DWM, primarily for on-site excavation and construction.

The kind and amount of sensors needed for RT-DWM will depend on the water management objectives and scale of implementation. In the examples considered below, an in-stream nitrate sensor is considered as in-stream nutrient concentrations are a common water quality management objective in Great Lakes watersheds. A nitrate sensor is used as there are at present no commercially available phosphorus sensors. An instream nitrate sensor may not be necessary for RT-DWM. Depending on the scale of implementation, instream monitoring may already be performed by USGS or other entities, which could be utilized to inform RT-DWM. Further, as DWM directly manages flow, and not nutrients, in-field moisture sensors and/or within DWM unit water gauges may provide information most relevant to RT-DWM. A range of RT-DWM scenarios, with and without sensor costs, are provided for comparison.

Table 4

Assumptions					
Fields per Nitrate Sensor	**20**				
Acres per DWM Unit	**20**				
P Load per Acre (lbs per acre)	**0.75**				
Nutrient Retention with DWM	**50%**				
Nutrient Retention of Conventional DWM vs RT-DWM	**80%**				
P Reductions_RTDWM (lbs per acre)	0.38				
P Reductions_Conventional DWM (lbs per acre)	0.30				
Capital Cost	4.00%				
Per Acre Costs					
	Annualized Cost per Acre			**NPV of Costs per Acre**	
	5	**10**	**20**	**NPV 2%**	**NPV 7%**
RT-DWM_All Costs	**$206.56**	**$144.54**	**$114.13**	**$1,728.27**	**$1,302.97**
RT-DWM_No Sensors	**$156.21**	**$116.91**	**$97.64**	$1,508.54	$1,093.51
RT-DWM_No Sensors & 50% cost reduction	**$78.16**	**$58.51**	**$48.87**	$754.32	$546.80
DWM	**$25.60**	**$17.16**	**$13.03**	**$194.45**	**$150.91**

Not surprisingly, given the additional costs of RT-DWM, even under the lower cost scenarios RT-DWM costs more per acre when annualized over 5, 10, or 20 year periods and as an initial Net Present Value relative to DWM (Table 4). The per-acre cost of RT-DWM is sensitive to the number of acres managed per drainage unit (more acres, lower per acre cost), as well as the number of fields per nitrate sensor.

For example, while holding other costs and factors constant, increasing the number of treated fields per nitrate sensor from 5 to 20 and the acres treated per drainage unit from 20 to 40, the annualized per acre cost over 10 years of RT-DWM is reduced from $176.59 per acre to $72.32 per acre. However, under realistic assumptions, and even considering sizable future cost reductions in RT-DWM technology and excluding the costs of sensors, the per-acre costs of RT-DWM remain noticeably more than DWM. It should be noted that using the average cost and sizing information is performed for a relative finding at a watershed scale. Individual sites will have a wider range of variability.

In consideration of economic returns from DWM for conventional corn and soybean yields, current commodity prices, and assuming no increase in other production costs, the yield benefit of DWM provides an increase in per acre annual returns sufficient to cover the installation and maintenance costs of DWM over a 5 to 10 year period. The period of time to pay off the investment of DWM will vary depending on realized benefits in a given year. During years where precipitation is adequate for crop needs there may be no benefit of DWM expected over Free Flowing drainage systems. At higher commodity prices and higher yields, the revenue increase is even greater, requiring an even shorter time period to repay installation costs. The magnitude of the return benefit is dependent on initial yield, commodity prices and the yield benefit of DWM; a range of these variables are presented in Table 5 to demonstrate the range of potential returns. Assuming that RT-DWM can provide an additional yield benefit beyond conventional DWM, e.g. 2%, the additional return per acre is still not sufficient to cover the additional costs of RT-DWM technology. Additional revenue streams or subsidies would be needed to offset the full cost of RT-DWM deployment. These opportunities and potential beneficiaries are discussed in the following sections.

Table 5

Increased Revenue from DWM Yield Benefits				
		Corn		Soybeans
Average Yield (bu/acre)	170	**175**	180	38
Yield benefit per acre (percentage)	2.0%	**3.0%**	5.0%	3.0%
Price per bushel	$3.25	**$4.00**	$5.00	$10.00
Increase in Annual Per Acre Return	**$11.05**	**$21.00**	**$45.00**	**$11.40**

Impact on Other Production Costs

Nutrient Input Costs- The fate of nutrients retained in-field remains an area of future research. Presuming that retained nutrients are available for future crops, a soil sampling based nutrient management plan would capture these nutrient credits in subsequent years, hypothetically providing a reduction in future nutrient needs and potential cost savings. At $0.50 per pound of N, a 5% nutrient retention benefit at 180 lbs of applied N per acre would create a potential future cost-savings of an undiscounted $4.75 per acre, representing a less than 3% reduction in fertilizer costs. Such a cost reduction may seem attractive, however annual variability of fertilizer prices are considerably greater. For example, from 1995 to 2013, the year-to-year change in Anhydrous Ammonia and Diammonium Phosphate (DAP) costs, as measured in dollars per material short ton, averaged 17% (ERS 2013). At the 180 lbs N per acre and an initial $0.50 per pound of N, a 17% change in annual fertilizer prices would result in a difference of $18 per acre.

