On-Farm Water Recycling as an Adaptation Strategy for Drained Agricultural Land in the Western Lake Erie Basin

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The goal of this project was to begin a process of analyzing the potential for increasing on-farm water storage as a climate change adaptation strategy. To gain understanding of the opportunities and barriers to on-farm water recycling in the Great Lakes region, we talked with drainage contractors, agency staff, farmers, extension specialists, irrigation dealers, and farmers who have and have not installed on-farm water recycling. We used historic yield data together with climate projections to estimate potential yield benefits that could be achieved by the Ohio WRSIS water recycling systems under expected future climate conditions. We have shared this information at drainage workshops, scientific conferences, and meetings and are developing fact sheets describing these systems that provide information that will benefit producer and agency decision-making about this new and promising practice.

Introduction: The need for on-farm water storage and recycling for climate change resilience

Agriculture in the Great Lakes region has benefited historically from regular precipitation patterns. The relatively steady precipitation, coupled with soils with good water-holding ability, has allowed agriculture in the region to become highly productive and a substantial contributor to the region’s economy. However, predicted shifts in temperature and precipitation patterns towards warmer and wetter winters and springs, a greater frequency of intense storms throughout the year, and more severe and longer droughts in the summer suggest the potential for decreased crop yields in the future unless ways are found to provide additional water to crops during the growing season, while also being able to quickly remove excess soil water when conditions are wet.

Subsurface (tile) drainage is widely used in crop production in this region, removing excess water, particularly in the spring, to enable timely field operations (Figure 1). While excess water needs to be drained in the spring and other periods of excessive precipitation, crops in drained areas also experience stress from lack of water during the drier summer months at the peak of the growing season. This suggests that storing drainage water on the farm and recycling it through irrigation during summer, when crops experience water deficit, will become more and more beneficial as the pattern of excess water at times and drought at other times is exacerbated by climate change.

Figure 1: Installation of drain tile, a feature of cropland across the Great Lakes region.

The goal of this project was to advance on-farm water recycling as an adaptation strategy, by analyzing data from historical research sites from the perspective of climate change, identifying opportunities for this practice to be implemented more widely in the region, and providing outreach to stakeholders in the region.

Overview of on-farm water recycling on drained cropland

On-farm water recycling is the practice of capturing water drained from fields during high-flow periods, storing it in a pond or reservoir, and irrigating it onto crops later in the season. When this practice captures tile drainage water, we are calling it drainage water recycling, a practice that has two major benefits:

- It will improve water quality because drained water, that typically contains nitrate and phosphorus, is diverted into the water storage pond. Storing the water and recycling it onto crops prevents it from causing water quality problems such as algae blooms in Lake Erie or hypoxia in the Gulf of Mexico.
- It will increase crop yields because although precipitation in the Midwest is generally plentiful, it does not occur exactly when needed by the crop. Tile drainage occurs mostly in the spring, while crop water use in mid- to late summer may result in periods when insufficient water is available.

Drainage water recycling can be a closed-loop system where the drained water from a field is recirculated onto the same field, or water drained from one field can be used...
to irrigate a different field. Irrigation may be through subirrigation that raises the soil water table by flooding the subsurface drain tiles, sprinkler systems such as a center pivot, or other technologies (Figure 2).

Figure 2: A drainage water recycling system consists of drainage into the pond (top left), which is irrigated onto a field (right)

Sites where on-farm water recycling has been implemented

The Ohio Wetland Reservoir Subirrigation System (WRSIS) sites were the focus of this project and are described below. We also made an extensive effort to identify other sites where drainage water recycling had been implemented in the Great Lakes region to better understand the potential. These sites are also described below. We identified and visited sites in three locations in the Great Lakes Basin: Ohio, Michigan, and Ontario. We had expected more such sites to have been implemented but found that barriers to implementation are extensive and not easy to overcome.

