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Potential Benefits of Drainage Water Recycling: A case study from Indiana

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DRAINAGE WATER RECYCLING: A NEW PRACTICE TO IMPROVE WATER QUALITY AND CROP PRODUCTION

Over the course of a year many Midwestern farms routinely suffer from feast and famine when it comes to water. Tile drainage systems remove excess water from poorly drained fields early in the season, only for crops to often suffer from lack of water later in the growing season. Both problems combined – too much and too little water – prevent crops from reaching their full yield potential, and in certain extreme situations, these problems can even lead to complete crop failures. In fact, excess and deficit water conditions account for as much as $7 billion in crop insurance payouts each year within the U.S. Midwest.

Managing these problems can be expensive, both monetarily and environmentally. Tile drains remove nutrients, such as nitrate-nitrogen and soluble reactive phosphorus, from fields and direct them to downstream rivers, lakes and other bodies of water, negatively affecting water quality. Despite billions of dollars spent each year to minimize these losses, there has been little change in the amount of nitrogen and phosphorus entering the nation's waterways. Rising temperatures and prolonged dry spells, which are expected to become more frequent in the future, are also driving more farmers to consider costly irrigation systems.

Drainage water recycling offers a potential way to address both problems. The system sends tile-drained water into ponds or reservoirs for storage until it is needed for irrigation, at which time it can be pumped back to the fields (Figure 1).

Potential benefits of drainage water recycling include increased crop yields, reduced nutrient loads in nearby waterways and downstream, and the recycling of nutrients in water that would otherwise be lost through traditional tile drainage. But how large will these benefits be, and how much needs to be invested to achieve them? In this case study we quantified the potential water quality and irrigation benefits of drainage water recycling for a range of reservoir sizes on an Indiana farm. We used weather and drain flow data measured over 10 years at the Davis Purdue Agricultural Center in east-central Indiana (see page 2). Measured concentrations of nitrate-nitrogen and soluble reactive phosphorus (referred to herein as nitrogen and phosphorus) were used in calculating nutrient loads and potential load reductions. Understanding the potential crop yield and nutrient loss reduction benefits at this site provides information that could be used elsewhere to estimate what benefits can be achieved from different investments.

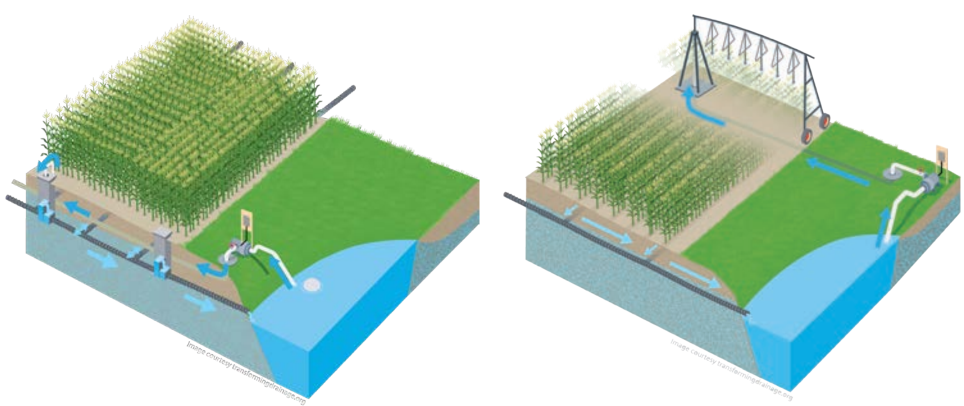


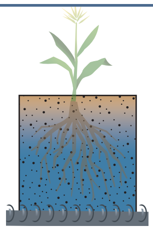
Figure 1. *A drainage water recycling system consists of storing drainage water in a reservoir, which is then used for field irrigation. Irrigation methods vary with site conditions and may include overhead irrigation (right) or subirrigation (left)*

Soil

Site characteristics and 10 years of measured precipitation, drain flow, and nutrients at the Davis Purdue Agricultural Center