Seed and Drying Costs- If yield targets are adjusted to reflect or account for improved yields, farmers could respond by increasing seed density rates and nutrient application rates, representing an increase in input costs. Precision agriculture can help producers identify optimal seeding rates. It is presumed that RT-DWM will help producers obtain additional yield while holding seeding and nutrient application rates constant, and if not, net returns from additional yield would offset additional input costs. Other affected management costs could potentially include the drying costs of additional harvested grain, but again, would be offset by a higher net return.

Crop Insurance- The potential for RT-DWM to increase yields, mitigate against flood or drought related crop losses and potentially stabilize yields over time lends itself well as a risk mitigation practice. Farmers rely on crop insurance as an important part of their risk mitigation strategy. Practices that can reduce risk, especially those that can be easily verified such as use of certain seed genetics, may be eligible for a premium reduction (Mine et al. 2014). Given the difficulty of providing the necessary field data to support such programs (Mine et al. 2014) and the relatively modest cost of crop insurance premiums for most operations, e.g. $33 per acre for rotation corn (Purdue 2014), it is not anticipated that a crop insurance premium reduction benefit would accrue to farmers in the foreseeable future, although this remains an area for future research.

Subsurface Irrigation: The soil moisture benefits of DWM can be further enhanced through a subsurface irrigation system, where water is pumped into the drainage unit and flow reversed into the tile. A water source, such as a constructed wetland or reservoir, is needed to supply the water for such a system. If the reservoir is storing and treating water removed from the field, retained nutrients can be reapplied to the field, providing additional nutrient saving benefits. Relative to surface, or center pivot irrigation, such a system may be more cost-effective.

Potential for Cost-Share or Financing Assistance for Drain Water Management Units

Across the Great Lakes states, cost-share assistance from the United States Department of Agriculture Natural Resource Conservation Service (NRCS) is available through the Environmental Quality Incentives Program, or EQIP. DWM related EQIP practices include the development of a Drain Water Management Plan (NRCS practice code CAP 130), performance of Drain Water Management (554), and the purchase of a Structure for Water Control (587). Funding amounts per practice potentially vary by state and by funding year. For reference, in FY 2015, Michigan NRCS will provide cost-share at the following rates: $1,940.07 to $2,355.63 for CAP 130, depending on whether there is an existing tile map; $1,411.74 per unit for 587; and $7.01/acre for 554 (MI NRCS 2015). Payment rates may be higher for socially disadvantaged, beginning, or limited resource farmers.

In addition to NRCS EQIP financial cost-share and technical assistance, other financial incentive programs are available to producers and landowners to purchase drain control structures. In Ohio, the State of Ohio Water Pollution Control Loan Fund (WPCLF) provides for a *Western Lake Erie Basin Linked Deposit Program*. Under this program, farmers may work with their local Soil Water Conservation District to become eligible for a reduced loan rate from a local lender to implement select conservation practices, including drain control structures (OEPA 2014). In FY15, $30M will be available for activities in the WLEB including the Maumee, Portage and Sandusky River watersheds. The installation of new or intensified tile drainage is not eligible under the program. Although the program is relatively new, low interest rates may limit the attractiveness of the program to lenders and farmers.

New Revenue Streams- Nutrient/Water Quality Trading

The combination of monitored nutrient reductions and a verifiable management record lend RT-DWM to new transactions, such as Nutrient or Water Quality Credits where such programs exist. In 2013, the value of Water Quality transactions in North America was estimated at $11.1M, 95% of which was Nitrogen based (Bennett and Carroll 2014). These programs are most commonly recognized as Water Quality Trading programs, although other transaction structures exist. Regardless of name, these programs are characterized by point-sources, such as municipalities or industrial entities, subsidizing activities that reduce nutrient loadings from non-point sources. In the Great Lakes region, pilot programs or state guidelines for water quality trading programs currently exist in Pennsylvania, Ohio, Michigan, Minnesota and Wisconsin (WRI 2009). Two of the longer running programs, the Great Miami River Watershed Pilot Project in Ohio and the Pennsylvania Water Quality Trading program, were both initiated in 2005 and have seen limited activity to date. The Penn Nutrient Credit Trading Program provides credits and trading for compliance with the state's Chesapeake Bay TMDL, and through public auctions has sold credits (pound of P) for approximately $2 per credit (Markit 2015). The lack of Water Quality Trading in the Great Lakes region is not unique, as programs in the United States have been characterized by limited participation among potential traders and an overall lack of trading activity (Shortle 2012). The USDA NRCS continues to invest Water Quality programs; in 2012 allocating $7M in targeted Conservation Innovation Grants to spur development of market infrastructure (Bennett and Carroll 2014). At this time, Water Quality Trading is not yet a mature technique, particularly for applications to agriculture, but rather an emerging method (Shortle 2012).

Summary of Value Proposition to Farmers

The potential yield benefits of DWM provide a sufficient economic incentive to farmers for the adoption of DWM, as demonstrated in Table 4 and Table 5. The availability of USDA NRCS cost-share programs to either wholly or partially fund the planning, purchase and management of drainage water only improve the economic return of DWM to the farmer. Cumulatively, DWM should provide a strong value proposition to many fields and farm operations in the Great Lakes Region. RT-DWM, however, entails additional expenses that under current conditions and production costs cannot be solely justified on economic return from crop production. Potential revenue streams that RT-DWM could generate, such as water quality trading or other point source nutrient reduction programs, are also not presently viable. Although there are potential time and management benefits of RT-DWM, the cost of these additional services cannot be justified without some sort of off-farm investment.