OHIO WRSIS sites

In northwest Ohio, researchers developed a system in the late 1990s called WRSIS, which included a constructed wetland and water storage reservoir (Figure 3). Runoff and subsurface drainage from cropland were collected into the wetland for partial treatment of nutrients and sediment and ecological benefits (Smiley and Allred, 2011; Allred et al. 2014a)) before being routed to a storage reservoir until needed to subirrigate the crops during dry parts of the growing season (Figure 4). Allred et al. (2014) showed that the increase in corn yield over 13 years averaged 19% overall, with a 27% increase in dry years. The soybean yield increase was 12% overall and 23% in dry years. Yield data from these systems were used to analyze the potential crop yield benefits under future climate change in this project. (See “Quantifying increase in crop yield benefits under climate change”)

Figure 3: The Ohio WRSIS Wetland Reservoir Subirrigation System (WRSIS) components.

Figure 4: Wetland Reservoir Subirrigation System at Van Wert County, Ohio.

Michigan irrigation ponds

In Michigan, specialty and other crops are often irrigated. Because of inadequate groundwater in some regions, as well as limitations on groundwater withdrawal to prevent adverse impacts on streams, some growers have implemented drainage water recycling. Their purpose was to ensure a reliable water supply for crop irrigation where wells alone would not be reliable. We visited several sites in the Saginaw Bay area, where such ponds had been
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installed by Michigan Valley Irrigation. On-farm storage reservoirs as large as 30 to 50 acre-feet (40,000 to 60,000 m³) have been excavated to provide storage for irrigation water (Figure 5). The farmers with whom we discussed these ponds believe they are profitable, and more such ponds are being built. The irrigation dealer estimated that his firm has worked with farmers to install about three dozen of these ponds in the Saginaw Bay area.

Costs for these ponds have been more than $100,000, but in some cases the cost has been reduced by leveraging resources and opportunities. At one farm, the pond was originally a borrow pit for a road construction project through the farmer’s property, which resulted in a very cost-effective installation. Other farmers were able to sell the sand excavated from the pond, which provided an additional economic benefit. We are not aware of any systematic study of these on-farm storage reservoirs, and are discussing possible grant applications with engineers at Michigan State University to improve our understanding of how the systems work.

Essex County, Ontario, Canada
In southwest Ontario, we visited sites where researchers at the Harrow Research Station have conducted research on water recycling for nearly 25 years (Drury et al., 1996, 2009; Tan et al., 1993; 2007).

On-farm water recycling has also been used by tomato farmers in the area because groundwater was insufficient to ensure irrigation throughout the summer. Many farmers constructed large storage ponds, similar to those in Michigan, around 2005 to 2010. We were able to discuss the system with one tomato farmer who told us that the irrigation system had worked well and the pond is still used. However, a group of farmers in the area eventually formed a cooperative to build a large irrigation pipe from

Figure 5: Drainage water recycling ponds (top) just after construction, and (bottom) after several years of use, showing the drainage pumping structure into it as well as the intake for the irrigation.

Figure 6: On-farm water recycling in Ontario includes ponds at the Whelan Experimental Farm, Woodslee, Ontario (top) and a pond at the Essex County Demonstration Farm constructed with a more natural shape for aesthetics (bottom).
Lake Erie to ensure sufficient water quantities, making the pond unnecessary. We also discussed these on-farm ponds with an engineer at the Essex Regional Conservation Authority, who was responsible for permitting these ponds. Conclusions from visiting all these sites are summarized in “Examining impacts using the DRAINMOD simulation model.”

Quantifying increase in crop yield benefits under climate change

To quantify yield increases from on-farm water recycling that could be expected under future climate change, historical data were assembled from the 12-year study of WRSIS installed at three sites in northwest Ohio described in detail in Allred et al., 2013 and 2014; and summarized in Table 1.

Table 1: Summary of the three Ohio on-farm recycling sites. All sites were in a corn-soybean rotation.