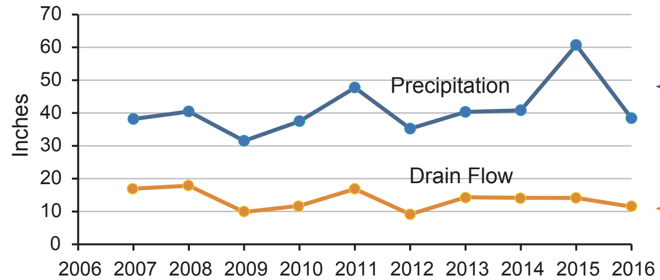
Soil texture: **Silt loam and silty clay loam**

Plant available water capacity between the soil surface and tile drain: **5.6 inches**



Precipitation and Drain Flow at the Site

Annual Total

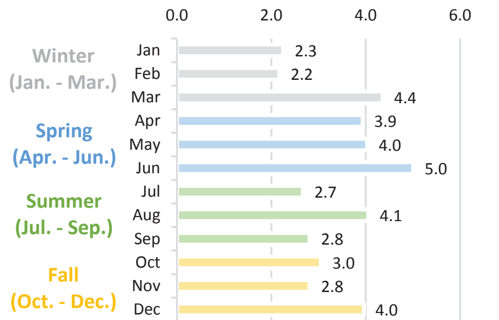


Annual precipitation ranged from **30 to 60 inches**, with an average of 41.1 inches.

Tile drain flow varied between 9 and 18 inches or **23% to 44% of annual precipitation**, with an average of 13.7 inches.

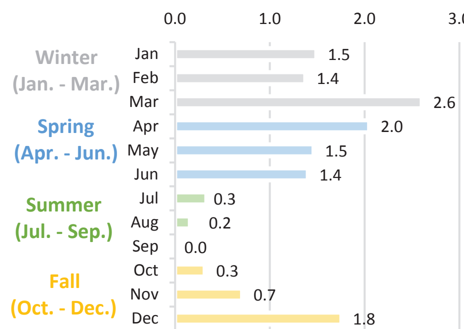
Monthly and Seasonal Distribution

Average Monthly Precipitation, in. (2007 - 2016)



Precipitation is well distributed across each season with about **45% occurring within the growing season (May-September)**.

Average Monthly Tile Drain Flow, in. (2007 - 2016)

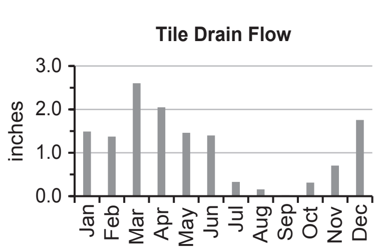


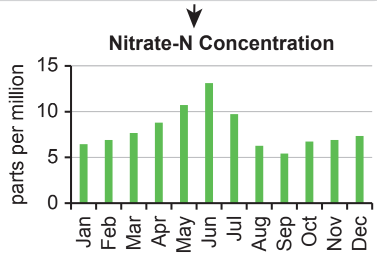
Drain flow occurs primarily in late Fall, Winter, and Spring (December to April), when plants are not growing. Only 25% occurs during the growing season.

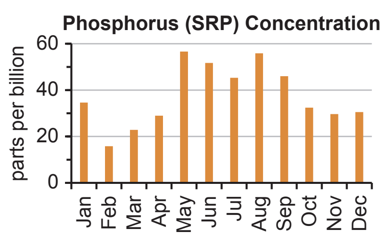
Nitrogen and Phosphorus Lost Through Drain Flow

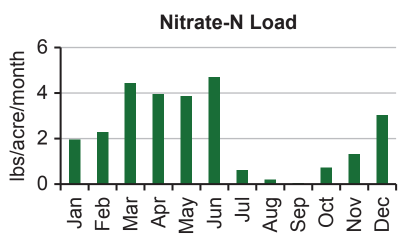
We measured volume of drain flow and concentration of nitrogen (in the form of nitrate) and phosphorus (in the form of soluble reactive phosphorus [SRP]). We used these measurements to calculate the amount lost (load) in lbs/acre/month. The seasonality of tile drain flow is a large driver of nutrient load. Average nitrate-N loads were 27 lbs/acre/year and the soluble reactive phosphorus loads were 0.1 lbs/acre/year.

