H2Ohio Technology Assessment Program (TAP)

Final Report

Assessment of Agricultural Nutrient Management Technology Submission

Automated Drainage Water Management (ADWM)

January 2022

TETRA TECH

EXECUTIVE SUMMARY

Ecosystem Services Exchange (ESE) of Adair, Iowa has submitted a technology proposal for Automated Drainage Water Management (ADWM) to Ohio Environmental Protection Agency' (Ohio EPA's) H2Ohio Technology Assessment Program (TAP) for the purpose of addressing the Lake Erie algal blooms and associated nutrient loading. The TAP objective addressed by ADWM is to reduce nutrient loading to rivers, streams, and lakes. ESE suggests and Tetra Tech concurs that ADWM within a conservation systems approach offers potential to improve water quality in the Lake Erie basin as well as farm economic viability via increased crop yields. ADWM affords easier, real-time control of the timing of water discharged from tile systems by allowing for the remote operation of water control gates in the field. ADWM also provides greater precision in the timing of managing water control gates compared to their manual operation. ADWM employs two-way telemetry to reduce labor associated with Drainage Water Management (DWM) and provides the producer real-time data to inform their management actions and automatically manage water levels and flow rates in tile-drained fields.

ADWM is cost effective, especially when the financial assistance available from the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and other sources for its planning, design, and implementation and the potential crop yield increases are considered. (NRCS financial assistance through the Environmental Quality Incentives Program alone will typically cover between 50 and 75 percent of the planning, design, and implementation costs of ADWM.) The estimated cost per pound of phosphorus reduced by ADWM compares favorably with other agricultural practices reviewed by Tetra Tech for The Nature Conservancy (Tetra Tech, 2019). ADWM also provides opportunity to remotely manage subsurface irrigation (NRCS Conservation Practice Standard Code No. 443) for greater conservation and crop yield benefits. Multiple studies indicate DWM can increase crop yields when plants are stressed, and tile flow is managed to improve soil water availability.

ADWM better enables producers to actively manage their systems based on real-time data and responds to the challenge of realizing the long-standing promise of the management of tile-drainage water. The technology features of ADWM, compared to manual DWM, address many of the key barriers to adoption. For instance, the labor burden for producers to physically manage multiple water control structures in the field is eliminated with real-time data fed to the operating system automatically managing soil water levels and tile flow rates based on established "triggers", with limited oversight needed. Site-specific data on flow and nutrients also provide real-time "line of sight" to water quality outcomes, measured and modeled. These data also can be correlated to yield changes and inform adaptive management for improvement.

This report evaluates ADWM against a suite of criteria identified by the TAP using information provided by ESE and obtained elsewhere. Tetra Tech determines that ADWM is very likely to be effective at reducing nutrient loading to Lake Erie, in direct proportion to the number of agricultural fields to which it is applied. Tetra Tech did not identify any negative impacts associated with environmental risks, supply chain limitations, or community perception. The estimated total costs are between \$1.85 per pound (/lb.) and \$2.77/lb. for nitrogen and \$55.00/lb. and \$110.00/lb. for phosphorus, which are within the range of other similar agricultural best management practices. The biggest barrier to applying ADWM at a scale large enough to make a significant impact is landowner willingness, which could be addressed through financial support provided by the H2Ohio

Initiative. A demonstration project targeting widespread adoption of ADWM within one or more Hydrologic Unit Code (HUC)-12 subwatersheds could evaluate the ability of financial incentives to spur landowners to use this technology and could also provide more detailed data about nutrient load reductions, crop yield increases, and potential constraints to using ADWM within the Lake Erie drainage basin.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS/ABBREVIATIONS

Acronyms/Abbreviations	Definition
$/lb.	dollars per pound
ACPF	Agricultural Conservation Planning Framework
ADC	Agri Drain Corporation
ADWM	Automated Drainage Water Management
CAP	Conservation Activity Plan
CDN	Conservation Drainage Network
DRP	dissolved reactive phosphorus
DWM	Drainage Water Management
EQIP	Environmental Quality Incentives Program
ESE	Ecosystem Services Exchange, LCC
HABs	Harmful Algal Blooms
HUC	Hydrologic Unit Code
IP	Intellectual Property
lbs.	pounds
LICA	Land Improvement Contractors of America
LLC	Limited Liability Corporation
NPS	Nonpoint Source
NRCS	Natural Resource Conservation Service
NRCS	Natural Resources Conservation Service
Ohio EPA	Ohio Environmental Protection Agency
PPE	Personal Protective Equipment
PLC	programmable logic controller
QAPP	Quality Assurance Project Plan
RFT	Request for Technology
SWCD	Soil and Water Conservation District
TAP	Technology Assessment Program
Tetra Tech	Tetra Tech, Inc.
TNC	The Nature Conservancy

Acronyms/Abbreviations	Definition
USDA	United States Department of Agriculture
WLEB	Western Lake Erie Basin

1.0 INTRODUCTION AND BACKGROUND

H2Ohio (http://h2.ohio.gov) is Ohio Governor Mike DeWine's comprehensive, data-driven water quality plan to reduce Harmful Algal Blooms (HABs), improve wastewater infrastructure, and prevent lead contamination. Governor DeWine's H2Ohio plan is an investment in targeted solutions such as :

- Reducing phosphorus runoff through increased implementation of agricultural best management practices and the restoration of wetlands;
- Improving wastewater infrastructure;
- Replacing failing home septic systems; and
- Preventing lead contamination in high-risk daycare centers and schools.

HABs have been a concern in Lake Erie for decades, and the State of Ohio has a long history of developing solutions to address them. In support of these efforts, state agencies are often presented with new approaches for addressing HABs. These approaches often involve technologies and products that are typically innovative, can be proprietary, and span multiple scientific disciplines. To evaluate these proposals for their efficacy and feasibility, the Ohio Environmental Protection Agency (Ohio EPA) worked with the Ohio Lake Erie Commission to create a public advisory council—the Technology Assistance Program (TAP) Team. The H2Ohio TAP Team is comprised of representatives from the private sector, public sector, trade associations, and non-profit companies. The H2Ohio TAP team is conducting an evaluation of technologies designed to treat, control, and reduce HABs in the Lake Erie watershed. H2Ohio initiated the TAP to solicit and evaluate technologies that support one or more of the following five goals:

1. Reduction of nutrient loading to rivers, streams, and lakes;
2. Removal of nutrients from rivers, streams, and lakes;
3. Reduction of the intensity or toxicity of algal blooms;
4. Recovery of nutrients from animal waste; and
5. Improvement of nutrient removal in wastewater treatment systems.

The H2Ohio TAP Team worked to solicit and prioritize technology proposals for further review. A Request for Technologies (RFT) was developed and issued by Ohio EPA in November 2020 (H2Ohio TAP, 2020). The H2Ohio TAP conducted a thorough evaluation of the 40+ proposals received in response to the RFT and selected 10 technologies for further evaluation. The developers of these 10 technologies were given an opportunity to provide additional information and supporting data to allow an independent evaluation of their technology by a third party, Tetra Tech.

As a contractor to the Ohio EPA, Tetra Tech conducted an independent third-party evaluation of the 10 technologies selected by the H2Ohio TAP team. The goal of the evaluation was to provide a general assessment of the potential effectiveness, implementability, readiness, and cost of deploying each technology. Select technologies may eventually be demonstrated in the field under future H2Ohio programs.

2.0 PURPOSE

The primary purpose of the technology assessment and evaluations was to conduct a comprehensive scientific evaluation of the selected technologies to determine if and how they could be utilized to address HABs in Lake Erie.

Based on input from Ohio EPA and the H2Ohio TAP team, Tetra Tech established primary (P1 & P2) and secondary (S1 & S2) objectives for the third-party evaluation program. The primary objectives are critical to the technology evaluation and involve conclusions regarding technology performance that are based on quantitative and semi-quantitative data. The primary objectives for the evaluations of the participating technologies are as follows:

- P1: Effectively assess the performance, cost-effectiveness, and reliability data gathered from each vendor with regard to one or more of the 5 H2Ohio goals:
  - Reduce nutrient loading to rivers, streams, and lakes:
  - Remove nutrients from rivers, streams, and lakes:
  - Reduce the intensity or toxicity of algal blooms
  - Recover nutrients from animal waste:
  - Improve nutrient removal in wastewater treatment systems, specifically with small (e.g. lagoon) and decentralized systems
- P2: Ensure that the evaluations are completed by appropriate personnel using a documented, consistent approach and level of detail, to include:
  - Proof of concept review
  - Fatal flaw analysis
  - Review of previous implementation of the technology or similar technologies
  - Review of data quality objectives
  - Review of quality assurance/quality control procedures and reports
  - Evaluation of scalability
  - Information gap evaluation
  - Evaluation of cost; both total and by unit, such as nutrient reduced/removed
  - Feasibility review for a proposed demonstration project
  - Feasibility review for full scale implementation
  - Statement of probability of success

The secondary objectives pertain to Tetra Tech's approach to assessing and presenting the information and thus support the primary objectives.

The secondary objectives for Tetra Tech's evaluation are as follows:

- S1: Prepare Comprehensive Scientific Assessment and Recommendations Reports for each technology that will support potential users' ability to make sound judgements on the applicability of the technology to a specific site and to compare the technology to alternatives.

- S2: Ensure that project deliverables follow consistent format and similar levels of detail. Each report will contain:
  - A summary of the technology and results of past uses of the technology;
  - Results of conceptual model review, fatal flaw analysis, and information gap evaluation;
  - A statement of probability of success and scalability of the project;
  - Verification of cost estimates at various implementation levels;
  - Results of the feasibility review for a potential demonstration project and full-scale implementation of the technology;
  - Verification of claims made by applicants.

The technology evaluation consisted of the (1) collection; (2) evaluation; and, (3) summarizing and reporting of data on the performance and cost of each technology. These data provided the basis for meeting the primary objectives.

Most data supporting these evaluations were provided by the technology developers and Tetra Tech attempted to verify it using independent sources, when available. Tetra Tech focused its verification efforts on key aspects of the technology (e.g., effectiveness, cost) as well as any claims that seemed questionable. Otherwise, Tetra Tech assumed information provided by the vendor to be accurate. Instances where Tetra Tech is unsure of a claim being made by the vendor are noted in the report. In some cases, information was also obtained from the peer-reviewed scientific literature. Tetra Tech worked with each developer to obtain the data necessary to meet the primary and secondary evaluation objectives.