Value Proposition to Downstream Beneficiaries

The management of flows with DWM or RT-DWM provides a unique suite of benefits to downstream users in a cost-effective manner. The primary benefit of interest to this report is the provision of P nutrient load reductions. As discussed in *Goals*, needed nutrient reductions to address watershed-scale pollution levels will require the management of nutrients transported through drainage. RT-DWM can provide for the optimal watershed-level provision of these reductions, and as discussed below, can do so cost-effectively relative to other watershed-level nutrient reduction strategies. Although not explored further in this report, DWM is also capable other off-farm benefits, such as capturing and decomposing bacteria and pathogens from applied manure, decreasing bacteria and pathogen loadings to surface waters (Frey et al. 2013, Wilkes et al. 2014). RT-DWM should provide equal, if not improved, bacteria and pathogen loading reductions.

Cost-Effectiveness of P Reductions Relative to Other Practices

The relative cost-effectiveness of DWM and RT-DWM as a P reduction practice is primarily dependent upon initial field P loads. Building off of the production and management costs in Table 4Table 6 , Table 6 presents the marginal cost of edge-of-field P reductions under initial P loads of 0.5, 0.75 and 1.4 pounds of P per acre while holding other factors constant (20 acres per DWM unit, 20 fields per sensor).

Annual total P loads measured in tile drains under prevailing conditions range from 0.4 – 1.6 kg/ha., or 0.35-1.42 lbs P/ac (King et al. 2014b). Intuitively, the greater the initial P load, and therefore the greater P reduction of DWM, the lower the marginal cost of P reductions from both DWM and RT-DWM. Changes in the relative efficiency of RT-DWM to DWM at retaining nutrients do not significantly impact the cost of P reductions. For example, assuming DWM is 70% and 90% as effective as RT-DWM, the cost of P reductions annualized over 20 years for DWM is reduced from$49.62 to $38.60 per lb of P and has no effect on the nutrient reduction costs of RT-DWM.

Table 6

Marginal Cost of Phosphorus Reductions from Drain Water Management									
Assumptions									
P Load per Acre (lbs per acre)	***0.5***			***0.75***			***1.4***		
Flow Retention with DWM	0.5			0.5			0.5		
Relative retention of Conventional DWM vs RT-DWM	0.8			0.8			0.8		
P Reductions_RTDWM (lbs per acre)	0.25			0.375			0.7		
P Reductions_Conventional DWM (lbs per acre)	0.2			0.3			0.56		
$/lb P									
Number of Years DWM Costs are Amortized	5	10	20	5	10	20	5	10	20
Swarm RT-DWM_All Costs	$826.22	$578.18	$456.51	$550.81	$385.45	$304.34	$295.08	$206.49	$163.04
Swarm RT-DWM_No Sensors	$624.84	$467.65	$390.54	$416.56	$311.77	$260.36	$223.16	$167.02	$139.48
Swarm RT-DWM_No Sensors & 50% cost reduction	$312.62	$234.02	$195.47	$208.41	$156.02	$130.31	$111.65	$83.58	$69.81
Conventional DWM	$128.01	$85.82	$65.13	$85.34	$57.22	$43.42	$45.72	$30.65	$23.26

Although the cost per pound of P reduction for RT-DWM is substantially greater than that of DWM, it can still provide cost-effective P reductions relative to other practices and strategies. One study estimating the costs of attaining Total Maximum Daily Load targets for the Chesapeake Bay region, looking at various portfolios of Best Management Practices and nutrient reduction strategies, estimated P reduction costs ranging from $62.27 (optimal practices implemented near watershed outlet) to $501.13 per lb of P if implementing all BMPs on all acres (Ribaudo, Savage and Aillery 2014). P reductions from performance-based payments were estimated to cost $97.18 to $408.83 per lb of P depending on scale of targeting, and enhancing targeting approaches produced reductions of $284.62 to $407.52 per lb of P (Ribaudo, Savage and Aillery 2014). An economic assessment of TMDL attainment in the Lower Fox river watershed in Wisconsin estimated similar per unit costs for P reductions at $84.37 per pound of under optimal BMP implementation and conversion of annual row crops to perennial biofuel crops (Blake and Godfrey 2009). Reduction costs for point sources in the Lower Fox were estimated at $109.20 per lb of P (Blake and Godfrey 2009). An economic feasibility study of P reductions in Wisconsin's Yahara watershed to achieve a 50% reduction in annual P loads estimated an average reduction costs of $74 per pound of P for rural non-point source activities, with in-field practices producing reductions at $49/lb P, cover for livestock facilities at $174/lb P, and wetland restoration at $328/lb P (Clean Lake Alliance 2012). Urban actions, such as leaf management, erosion control, maintain storm facilities, were estimated to provide P reductions at $111/lb of P. All costs are presented as the 20 year Net Present Value.

