Drainage Water Recycling for Crop Production and Water Quality in Iowa

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What is drainage water recycling? Why do it?

Drainage water recycling is a practice that combines crop production benefits for the farmer and water quality benefits downstream[1]. A drainage water recycling system captures water drained from farm fields and stores it in a reservoir for later use as supplemental irrigation. The Iowa Soybean Association's (ISA) Research Center for Farming Innovation (RCFI) has been collaborating with researchers from Iowa State University to evaluate this practice in Iowa.

A drainage water recycling system consists of a storage reservoir to capture agricultural drainage water, an irrigation system to apply the water to the crop field and associated infrastructure to convey water to and from the storage reservoir (Figure 1). Drainage water recycling systems can be designed with different configurations to suit different conditions. Irrigation can be supplied via subirrigation, where water is applied back to the field through the drainage system to raise the water table for access by the crop roots, or through more conventional irrigation systems like center pivots or other sprinkler or drip irrigation systems. Drainage water recycling can also be implemented at different scales, ranging from the individual field or farm scale to larger scales where multiple farms contribute or withdraw water from shared infrastructure.

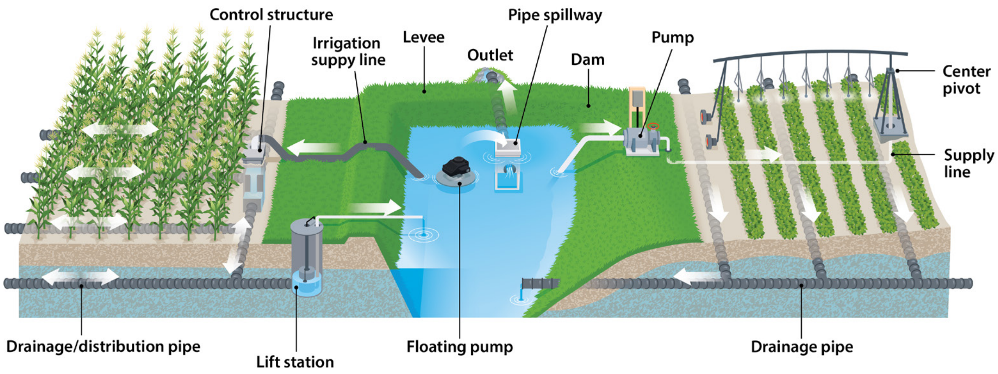

Figure 1. Drainage water recycling systems can have multiple configurations. Examples shown include subirrigation (left) or center pivot (right) for the irrigation system and excavation with a raised levee (left) or an embankment dam (right) for the reservoir. Figure from Hay et al. (2021)[1], used under CC BY NC ND 4.0.

Although precipitation in Iowa is generally adequate to produce good crops, the timing and volume doesn't always coincide with crop water use, which limits yields. Drainage systems are used to remove excess precipitation in the spring, but in many summers, there are periods when available soil water is not enough to fully meet crop water demands. Water management challenges of wetter springs and more frequent and extended droughts are expected to continue to worsen in the future[2]. By storing drainage water in the spring for reuse as irrigation during dry periods, drainage water recycling can increase crop yields and make cropping systems more resilient to short-term and long-term droughts.

Drainage water recycling also benefits water quality by capturing nitrogen and phosphorus that would otherwise be carried downstream with the drainage water. Storage in the reservoir can reduce the concentrations of nitrogen and phosphorus, and recycling the water and nutrients back into the field with irrigation reduces the loss of these nutrients. Reducing the loss of nitrogen and phosphorus to downstream waters improves local water quality conditions and helps address the goals of the Iowa Nutrient Reduction Strategy to reduce the size of the hypoxia zone in the Gulf of Mexico.

Depending on how drainage water recycling systems are designed and managed, they can provide additional benefits. Adding storage to drainage systems can provide additional capacity to undersized systems[3]. Reservoirs for drainage water recycling can also buffer high flows downstream at the local level at times when storage is available in the reservoir. If enough sites are implemented in a watershed, drainage water recycling may beneficially impact high flows in larger streams and rivers. Additionally, drainage water recycling reservoirs may also provide wildlife habitat, biodiversity, and other ecological service benefits.