Tetra Tech then completed an independent evaluation of the data provided by each developer and prepared separate reports for each technology evaluation, following a consistent report format. This report provides a summary of our review of ADWM.

3.0 TECHNOLOGY OVERVIEW

Drainage water management (DWM) is a proven conservation practice supported by a specific United States Department of Agriculture (USDA) Natural Resource Conservation Service (NRCS) conservation practice standard (Practice Code No. 554) since December 20, 2001. DWM has demonstrated water quality and crop production benefits in tile-drained cropland settings in the Upper Midwest, Great Lakes, and Mid-Atlantic Regions. Scientific data and outcome assessments have affirmed that manual DWM requires: 1) site-specific planning/design to ensure proper use, and 2) active real-time management of the system to ensure water control actions are appropriate and timely for intended benefits.

Automated Drainage Water Management (ADWM) is DWM, but with significant technological and performance improvements because of its automation features, including electronic data accessibility. Based on information provided by ESE, ADWM's innovative technological improvements to DWM are fully developed, have been installed in actual farm operations, and are currently available for implementation. A significant benefit of ADWM is that it can remove many of the long-standing barriers to producer adoption of this conservation practice and provide real-time access to data to better manage agricultural fields and assess both water quality and crop production benefits.

4.0 TECHNOLOGY EVALUATION

This section of the report addresses each of the criteria identified by Ohio EPA to be included in the independent evaluation process.

4.1 CONCEPTUAL MODEL REVIEW

Manual DWM has two main requirements for successful implementation: site-specific planning and design to ensure proper use, and active management of the system to ensure water control actions are appropriate and timely. The enhancement that ADWM offers is a technological innovation and performance improvement that requires less labor-intensive management efforts.

With ADWM, electronically actuated slide-gate valves, electronic water level sensors, programmable logic controllers, solar power, cellular communication, cloud data management, web-based user interfaces, and float operated water gates are all possible technology components. Electronically actuated slide gate valves can be installed in water level control structures to enable tile drainage to be either restricted or free flowing, depending on conditions in the field and anticipated field operations (e.g., planting). An electronic water level sensor is used with this control structure, passing information to the programmable logic controller (PLC). The PLC serves to automatically control the actuation of the slide gate valve according to inputs such as time, date, water level and/or user inputs. The attraction of a PLC is that it also provides a human-machine interface allowing for a producer to interact with the ADWM system either in-field or remotely. Figure 1 provides a visual representation of a possible ADWM system, which includes an automatic in-line water level control structure, two-way communication unit, and solar panel for in-field power supply (White, 2021).

ADWM affords easier, real-time control of the timing of water discharge from tile systems, does it remotely without the producer having to physically manage water control gates in the field, and provides for greater precision in the timing of management actions. Innovative ADWM employs two-way telemetry, which is claimed by ESE to greatly reduce the labor burden and provides the producer current data to inform their management actions and/or to automatically manage water levels and flow rates in tile-drained fields. ADWM also provides the opportunity to remotely manage sub irrigation for greater conservation and crop production benefits.

The lifespan of an integrated ADWM system is dependent on the lifespan of its three components:

- The average lifespan of drainage tile is up to 100 years;
- The water control structure to physically manage water flow has an average lifespan of up to 30 years; and
- The electronic automation system and supporting solar panel has an average estimated lifespan of up to 20 years (with proper maintenance and upgrades).

ADWM applied in a conservation systems approach offers great promise to improve both the environmental performance of agriculture and farm economic viability in tile-drained landscapes. ADWM is claimed as an innovative, cost-effective, and efficient technological improvement to overcome many of the barriers to the adoption of manual DWM.

Figure 1 - Visual representation of ADC's *Smart Drainage System*

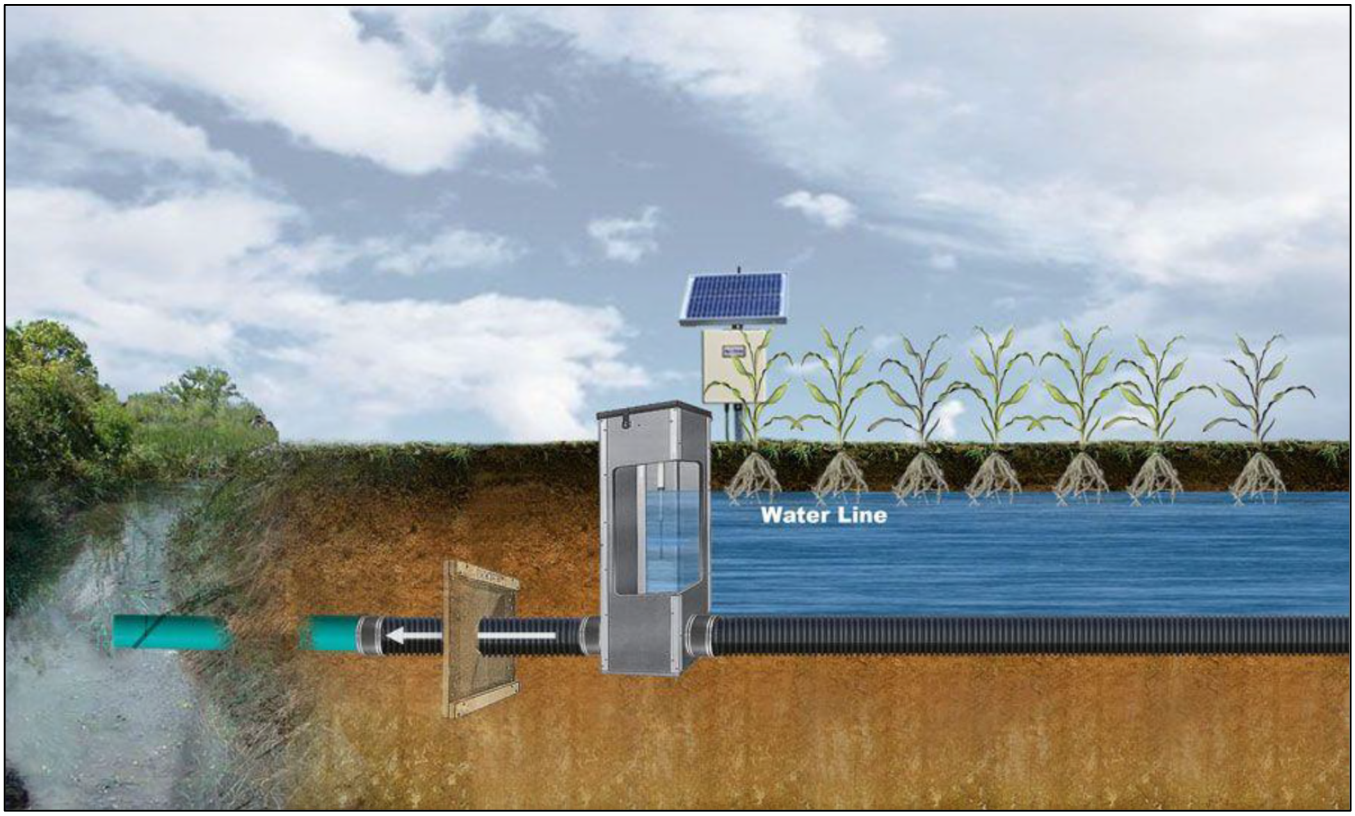


Image provided courtesy of Ecosystem Services Exchange (White, 2021)

4.2 FATAL FLAW ANALYSIS

Fatal flaws of ADWM are not apparent, aside from producer reluctance to adopt use of manual DWM and their limited awareness of this technological innovation that improves the ease and precision of drainage water management. ESE's sister company, Agri Drain Corporation (ADC), already has a patented ADWM system called *Smart Drainage System*. This technology is claimed to give producers the ability to automatically and remotely (if desired) manage their drainage systems for proper soil moisture and maximum crop yield, all while reducing nutrient loss and risks related to drought or excessive moisture in the field.

ADC's *Smart Drainage System* features a PVC slide gate valve, where components slide into tracks of an inline structure; a power actuator to open and close the slide gate valve; a water level sensor to monitor water level in the structure; a solar panel and battery to power the system; a programmable controller with cellular/cloud-based communication, and; a weather-proof enclosure. It is designed to be compatible with drainage pipe sizes up to 12 inches in diameter. These technologies allows producers to monitor and manage their system remotely and open or close the valve on demand or automatically based on desired set-points. Lastly, the web-based *Smart Drainage* site dashboard displays the water level, battery condition, valve position, and set points for the system. It is possible that producers who are not comfortable with the technological aspects of ADWM will see this as a barrier to adoption, although this is less likely as producers embrace the incorporation of more and more technological innovation into their operations at an increasing pace.

ESE explained to Tetra Tech that there are 16 agricultural sites in the United States using their ADWM technology. Additional information about these sites includes the following:

- 14 of the sites involve the automation of DWM (thus ADWM), including 3 sites in Ohio
- 12 of the 14 sites include the full, multi-level use of ADWM (the ultimate target)
- the 2 remaining sites involve automation for bioreactor level monitoring.

Each system drains at least 20 acres of land, and according to ESE the performance of these systems has been good with no major maintenance issues noted. Additionally, ESE states that 8 more sites are under development for multi-level ADWM: 6 in Illinois and one each in Delaware and Maryland. These 8 sites involve the retrofit/upgrade of existing manual DWM sites.

Relevant failures that have occurred in DWM systems have involved the need to replace actuators, most often due to motor burn outs if small grains or rocks become lodged in the motor track. In one DWM application installed by ESE/ADC, an actuator required replacement due to water ingress as a result of flooding in the area surrounding the water level control structure to a level the structure was not designed for. Also, one occurrence of water ingress to the actuator electrical connector has also been noted by ESE. Replacement of the connector, actuator, and circuit protection fuse were required to ensure reliable operation once repairs were completed. Pressure transducers for sensing water level have also failed in the field, but the failure mode has not been analyzed by the manufacturer of these transducers. Replacement of the pressure transducer is said to remedy the issue in all of those circumstances. None of these failures are considered fatal flaws and are instead elements of routine maintenance common to this type of equipment.

4.2.1 Barriers to Adoption

There is limited literature information that focuses on barriers to producer adoption of DWM and ADWM, and no known U.S.-specific surveys of producers' intentions regarding the adoption of DWM. Therefore much of the information that ESE has identified regarding the barriers to producer adoption of manual DWM are based on: 1) practical field experience in working directly with producers and land improvement/drainage contractors; 2) the knowledge and experience of ESE's leaders in formulating and delivering federal conservation programs at field, state, regional, and national levels; and, 3) ESE's history of working closely with researchers to advance the technologies associated with the improved precision and automated management of tile-drainage water. Barriers to DWM adoption by producers and whether they are addressed by ADWM are listed in Table 1.