LINKING BENEFITS TO PROVIDE VALUE FROM FARM TO WATERSHED

The benefits of effective DWM are shared by many, providing incentives for numerous end-users to implement, scale and optimally manage DWM. As previously discussed, USDA cost-share is available for the development of a drainage plan (CAP130), purchase and installation of a drainage control structure (587) and to perform drain management throughout the year (554). Even with the availability of these funds, as well as other enrollment programs, adoption of conventional DWM remains relatively low. According to the most recent USDA-NRCS statistics on DWM adoption (USDA NRCS 2013), development of drainage plans and acres under drain water management have been increasing from FY12 through FY14 (June to June) in Indiana, Ohio, Michigan and Wisconsin (Table 7). Adoption rates will likely increase for FY15 as well. These estimates of DWM adoption are conservative as farmers are likely performing DWM independently of NRCS support programs. Still, given the magnitude of acres suitable for DWM, adoption rates remain well below the potential of this practice indicating that additional financial or non-financial barriers of adoption exist.

Table 7 Enrollment in NRCS DWM practices in Great Lake states

		FY12		FY13		FY14		FY15	
		No.	*acres*	*No.*	*acres*	*No.*	*acres*	*No.*	*acres*
Indiana	Conservation Activity Plan 130	1	144	4	219	6	228	0	0
	Drainage Water Management 554	15	752	12	603	16	639	13	654
Michigan	Conservation Activity Plan 130	0	0	3	203	21	603	3	203
	Drainage Water Management 554	30	1,309	145	6,405	200	8,546	188	8,426
Ohio	Conservation Activity Plan 130	0	0	0	0	0	0	0	0
	Drainage Water Management 554	47	2,504	34	1,577	67	2,664	88	2,960
Wisconsin	Conservation Activity Plan 130	0	0	3	93	6	416	0	0
	Drainage Water Management 554	0	0	2	76	8	117	0	0
Total	Conservation Activity Plan 130	**1**	**144**	**10**	**515**	**33**	**1,247**	**3**	**203**
	Drainage Water Management 554	**92**	**4,565**	**193**	**8,661**	**291**	**11,966**	**289**	**12,040**

Overcoming Barriers of Adoption: Aggregation Mechanisms to Link Benefits

RT-DWM provides a framework that can help producers overcome barriers to adoption of DWM. Professional accounts from drainage equipment manufacturers, conservation district staff, agronomy advisors, and university researchers that actively work with producers to install and manage drainage units identified a common progression in drain water management as producers develop trust in the technology. These phases of adoption are outlined below.

Implementation: Producers install drainage control structure. One account from the October workshop on producer interest in DWM was that numerous producers in southeast Michigan were implementing drainage control structures in part out of regulatory concern. These producers believed that a drainage control structure provided them an opportunity to visibly demonstrate their efforts to reduce field and farm nutrient losses. Another common motive for adoption identified was purely economic benefit from improving agronomic performance and providing an improvement in their land value.

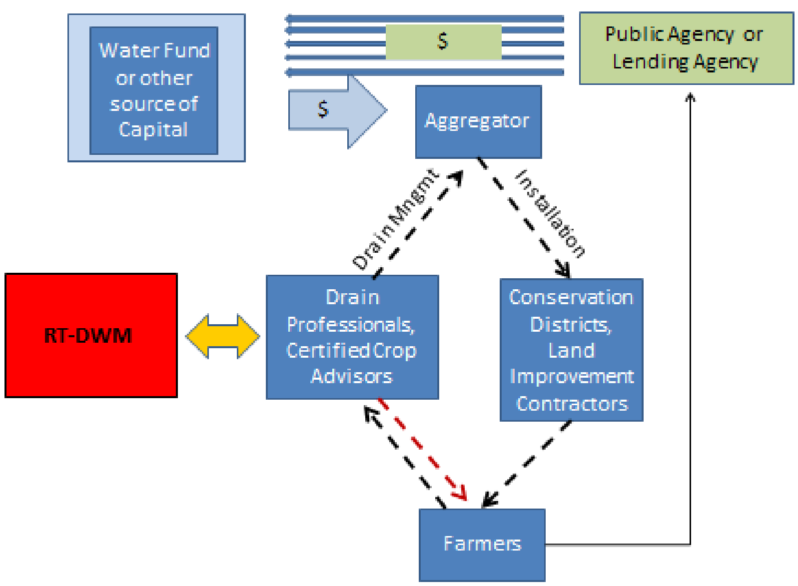
Passive Management: After installation, levels of actual drain water management vary. Accounts of producers not utilizing the drain control structure, in essence maintaining a Free Flow system, are common. Producers are especially reluctant to maintain any amount of water in their systems during the growing season, concerned that water levels will negatively impact yields. This learning stage is characterized by conservative and inactive management of water levels.

Active Management: Once producers become comfortable with retaining water in their tiles during the growing season, perhaps experiencing a beneficial yield impact, there is a greater tolerance of higher in-field water levels and more active management of water levels. In addition to trust in the level of water in their fields, a barrier preventing more active management becomes time and the information or expertise for more precise drain water management.

A new and uncharted phase of drainage management could be **RT-DWM.** The automated and precision management of RT-DWM can provide a valuable service to producers, eliminating the need for constant monitoring of drainage structures, anticipating impacts from current and future weather conditions and manipulating gates within drainage control structures to manage in-field water levels. This service would be similar to those provided for the management of other production variables such as nutrient application, seeding, or combining. RT-DWM provides the information for precision management while removing the management burden from the producer. It is assumed these benefits would assist producers in overcoming risk-related barriers to adoption of DWM.