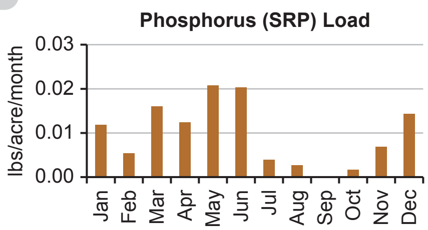
FLOW × CONCENTRATION = LOAD











QUANTIFYING BENEFITS OF A POTENTIAL DRAINAGE WATER RECYCLING SYSTEM

To assess the potential benefits of drainage water recycling, we developed a model called Evaluating Drainage Water Recycling Decisions (EDWRD) that takes into account local drainage patterns, soil types, and weather. EDWRD can serve as a tool to determine the potential for water recycling on local and regional levels by combining a reservoir and field water balance to simulate the movement of water across each day. Figure 2 shows the components of the model, which are described below.

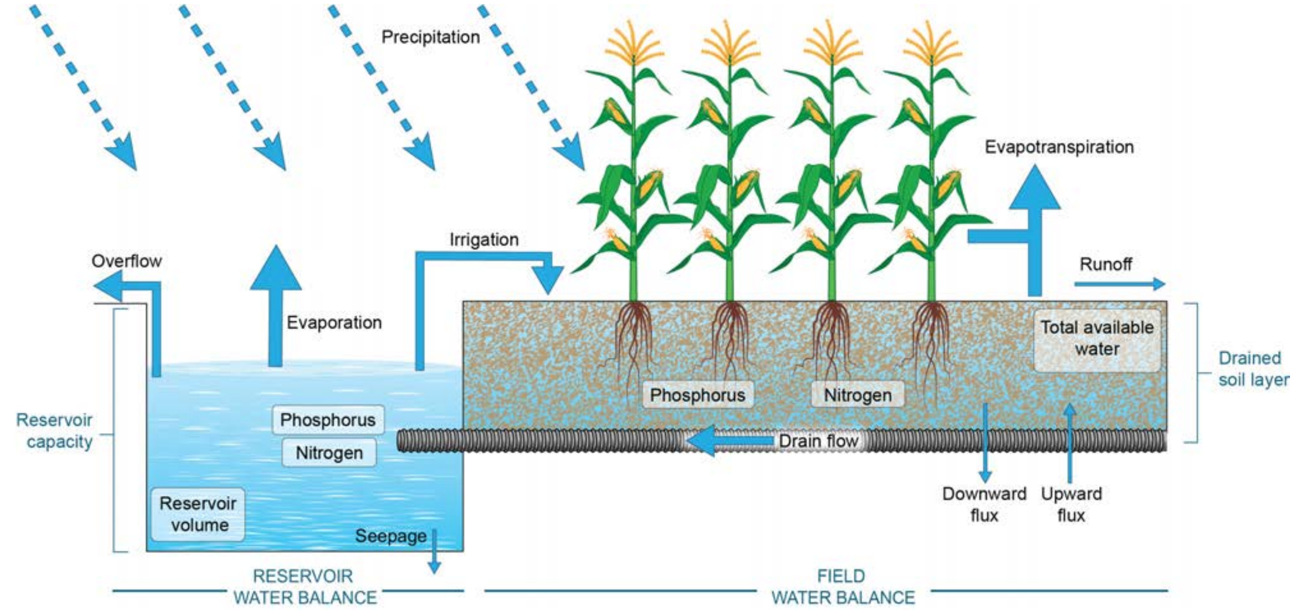


Figure 2. *Diagram of the model Evaluating Drainage Water Recycling Decisions (EDWARD), which conducts a daily reservoir and field water balance to simulate drainage water recycling systems. EDWRD can be accessed online at https://transformingdrainage.org/tools/edwrd/.*

RESERVOIR WATER BALANCE

The reservoir is defined by its potential storage volume. For this case study, we used EDWRD to evaluate reservoir sizes with an average depth of 10 feet and a surface area ranging from 2 percent to 10 percent of the field's surface area (Figure 3). As an example, for a 100-acre field these reservoir areas would be 2 acres, 4 acres, 6 acres, 8 acres, or 10 acres. We determined the daily stored water volume based on the volume of the water on the previous day, precipitation falling on the reservoir, inflow from tile drains, the amount withdrawn for irrigation, seepage losses, evaporation, and overflows when the reservoir is full. .