Summary of previous work

Drainage water recycling is not a new practice. In the late 1980s and early 1990s, researchers from Iowa State University evaluated a drainage water recycling system at the Ankeny Research Center for crop yield and water quality benefits[4]. They found it produced high yields and provided water quality and other natural resource benefits. Because of the relatively high investments required, however, they suggested the greatest potential for the practice was for higher value crops unless there were water quality concerns to help justify the system.

In Ohio, three sites were monitored from 1996 to 2008 where drainage water was recycled by diverting it into a wetland for nutrient and sediment removal, transferring it to a storage reservoir, and then adding it back to the field as subirrigation through the drainage pipes[5]. Fields with subirrigation with the recycled drainage had corn and soybean yields that were 19.1% and 12.1% greater, respectively, than yields from conventional drainage alone. The wetland and reservoir systems could also provide additional benefits for reduced nutrient and sediment losses and added wildlife habitat[5][6].

A review of available research on corn yield response from seven sites across the Midwest, in Minnesota, Missouri and Ohio, found drainage water recycling adds resilience and increases yield stability. Corn yields were 19 bushels/acre greater on average with drainage water recycling than with conventional drainage, and yield variability was reduced by 28%[7].

Figure 2. Drainage water recycling site near Story City captures drainage from 20 acres and pumps water from an adjacent stream to irrigate 60 acres.

Research sites in Iowa

The combination of current water quality issues, the Iowa Nutrient Reduction Strategy, the impact of recent droughts, and a lack of recent local data on drainage water recycling has renewed interest in drainage water recycling in Iowa. Three drainage water recycling sites in Iowa are being monitored for impacts on crop yield and water quality though a partnership between Iowa State University and ISA's Research Center for Farming Innovation with support from the Iowa Department of Agriculture and Land Stewardship.

The first site near Story City was constructed in 2015. It captures the subsurface drainage from about 20 acres of a 160 acre field (Figure 2). In addition to the drainage water, the owner has a permit to pump water from an adjacent stream to help fill the reservoir. Because pumping is stopped when the reservoir fills, there is generally no overflow from the reservoir. Approximately 60 acres of the field are irrigated with a center pivot. A portion of the remainder of the field with similar soils and the same management serves as a control for comparing rainfed crop yields to yields with supplemental irrigation.

The second site near Lake City was established in 2021 (Figure 3). The reservoir was created by constructing an embankment in a waterway that receives the outflow from a 4 ft. by 6 ft. box culvert and a 30 in. tile outlet from an upstream drainage district. The water passes through a wetland area before entering the deeper water storage for irrigation withdrawals. The reservoir area when full is 3.72 acres and holds about 15 acre-feet of water. Since all water from the waterway passes through the reservoir, there is an outlet structure to release water when inflows exceed the reservoir storage capacity. Water from the reservoir is used to irrigate approximately 53 acres with a center pivot in an adjacent field.

The third site near Dayton began operation in 2023 (Figure 4). A portion of the corner of a quarter section field was excavated to create the reservoir, removing some land from production. The reservoir is filled by pumping water from a sump connected to an 18 in. county main. The reservoir surface area is 3.25 acres and holds 37 acre-feet. Similar to Story City, pumping ceases when the reservoir is full, so there will generally be no overflow. A center pivot is used to irrigate approximately 106 acres of the field.

All three sites are monitored for water volume flowing into the reservoirs, volume of water pumped for irrigation, and any overflows. Reservoir depths are also measured and evaporation and seepage losses from the reservoirs are estimated. Water quality samples for nitrogen and phosphorus concentrations are also collected from the reservoirs and the inflows to and outflows from the reservoirs.