The aggregation framework that can help mobilize RT-DWM, coordinate management at a watershed-scale, and assist producers in overcoming adoption barriers to improve agronomic performance can also create new business opportunities for multiple stakeholders. A DWM Fund could address many of the issues by providing scalable funding to drive down DWM equipment and installation costs, eliminate or reduce farmer enrollment and contracting efforts, create a new business opportunity for conservation agents and agriculture professionals, and provide verifiable environemtal outcomes from water management. Watershed-level management requires watershed-level coordination. This unique attribute of RT-DWM and the dependency on other participating fields creates novel business and economic opportunities for Land Improvement Contractors, drain authorities and others. An outline of a potential structure for a DWM Fund is presented below with additional details in Appendix D.

Figure 17 Hypothetical DWM Fund for Watershed RT-DWM



As proposed, RT-DWM can help producers overcome DWM adoption barriers, scale DWM and insure P reductions at the field scale while also providing nutrient reductions at a watershed scale that likely cannot otherwise be achieved through the implementation of surface best management practices alone. We've also demonstrated the private return to an individual farmer for RT-DWM is not yet sufficient to pay for this technology. Given this disconnect of public and private benefit, public investment in RT-DWM may be appropriate.

DISCUSSION AND CONCLUSIONS

This report set out to address two questions as posed by the Great Lakes Protection Fund: 1.) could RT-DWM provide meaningful nutrient load reduction to the Great Lakes, and 2.) what are the potential ecological and agronomic benefits associated with RT-DWM implementation. Our modeling, analysis, reviews of the literature, and consultation of experts indicate that DWM can provide meaningful nutrient reductions while also producing agronomic, economic and environmental benefits to farmers and watershed communities. Although assumptions regarding the efficacy of RT-DWM relative to DWM, both in terms of nutrient reductions and agronomic benefit, warrant further exploration, it is likely that RT-DWM can provide cost-effective nutrient reductions as part of a watershed-scale nutrient reduction strategy.

Our load reduction scenarios indicate that RT-DWM may result in a significant percentage nutrient load reduction in western Lake Erie and Saginaw Bay, depending on the scale at which it is implemented. If RT-DWM results in load reductions midway between the two scenarios presented, then our results suggest that a several percent reduction could be attainable for Lake Huron and Lake Erie. Such a reduction in SRP to western Lake Erie would significantly assist in meeting the 40 percent goal set by the Ohio Lake Erie Phosphorus task force (2013).

The scenarios were run for N, not for SRP. But available evidence does indicate that tile flow reductions caused by DWM will result in similar reductions in SRP and that the reductions will scale similarly to N load reductions in the scenarios. Although management strategies in western Lake Erie focus on SRP rather than N, N loadings to western Lake Erie are significant and should not be ignored. N concentrations in tile can be very high. In a Lenawee County study (western Lake Erie Basin), all tile water samples exceeded USEPA's recommended nutrient criterion with concentrations greater than 20 mg/L for 59 out of 59 samples (Haack and Duris, 2008). Additionally N may play a role in nutrient limiting switching between N and P in western Lake Erie during the growing season and contribute to harmful algal blooms (Chaffin et al., 2014)

RT-DWM is just one management practice among many. It is, however, one of the few management practices that will address subsurface drainage via tiles. Conventional BMPs primarily address nutrient reductions from surface runoff. As discussed previously, those BMPs are not expected to be sufficient to meet larger watershed goals, such as a 40 percent reduction for western Lake Erie, even when implemented at high rates. Reducing nutrient loss from subsurface drainage also will be necessary.

Reductions in N and P from RT-DWM can provide significant benefits to instream aquatic ecosystems, as demonstrated across four watersheds in Lake Huron's Saginaw Bay. Our analyses indicate that RT-DWM as a stand-alone practice can improve aquatic ecosystems in many of these subwatersheds, as measured by improvements in the modeled Index of Biotic Integrity. In relation to previously established watershed goals for aquatic ecosystem health, RT-DWM could help move many of these subwatersheds to their target condition. Although RT-DWM shows promise as a single practice to improve the health of aquatic ecosystems, a portfolio of conservation practices will still be needed.

There is a business case for individual farmers to implement DWM, but not yet for RT-DWM. A yield improvement of approximately 3 percent is a reasonable expectation for DWM. Such an improvement is sufficient to cover the cost of DWM adoption over a 10-20 year time period. The technology and equipment necessary for RT-DWM make it more expensive to implement than DWM, and, under current economic conditions, does not provide a sufficient economic return for farmers or landowners to justify private individual investment. Moreover, even with Federal cost-share and technical assistance for DWM, adoption of DWM is relatively low in the Midwest. Other barriers to adoption remain. RT-DWM may be able to help farmers move past these barriers, by providing a service that can greatly simplify individual management requirements, reduce risk, and deliver precise water moisture management for agronomic performance.

At a watershed scale, RT-DWM provides cost-effective nutrient reductions as measured by dollars per pound of P avoided or retained, when compared to other watershed-scale nutrient reduction strategies and practices. To achieve significant load reductions, RT-DWM may require watershed-level management. If managed at this scale, RT-DWM can create new business opportunities and provide a beneficial service to farmers (precision-based water management) and watersheds (cost-effective P reductions). Given the public benefits of widely implemented RT-DWM, some form of public financial support could be used to finance the additional costs of RT-DWM relative to DWM.