FIELD WATER BALANCE

We can determine the daily amount of available water within the drained soil layer based on data from the site. Water is added through precipitation that infiltrates into the soil, irrigation, and upward flux from the shallow groundwater table. Water is depleted through evapotranspiration, drainage, and downward flux of water into the groundwater table.

USING EDWRD TO EVALUATE POTENTIAL BENEFITS

The EDWRD model calculates the water stored in the reservoir and field each day, as well as irrigation provided and nutrients captured and recycled. By adding these over the entire year, it quantifies water quality and crop benefits as described in Reinhart et al. (2019) and Reinhart (2020).

Figure 3. *This case study evaluated a range of reservoir sizes representing between 2 percent and 10 percent of the overall field area (assumed average depth of 10 feet).*

WATER QUALITY BENEFITS OF DRAINAGE WATER RECYCLING

The water quality benefits are based on the overall amount and percentage of tile drain flow, nitrogen, and phosphorus that would be captured by a reservoir over 10 years of varying precipitation. Figure 4 shows the average (black bar) and range (colored bars) over the 10 years for each reservoir size, ranging from 2% of the field area to 10% of the field area .

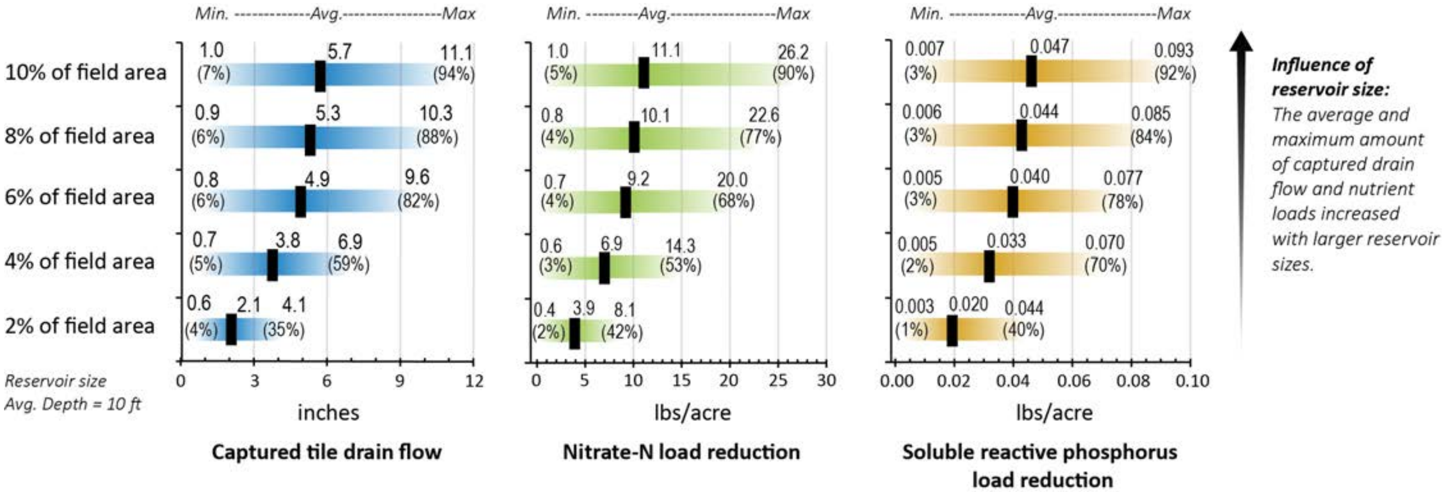


Figure 4. *Minimum, average, and maximum annual water quality benefits for various reservoir sizes. The horizontal, colored bars indicate the overall range for each benefit. The vertical black bars indicate the average amount of each benefit.*

Tile drain flow captured: The average annual amount of captured tile drain flow (water not released downstream) across the 10-year study period ranged from 2.1 inches for the smallest reservoir size to 5.7 inches for the largest reservoir size. This amount varies based on rainfall each year. Less drain flow and nutrients can be captured during wet years (low end, or left side, of each range for the graphs in Figure 4) than in dry years (high end, or right side, of each range for the graphs in Figure 4).