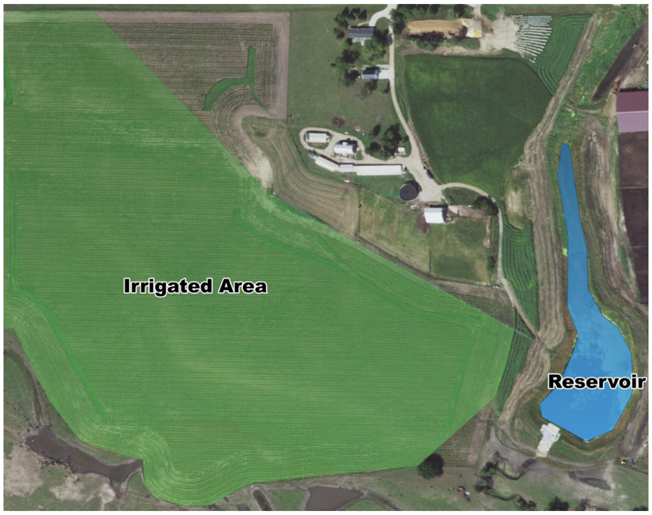

Figure 3. Drainage water recycling site near Lake City captures outflow from an upstream drainage district to irrigate approximately 53 acres.

Figure 4. Drainage water recycling site near Dayton pumps water from a county drainage main to irrigate about 106 acres.

Crop yield results

Corn yield data from the Story City site have shown that irrigated yields have been consistently greater than yields from the control (rainfed) portion of the field (Figure 5). The largest yield increase of 119 bushels/acre was in 2017, when corn yields were more than doubled. In 2018, no irrigation was applied, and yields were similar. Yield increases from irrigation in other years ranged from 16 to 31 bushels/acre. In 2020, a derecho damaged the center pivot and the crop. The overall average yield increase, not including 2020, was 35 bushels/acre.

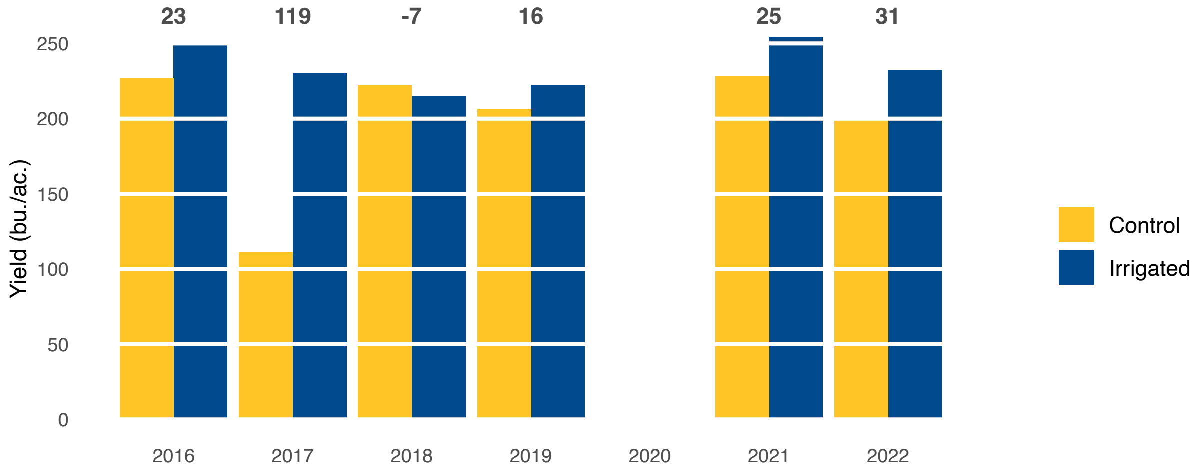

Figure 5. Corn yields at the Story City drainage water recycling site. The difference between the irrigated and control yields are indicated above each pair of bars. No irrigation was applied in 2018, and a derecho damaged the center pivot and crop in 2020. The average yield increase from irrigation over all years, not including 2020, was 35 bushels/acre.

Storage size

The yield data from Story City were used to calibrate a crop model to determine corn yield benefits under different levels of water availability[8]. Two scenarios were modeled. The first was historic climate conditions for a study period of 1980 to 2019. The second scenario was for projected climate conditions assuming continued trends of greater spring precipitation and less summer precipitation. In the projected climate scenario, precipitation was increased 15% and summer precipitation was reduced by 15% from historic conditions. Corn yield benefits from irrigation were greater under the projected climate scenario suggesting that drainage water recycling will become more profitable over time (Figure 6). In both scenarios, there was little or no difference between the yield benefits with 6 inches and unlimited water availability. Although these results are specific to Story City, they give us a starting point to inform decisions on the contributing drainage area and the choice of reservoir size. A reservoir that can consistently capture six inches of irrigation water should maximize the irrigation benefits. Reservoirs that would consistently capture less than four inches of irrigation water may not be worth the investment in irrigation infrastructure.