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Size of subirrigated; control field (ha)</th>
<th>Dominant soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defiance County</td>
<td>41.33 N, 84.43 W</td>
<td>2.2; 8.1</td>
<td>Paulding Clay</td>
</tr>
<tr>
<td>Fulton County</td>
<td>41.60 N, 83.98 W</td>
<td>8.1; 8.1</td>
<td>Nappanee Loam</td>
</tr>
<tr>
<td>Van Wert County</td>
<td>40.88 N, 84.56 W</td>
<td>12.2; 6.1</td>
<td>Hoytville Clay</td>
</tr>
</tbody>
</table>

Historical precipitation, temperature, and solar radiation data were analyzed and used to derive Priestly-Taylor Potential Evapotranspiration (PET), crop adjusted PET, and to classify each growing season into quintiles of extremely dry, dry, near average, wet, and extremely wet, and the yield increases using on-farm water recycling were determined. Future climate projections and a modeled historical period from the North American Regional Climate Change Assessment Program (NARCCAP; Mearns et al., 2007) were also examined and bias-corrected to evaluate three modeled projections of future climate over Northwestern Ohio for the mid-21st century (2041-2070). Future climate were also divided into the quintiles based on historical data, showing that the distribution of growing season precipitation, temperature, and solar radiation are expected to shift from historic patterns. These shifts will likely have dramatic effects on PET patterns. The new distribution was used to estimate the expected yield benefits under the same on-farm water recycling practices.

For corn, the yield increased by an average of 20% under historical precipitation and 28-30% (depending on the model) under modeled climate for 2041-2070 (Figure 7). For soybeans, the yield benefit increased from 12-13% under historical precipitation to 20-24% in the modeled 2041-2070 climate. The increase in yield benefits was expected, but quantifying it using historical records provides useful information for farmers, contractors, and agency stakeholders that supports the growing usefulness of storing drainage water. These results are being developed into a research paper, which will be submitted for publication.

Examine impacts using the DRAINMOD simulation model

The historical and future climate datasets generated in the analysis described above were used in DRAINMOD model, which is the most widely used and internationally recognized model to predict and design subsurface drainage systems (Skaggs et al., 2012). Annual subirrigation and drainage management, as well as crop yields documented in Allred et al. (2014) were used to set up, calibrate, and validate the model. Soil hydraulic properties (water characteristic data, Green-Ampt infiltration equations parameters, upflux vs. water table depth, volume drained vs. water table depth) were calculated using the soil utility program of DRAINMOD based on pedotransfer function parameters obtained using the ROSETTA software (Schaap et al., 2001). Simulations of the control field with drainage only, as well as the subirrigated field with controlled drainage, were compared.

After calibration, DRAINMOD simulations were considered to be adequate and used to further analyze the historic and
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Figure 8: Daily water table depth with and without subirrigation (red lines) simulated using DRAINMOD for three years of the historic data (1997-1999) at the Fulton County site, showing the impact of subirrigation during the summer periods when it was applied. Precipitation and drain flow are also included, with subirrigation shown as negative drain flow.

potential impacts of subirrigation on crop yields (Figure 8). DRAINMOD predicts crop yield by estimating stress on crops due to lack of moisture (drought stress), excess moisture, and delay in planting due to excess moisture. Drought stress decreased significantly under subirrigation, from 33 cm-days to 1 cm-day, which is responsible for the strong crop yield benefits measured at this site. Stress due to excess moisture increased, however, which demonstrates the importance of management in successfully subirrigating crops. Simulations have also been run with each of the future climate projection datasets, which show increasing benefits as the growing season climate becomes hotter. The amount of water needed for subirrigation to maintain the water table at the desired level will also become greater, which suggests the benefit of constructing ponds to store water from the spring. These results are still preliminary but will provide the basis for a future research paper examining benefits and management strategies for subirrigation under future climate conditions.

Stakeholder views on barriers and opportunities for on-farm water recycling

In addition to the water recycling sites we visited, we collected feedback from people knowledgeable about Midwestern agricultural drainage on the potential of this practice and barriers to be addressed. This was not intended to be a scientifically-valid survey, but rather to elicit general reactions, concerns, and ideas.