Nutrient load reduction: By capturing this drain flow, the drainage water recycling system would reduce nitrate-N load by 3.9 lbs/acre to 11.1 lbs/acre (16% to 42% of the annual load), and phosphorus (SRP) reductions of 0.02 lbs/acre to 0.05 lbs/acre (18% to 73% of the annual load). In the best years, the smallest reservoir could capture 42% of nitrate lost from the field and the largest reservoir could capture 90%, demonstrating that larger reservoirs can capture more drain flow, nitrogen, and phosphorus.

Annual amounts of captured drain flow and nutrient loads vary each year because weather patterns and rainfall amounts are different. In general, during wet years, when little irrigation is needed, the reservoir fills quickly and remains full, reducing the ability for reservoirs to capture tile drain flow and nutrients. During drier conditions, irrigation withdrawals from the reservoir create storage capacity within the reservoir to capture and store greater amounts of tile drain flow and nutrients.

IRRIGATION BENEFITS OF DRAINAGE WATER RECYCLING

The benefits to crop yield are based on the amount of irrigation water that could be supplied in relation to the annual irrigation demand. The irrigation demand, which is the "ideal" amount of water that would be applied based on crop need if the water supply was unlimited, is shown as the red bar in Figure 5. Since it depends on the weather in each year, it is much higher in a dry year (e.g., 6 inches in 2009) than a wet year (e.g., 0.7 inches in 2015).

Amounts of irrigation that could be supplied from various sizes of reservoir are shown in the blue bars.

A reservoir size of 2% of the field (in the lightest blue) could store enough water to meet irrigation needs in only 2 of the 10 years (2014 and 2015, when irrigation demand was low). During the other years, the reservoir could supply enough water to irrigate between 2 and 3 inches, or about 30 to 80 percent of the annual irrigation demand.

A reservoir size of 4% of the field size could meet the annual irrigation demands in six of 10 years (2008, 2010, and 2013-16). In the other four years, it would contain enough water to meet about 70 percent or more of the irrigation need.

We estimate that reservoir sizes of 6% of the field area or more could store enough water to meet irrigation needs in all 10 years.