Two major assumptions were made in proposing this project and, as stated in the Introduction to this report, were not considered as a part of this project. The first is that RT-DWM will outperform DWM. The second is that farmers will be motivated to implement RT-DWM. The former is best addressed by either field experiments or application of a detailed hydrologic model to a real field situation. The latter assumption is more in the realm of social science. Because of the significant potential for RT-DWM to be successful, the project team recommends that a second phase of the project focus on addressing these two assumptions.

REFERENCES CITED

Agricultural Drain Management Coalition. 2012. Drainage Water Management for Midwestern Row Crop Agriculture. A final report to the USDA: Conservation Innovation Grant 68-3A75-6-116. http://admcoalition.com/wp-content/uploads/2012/04/cigreport.pdf

Allerland J.E., J.A. Klang and M.S. Keiser. 2013. Drainage Water Management Yield Effects and Farm Profitability. A report prepared for the Ag Drainage Management Coalition.

Bennett, G., and N. Carroll. 2014. Gaining Depth: State of Watershed Investment 2014. Available online at www.ecosystemmarketplace.com/reports/sowi2014.

Blake, L.J., and C. Godfrey. 2009. Watershed-Level Optimization of BMP Selection for Cost-Effective Pollutant Load Reduction in the Lower Fox River Basin and Green Bay, Wisconsin. *Proceedings of the Water Environment Federation* 2009.6 (2009): 570-599.

Bosch, N.S., J.D. Allan, J.P. Selegean, and D. Scavia. 2013. Scenario-testing of agricultural best management practices in Lake Erie watersheds. *Journal of Great Lakes Research* 39:429-436.

Chaffin, J.D., Bridgeman, T.B., Bade, D.L. and C.N. Mobilian. 2014. Summer phytoplankton nutrient limitation in Maumee Bay during high-flow and low-flow years. *Journal of Great Lakes Research*, vol 40, pp. 524-531.

Cicek, H., M. Sunohara, G. Wilkes, H. McNairn, F. Pick, E. Topp and D.R. Lapen. 2010. Using Vegetation indices from satellite remote sensing to assess corn and soybean response to controlled tile drainage. *Agricultural Water Management*. 98(2): 261-270.

Clean Lake Alliance. 2012 Yahara CLEAN Strategic Action Plan for Phosphorus Reduction. Available online at: https://www.cleanlakesalliance.com/wp-content/uploads/2012/11/Strategic-Action-Plan-11092012.pdf.

Delbecq, B.A., J.P. Brown, R.J.G.M. Florax, E.J. Kladivko, A.P. Nistor, J.M. Lowenberg-DeBoer. 2012. The impact of drainage water management technology on corn yields. *Agronomy Journal* 104(4):1100-1109.

Drury, C.F., C.S. Tan, W.D. Reynolds, T.W. Welacky, T.O. Oloya, and J.D. Gaynor. 2009. Managing tile drainage, subirrigation, and nitrogen fertilization to enhance crop yields and reduce nitrate loss. *Journal of Environmental Quality* 38(3):1193-1204

Frankenberger, J., E. Kladivko, G. Sands, D. Jaynes, N. Fausey, M. Helmers, R. Cooke, J. Strock, K. Nelson, L. Brown (2006) Drainage water management for the Midwest: Questions and answers about drainage water management for the Midwest. Purdue Extension Publication WQ-44.

Fausey, N.R. 2005. Drainage management for humid regions. *International Agricultural Engineering Journal* 14(4):209-214.

Frey, S.K., E. Topp, B.R. Ball, M. Edwards, N. Gottschall, M. Sunohara, E. Zoski, and D.R. Lapen. 2013. Tile Drainage Management Influences on Surface-Water and Groundwater Quality following Liquid Manure Application. *Journal of Environmental Quality*. 42(3): 881-892.

Haack, S.K., and J.D. Duris. 2008. Chemical and microbiological water quality of subsurface agricultural drains during a field trial of liquid dairy manure effluent application rate and varying tillage practices, Upper Tiffin Watershed, Southeastern Michigan, U.S. Geological Survey Open-File Report 2008-1189, 38 p.

Ghane, E., N.R. Fausey, V.S. Shedekar, H.P. Piepho, Y. Shang, and L.C. Brown. 2012. Crop yield evaluation under controlled drainage in Ohio, United States. *Journal of Soil and Water Conservation* 67(6):465-473.

Kim, S.J., B. Sohngen, and A.G. Sam. 2014. The Implications of Environmental Policy on Nutrient Outputs in Agricultural Watersheds. Working Paper. The Ohio State University Department of Environmental, Agricultural and Development Economics. Available online at: http://aede.osu.edu/sites/aede/files/publication_files/WQ_dailydata_1002.pdf

King, K.W., Williams, M.R., Macrae, M.L., Fausey, N.R., Frankenberger, J., Smith, D.R., Kleinman, P.J.A., and L.C. Brown. 2014a, Phosphorus Transport in Agricultural Subsurface Drainage: A Review, *Journal of Environmental Quality*, doi:10.2134/jeq2014.04.0163.

King, K.W., Williams, M.R., and N.R. Fausey. 2014b. Contributions of Systematic Tile Drainage to Watershed-Scale Phosphorus Transport, *Journal of Environmental Quality*, doi:10.2134/jeq2014.04.0149.

Lemke, A.M., K.G. Kirkham, T.T. Lindebaum, M.E. Herbert, T.H. Tear, W.L. Perry, and J.R. Herket. 2011. Evaluating Agricultural Best Management Practices in Tile-Drained Subwatersheds of the Mackinaw River, Illinois. *Journal of Environmental Quality* 40(4): 1215-1228.