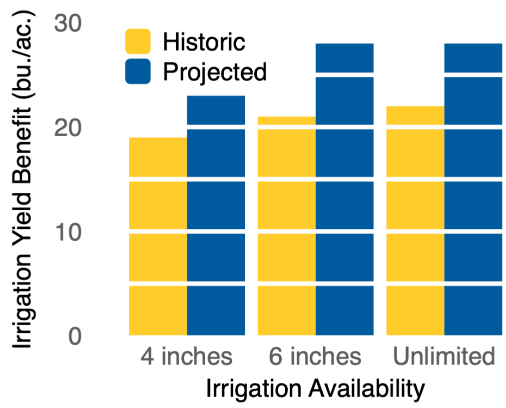

Figure 6. Irrigation yield benefit (irrigated yield minus rainfed yield) for different levels of irrigation water availability for historic (1980 to 2019) and projected (15% greater spring and 15% less summer precipitation) climate scenarios.

Water quality benefits

Drainage water recycling benefits water quality by diverting drainage water containing nutrients (nitrogen and phosphorus) into a reservoir. Storing and recycling the water and nutrients reduces the amount of nutrients released downstream. From the three study sites, there are now four site-years of water quality data for evaluating the water quality benefits of drainage water recycling in Iowa[9]. Monitored water volumes and nutrient concentrations were used to calculate nutrient loads (pounds of nitrogen and phosphorus) in the reservoir inflows and outflows. Overall load reductions were calculated as reservoir inflow minus seepage losses and any outflows back to surface water. Nutrients in the irrigation water were assumed to be available for crop uptake or would otherwise be reduced or recaptured before they could return to surface water.

In all four site-years, there were substantial reductions in nitrogen (Figure 7; top). The pumped sites (Story City and Dayton) had high percentage load reductions of 90% and 92%, respectively. Because there was no outflow at either site, the overall nitrogen load was reduced by nitrogen concentration reductions within the reservoir and by recycling water and nitrogen back to field as irrigation. Since Lake City is a flow-through reservoir where all the water in the waterway passes through the reservoir, the percentage reduction of nitrogen loads depended on inflows. There were much greater inflows in 2022, exceeding the storage capacity of the reservoir and generating greater outflows back to the stream. Inflows were less in the drier year of 2023, so outflows were less. Therefore, the percentage load reduction was less in 2022 because of the greater outflows compared to 2023. However, in looking at the amounts of the nitrogen load reductions, the total pounds of nitrogen load reduced at Lake City was much greater than at the other sites because, as a flow-through reservoir, it treated more water. Similarly, although the percentage load reduction at Lake City was less in 2022 than 2023, the overall amount of nitrogen removed was greater in 2022 because more water flowed through the reservoir.

The story for phosphorus is more complicated (Figure 7; bottom). At the pumped sites (Story City and Dayton), the results were similar to those for nitrogen. Phosphorus loads were reduced by concentration reductions in the reservoir and by recycling water and phosphorus back to the field as irrigation. Unlike the pumped sites, however, phosphorus concentrations increased from the inflow sampling site to the outflow sampling site at the reservoir at Lake City. Phosphorus load reductions varied by year. In 2022, with greater inflows, phosphorus concentration increases in the