Table 1 - ESE's List of Key Barriers to DWM Adoption

Barrier to DWM Adoption (cited by ESE)	Does ADWM Address?
Time, effort, and physical challenges of managing manual DWM water control structures in the field at the right time for busy producers who have many competing priorities	Yes
Public and private sector technical assistance to support producers that is inconsistent regarding its availability, experience, and proven abilities to plan, design, and assist installation of DWM	No

Barrier to DWM Adoption (cited by ESE)	Does ADWM Address?
Financial assistance from state and federal conservation programs that is not simple to access and administer, is transaction and labor intensive, and not always available at the time it is needed given limited seasonal windows for practice installation	No, financial assistance process is the same for DWM and ADWM
Lack of research findings that are synthesized and translated into practical information and tools for producers to easily use - especially crop yield benefits	No
Lack of a site-specific decision support tool based on science and real-time data to help a producer manage his/her installed DWM system, or manage multiple DWM systems in a synchronized manner	Yes (ESE developing decision-support tool for use with ADWM)
Lack of technical consultative services available to assist a producer in managing and troubleshooting an installed DWM system	Yes (if sold/supported by ESE)
Limited coordinated and sustained partnerships to bring focused multi-year commitments and resources to assist producers in priority small watersheds with DWM to achieve adoption to scale	No, unless ADWM is adopted to scale
Limited education, communication, and marketing in a coordinated and sustained manner about the benefits of DWM, both on-site and off-site	No, not currently as the same applies to ADWM
No systematic and coordinated pilot project approach across the roughly 30 million cropland acres of opportunity for DWM in the Upper Mississippi River and Great Lakes Basins to grow adoption (a multi-year public-private strategic approach is absent leading to "random acts of DWM", which is less conducive to greater transferability and growth of adoption)	No
Little identification/enlistment of early adopters to discuss lessons learned and be champions to help foster greater adoption	No, not currently but is being addressed by ESE

ADWM does not remove or mitigate all the above-listed barriers to producer adoption of manual DWM. Many of the barriers are related to larger issues such as lack of robust public/private strategies and sustained commitment, conservation programs that are cumbersome and not focused on manual DWM/ADWM adoption, constraints related to the availability of experienced technical support, lack of synthesized research findings on both water quality and crop yield results, and lack of sustained educational and information efforts.

ESE requested members of the Conservation Drainage Network (CDN) to complete a survey regarding their views as knowledgeable and experienced researchers and practitioners on the barriers to producer adoption of this technology. CDN membership is composed of researchers, public agency technical and programmatic staff, producer organization representatives, land improvement and drainage contractors, technical service providers, nonprofits, and farmers. Survey responses were gathered between June 1, 2021 and July 2, 2021, and results of the survey indicate that two primary barriers to DWM adoption are that there are (1) unclear results related to the crop yield impacts of DWM, and (2) the lack of timely, experienced, and proficient technical assistance to guide planning, design, and implementation of DWM. Other high-ranking adoption barriers include:

- Uncertainty about the benefits of DWM versus the costs of DWM implementation including installation, manual management, and repairs;
- Increased on-farm labor requirements to manage DWM and lack of awareness of automated flow control structures to reduce labor burden and facilitate real-time management;
- Lack of consistent and sustained educational and marketing efforts to promote DWM by conservation agencies, producer organizations, drainage contractors, and others;
- Difficulty in securing financial assistance from conservation programs in a timely manner, including cumbersome and/or complex program requirements;
- Lack of producer awareness about the multiple benefits of DWM, including limited sharing of producer testimonials and communication of lessons learned; and
- Existing tile drainage layout and/or other field physical challenges that make retrofitting to install water control structures complicated and/or expensive.

Approximately 30 individuals filled out the survey request, and most of the responders have 5 to 20 years of experience with manual DWM. Regarding experience and knowledge of automated DWM, 53% of survey responders are knowledgeable and 27% identified themselves as expert, meaning they could design and install an ADWM system. The remaining CDN members who responded to the survey only have awareness of ADWM technology.

Respondents to the CDN member survey believe that ADWM can help alleviate barriers to adoption of manual DWM by mitigating challenges related to labor and physical constraints and helping producers manage on-farm resources more efficiently. For example, one survey respondent said ADWM can alleviate “labor demands (i.e. continually checking water levels of a tile control system).” Additionally, another CDN member said they believe ADWM can “eliminate most all post-installation issues a farmer would have. It simplifies a lot of guess work of management and gives them control of another resource on their farm.” A commonality among the respondents’’ take on ADWM is that to increase the adoption of DWM, producers need a clear roadmap to navigate financial assistance and cost share programs available for these drainage systems. Furthermore, it is believed that research gaps need to be addressed and the costs versus the benefits of DWM should be clarified for individual producers. Finally, increased awareness surrounding DWM should be prioritized through outreach and education. The conservation drainage community can help with this need through “education, consistent promotion across stakeholder groups, and cost/benefit analysis.”

4.3 REVIEW OF PREVIOUS IMPLEMENTATION OF ADWM

ADWM has been available for producer implementation via ESE since 2005, with ongoing and significant improvements to the technology since then. Past implementation of DWM and the effect of DWM on water quality has been assessed in several studies, though its implementation by producers in a conservation systems approach has been limited. Research results report reduced nutrient loading ranging from 25% to over 50% for dissolved phosphorus (Ross et al., 2016) (Feset et al., 2010) and 17% to 94% for nitrates (Skaggs et al., 2010), depending on site-specific conditions and the water management regime. In a case study near central Ohio in the Upper Big Walnut Creek watershed, a 15-hectare field with DWM saw a 65 to 74% reduction in dissolved reactive phosphorus (DRP) loading compared to the free-draining scenario (Van Wagner, 2016). However, DWM did not significantly affect DRP concentration. In an article on bioreactors and controlled drainage from Michigan State University Extension (Harrigan, 2015), Dr. Larry Geohring of Cornell University is cited as claiming to expect 10 to 20% reduction in total phosphorus load with properly managed control structures compared to conventional free-flowing drainage. Phosphorus-focused research surrounding DWM has not been as robust compared to nitrogen, and needs to be studied more, but the consensus is that DWM does correspond to reduced nutrient loading from tile drainage (King et al., 2015). The reduction in loading appears to be due more to the reduction in tile discharge than due to reduced nutrient concentrations.

Crop yield increases from one field study showed DWM sites with corn and soybean yield increases ranging from 1% to 19%, but also an equal number of sites showing no yield increases (Skaggs et al., 2012). Multiple studies indicate DWM is likely to increase crop yields when plants are under dry stress and tile flow is managed to improve soil water availability. However, DWM is less likely to influence crop yield when precipitation conditions keep soil water available to meet plant demands (Schafer et al., n.d.). Long term and representing many different climates, soil conditions, and degree of drainage management intervention, an average 5 percent yield improvement is typically achieved with manual DWM (Crabbé et al., 2012) (Ghane et al., 2012) (Skaggs et al., 2012). In a study by Ghane et al. in northwest Ohio, United States, a multiple field trial was conducted to assess yield stability and performance using DWM specific to Western Lake Erie and nearby areas. Yield data were collected for seven demonstration sites (fields) on private farms located in northwest Ohio from 2008 to 2011. All the sites are subsurface drained with 4-inch drains at a depth of 2.5 to 4 ft, and a corn/soybean rotation was the most common cropping practice across the sites. The inline water level control structures were provided by ADC, ESE's sister company and DWM equipment manufacturer. Based on a mixed model analysis of the sites, the implementation of DWM (controlled drainage) improved crop yield for corn, popcorn, and soybean by 3.3%, 3.1%, and 2.1%, respectively.

Regarding DWM projects supported by ESE and other partners, Ohio's Blanchard River Demonstration Farms Project implemented 10 acres of drainage water management on Kurt Farms in Hardin County. This conservation practice (along with others) was implemented with assistance from the Hardin County Soil and Water Conservation District (SWCD) and The Nature Conservancy (TNC). During the September 2020 farm drainage field day for the Michigan Land Improvement Contractors Association (LICA), ESE and ADC installed both manual and automated in-line water level control structures to monitor water levels and flow rates in a DWM system. Recently in May 2021, producers in 41 southern Minnesota counties with well-functioning tile drainage systems on their farms were offered "turn-key" ESE assistance with planning, design and installation of conservation drainage practices including DWM (Turn-key, n.d.). Funding for up to 68 site assessments and feasibility studies on farms for DWM and other tile drainage management is available through the USDA's NRCS under a collaborative project named "Managed Tile Drainage Systems", of which ESE is the technical service provider. The current number of producers opting to participate in this Minnesota project is 37 as of early September 2021.

Though the study results of nutrient loss reduction via manual DWM are promising, little to no literature specifically focused on ADWM was found. Current research efforts on a 115-acre farm field in Bath, NC, North Carolina State University researchers have implemented a real-time water management system involving ADWM (Shore , 2020). Showcased in late 2020, crop yield and nutrient loss monitoring is ongoing, and results have not been published.

Most of the previous yield and nutrient loss reduction studies via DWM were done without the benefit of real-time, automatic management of water level control structures. ESE is hypothesizing that intensive soil moisture monitoring and automated real-time water level and flow rate management should result in increased yields, but it appears this has not yet been quantified by the ESE team and partners in a thorough case study. It is worth noting, however, that during the virtual CDN meeting session in April 2021, agronomist and Research Director for Crop-Tech Consulting, Inc. Isaac Ferrie gave a presentation on manual DWM and the benefits seen regarding crop yield increase and nutrient loss reduction in a case study on McLaughlin Dooley Farms in Le Roy, Illinois (CDN, 2021). Ferrie and his team have collaborated with the farm on over 4,000 loads that have been harvested since the monitoring project began. Across 3 years of corn yield data, normalized corn yield benefit is found as an average of 5.8 bushels per acre on the low end with 120-ft tile gate spacing to 12.5 bushels per acre on the high end with 30-ft tile gate spacing. Across 2 years of soybean yield monitoring, the average yield benefit is 2.6 bushels per acre on the low end (120-ft tile gate spacing) to 6.8 bushels per acre on the high end (30-ft tile gate spacing). Nitrogen nutrient loss reductions ranged from 16% to 40% across a year-long monitoring period in 2016. Plans are being developed to automate some of these manual DWM systems to be able to compare manual DWM versus ADWM results moving forward.

