2016

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An ASABE Meeting Presentation
DOI: 10.13031/ids.20162557416
Paper Number: 162557416

Drainage Water Storage for Improved Resiliency and Environmental Performance of Agricultural Landscapes

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Written for presentation at the
10th International Drainage Symposium
Partners
University of Minnesota Water Resources Center
American Society of Agricultural and Biological Engineers
Minneapolis, Minnesota
September 7 – 9, 2016

ABSTRACT. *Drained lands, which include some of the most productive lands in the world, can experience both water excess and water deficit within a year. Storing drained water within the landscape could increase the sustainability of water for agriculture, particularly as intense rainfall and prolonged summer drought continue to increase under future climate change. A team of researchers and extension specialists from nine states are currently working towards a vision of transforming the process of designing and implementing agricultural drainage to include storage through the use of controlled drainage, saturated buffers, and drainage water recycling (i.e. capture, storage, and reuse). Field research data from experimental drainage sites from across the U.S. Corn Belt have been brought together in a database to support synthesis and modeling to determine economic and environmental impacts of drainage water storage. Results from this effort will extend the strategies and tools to agricultural producers, the drainage industry, watershed managers, agencies, and policy makers, and educate the next generation of engineers and scientists to design drainage systems that include water storage in the landscape.*

Keywords. *controlled drainage, drainage water recycling, saturated buffer, tile drainage, water quality, water storage*

Introduction

In the U.S. Midwest, which accounts for more than 40% of world corn and soybean production (USDA Foreign Agricultural Service, 2014), subsurface tile drainage is widely implemented. Although annual precipitation is approximately in balance with crop water use in this region, rainfall does not always occur when it is needed by crops. The Third National Climate Assessment (Melillo et al., 2014) projects that future annual rainfall will be characterized by intense rainfall events punctuated by dry periods, significantly impacting productivity of rainfed crop systems (Hatfield et al., 2014). Irrigation, which was rare in much of the region except for areas of sandy soil, has seen a surge of interest in recent years as the potential of drought has become more evident (USDA National Agricultural Statistics Service, 2002, 2007, 2012).

Water quality issues on drained agricultural land in the Midwest are also gaining importance. Nitrate loss from drained land is a focus of national effort to reduce hypoxia in the Gulf of Mexico. Tile drains are also pathways for phosphorus loss from drained land (Smith et al., 2015), contributing to harmful algal blooms in locations such as Lake Erie. The lack of measurable progress from conservation practice implementation suggests a need for new practices, or new strategies to increase adoption of practices that work, especially as climate change will likely exacerbate these issues.

A multi-state effort funded through the U.S. Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA), Agriculture and Food Research Initiative is coordinating efforts to evaluate and extend the practice of capturing and storing tile drain water (drainage water storage) in agricultural landscapes. The project, called Managing Water for Increased Resiliency of Drained Agricultural Landscapes, is also known as Transforming Drainage (http://transformingdrainage.org). This paper reviews opportunities for drainage water storage, describes field research locations where practices are being evaluated, and outlines the network of researchers and extension specialists working together to advance drainage water storage.

Drainage Water Storage in Agricultural Landscapes

Drainage water management practices that store water in the landscape for use by crops later in the season can address both the challenge of crop loss due to increased seasonality of precipitation and of water quality degradation from drained land. Drainage storage provides hydrologic capacitance, thereby making cropping systems more resilient to climate variability and change (Baker et al., 2012). Three such practices are described below which store drainage water:

- in the soil profile of cropped fields (controlled drainage),
- in buffers or non-crop areas at the edge of fields (saturated buffers), and
- in on-farm ponds or reservoirs (drainage water recycling).

Each of the three practices has been evaluated in the past at individual field sites across the Midwest. The Transforming Drainage project brings this work together with current research in order to synthesize results, develop recommendations, and provide tools to improve decision-making.

Controlled Drainage

Controlled drainage, also known as drainage water management, is the practice of using a water control structure to raise the height of the drainage outlet, holding water in the field during periods when drainage is not needed (Figure 1; Frankenberger et al., 2006; Strock et al., 2011). Unlike conventional drainage systems that remove excess water to the design drain depth whenever it occurs, controlled drainage stores water by increasing the retention time of water in the soil profile thereby reducing annual drainage volumes. Controlled drainage has been shown to be effective in reducing the outflow of water and nitrate-nitrogen (nitrate-N) from drainage systems (Adeuya et al., 2012; Cooke and Verma, 2012; Helmers et al., 2012; Jaynes, 2012). There are currently 17 controlled drainage field sites represented in the Transforming Drainage project (Table 1).