Potential of this practice for the Midwest

Most respondents easily see the potential of on-farm water recycling. One even went so far as to say "If this can be done in such a way that it is feasible, this could be the future of drainage," and another responded that the potential was "tremendous." However, they also pointed out the considerable costs, particularly for the land used but also in pond construction and irrigation costs such as pumping. Example responses on the overall potential for this practice in the Midwest are below:

- "I farm 800 acres, have been interested in tile water capture and irrigation use for 25 years. Every year, we could use some supplemental water in July-Aug. It would also supply some late season N side-dress."
- "If you add up all the potential benefits, crop insurance, nutrient reduction etc. it may pay."
- "I am unsure about the feasibility. I understand the process but think it will be hard to motivate/convince farmers to change their practices."
- "As grain prices rise, this practice will rise."
- "This practice could increase crop yields by 10-20% by just irrigating corn-soybeans in the month of August"
alone. Plus, we could utilize nitrogen from drainage water. This would be an excellent approach in response to climate change. Earlier ... we used to get a drought year once in 10 years, but in last 10 years, we are seeing more extreme events."

• "Limited to areas it will fit in the landscape, but if kept open enough to provide recreation or irrigation, and NRCS or other funds available, would be worth it for landowners."

Barriers to address

Drainage stakeholders also provided what they see as the primary barriers to implementation. Responses include:

• "Dollars. If a farmer can see a chance this will benefit him financially he will do it."
• "Cost, liability, uncertainty, and skepticism."
• "Permits – EPA or state". (Plus many similar responses.)

It became clear that in addition to costs, the major barrier the stakeholders perceived was related to permits. Given this concern, we have begun working with regulators to clarify situations in which permits would be required. We held a meeting with USDA Natural Resources Conservation Service staff in Indiana, together with the state permitting agency and the US Army Corps of Engineers, to begin to clarify permits needed. Although this is sometimes perceived as insurmountable, permits are regularly issued in these situations, and the water quality benefits of on-farm recycling ponds may outweigh other concerns in many cases.

Location considerations and siting strategies

We received many suggestions on siting considerations that will make the practice function better.

• The practice is "limited by topography. Totally excavated storage is expensive."
• "Limited to areas where good groundwater aquifers available for prolonged dry periods in case not enough drainage water to fill reservoir"
• "In landscapes having variable topography, site reservoirs on highest ground. Have to pump water anyway, pump into reservoir and gravity subirrigate. Siting reservoirs in low ground results in effective water storage during April-June excess period only above ground level because groundwater table at or near land surface. Can use deep excavation, smaller footprint storage on higher ground."
• "If there is a high water table the pond will fill naturally so any extra water from the tile would overflow."
• "Pump tile baseflow into reservoir — cheaper than pumping high flows."
• "Ditches could serve as already built "reservoirs", although there would be challenges such as water backing up in fields/tiles."
• "To successfully subirrigate may require additional laterals to increase drainage intensity."

Key Lessons Learned

The stakeholders with whom we discussed this practice understood that climate change, or increasing climate variability, will lead to increased need for and benefits of practices that enhance water storage on the farm. The potential for this practice was viewed as very positive, even though most stakeholders correctly raised questions about costs in land, construction, and time.

On-farm water recycling ponds are rare in the landscape today, but a few examples exist in the Great Lakes region. They have been implemented primarily where both irrigation is needed for high value crops and groundwater is inadequate to provide the rates needed. Regulatory considerations related to groundwater withdrawals impacts have also played a role, although that was not explored in depth and more study is needed.

Crop yield benefits of irrigation from ponds can be considerable. At the WRSIS sites, corn yield increased by an average of 20% under historical precipitation and was projected to increase by 28-30% (depending on the model) under modeled climate for 2041-2070. For soybeans, the yield benefit increased from 12-13% under historical precipitation to 20-24% in the modeled 2041-2070 climate.

Construction costs can be more than $100,000 per pond but can be reduced by opportunities such as sand or aggregate removal or serving as the borrow pit for road construction. Recreational use of these ponds is theoretically possible, but we did not see that as a co-benefit of the ponds we identified.