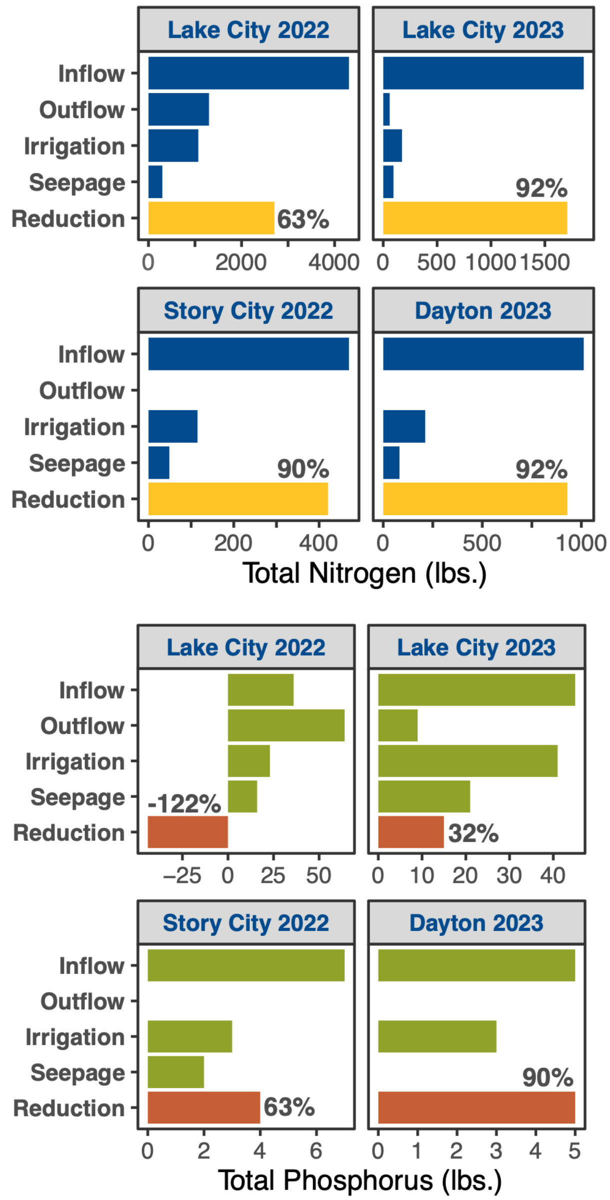

Figure 7. Nitrogen (top) and phosphorus (bottom) loads of drainage water recycling systems for four site years. Percentage reduction is indicated adjacent to the reduction bar. Units are in pounds of total nitrogen and phosphorus. Note that the scales are different for each site year.

reservoir, and greater outflows, there was a load increase (instead of a reduction) in phosphorus released back to the stream. In 2023, with less inflows, a greater percentage of phosphorus recycled in the irrigation water, and less outflows, there was an overall phosphorus load reduction downstream despite the phosphorus concentration increases in the reservoir. The reasons for the phosphorus results at Lake City are not fully known, but it is suspected that they may be a function of the reservoir design differences. Because the reservoir was constructed in a waterway, sediments potentially high in phosphorus may have been disturbed during construction and have released phosphorus into the water flowing through the reservoir. Also, because of logistical considerations, the sampling point for phosphorus concentrations in reservoir releases is not located at the outlet structure and is instead located downstream in the channel of the waterway below the reservoir. Phosphorus concentrations of water collected in the outlet channel were greater than those in the reservoir itself. So, phosphorus concentrations may be increasing from streambank erosion downstream of the reservoir.

Overall, the water quality results are promising. Story City and Dayton showed substantial reductions in both nitrogen and phosphorus loads. Because more water flowed through the Lake City reservoir, it was able to remove even greater amounts of nitrogen. Continued monitoring at Lake City will help determine if phosphorus losses decline with additional time post-construction. Otherwise, additional considerations for phosphorus may be needed for in-channel reservoirs, particularly where there are phosphorus sensitive waters downstream.

Regional feasibility assessments

To get a better idea of the potential for drainage water recycling at the landscape scale, ISA contracted with ISG on feasibility assessments in four areas of Iowa (Figure 8). A geospatial analysis was used to identify potential sites based on fields that:

- Are able to accommodate a 1,300 ft. center pivot making a full rotation. The subirrigation suitability layer from the Transforming Drainage Subirrigation Suitability Tool[10] was included as well to identify fields that might be suitable for that irrigation method.
- Are not intersected by ditches, streams, or rivers.
- Have the presence of a depressional area that could be a probable location of a drainage main for interception or an opportune spot for locating storage or receiving spoils.
- Are located in close proximity to drainage district infrastructure.
- Have an absence of utility infrastructure restrictions.
- Are not located near an airport (for bird interference considerations).