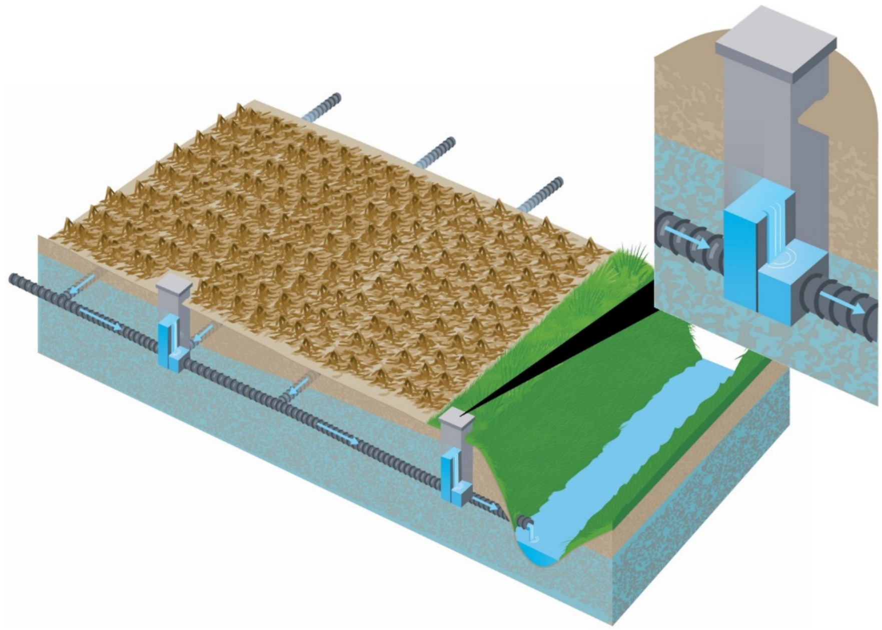

Figure 1. Controlled drainage consists of water control structures which manage the soil water table depth. Multiple control structures are used to manage a relatively even subsurface water table across variable surface topography.

Table 1. Field research sites represented in the Transforming Drainage project where controlled drainage is being evaluated. Additional information about each site is available at https://transformingdrainage.org/experimental-sites/sites/

Site Name	Site Location	Lead Investigator(s)
Story City Farm	Story County, IA	Dan Jaynes, USDA-ARS
Davis Purdue Agricultural Center	Randolph County, IN	Jane Frankenberger, Eileen Kladivko, and Laura Bowling, Purdue University
Hicks Farm	Redwood County, MN	Jeffrey Strock, University of Minnesota
Greenley Research Center-MUDS2	Knox County, MO	Kelly Nelson, University of Missouri
Bee Ridge Farm	Knox County, MO	
Upper Big Walnut Creek	Delaware County, OH	Kevin King, Mark Williams, and Norman Fausey, USDA-ARS
South Dakota State University-Southeast Research Farm	Clay County, SD	Laurent Ahiablame, South Dakota State University
Iowa State University-Southeast Research Farm	Washington County, IA	Matthew Helmers, Iowa State University
Poole Farm	Beaufort County, NC	Mohamed Youssef, North Carolina State University
Tidewater Research Station	Washington County, NC	
Auglaize-E	Auglaize County, OH	Norman Fausey, USDA-ARS and Larry Brown, The Ohio State University
Crawford	Crawford County, OH	
Defiance	Defiance County, OH	
Hardin	Hardin County, OH	
Henry	Henry County, OH	
Auglaize-SE	Auglaize County, OH	
Fairmount Farm	Richland County, ND	Xinhua Jia, North Dakota State University

Saturated Buffer

Saturated buffers store water within the soil profile of field buffers (Figure 2). Early results for saturated buffers indicate that the practice can be effective for removing nitrate-N from tile drain water before it is discharged into surface waters by diverting a fraction of the tile flow through riparian buffers as shallow groundwater where it becomes available for plant uptake and denitrification (Jaynes and Isenhart, 2014; Utt et al., 2015). The water diverted into saturated buffers is also available for evapotranspiration by the perennial buffer vegetation, increasing biomass production. The focus to date on saturated buffers has been on nutrient removal potential, but additional research regarding opportunities to temporarily store water and modify the hydrograph of local streams and drainage ditches is needed. There are currently two saturated buffer field sites represented in the Transforming Drainage project (Table 2).