The on-farm economic benefits will depend on the price of the crops, the specific soils at each location, and other considerations. On-farm water recycling systems are most economical in locations such as:

• where high value crop like seed corn or specialty crops are grown, as irrigation is more likely to be profitable,
• where groundwater is inadequate to meet irrigation needs,
• where costs of excavating a pond can be offset by economic opportunities for the spoil, and/or
• where a pond is already planned or exists, for example due to road construction.

Off-site economic benefits to society based on the nutrient loss reduction are likely to be add considerable value to the systems but were not quantified in this project. Reducing phosphorus loss from drained cropland is a critical and urgent need, and on-farm water recycling is one tool that should be included in the conservation toolkit. More research is needed to quantify the benefits and provide a basis for payments for these conservation practices.

Additional questions to be answered to move the practice forward

As we knew at the beginning of the project, many questions remain unanswered. This project has provided information about the expected increase in yield benefits under future climate conditions, and these findings will likely encourage interest in the practice. Similar analyses need to be done throughout the region, and future analyses will benefit from the methods developed in the project. Design guidelines and tools need to be developed to guide designers in making decisions. Costs are very uncertain and will need to be estimated for various situations. Example questions that drainage stakeholders raised are listed below. These questions can inform future studies and projects.

1. How large does the pond need to be to store water for various risk levels, for example to supply needed irrigation 8 out of 10 years? What ratio of drainage area to storage is needed to accomplish this?
2. How should systems be managed, and what maintenance is needed?
3. What is the agronomic value of nutrients, both N and P, that can be recycled to meet crop needs?
4. Is there potential for payments for additional ecosystem services or other benefits such as reducing greenhouse gas emissions, or reducing crop insurance risk?

Several questions related to downstream **hydrology** have been raised:
5. If downstream flow is reduced during some periods, what would be the impact on aquatic ecosystems?
6. To what extent is downstream flood risk reduced?

7. What is the potential for groundwater recharge, both into and out of the ponds?

In addition to these concerns and questions addressed by drainage contractors and other stakeholders, we have gathered together other questions from federal agencies, design engineers, and others.

8. How can reservoirs/pond systems be designed to enhance wildlife benefits?
9. What other environmental considerations should be taken into account to maximize societal benefits, especially if cost-share is provided by conservation agencies?
10. What safety considerations need to be included if the reservoir is raised?
11. What is the life expectancy of such ponds?

This long list of questions is daunting but not surprising, when considering a practice that could affect the agricultural landscape in such a significant way. Answering them will require additional research, on-farm demonstrations, analyses, and discussions in the future. This project has laid a foundation for understanding the need for and benefits of on-farm water recycling, allowed for in-depth analysis of historical data on these systems, and provided the opportunity to assess existing systems and perceptions of stakeholders who have used or considered them.

Future work

Because of the need to answer additional questions, we are very pleased that a larger, regional effort has been funded by the USDA National Institutes of Food and Agriculture to continue this work. That project, called “Managing Water for Increased Resiliency of Drained Agricultural Landscapes”, which we have shortened to “Transforming Drainage” to convey the transformation envisioned.

Figure 9: On-farm water recycling research and outreach will continue through an eight-state project funded by USDA-NIFA through 2020. The project logo provides the url for more information.
involves eight states, fifteen researchers, and $5 million in funding.

The project funded by GLISA provides an excellent foundation for the new project, through the synthesis of historical data, analysis with future climate projections, the cultivation of new partnerships, and development of outreach strategies that will lead to more impact in coming years.

Acknowledgements

We would like to thank Steve Miller and Lyndon Kelley of Michigan State University for arranging visits to the Michigan sites, Neil Krieger of Michigan Valley Irrigation in Vassar MI for providing information on these systems, and Bob and Ed Mantey of Caro MI for sharing their experiences. We also thank Chin Tan and TQ Zhang of Agriculture and Agri-Food Canada in Harrow, Ontario for providing a tour of their extraordinary research sites as well as an on-farm system in Essex County, and for sharing insights from decades of research on these systems.

References