The geospatial analysis identified 503 potential sites with up to 137,829 acres suitable for drainage water recycling within the four regions evaluated. This information will be used to target potential sites for implementation projects based on landowner interest.

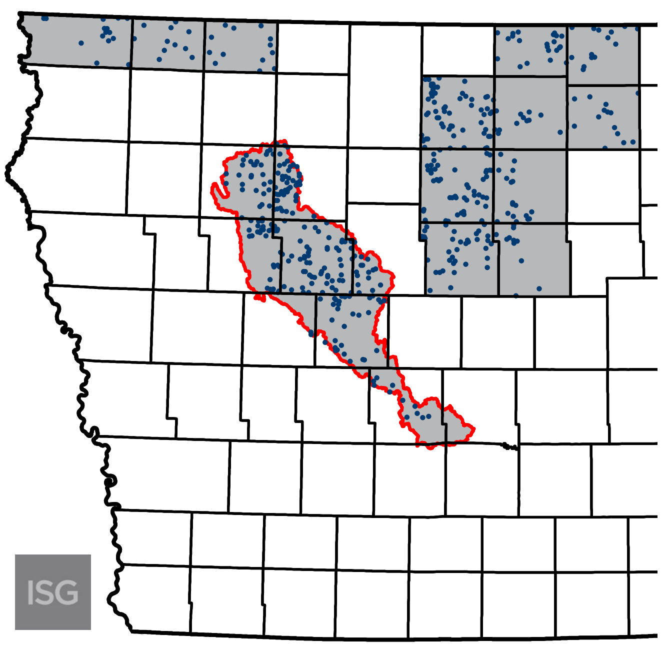

Figure 8. Sites (blue dots) meeting GIS criteria as potential locations for drainage water recycling in the North Raccoon River Watershed (red outline) and shaded counties of Iowa. Map developed by ISG.

Conclusions and recommendations

Drainage water recycling has shown strong potential as a practice that both boosts crop production and improves water quality. Storage and recycling of drainage water can help create cropping systems that are more resilient to climate risks and provide long-term sustainability. Increased water storage can potentially provide other benefits, depending on design and management, such as wildlife habitat and flood peak reduction.

Many questions remain and additional research is needed to further support expanded implementation and financing of drainage water recycling systems. Among the research needs are:

- Detailed economic analyses to quantify the costs and benefits of drainage water recycling systems to determine return on investment for supplemental irrigation and environmental benefits to support financing of drainage water storage through cost share or market-based programs.
- Additional sites with continued monitoring to better understand how different climate, soils, and designs impact drainage water recycling systems over time.
- A better understanding of the contributing drainage area needed to capture adequate water supplies for supplemental irrigation and provide target levels of nutrient load reduction.
- Impacts of drainage water recycling on streamflow at larger (watershed) scales.
- Irrigation management for drainage water recycling systems.
- Sustainable intensification of cropping systems with supplemental irrigation.
- Impacts of drainage water recycling on greenhouse gasses.
- Wildlife habitat and biodiversity impacts of drainage water recycling.
- Multi-objective management strategies to maximize benefits and avoid negative impacts.
- Expand the feasibility analyses with additional information to identify and target the best locations for drainage water recycling in Iowa.

Aerial view of the drainage water recycling reservoir at the Dayton site filled from pumping water from an adjacent county drainage main.

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For More Information

Transforming Drainage drainage water recycling practice page with videos, publications, and additional information: https://transformingdrainage.org/practices/drainage-water-recycling/

Evaluating Drainage Water Recycling Decisions (EDWRD) online tool to estimate potential irrigation and water quality benefits from drainage water recycling for varying reservoir sizes: https://transformingdrainage.org/tools/edwrd/

Subirrigation Suitability Tool to identify potential locations suitable for subirrigation in the Midwest using an online mapping application based on soils information: https://transformingdrainage.org/tools/subirrigation-suitability-tool/

GIS story map of potential drainage water recycling locations in four areas of Iowa developed by ISG: https://isg.maps.arcgis.com/apps/MapSeries/index.html?appid=1cddbab60dab444985950ca219a461d0

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