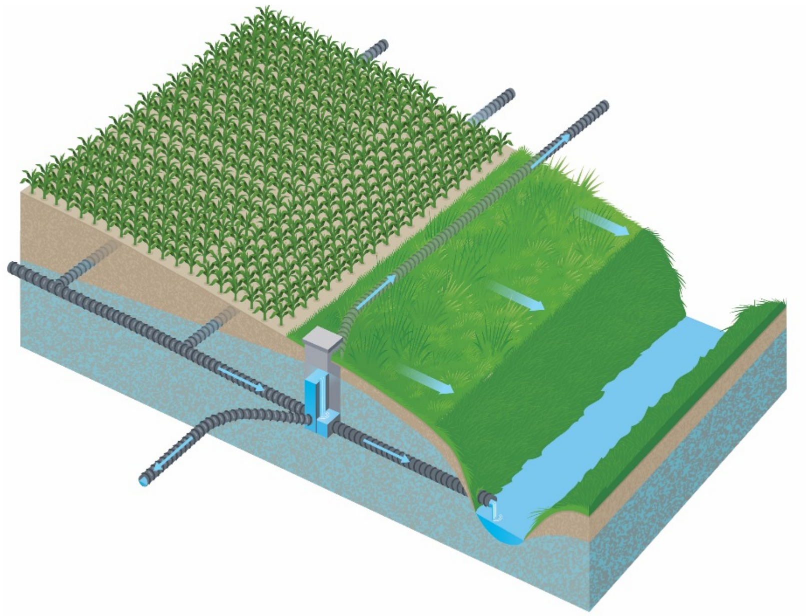

Figure 2. Saturated buffers manage soil water table depth within the buffer zone and divert tile drain water laterally through subsurface drain tile, referred to as distribution lines. This drainage water is stored in the buffer soil profile and travels through shallow groundwater flow to the outlet, in this case an open ditch.

Table 2. Field research sites represented in the Transforming Drainage project where saturated buffers are being evaluated. Additional information about each site is available at https://transformingdrainage.org/experimental-sites/ sites/

Site Name	Site Location	Lead Investigator
Bear Creek	Hamilton County, IA	Dan Jaynes, USDA-ARS
Maass Farm	Hamilton County, IA	

Drainage Water Recycling

Drainage water recycling diverts subsurface drainage water into on-farm ponds or reservoirs, where it is stored until it can be delivered to crops later in the season through irrigation (Figure 3). Where implemented, these systems have shown crop production benefits. In Missouri and Ohio, corn grain yields increased up to 50% (Nelson and Smoot, 2012; Allred et al., 2014), while soybean yields increased up to 29% (Nelson et al., 2011; Allred et al., 2014). Water quality benefits have also been demonstrated, since nutrients in both subsurface drainage and surface runoff can be recycled back onto the crop field during the growing season (Tan et al., 1993; Haverstock et al., 2010; Wesstrom and Joel, 2010). Allred et al. (2003) included both a wetland and a reservoir in a system they called the Wetland-Reservoir Subirrigation System (WRSIS) for additional ecological benefits (Smiley and Allred, 2011). There are currently 10 drainage water recycling sites represented in the Transforming Drainage project (Table 3).