ESE also hypothesizes that intensive soil moisture monitoring and automated real-time water level and flow rate management will result in significantly larger nutrient load reductions compared to manual DWM. Tetra Tech agrees with this assessment given that it has been demonstrated that a large portion of the annual nutrient load from a watershed is often associated with only a few large events. If ADWM enables more targeted management of these events compared to DWM, the annual nutrient load reduced by ADWM could be significantly more than DWM.

4.4 COST EVALUATION

Costs to implement ADWM are significant at both the farm-scale and for “scale-up” scenarios. Table 2 displays ESE’s estimated cost to retrofit (i.e., the field has an existing tile drainage system) a field with 40 acres of cropland for both an operational manual DWM system and an AWDM system. Note that the $2,500 company cost to plan the system is not included in the estimate but is typically covered by NRCS for producers participating in the Environmental Quality Incentives Program (EQIP) who enter into a financial assistance agreement with NRCS for the development of a conservation activity plan for drainage water management (CAP 130). Without that cost, the estimated total cost for ADWM planning and installation on a 40-acre field is $13,675, with an estimated additional $300 per year in annual automation data fees to operate ADWM. Data storage for ADWM is provided via cloud database. Data successfully uploaded to the cloud database is guaranteed to be stored for 1 year and can be available for as long as 2 years before being deleted during regular system cleanup tasks. The typical duration between upload and deletion is 18 months.

Maintenance costs are expected to be minimal based on ESE's previous experience. This is compared to $6,300 estimated total cost for manual DWM implementation plus $480 per year estimated for labor and mileage associated with water control gate adjustment.

Table 2 - Estimated Manual DWM and ADWM Cost and Comparison

Component or Service to Achieve Manual DWM and ADWM Implementation/Operation Per Site (40 Acre Benefit)	Quantity (#)	Cost Per Unit ($)	Total Cost ($) for Manual DWM	Total Cost ($) for ADWM
Automatic valve, controller, solar panel, and battery – up to 12-inch size tile	1	6,875	0	6,875
Standard water level control structure	1	1,000	1,000	1,000
"Watergates" for water control	3	500	1,500	1,500
Suite of pipes, fittings, and accessories to retrofit existing tile system	1	1,000	1,000	1,000
Installation of all materials and equipment	1	2,800	2,800	2,800
Automation system configuration and startup to achieve operational status	1	500	0	500
Total Cost ($)	**40-Acre Benefit**	**Not Applicable**	**6,300**	**13,675**

NOTE: Table 2 does not include the average cost to develop the needed conservation plan before designing and implementing both a manual DWM and ADWM system. This cost is assumed to be $2,500 for a manual DWM and ADWM system that benefits 40 cropland acres. Much of this cost is covered for eligible producers by NRCS through its Conservation Activity Plan (CAP 130) financial assistance under the Environmental Quality Incentives Program (EQIP). Table 3 also does not include the annual data fees that are required annually to operate ADWM. This cost is estimated at $300 per year for a 40-acre ADWM system.

Table 3 displays ESE's estimated per acre costs and yield benefits for both manual DWM and ADWM. With these estimates, ESE is assuming ADWM's greater precision management of the soil water regime will double the yield increase that manual DWM affords, especially because ADWM will be actively used during the growing season. Based on ESE's observation and experience, it is estimated that the average yield increase for corn for grain will be 2 to 4 bushels per acre for DWM and 4 to 8 bushels per acres for ADWM, with ADWM having on average a 3 bushels per acre advantage over manual DWM and a 6 bushels per acre advantage over uncontrolled free tile drainage. Other assumptions used by ESE to estimate the costs and corn yield returns from ADWM as compared to manual DWM are identified in the following paragraphs, including the total costs of system implementation for a 40-acre cropland field, and Iowa's 2020 average for corn yields and March 2021 average price per bushel of corn. However, it should be noted that the yield increase from manual to automatic DWM is an educated assumption; acres were not monitored for yield to inform this assumption.

Using the assumptions and estimated averages identified in Tables 2 and 3, it is estimated that it would take approximately 11 years for the projected corn yield increases to pay for the implementation costs of a manual DWM system and roughly 12 years for the pay-off of an ADWM system. However, with conservation program financial assistance offered through the NRCS EQIP, up to 75 % of a producer's costs in implementing DWM or ADWM can be covered. Assuming EQIP covers 75% of the cost to implement ADWM, this would reduce a producer's out-of-pocket costs to $3,419, corresponding to a three-year payback period with the estimated corn yield increases from Table 3.

Estimates for ADWM do not account for annual data fees. For an ADWM system serving 40 cropland acres, the annual data fee is estimated by ESE to be $300 per year for one primary water level control structure. At $4.89 per bushel of corn, it will take 61 bushels of corn yield increase to cover this cost annually. Thus, the above estimates for ADWM slightly underestimate the years for the yield increase to cover implementation costs of the system when annual data fees are factored in after implementation and operation for year one. In comparison, however, to manage a manual DWM system to a level similar to the intensity and frequency of ADWM, it is estimated it would take $480 per year, or $180 more per year than for ADWM. It is also possible that the data fees for ADWM will be reduced in the future, assuming widespread adoption of ADWM, due to economies of scale, continuing technological advancements, and competition.

The annual management cost estimate for a DWM system is based on May 2021 discussions between ADC's President and the Director of Research at Crop-Tech Consulting, Inc. ADC's President, Charlie Schafer, estimates that for an average Upper Midwest growing season, there would be four precipitation events of one-half inch or more. Each of the four precipitation events would require in-field manual adjustments of the DWM system's water control structure, thus a round trip between the farmstead and field to adjust the structure concurrent with the precipitation event to retain water so nutrients do not flush out, and another round trip 24 to 36 hours after the event to return the structure to the pre-event water control regime so crops do not become waterlogged. Additionally, the manual DWM system would require four additional round trips per year for seasonal adjustments; spring, summer, fall, and winter. With eight round trips to a manual DWM structure per year, at 20 miles per round trip and $0.50 per mile, and one hour per round trip with the producer's time valued at $30 per hour, the total cost for a producer to achieve a similar level of timely and active management of water flow as compared to ADWM would be approximately $480 per year.

Table 3 - Comparison of Estimated Costs and Benefits of Manual DWM and ADWM

Categories for Comparison	Baseline (Free Drainage)	Manual DWM	ADWM	Difference Between Manual DWM and ADWM
Total installation cost of system	Not applicable	$157.50 per acre & $6,300 per 40 acres	$341.88 per acre & $13,675 per 40 acres	$ 184.38 per acre and $7,375 per 40 acres
Estimated yield increase per year	Not applicable	2 to 4 bushels per acre (use 3 as average)	4 to 8 bushels per acre (use 6 as average)	2 to 4 bushels per acre (use 3 as average)
Average yield per acre (2020 Iowa)	178 bushels per acre	181 bushels per acre	184 bushels per acre	3 bushels per acre
Price per bushel (March 2021 Iowa)	$4.89	$4.89	$4.89	Not applicable
Annual dollar value of increased yield	Not applicable	$14.67 per acre & $586.80 per 40 acres	$29.34 per acre & $1,173.60 per 40 acres	$14.67 per acre & $586.80 per 40 acres
Years for yield increase to cover implementation costs of system	Not applicable	10.7 years, assuming $4.89 per bushel and 120 bushels increase for 40 acres per year	11.6 years, assuming $4.89 per bushel and 240 bushels increase for 40 acres per year	0.9 years longer to cover the cost of ADWM as compared to manual DWM based solely on yield increases

Note: This table is based on Retrofit of 40-Acre Cropland Field and Using Average Figures from Iowa for "Corn for Grain"

Tables 4 through 6 were prepared by ESE and provide an assessment of the estimated costs related to the planning, installation, and data fees associated with the implementation of ADWM for the anticipated 20-year lifespan of a system benefitting 40 acres of cropland. These costs are then shown at various "scale-up" levels, ranging from 25 percent of the estimated suitable cropland acres in Lake Erie Basin (Ohio counties only) receiving ADWM implementation to 100 percent of the suitable cropland acres receiving implementation.

Concurrent with this assessment of ADWM implementation costs is an evaluation of costs per pound of nitrogen and phosphorus reduction per acre per year, and the reductions in edge-of-field loss of these two nutrients for the same "scale-up" scenarios used to estimate the costs of ADWM implementation.

A few observations to point out are as follows:

- Costs to implement ADWM are significant at both the farm-scale and for the various "scale-up" scenarios. However, financial assistance from conservation programs offsets a significant portion of these costs for a producer. When anticipated crop yield increases are accounted for because of ADWM's ability to remotely manage tile flows during the growing season with real-time actions, the return on investment over the 20-year lifespan (even after accounting for the costs of annual data fees) from ADWM exceeds its total costs even without financial assistance from conservation programs.

- Estimates do not account for the added/synergistic benefits of companion and complementary conservation practices applied with ADWM both in-field and at the edge-of-field. ADWM affords timely and precision water management in a field, setting the critical foundation that enables improvement in the effectiveness of other conservation and management practices. Similarly, on-farm returns on the investment in ADWM do not account for the value of the "saved" nutrients. This is, the reduced nutrient loss through tile drainage because ADWM implementation increases the availability of these nutrients in the soil profile for crop use. Even at a relatively low price of $0.45 per lb. as the cost of nitrogen applied, a properly managed ADWM system serving 40 cropland acres would help to save $18 per lb. for crop production.

- The opportunity for ADWM implementation in Lake Erie Basin (Ohio) is significant, with over 914,000 estimated suitable cropland acres. Equally impressive are the estimated annual nutrient loss reductions at edge-of-field: 9.1 to 13.7 million pounds per year for nitrogen, and 228,587 to 457,173 per year for phosphorus if all 914,000 suitable cropland acres received ADWM.

- These estimates could be improved through modeling on a "regional scale" such as by using the Nutrient Tracking Tools new capabilities and/or in combination with the Conservation Effects Assessment Project led by NRCS since 2003. This modeling needs to be carried out by experienced modelers/scientists, with practical input from technical assistance providers and other conservationists.

- The recent assessment of barriers to the adoption of drainage water management conducted by ESE through the Conservation Drainage Network will help to further inform actions needed to improve producer adoption of ADWM and achieve its more widespread use at scale in Lake Erie Basin and other watersheds with a high proportion of tile-drained cropland.