Markit Financial Information Services: Pennvest Nutrient Credit Trading Program. Website: http://www.markit.com/Product/Pennvest

Michigan NRCS 2015. Environmental Quality Incentives Program. Website: http://www.nrcs.usda.gov/wps/portal/nrcs/main/mi/programs/financial/eqip/

Mine, S. , S. Zoubek, D. Cory-Watson, and M. Lowe. 2014. Adoption of Conservation Agriculture: Economic Incentives in the Iowa Corn Value Chain. Datu Research. Available online at: http://www.daturesearch.com/wp-content/uploads/Datu_Iowa-Conservation-Agriculture_FINAL.pdf

Nangia, V., M.D. Sunohara, E. Topp, E.G. Gregorich, C.F. Drury, N. Gottschall and D.R. Lapen. 2013. Measuring and modeling the effect of drainage water management on soil greenhouse gas fluxes from corn and soybean fields. *Journal of Environmental Management* 129:652-664.

Nejadhashemi, A.P., B.J. Wardynsky, and J.D. Munoz. 2011. Evaluating the impacts of land use changes on hydrologic responses in the agricultural regions of Michigan and Wisconsin. *Hydrologic Earth Systems Science Discussion* 8:3421-3468.

Nistor, A.P., and J. Lowenberg-DeBoer. 2007. Drainage water management impact on farm profitability. *Journal of Soil and Water Conservation* 62(6):443-446.

NRCS, 2012, Drainage Water Management Maps and Spreadsheet. Website: http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/?cid=stelprdb1046651

Ohio Environmental Pollution Agency (OEPA). 2014. State of Ohio Water Pollution Control Loan Fund: Final 2015 Program Management Plan. December 18, 2014.

Ohio Lake Erie Phosphorus Task Force, 2013, Ohio Lake Erie Phosphorus Task Force Phase II Final Report, 96p.

Purdue 2014. 2015 Purdue Crop Cost & Return Guide: September 2014 Estimates. Purdue Extension ID-166-W. Available online at: https://www.agecon.purdue.edu/commercialag/resources/farmmgmt/materials/id-166-w_2015%20-%20september%20projections.pdf

Ribaudo M., J. Savage and M. Aillery. 2014. An Economic Assessment of Policy Options to Reduce Agricultural Pollutants in the Chesapeake Bay. USDA-Economic Research Service. Economic Research Report Number 166. Available at http://ers.usda.gov/media/1469631/err166.pdf

Richards, R.P, Alameddine, I., Allan, J.D., Baker, D.B., Bosch, N.S., Confesor, R., DePinto, J.V., Dolan, D.M., Ruetter, J.M., and D. Scavia. 2012. Discussion of “Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models” by Dale M. Robertson and David A. Saad. *Journal of the American Water Resources Association*, vol. 49, no. 3, pp 714-724.

Robertson, D.M., and D.A. Saad. 2011. Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models, *Journal of the American Water Resources Association*, vol. 47, no. 5, pp 1011-1033.

Saad, D.A., Schwartz, G.E., Robertson, D.M., and N.L. Booth. 2011. A Multi-Agency Nutrient Dataset Used to Estimate Loads, Improve Monitoring Design, and Calibrate Regional Nutrient Sparrow Models, *Journal of the American Water Resources Association*, vol. 47, no. 5, pp. 933-949.

Selman, M., S. Greenhalgh, E. Branosky, C. Jones and J. Guiling. 2009. Water Quality Trading Programs: An International Overview. World Resource Institute Issue Brief. Available online at: http://pdf.wri.org/water_trading_quality_programs_international_overview.pdf

Sugg, Z. 2007. Assessing U.S. Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent?, World Resources Institute, 8p.

Shortle, J. 2012. Water Quality Trading in Agriculture. A report to the Organization for Economic Co-operation and Development. 50p.

Skaggs, R.W., Fausey, N.R., and R.O. Evans. 2012. Drainage Water Management, *Journal of Soil and Water Conservation*, vol. 67, no. 6, pp 167A-172A.

Smith, D.R., King, K.W., Johnson, L., Francesconi, W., Richards, P, Baker, D., and A.N. Sharpley. 2014. Surface Runoff and Tile Drainage Transport of Phosphorus in the Midwestern United States, *Journal of Environmental Quality*, doi:10.2134/jeq2014.04.0176

Sowa , S.P., M. Herbert, L. Cole, S. Mysorekar, J. Legge, T. Bowe, A. Nejadhashemi, M. Einheuser, and L. Wang. 2011. Assessing benefits of conservation practices to the biological integrity of agricultural streams in MI and WI. Final Report submitted to NRCS Conservation Effects Assessment Project. 56 pp. Available online at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1047736.pdf

Sowa, S.P., M. Herbert, K.R. Hall, L. Cole, S. Mysorekar, M. Fales, T. Bowe, G. Annis, A. Nejadhashemi, and L. Wang. 2013. Assessing the Ability of Conservation Practices to Restore Biological Communities in Agricultural Watersheds. Final Report submitted to NRCS Conservation Effects Assessment Project. 69 pp. Available online at: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1088482.pdf

USDA Economic Research Service (ERS). 2013. Fertilizer Use and Price. Website: http://www.ers.usda.gov/data-products/fertilizer-use-and-price.aspx#26727

USDA Natural Resource Conservation Service (NRCS). 2013 *Ag Drainage Water Management Fiscal Year 2013 Progress Report*. 40 p.