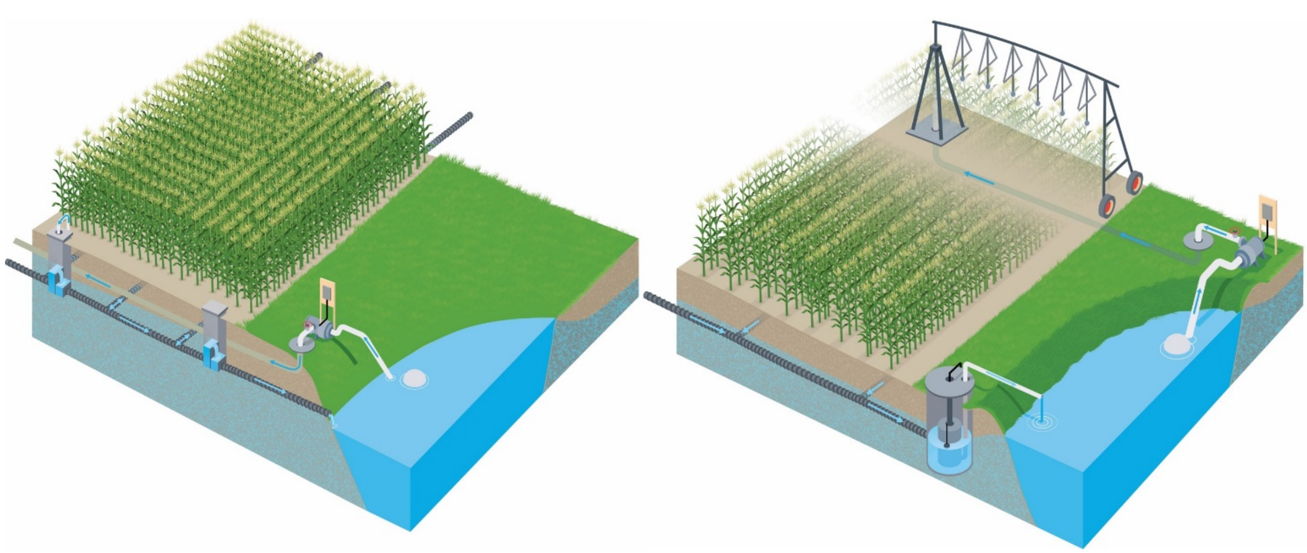

Figure 3. Drainage water recycling captures tile drain water in a pond or reservoir to be used later in the season for crop irrigation. Many variations exist in pond-reservoir type (e.g. excavated, embankment, diked) and irrigation method (e.g. subirrigation, overhead irrigation).

Table 3. Field research sites represented in the Transforming Drainage project where drainage water recycling is being evaluated. Additional information about each site is available at https://transformingdrainage.org/experimental-sites/sites/

Site Name	Site Location	Lead Investigator
Hicks Farm	Redwood County, MN	Jeff Strock, University of Minnesota
Southwest Research and Outreach Center	Redwood County, MN	
Ross Jones Farm	Shelby County, MO	Kelly Nelson, University of Missouri
Greenley Research Center-MUDS3	Knox County, MO	
Defiance (WRSIS)	Defiance County, OH	Larry Brown, The Ohio State University and Barry Allred and Norman Fausey, USDA-ARS
Fulton WRSIS	Fulton County, OH	
Van Wert WRSIS	Van Wert County, OH	
Purdue Agronomy Center for Research and Education	Tippecanoe County, IN	Laura Bowling, Purdue University
Poole Farm	Beaufort County, NC	Mohamed Youssef, North Carolina State University
Clay County Farm	Clay County, MN	Xinhua Jia, North Dakota State University

A Collaborative Project to Transform Drainage

The Transforming Drainage project team includes 35 researchers and extension specialists from across eight states in the U.S. Corn Belt and North Carolina. With input from an 11-member advisory committee representing agricultural producers, drainage contractors, private industry, conservation agencies and organizations, and academia, the project team is working to advance drainage water storage through the practices of controlled drainage, saturated buffers and drainage water recycling. The primary objectives of this project are to:

- Strengthen and broaden the network of drainage researchers and stakeholders to advance and coordinate research, extension, and implementation of drainage water storage systems.
- Determine economic and environmental benefits and costs of storing drainage water at field sites across the region.
- Extend estimates of benefits and costs both temporally, accounting for future climate change, and spatially across the region through modeling
- Develop strategies and tools to apply the research findings in decision-making on the farm, in watersheds, and in state and national policy.
- Extend the strategies and tools to agricultural producers, the drainage industry, watershed managers, agencies, and policy makers to bring about transformation of drainage strategies.
- Educate the next generation of engineers and scientists to design drainage systems that include drainage water storage in the landscape.

The Transforming Drainage project addresses the need to provide more secure water for crops throughout the growing season while maintaining adequate drainage during periods of excess rainfall and limiting nutrient losses from tile-drained agricultural landscapes.

A Regional Research Database

The Transforming Drainage project has connected the field- and plot-level research sites listed above, from past and current experiments across the region, in an expansive dataset to address and support regional evaluation of drainage water storage practices. There are currently 186 site-years of data in the database spanning a variety of soil types, environments, management, and weather (Figure 4). Data and methodologies are entered by team members through a Google Cloud-based interface allowing real-time management by data managers as well as export functions for researchers (Herzmann et al., 2014). Data entered online is then synced to and stored on a traditional relational database supported at Iowa State University. The project database currently houses 94 variables from some or all sites which include water quality and quantity data, soil characteristics, agronomic management data, on-site climate data, and greenhouse gas data to allow for characterization of production and water quality impacts across drainage water storage practices. The average size of datasets, in years, across sites represented in the database is 7.5 years with data collection starting as early as 1996. The project database has supported the expansion of research questions, both spatially and temporally, and facilitated discussions around new insights into the planning and performance of drainage water storage systems.