Table 4 assumes the average annual expected nutrient reduction from ADWM will be 10 to 15 pounds per acre for nitrogen and 0.25 to 0.50 pounds per acre for phosphorus. Assuming an average cost of $554 (rounded) per acre to plan, install, configure, and manage the data/system for the 20-year lifespan of an ADWM system applied to existing tile drainage for a 40-acre cropland field, the annual expected cost per acre per year for nitrogen reduction would range from $2.77 to $1.85 per pound, and $110.84 to $55.44 per pound for phosphorus. A typical 40-acre cropland field with ADWM implemented would reduce nitrogen by 400 to 600 pounds per year, and phosphorus loss by 10 to 20 pounds per year. The costs for a producer to plan and install an ADWM system would be no more than 25 percent of these specific costs because of NRCS conservation program financial assistance readily available for these elements of ADWM. However, annual data management costs of $300 per 40-acre ADWM system would increase producer costs by $6,000 over the 20-year lifespan of the system. Thus, the producer share of total costs is estimated at 45.3 percent over the 20-year lifespan. However, expected crop yield increases (estimate at 6 bushels per acre per year) from the active management of soil water levels through ADWM during the growing season would return an estimated $23,472 to the producer over the 20-year period, more than double the producer's share of the ADWM system costs estimated at $10,044.

Table 4 - Annual Estimated Cost Per Acre for Nitrogen and Phosphorus Reduction

ADWM Components = Planning + Equipment + Installation + System Configuration + Data Management Over 20-Year Lifespan	Total Cost Without Any Conservation Program Assistance ($)	Public Share (75%) of Costs Under Typical Conservation Program Assistance ($)	Producer Share (25%) of Costs Under Typical Conservation Program Assistance ($)
Conservation Activity Plan for ADWM (CAP 130)	2,500	1,875	625
Equipment and Installation	13,175	9,881.25	3,293.75
Automation System Configuration and Startup	500	375	125
Data fees for entire 20-year lifespan of ADWM system (estimated @$300 per year)	6,000	0 No conservation program assistance currently available	6,000
TOTAL COST for entire 20-year lifespan of an ADWM system that benefits 40 acres	**22,175** **(100%)**	**12,131.25** **(54.7% of total cost)**	**10,043.75** **(45.3% of total cost)**
Cost per acre for entire 20-year ADWM system lifespan	554.38	303.28	251.09
Cost per acre for one year, with costs spread evenly over 20 years	27.72	15.16	12.55
Cost per pound of nutrient reduction per acre per year	**Nitrogen – 2.77 to 1.85** **Phosphorus – 110.88 to 55.44**	**Nitrogen – 1.52 to 1.01** **Phosphorus – 60.64 to 30.32**	**Nitrogen – 1.26 to 0.84** **Phosphorus – 50.20 to 25.10**

Table 5 - Estimation of Cropland Acres Suitable for ADWM

Assessment Category	Acres Suitable for ADWM	ESE Notes
NRCS Estimate of Cropland Acres Suitable for Drainage Water Management for 9 Upper Mississippi River and Great Lakes Basin States (February 1, 2021 – NRCS Central National Technology Support Center, TX Map 2012-42)	29,214,939 acres	This 2012 estimate is still relevant almost ten years later because the growth of DWM (ADWM) systems installed on these cropland acres has been insignificant in comparison to the total acres of opportunity. See note number 1 below.
NRCS Estimate of Cropland Acres Suitable for Drainage Water Management for Ohio in its entirety (February 1, 2021 – NRCS Central National Technology Support Center, TX Map 2012-42)	2,146,231 acres	This estimate includes all counties in Ohio, not only the 35 counties that drain wholly or partially through Lake Erie Basin.
ESE's Estimate of Cropland Acres Suitable for Drainage Water Management in the 35 Ohio Counties that Completely or Partially Drain through Lake Erie Basin	914,346 acres	This estimate was based on the cropland acres identified by NRCS as suitable for DWM (ADWM) for the 35 Ohio counties that drain through Lake Erie Basin. Of these counties, 18 drain entirely to the Basin; the other 17 counties have varying portions of their acres that drain to the Basin. If a county, such as Auglaize, had 77 percent of its acres drain to the Basin, then it was assumed 77 percent of its total suitable acres for DWM (ADWM) also drained to the Basin. This approach provides a rough approximation of suitable acres only.

NOTES:

- **Assumed if a field is suitable for manual DWM, it is suitable for ADWM as the same NRCS conservation practice standard (Code 554) applies to both.**
- **For comparison purposes, new EQIP obligations for Ohio during FY2020 were $33.5 million, inclusive of both technical and financial assistance funds. Additionally, Ohio had 1,214 active EQIP contracts with an open obligation value of $128.5 million in FY2020.**

Table 6 - "Scaling-Up" ADWM Implementation

Assessment Categories	25 % of Suitable Acres	50 % of Suitable Acres	75 % of Suitable Acres	100 % of Suitable Acres
Cropland acres benefitting from ADWM	228,587 acres	457,175 acres	685,760 acres	914,346 acres
Total ADWM cost for cropland acres benefitted:	$127 M	$254 M	$380 M	$507 M
Public share at 54.7 percent of total cost	$70 M	$139 M	$208 M	$277 M
Producer share at 45.3 percent of total cost	$58 M	$115 M	$172 M	$230 M
Nitrogen loss reduction – total lbs. for cropland acres benefitted, per year				
Upper end of range @ 15 lbs. per acre, per year	3.4 M lbs.	6.9 M lbs.	10.3 M lbs.	13.7 M lbs.
Lower end of range @ 10 lbs. per acre, per year	2.3 M lbs.	4.6 M lbs.	6.9 M lbs.	9.1 M lbs.
Phosphorus loss reduction – total lbs. for cropland acres benefitted, per year				
Upper end of range @ 0.5 lbs. per acre, per year	114,294 lbs.	228,588 lbs.	342,880 lbs.	457,173 lbs.
Lower end of range @ 0.25 lbs. per acre, per year	57,147 lbs.	114,294 lbs.	171,440 lbs.	228,587 lbs.

Note: Estimated Costs and Nutrient Loss Reductions by Scenario Based on Percent of Suitable Cropland Acres Benefitted.

4.5 SCALABILITY EVALUATION

As ADWM works on a field scale, the amount of ADWM necessary is directly related to the acres treated by nutrients. Therefore, scalability is straightforward for ADWM systems. However, to date the cropland acres under DWM practices are magnitudes below the reasonable expectation for how many acres could benefit from this conservation practice. In ESE's opinion, this is largely due to the fact that manual DWM, which has been promoted over the last few decades, does not address significant barriers to producer adoption, including the time and effort required for active water control gate management in the field, lack of experienced technical support for planning and implementation, and lack of automated data collection (Christensen, 2021). The incorporation of ADWM could address those barriers, but ESE believes that site-specific planning and implementation of ADWM must be brought to scale within the Lake Erie Basin to fully realize and optimize the benefits of this conservation practice.

To support the need for more widespread understanding and buy-in from the producer community for scalability to be successful, ESE lays out an assessment of the estimated costs per pound of nitrogen and phosphorus reduction per acre per year, and the reductions in edge-of-field losses of these nutrients for the scale-up scenario to the 35 Ohio counties contributing to the Lake Erie Basin. Table 4 assumes the average annual expected nutrient reduction from ADWM will be 10 to 15 pounds per acre for nitrogen and 0.25 to 0.50 pounds per acre for phosphorus. Assuming an average cost of $554 (rounded) per acre to plan, install, configure, and manage the data/system for the 20-year lifespan of an ADWM system applied to existing tile drainage for a 40-acre cropland field, the annual expected cost per acre per year for nitrogen reduction would range from $2.77 to $1.85 per pound, and $110.84 to $55.44 per pound for phosphorus. A typical 40-acre cropland field with ADWM implemented would reduce nitrogen by 400 to 600 pounds per year, and phosphorus loss by 10 to 20 pounds per year.

The estimated cost per pound of phosphorus reduced compares favorably with other agricultural practices reviewed by Tetra Tech for The Nature Conservancy (Tetra Tech, 2019). For example, Tetra Tech estimated that agricultural best management practices such as conservation tillage, cover crops, and nutrient management plans cost between $10 and $300 per pound of phosphorus removed, with a large range of uncertainty due to location, design, treatment area, etc. Tetra Tech's estimated cost for manual DWM ranged from $280.11 to $43.25 per pound.

The opportunity for ADWM implementation in Lake Erie Basin (Ohio) is substantial, with over 914,000 estimated suitable cropland acres. Table 5 is based on an assessment conducted by NRCS in 2012 of the cropland acres suitable for DWM/ADWM in 9 Upper Mississippi River and Great Lakes Basin states, including Ohio. Data for a state is provided by NRCS to the county level. Suitable cropland acres were determined by the NRCS using three criteria: representative slope of less than one percent, representative soil classified as hydric, and depth to water table of less than 18 inches. According to ESE, data from the NRCS Environmental Quality Incentives Program (EQIP) is a valid indicator of the total installation of DWM/ADWM because most implementation occurs with EQIP assistance. Publicly accessible data from NRCS posted on the web shows only 2,558 systems installed benefitting 105,288 acres between fiscal years 2009 and FY2020. These 105,288 acres represent only 0.36 percent of the 29.2 million cropland acres identified by NRCS in 2012 as suitable for DWM/ADWM.

ESE also points out estimated annual nutrient loss reductions at edge-of-field as 9.1 to 13.7 million pounds per year for nitrogen, and 228,587 to 457,173 per year for phosphorus, assuming all 914,000 suitable cropland acres received ADWM. These estimates are summarized in further detail, based on percent of suitable acres with ADWM implemented, in Table 6.

4.6 INFORMATION GAP EVALUATION

Based on ESE's technology submission for ADWM, it is necessary to obtain more information about the performance of ADWM compared to manual DWM, and how ADWM outperforms manual DWM. To Tetra Tech's knowledge, no paired studies directly comparing DWM to ADWM have been performed.

Based on the experience of ESE in helping producers to plan, design, and implement both manual DWM and ADWM, it is believed that ADWM will outperform DWM both with regard to the nutrient load reduction through tile outlets and with regard to crop resilience and yields. There is also the expectation that the automation features of ADWM will create greater incentive for producers to adopt ADWM when its benefits over manual DWM are fully understood. However, with the overall lack of case studies specific to ADWM implementation, it is difficult to evaluate the accuracy of these expectations.

There is also an information gap regarding the barriers to adoption for manual DWM and ADWM systems. Although ESE led a DWM-specific survey on this topic (refer to Section 4.2.1), this issue remains a significant one that will affect the ability of ADWM to result in large scale reductions in nutrient loading to Lake Erie. Finally, a study by Williams et al. (2015) states that future research should focus on quantifying the effect of DWM on nutrient transport in other flow paths beyond tile, such as lateral seepage or surface runoff, to further evaluate drainage water management as a best management practice in tile drained landscapes.