Wilkes, G., J. Brassard, T.A. Edge, V. Gannon, N. Gottschall, C.C. Jokinen, T. H. Jones, I.U.H. Khan, R. Marti, M.D. Sunohara, E Topp, and D.R. Lapen. 2014. *Applied and Environmental Microbiology* 80(12): 3708-3720.

Williams, M.R., K.W. King, N.R. Fausey. 2015. Drainage water management effects on tile discharge and water quality. *Agricultural Water Management* 148:43-51.

APPENDIX A- TEAM MEMBERS

Dennis McGrath, Great Lakes Project Director, The Nature Conservancy, Lansing, MI

Jim Nicholas, nicholas-h2o. Lansing, MI

Randy Dell, Great Lakes Agriculture Strategy Manager, The Nature Conservancy. Lansing, MI

Dr. Harold Reetz, Reetz Agronomics, LLC. Monticello, IL

Dr. Kris Johnson, Senior Scientist- North America Water, The Nature Conservancy, Minneapolis, MN

APPENDIX B-WORKSHOP PARTICIPANTS

Dr. Barry Allred- USDA ARS. Columbus,OH .

Dr. Larry Brown- Professor, Department of Food, Agricultural and Biological Engineering, The Ohio State University.

Brady Harrington, P.E.- Intercounty Drains, Michigan Department of Agricultural and Rural Development

Kent Herrick, P.E.- RDS Sensors

Jim Klang, P.E.- Keiser and Associates LLC.

Charlie Schaeffer- President, AgriDrain.

Mark Seger- Conservation Engineer, Ohio Department of Natural Resources- Division of Soil and Water Resources.

Tom Van Wagner- PT Consultants and retired Lenawee County NRCS District Conservationist.

Participated Remotely:

Dr. Jane Frankenberger, Professor Agricultural and Biological Engineering, Purdue University.

APPENDIX C- DWM AND RT-DWM BUDGETS

Conventional DWM				Swarm RT-DWM		
Budget Item	***Units***	***Cost***		***Budget Item***	***Units***	***Cost***
DWM Unit		**$1,199.60**		**DWM Unit**	**1**	**$7,291**
10" box (6 ft)	1	$655.69		10" box (6 ft)	1	$655.69
Coupler (6"P @ $23.88 each)	2	$47.76		Coupler (6"P @ $23.88 each)	2	$47.76
Valterra Valve (8" panel)	1	$464.13		Primary Remote Infinitely Variable Controller	1	$2,770.62
Stop log boards (5"molded @2, 7" @1)		$32.02		Solar Power Connection Primary	1	$665.73
				Solar Panel Kit Primary	1	$510.65
				Valterra Valve (8" panel)	1	$464.13
				Stop log boards (5"molded @2, 7" @1)		$32.02
				Actuator	1	$259.72
				Modem Option	1	$1,884.19
Labor, Installation		**$465.50**		**Labor, Installation**		**$465.50**
Labor @ $30/hr	10	$300.00		Labor @ $30/hr	10	$300.00
Excavation		$3.00		Excavation		$3.00
Construction Equipment		$100.00		Construction Equipment		$100.00
Reseed		$62.50		Reseed		$62.50
				Sensor		
				Nitrate Sensor	1	$33,000
				Telemetry (per nitrate sensor	1	$1,650
				Gateway (per DWM unit)	1	$2,750
Management of DWM Unit				**Communications, Data Management**	Monthly	Annual
per acre, per year		**$6.90**		Fees per DWM unit	$115	$1,380
				Algorithm Development, Support		
				Per Acre (One Time)		$0.10

APPENDIX D- EXAMPLE DWM FUND

Water Fund or Capital Source
Role: Provide necessary upfront capital to administer program.
Benefit: Environmental and economic return on investment.
Potential entities: Water Fund, Impact Investor, Foundation, Government Agency, or combinations thereof.

Aggregator
Role: Primary administrator of funds and overall coordinator of work activities including: equipment purchase, engineering and installation of drain units, and management of money. Overall role is to minimize participation burden for all parties, primarily farmers.
Benefit: Dramatically increase scale of conservation delivery, cover administration costs.
Potential entities: ?

Conservation Districts
Role: Contract and manage installation of drainage units in coordination with Land Improvement Companies (LIC). Serve as an initial point of contact for land managers/farmers. On the water management side, could potentially be under contract with farmers to monitor and manage drainage gates and in-field water levels.
Benefit: Cover staff time, offer a new conservation service, and increase scale of conservation.

CCA, Drain Professional, RT-DWM
Role: Perform monitoring and management of drain gates to manage in-field water levels for a fee to the farmer, e.g. $2 per acre per year. Farmers may be more receptive to allowing CCAs manage drain gates as they would be viewed as managing for optimum agronomic performance.
Benefit: New business opportunity, opportunity for increased interaction and relation building with customers.

Farmers
Role: Enroll in program, pay annual management fee to Certified Crop Advisor or Conservation District for certifiable drainage management; pay off principal of loan over five years (should have option to repay ahead of schedule).
Benefit: Acquire DWM unit at reduced cost with no out-of-pocket expense or effort for purchase and installation; increased yield from improved water moisture retention, and verifiable demonstration of of water management.