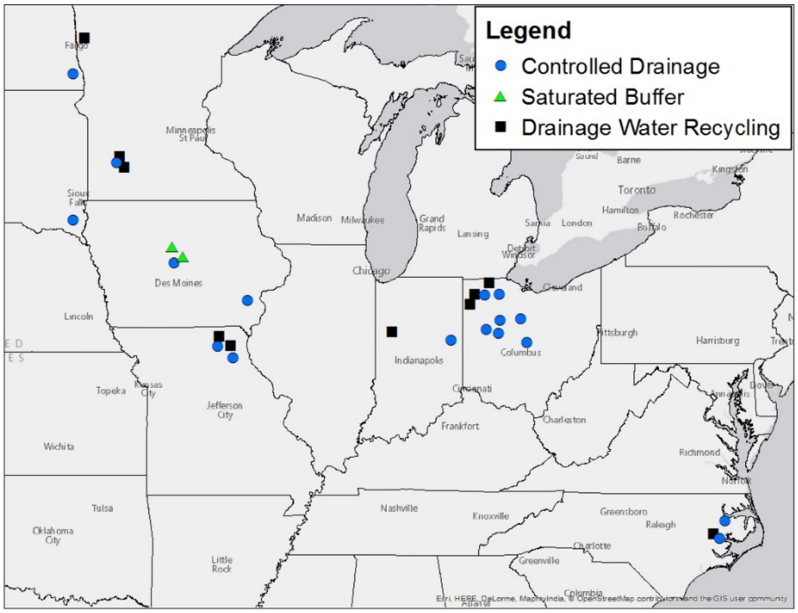

Figure 4. Field research sites included in the Transforming Drainage project

Synthesis, Modeling and Tools

With the establishment of the central project database, regional collaboration in data synthesis and evaluation is currently underway to provide insights into factors controlling agronomic and environmental performance of these drainage water storage practices and identify where drainage water storage can most effectively be applied. Collaboration in synthesis will allow for evaluating practice performance across the region, identifying what factors (e.g. precipitation patterns, soils, drainage characteristics, and/or cropping systems) have the greatest impact on performance. An economic analysis is being completed to collect data to characterize the cost of drainage water storage systems. This analysis will be used to establish a dataset documenting the variation across the project area in practice adoption costs (e.g. cost of land removed from production), capital expenditures, operation and maintenance, yield impacts, and impact on farm management practices (e.g. cropping rotation, equipment, fertility, pest management, etc.).

Modeling efforts are being completed at research sites in each of the nine states to assess the effects of drainage water storage practices on water and nutrient budgets as well as crop growth and yield using the agro-ecosystem model DRAINMOD. Following model testing at field-scales, drainage water storage will be simulated across the region to assess the impacts of drainage water storage on adapting cropping systems to climate change scenarios. Results from synthesis and modeling will be used to develop tools and information to aid decision-making related to water management in drained agricultural landscapes. The Transforming Drainage project has begun to collect information from drainage stakeholders on tool concepts and delivery platforms that will be utilized by the project. Information collected from these user groups will be used to guide the development and function of these tools.

Extending the Network

In order to achieve the objective of “transforming drainage” to include storage in the landscape, a diverse network of partners is needed. The project is working to strengthen and broaden the network of drainage stakeholders so that research, extension, and education activities can be coordinated across existing networks such as the Agricultural Drainage Management Systems Task Force, Agricultural Drainage Management Coalition, Land Improvement Contractors of America, state commodity groups, state agencies, and professional societies and organizations. The project has created opportunities to establish new collaborations and partnerships to further extend drainage water storage concepts into research and extension efforts. A formal set of collaboration guidelines was developed to help guide the process of establishing these agreements. Collaborators are defined as individuals or organizations who help advance project goals and strengthen the network of drainage stakeholders. There are currently 11 project collaborators who engage in activities such as extension and outreach, work with project team members on extension and peer-review publications, participate in discussions on modeling and decision tools, and coordinate and share data from field research. As part of the collaboration, the project provides opportunities to collaborators to network with teams of researchers and specialists from across the region, co-author publications and tools, and develop proposals to leverage project funding.

Conclusion

The Transforming Drainage project will continue to strengthen and support the existing network of drainage researchers and stakeholders through new collaborations and partnerships so that research, extension, and implementation of drainage water storage advances to meet future challenges. Upon completion of this funded project, the project research database will be made publicly available to further advance and coordinate drainage research. This project will result in new understanding, tools, and strategies to increase the resiliency of drained agricultural land through water storage. Our vision is to begin transforming the process of designing and implementing agricultural drainage so that storing water in the landscape will be considered for each drainage system and that drainage water storages practices, such as drainage water recycling, will be found throughout the landscape.

Acknowledgements

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2015-68007-23193, “Managing Water for Increased Resiliency of Drained Agricultural Landscapes”, http://transformingdrainage.org. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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