4.7 FEASIBILITY FOR LARGE-SCALE TECHNOLOGY DEMONSTRATION

A large-scale technology demonstration is very feasible with ADWM. The technology is already operating on a number of fields with units typically treating 40 acres through the use of float operated water gates connected in-line with the drainage tiles for adjacent fields. These water gates serve to maintain an increase in the water level from the downstream side of the valve to the upstream side. This method increases the possible acreage that can be served by a single water level control structure. Figure 2 shows in-line water gates and how they increase the cropland acres that may benefit from a single control structure for sloping, adjacent fields.

The USDA NRCS explains in their Conservation Practice Code 554 summary of DWM that DWM performs best in flat topography landscapes with intensive tile systems and on fields 20 acres or more in size (USDA, 2019). According to ESE's proposal, 12-digit HUCs are the appropriate small watershed level to demonstrate ADWM because they provide enough acres to achieve multiple applications across multiple operations. HUC12s also provide enough consistency in physiography and types of farming operations to effectively evaluate results, gain lessons learned, and apply continuous improvement and adaptive management.

If ESE were to receive funds for a large-scale ADWM demonstration project, their preference would be to introduce a multitude of ADWM systems across a selected HUC12 watershed and monitor nutrient loading and crop yield effects. Funding would be managed between Ohio and ESE, and ESE would work with land contractors to install and producers to manage the ADWM systems. There would be no cost to producers for implementation in a properly designed multi-year cooperative funding agreement, which also could include other contributing partner agencies and organizations that share concerns for the Lake Erie Basin and producer adoption of innovative conservation technologies and approaches. The selected HUC12 watershed would need to have limited topographic slope and significant acres of tile-drained cropland; there are many such HUC12 watersheds within the Lake Erie Basin.

Figure 2 – Example of In-line Water Gates

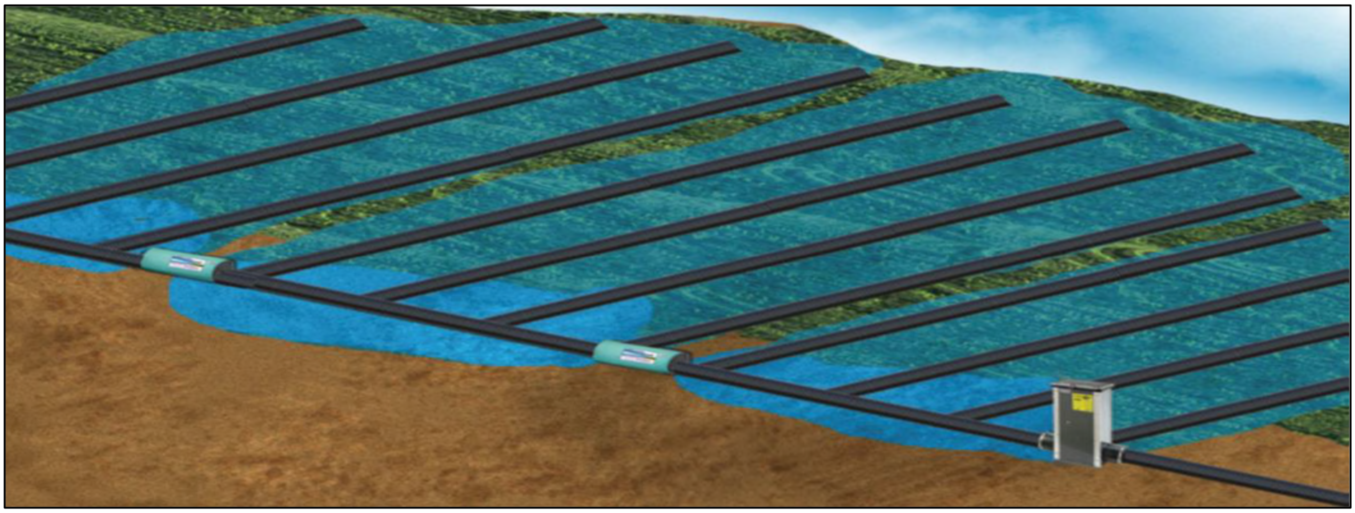


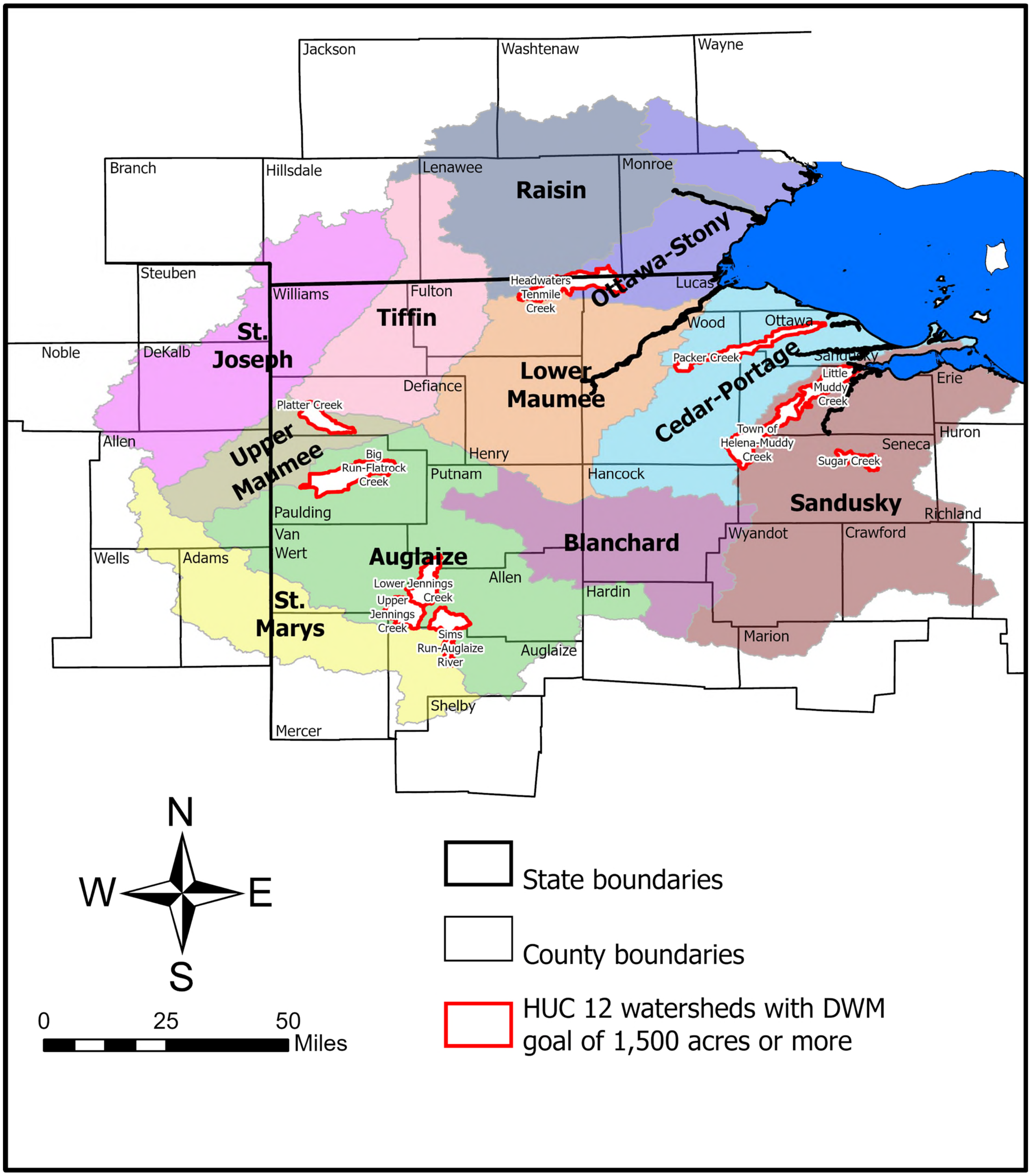
Image provided courtesy of Ecosystem Services Exchange (White, 2021)

4.8 FEASIBILITY FOR FULL-SCALE IMPLEMENTATION

A February 18, 2015 report titled Real Time-Drainage Water Management in the Great Lakes, published by TNC, estimated the annual nutrient load reduction under realistic scenarios modeled for active drainage water management could reach or exceed 15 percent for the Lake Erie Basin (TNC & Nicholas-h2o, 2015). Therefore, the potential exists for both phosphorous and nitrogen reductions with the widespread adoption of ADWM in the southern Great Lakes region. Western Lake Erie Basin (WLEB) is approximately 18,648 square kilometers in size and has over half of its land use in corn and soybean fields. With much of that land already tile drained or suitable for tile drainage, there is opportunity for ADWM implementation to help reduce nitrogen and phosphorus loss on a large watershed scale. However, the challenge will be to improve producer awareness of the availability of ADWM, its advantages and benefits, and work with partnering agencies and organizations to foster producer adoption of this innovative technology.

Upon review of 60 EPA-approved 9-Element Nonpoint Source Implementation Strategy Plans specific to the Western Lake Erie Basin (Attachment A), ESE determined an aggregate established goal in these 60 plans for manual drainage water management is 43,415 acres in the WLEB. HUC-12 subwatersheds with plans that identified at least 1,500 acres of DWM are shown in Figure 3. If ESE is selected as a pilot project partner for the implementation of ADWM via H2Ohio TAP, the Nonpoint Source Plans and goals for WLEB HUC-12s provide good information on the best candidates for ADWM project sites. Overcoming the barriers to DWM adoption for producers and creating partnership commitment and momentum to support its implementation and informed active management, will be critical if this conservation measure is to see widespread adoption proportionate with the need and the scope/magnitude of the Lake Erie Basin opportunity that exists.

Figure 3 - HUC-12 watersheds with 9-Element NPS Implementation Strategy Plans



4.9 PROBABILITY OF SUCCESS

Previous studies of DWM and ADWM demonstrate that this technology will result in reducing nutrient loads that are contributing to the Lake Erie algal blooms if it is installed on a large-scale basis. As stated in Section 0, approximately 15 percent of the Lake Erie Basin, or 1.1 million acres, may be suitable for ADWM. The probability of success is therefore high if it can be deployed at a sufficient scale, which in turn is dependent on the financial incentives offered to landowners and their greater awareness of the positive crop yield impacts.

4.10 FINANCIAL VIABILITY

Ecosystem Services Exchange (ESE) was incorporated in 2010 as a limited liability corporation (LLC). The company currently has over $875,000 in active agreements and contracts for its technical services related to the implementation of ADWM and other water management technologies. ESE has deployed water management conservation practices in Delaware, Illinois, Indiana, Iowa, Maryland, Minnesota, Nebraska, North Carolina, North Dakota, Ohio, South Dakota, and Wisconsin. Seven full- and part-time employees make up the company's staff, and ESE's four leaders have a plethora of experience in the USDA, Capitol Hill, and agricultural drainage management sectors.

ESE is a Technical Service Provider, certified by the Agricultural Drainage Management Coalition under the USDA NRCS requirements for planning, design, and implementation assistance for a wide range of water management conservation practices, including ADWM. ESE works closely with its sister company, Agri Drain Corporation (ADC), in the further development and implementation of ADWM. ADC is a highly respected and successful commercial entity that is an American manufacturer of control systems for drainage water management. They provide structures, valves, gates and all other materials necessary for operational ADWM systems.

ESE's Intellectual Property (IP) licensing agreement and direct relationship with ADC also provides ESE with direct access to thousands of land improvement contractors in the U.S. and Canada. ESE also is authorized to use several patented products licensed to ADC, including innovative systems and methods to remotely manage and monitor water levels and flow rates in tile-drained fields in the form of ADWM.

4.11 QAPP

ESE did not provide any raw data to support the technology evaluation and therefore no Quality Assurance Project Plan (QAPP) was provided. Instead, information about the performance of DWM and ADWM was obtained from the literature, much of which was peer-reviewed. The underlying data are therefore assumed to be of high quality.

4.12 DATA VALIDATION

Since most of the data used to prepare this evaluation were provided by parties other than ESE, the data are considered to be validated.

4.13 SUPPLY CHAIN

ADWM system technology relies on several contributing components. However, Tetra Tech did not identify any supply chain risks. If solar panels and other electronic components that contribute to the ADWM system are readily available, then supply chain issues should not be present.

4.14 ENVIRONMENTAL RISKS

It seems unlikely that deploying ADWM would create an risks to the environment. One of the main goals of ADWM is to benefit the environment by reducing the transport of water and pollutants from agricultural cropland to water bodies.

4.14.1 Health & Safety

It appears unlikely that implementation of ADWM technology significant poses risks to the health and safety of those deploying the systems. However, wearing personal protective equipment (PPE) is likely required when installing ADWM systems there could be confined space entry requirements to access the systems below ground if maintenance is necessary.

4.15 COMMUNITY PERCEPTION & DISPROPORTIONATE IMPACT

It is claimed that ADWM technology aligns with the values, experiences, and needs of agricultural producers and their communities. ESE cites several reasons for ADWM's compatibility with producers and their communities as it is a science-based conservation practice that can be readily combined with other conservation practices for increased productivity and improved water quality. ADWM demonstrates that agricultural production and conservation are compatible goals for a producer. Furthermore, ADWM uses management concepts that are not new to producers. Rather, ADWM enables a producer to more readily implement water and nutrient management concepts in a practical way that is less labor-intensive as manual DWM.

ESE explains that ADWM takes advantage of improved technology at an opportune time in today's agricultural production society, where producers are better informed and more receptive to incorporating technology that will improve agricultural operations. Given the possibility for NRCS financial assistance as well as the anticipated crop yield increase during dry periods when free flowing tile drainage would otherwise lose water storage, ADWM is regarded by ESE as a cost-effective practice. Lastly, ADWM coincides well with producers who are adept at combining agricultural knowledge with innovative technology to optimize operations. The biggest obstacle here is for ESE and other entities to convince producers to adopt ADWM for their tile-drained cropland.

4.16 WASTE/BY-PRODUCT MANAGEMENT REQUIREMENTS

It is unlikely that waste and/or by-product management requirements will impact the implementation of ADWM systems. There may be recycling opportunity for the electronic and solar components of ADWM once the system reaches its lifecycle. This recycling opportunity, if it exists, could be managed between the producer who has adopted an ADWM system and the vendor.

5.0 LIST OF REMAINING DATA GAPS

As explained in Section 4.6, the primary information gaps relating to ADWM are:

1. The performance of automated DWM compared to manual DWM; and
2. The willingness of landowners to adopt ADWM on a large enough scale to significantly reduce nutrient loading to Lake Erie.

6.0 FINDINGS AND OPINIONS

Based on our review of the available information and discussions with ESE, Tetra Tech has reached the following conclusions regarding ADWM:

- Agreement that related technology, DWM, is effective at reducing nutrient loading. There is also the potential for ADWM to be even more effective at reducing tile discharge during large events when most of the annual loading occurs because of the ability to better manage the tile gates.

- Additional research needed on how ADWM performs at controlling nutrient loads (i.e., instead of relying on DWM studies as surrogates). This could be a goal of a pilot project funded by H2Ohio.

- ADWM is a cost effective technology when compared to other practices intended to address nutrient loading, especially when the financial assistance available from NRCS and other sources for its planning, design, and implementation and the potential crop yield increases are considered. Estimated total cost of reducing phosphorus at $55/lb. to $110/lb. is within the range of other similar agricultural best management practices.

- ADWM has strong potential for scalability, as there are numerous fields within the Western Lake Erie basin where ADWM could be applied.

- Biggest barrier to widespread adoption of ADWM is landowner willingness, which could be further evaluated through a pilot project funded by H2Ohio.

7.0 REFERENCES

Christensen, Tom. (2021). Review of Preliminary Highlights of Results, "Barriers to Producer Adoption of Drainage Water Management (DWM)." Survey of Conservation Drainage Network (CDN) Members, July 6, 2021.

Conservation Drainage Network (CDN). (2021). "CDN 2021 Session1." April 7, 2021. www.youtube.com. https://www.youtube.com/watch?v=FMrL5DlU8lI .

Crabbé, P., Lapen, D. R., Clark, H., Sunohara, M. & Liu, Y. (2012) .Economic benefits of controlled tile drainage: Watershed evaluation of beneficial management practices, South Nation river basin, Ontario. Water Qual. Res. J. Can. 47, 30–41.

Feset, S.E., Strock, J.S., Sands, G.R., Birr, A.S. (2010). 9th International Drainage Symposium held jointly with CIGR and CSBE/SCGAB Proceedings, 13-16 June 2010 IDS-CSBE-100154.(doi:10.13031/2013.32137)

Ghane, E., Fausey, N.R., Shedekar, V. S., Piepho, H. P., Shang, Y. & Brown, L. C. (2012). Crop yield evaluation under controlled drainage in Ohio, United States. J. Soil Water Conserv. 67, 465–473.

H2Ohio Technology Assessment Program (H2Ohio TAP), Lake Erie Algal Bloom. (2020). Request for Technologies.

Harrigan, Tim. (2015). "Feeding Our Crops and Protecting Our Water with Bioreactors and Controlled Drainage." May 7, 2015. MSU Extension.

King, K.W., Williams, M.R., Macrae, M.L., Fausey, N.R., Frankenberger, J., Smith, D.R., Kleinman, P.J.A. and Brown, L.C. (2015). Phosphorus Transport in Agricultural Subsurface Drainage: A Review. J. Environ. Qual., 44: 467-485. https://doi.org/10.2134/jeq2014.04.0163

Ross, J.A., Herbert, M.E., Sowa, S.P., Frankenberger, J.R., King, K.W., Christopher, S.F., Tank, J.L., Arnold, J.G., White, M.J., Yen, H. (2016). A synthesis and comparative evaluation of factors influencing the effectiveness of drainage water management. Agric. Water Manag. 178, 366–376. https://doi.org/10.1016/j.agwat.2016.10.011.

Schafer, Charles, Dave White, Alex Echols, and Thomas Christensen. (n.d.). "Seizing the Opportunity: Realizing the Full Benefits of Drainage Water Management." Accessed July 2, 2021. https://www.swcs.org/static/media/cms/75th_Book__Chapter_13_413824251E8F0.pdf .

Shore, Dee. (2020). "Not Too Wet, Not Too Dry." College of Agriculture and Life Sciences. November 5, 2020. https://cals.ncsu.edu/news/research-for-better-water-management-not-too-wet-not-too-dry/.

Skaggs, R.W., M. A. Youssef, J. W. Gilliam, and R. O. Evans. (2010). "Effect of Controlled Drainage on Water and Nitrogen Balances in Drained Lands." Transactions of the ASABE 53 (6): 1843–50. https://doi.org/10.13031/2013.35810.

Skaggs, R.W., N.R. Fausey, and R.O. Evans. (2012). Drainage water management. Journal of Soil and Water Conservation 67(6):167A-172A. https://doi.org/10.2489/ jswc.67.6.167A.

Tetra Tech, Inc. (2019). Cost Benefit Synthesis of Best Management Practices to Address Nutrients and Sediment in Ohio. Prepared for The Nature Conservancy. December 4, 2019.

The Nature Conservancy and Nicholas-h2o . (2015). Real Time-Drainage Water Management in the Great Lakes, Final Report to the Great Lakes Protection Fund. Prepared by The Nature Conservancy and Nicholas-h2o. 2/18/2015. 37 pages.

"Turn-Key" Assistance for Conservation Drainage Practices Offered for Eligible Farmers in Select Minnesota Counties". (n.d.). www.licanational.com. https://www.licanational.com/wp-content/uploads/2021/06/ESE-News-Release-Turn-Key-Assistance-for-Conservation-Drainage-Practices-Offered-for-Eligible-Farmers-in-Select-Minnesota-Counties-003.pdf .

United States Department of Agriculture (USDA). (2019). "Drainage Water Management." USDA.gov. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/?cid=nrcs144p2_027166 .

Van Wagner, Tom. (2016). Making Drainage Water Management Work on Your Farm. 2016 Michigan Watershed Summit. https://www.mi-wea.org/docs/6B%20Tom%20VanWagner%20Watershed%20Summit.pdf

White, Dave. (2021). H2Ohio Technology Assessment Program (TAP), Automated Drainage Water Management (ADWM) Technology Submission. Adair, IA: Ecosystem Services Exchange.

Williams, M.R., K.W. King, and N.R. Fausey. (2015). "Drainage Water Management Effects on Tile Discharge and Water Quality." Agricultural Water Management 148 (January): 43–51. https://doi.org/10.1016/j.agwat.2014.09.017.

ATTACHMENT A

Western Lake Erie Basin (WLEB)

Established "Acres Treated" Goals for Drainage Water Management (DWM)

in

Ohio EPA Approved 9-Element Nonpoint Source Implementation Strategies

for

12-Digit HUCs as of July 11, 2021

12-Digit HUC	HUC Name	9-Element NPS Plan Date	HUC SQ MI	% of HUC in Row Crops	DWM Acre Goal for HUC
041000010301	Shantee Creek	Version 1.0, November 20, 2018	15.8	0 (22 ac.)	0
041000010303	Prairie Ditch	Version 1.0, June 15, 2018	18.6	73.7	750
041000010304	Headwaters Tenmile Creek	Version 1.0, July 5, 2018	48.3	89.1	1,600
041000010306	Tenmile Creek	Version 1.0, Aug. 24, 2017	146.5	19.1	750
041000010307	Heldman Ditch-Ottawa River Version 1.1 Version 1.2 Version 1.3	Version 1.0, Aug. 2, 2017 Version 1.1, October 3, 2018 Version 1.2, April 12, 2019 Version 1.3, January 5, 2021	28.1	0.1	0
041000010308	Sibley Creek-Ottawa River	Version 1.0, October 22, 2018	22.4	0	0
041000010309	Detwiler Ditch	Version 1.0, October 10, 2018	7.4	0	0
041000040203	Blierdofer Ditch	Version 1.0, January 24, 2020	14.6	71.8	400
041000040301	Little Black Creek	Version 1.0, January 16, 2020	25.0	91.6	500
041000040302	Black Creek	Version 1.0, January 14, 2020	29.5	91.4	500
041000040303	Yankee Run	Version 1.0, December 6, 2019	59.4	84.0	0 ACPF @ 10,809
041000040305	Town of Wilshire - Saint Marys River	Version 1.0, January 30, 2020	13.4	90.0	400

12-Digit HUC	HUC Name	9-Element NPS Plan Date	HUC SQ MI	% of HUC in Row Crops	DWM Acre Goal for HUC
					ACPF @ 2,454
041000040401	Twentyseven Mile Creek	Version 1.0, January 30, 2020	28.7	88.0	500 ACPF @ 6,645
041000050206	Platter Creek	Version 1.0, January 16, 2020	21.7	88.4	2,400
041000060303	Flat Run	Version 1.0, February 28, 2020	33.0	80.3	600
041000060502	Brush Creek Version 1.1	Version 1.0, August 3, 2020 Version 1.1, January 19, 2021	66.0	83.2	1,300
041000070203	Sims Run - Auglaize River	Version 1.0, April 29, 2020	28.8	67.6	1,600
041000070204	Sixmile Creek - Auglaize River	Version 1.0, April 15, 2020	29.9	78.1	1,350
041000070301	Upper Hog Creek	Version 1.0, January 15, 2020	21.7	84.7	400
041000070302	Middle Hog Creek	Version 1.0, April 15, 2020	30.4	81.7	400
041000070303	Little Hog Creek	Version 1.0, April 15, 2020	22.2	70.0	100
041000070304	Lower Hog Creek	Version 1.0, April 15, 2020	16.1	77.4	200
041000070403	Honey Run	Version 1.0, February 7, 2020	13.3	77.3	700
041000070604	Dry Fork-Little Auglaize River	Version 1.0, February 26, 2020	57.1	85.8	320
041000070901	Upper Jennings Creek	Version 1.0, April 15, 2020	27.0	90.5	3,800
041000070903	Lower Jennings Creek	Version 1.0, April 15, 2020	28.1	86.7	1,700
041000070904	Big Run-Auglaize River	Version 1.0, February 3, 2020	21.0	86.1	250
041000070905	Lapp Ditch-Auglaize River	Version 1.0, May 19, 2020	21.2	92.0	300
041000070906	Prairie Creek (Putnam County)	Version 1.0, February 26, 2020	13.8	87.9	220
041000070907	Town of Oakwood-Auglaize River	Version 1.0, February 26, 2020	16.5	85.4	280

12-Digit HUC	HUC Name	9-Element NPS Plan Date	HUC SQ MI	% of HUC in Row Crops	DWM Acre Goal for HUC
041000071205	Wildcat Creek-Flatrock Creek	Version 1.0, February 3, 2020	55.8	88.7	1,100
041000071206	Big Run - Flatrock Creek	Version 1.0, March 6, 2020	48.3	78.8	1,700
041000071207	Little Flatrock Creek	Version 1.0, March 3, 2020	17.8	88.3	600
041000071208	Sixmile Creek - Paulding	Version 1.0, March 6, 2020	28.3	80.9	850
041000071209	Eagle Creek - Auglaize River	Version 1.0, March 6, 2020	34.3	61.4	1,000
041000080103	The Outlet-Blanchard River	Version 1.0, October 10, 2018	N/A	N/A	N/A
041000080205	Blanchard River-City of Findlay	Version 1.0, February 20, 2019	15.9	38.4	100
041000080301	Upper Eagle Creek	Version 1.0, May 29, 2020	26.4	80.8	200
041000080304	Howard Run-Blanchard River	Version 1.0, June 4 2020	36.1	54.4	100
041000080403	Marsh Run-Little Riley	Version 1.0, September 26, 2018	N/A	N/A	N/A
041000080405	Lower Riley Creek-Blanchard River	Version 1.0, January 30, 2019	25.2	77.4	500
041000080501	Tiderishi Creek	Version 1.0, April 5, 2018	19.2	79.6	400
041000080602	Pike Run	Version 1.0, June 24, 2020	28.6	78.5	200
041000090201	Preston Run-Maumee River	Version 1.0, Aug. 7, 2017	17.1	52.0	15
041000090701	Ai Creek	Version 1.0, July 20, 2018	N/A	N/A	N/A
041000090702	Fewless Creek - Swan Creek	Version 1.0, June 25, 2018	28.3	85.5	1,450
041000090703	Gale Run-Swan Creek	Version 1.0, November 16, 2018	N/A	N/A	N/A
041000100705	Berger Ditch	Version 1.0, November 20, 2018	N/A	N/A	N/A

12-Digit HUC	HUC Name	9-Element NPS Plan Date	HUC SQ MI	% of HUC in Row Crops	DWM Acre Goal for HUC
041000090801	Upper Blue Creek	Version 1.0, November 16, 2018	N/A	N/A	N/A
041000090802	Lower Blue Creek	Version 1.0, July 6, 2018	24.5	76.3	1,080
041000090803	Wolf Creek	Version 1.0, Aug. 17, 2017	27.1	13.0	160
041000090804	Heilman Ditch-Swan Creek Version 1.1 Version 1.3	Version 1.0, May 22, 2017 Version 1.1, August 21, 2019 Version 1.3, February 2, 2021	36.8	31.1	300
041000090901	Grassy Creek Diversion	Version 1.0, August 7, 2018	24.8	77.6	500
041000090902	Grassy Creek	Version 1.0, October 25, 2018	N/A	N/A	N/A
041000090904	Delaware Creek-Maumee River Version 1.1	Version 1.0, May 10, 2017 Version 1.1, May 12, 2020	13.7	0.54	0
041000100601	Upper Toussaint	Version 1.0, August 21, 2018	74.0	79.0	950
041000100602	Packer Creek	Version 1.0, July 20, 2018	34.5	82.7	1,950
041000100603	Lower Toussaint River	Version 1.0, May 16, 2018	30.6	70.7	0
041000100701	Turtle Creek	Version 1.0, June 12, 2018	40.6	67.3	0
041000100702	Crane Creek	Version 1.0, June 15, 2018	56.4	74.7	0
041000100703	Cedar Creek-Frontal Lake Erie	Version 1.0, July 16, 2018	58.0	63.3	0
041000100704	Wolf Creek-Frontal Lake Erie	Version 1.0, August 21, 2018	15.2	53.5	790
041000100706	Otter Creek - Frontal Lake Erie	Version 1.0, May 12, 2017	21.1	25.6	0
041000111104	Sugar Creek	Version 1.0, June 29, 2020	13.5	71.0	2,150 **ACPF @ 1,906**
041000111301	Muskellunge Creek	Version 1.0, June 16, 2020	46.3	81.0	0 **ACPF @ 16,931**

12-Digit HUC	HUC Name	9-Element NPS Plan Date	HUC SQ MI	% of HUC in Row Crops	DWM Acre Goal for HUC
041000111402	Town of Helena - Muddy Creek	Version 1.0, June 29, 2020	45.2	82.0	3,500 ACPF @ 16,976
041000111403	Little Muddy Creek	Version 1.0, May 28, 2020	28.5	84.0	2,000 ACPF @ 10,747
TOTALS	Not Applicable	Not Applicable	**1,897.6 SQ MI (1.21 M Acres)**	Not Applicable	**43,415 Acres**

NOTES:

1. Source: Ohio EPA website on July 11, 2021 under "Ohio Nonpoint Source Pollution Control Program" with link to "Approved 9-Element NPS-ISs". Each individual NPS plan was reviewed for these numbers: SQ MI in HUC-12, % Row Crop in HUC-12, and DWM Acre Goal in each HUC-12.
2. Both SQ MI (square miles in HUC-12) and % Row Crop (% of HUC-12 in row crop production) were rounded.
3. Yellow/beige highlighted rows denote NPS plans where the DWM goal exceeds 1,500 acres.
4. ACPF – Denotes use of Agricultural Conservation Planning Framework (ACPF) in the NPS plan development. ACPF is a watershed-based tool to aid conservation planning and is semi-automated within ArcGIS software. ACPF was used in these seven HUC-12s noted above to estimate the potential suitable cropland acres for drainage water management (DWM). NPS plan development in other HUC-12s also may have used ACPF, but it was not noted in the NPS plan.
5. Seven NPS plans listed above were not accessible on Ohio EPA's website. The links for these plans brought up no plan or other information.
6. In a few NPS plans, the goals for DWM are used interchangeably with saturated buffers or grassed waterways, even though it is unlikely the effect of phosphorus reductions would be the same for each of these three conservation practices on a site-specific basis.
7. A few NPS plans without goals for DWM but with a high percentage of the watershed in row crop production did not establish DWM goals but reference use of ag "BMPs" generically.
8. Soil and water conservation districts were responsible for the development of the NPS plans posted on Ohio EPA's website. The development of many plans was assisted either by Tetra Tech or Civil and Environmental Consultants, Inc. of Toledo, Ohio.
9. Western Lake Erie Basin (WLEB) is between 6 and 7 million acres in size; an exact acreage number could not be readily located.