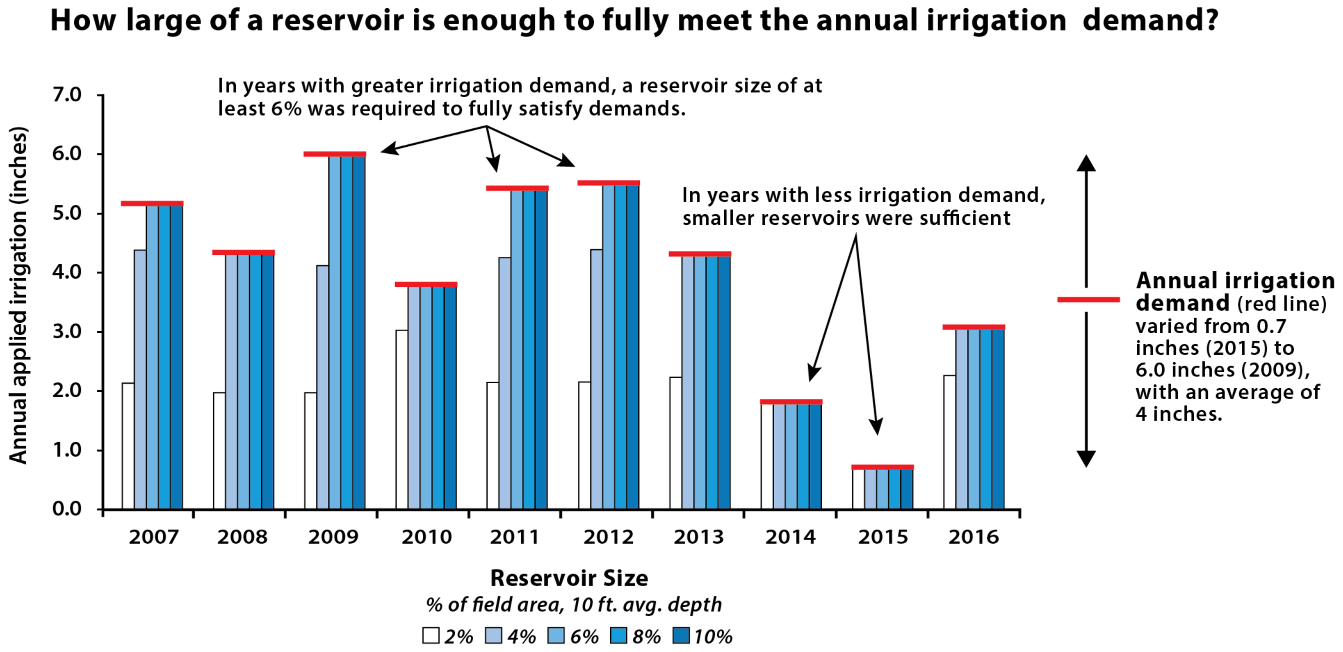


Figure 5. *The amount of applied irrigation, in relation to the annual irrigation demand, for each reservoir size between 2007 and 2016.*

FACTORS INFLUENCING BENEFITS FROM DRAINAGE WATER RECYCLING

PRECIPITATION PATTERNS

The timing and amount of precipitation determines the benefits provided by drainage water recycling, in terms of both meeting irrigation needs and improving water quality. An alternating cycle of wet non-growing season and dry growing season creates the most opportunity for drainage water recycling to provide irrigation and water quality benefits. However, if exceptionally wet or dry conditions persist for extended periods (i.e., multiple seasons or years) larger reservoirs would be required to provide the desired benefits. In consistently wet conditions, there would be little irrigation demand, and therefore little to no irrigation water use, to create additional storage capacity, limiting water quality benefits. In dry conditions the reservoir is not recharged, limiting water available to satisfy irrigation demands between precipitation events.

SOIL CHARACTERISTICS

Soils with high water-holding capacity have little need for irrigation, which limits the potential water quality benefits provided by drainage water recycling. The silty clay loam soil at the Davis Purdue Agricultural Center had a water-holding capacity of about 5.6 inches above the tile drain. During extended periods without precipitation, crops would benefit from irrigation to meet water requirements, creating the opportunity for drainage water recycling to provide irrigation and water quality benefits at the site.

Shallow water tables created by impervious layers in the soil profile can provide additional water to crops during the growing season through capillary rise. This extra contribution of water may decrease the size of reservoir needed to satisfy irrigation demands at a site, but may also reduce the potential water quality benefits since less water is needed for irrigation.

RESERVOIR SIZE

Larger reservoirs provide greater potential benefits from drainage water recycling, regardless of other characteristics, up to a certain threshold size. At the Indiana location presented in this case study, a reservoir that is 6 percent of the field area in size and 10 feet deep could capture enough water to meet irrigation demands all 10 years analyzed. A larger reservoir would not provide greater irrigation benefits except in rare years, although it may still be advantageous due to its capacity to capture and recycle more nutrients. A smaller reservoir would more often fail to meet irrigation needs, but still would provide benefits in reducing the number of days in which plants suffered from drought stress and reducing nutrient outflows downstream.

Determining the appropriate reservoir size is a trade-off between greater benefits and increased costs of a larger reservoir (Box 1). The benefits will depend on the amount and timing of precipitation and the soil characteristics, which need to be estimated for the specific conditions of a particular site (Figure 6). These two factors together will influence the amount of drainage from the field that will serve as a supply of water for the reservoir as well as the total annual irrigation demand that determines how much water will be needed as supplemental irrigation for the crop. The Evaluating Drainage Water Recycling Decisions (EDWRD) tool can be used to help make these calculations (see page 3).

Figure 6*. This reservoir has been designed and sized appropriately to capture water from the tile drained field and supply sufficient water as subirrigation during the growing season.*

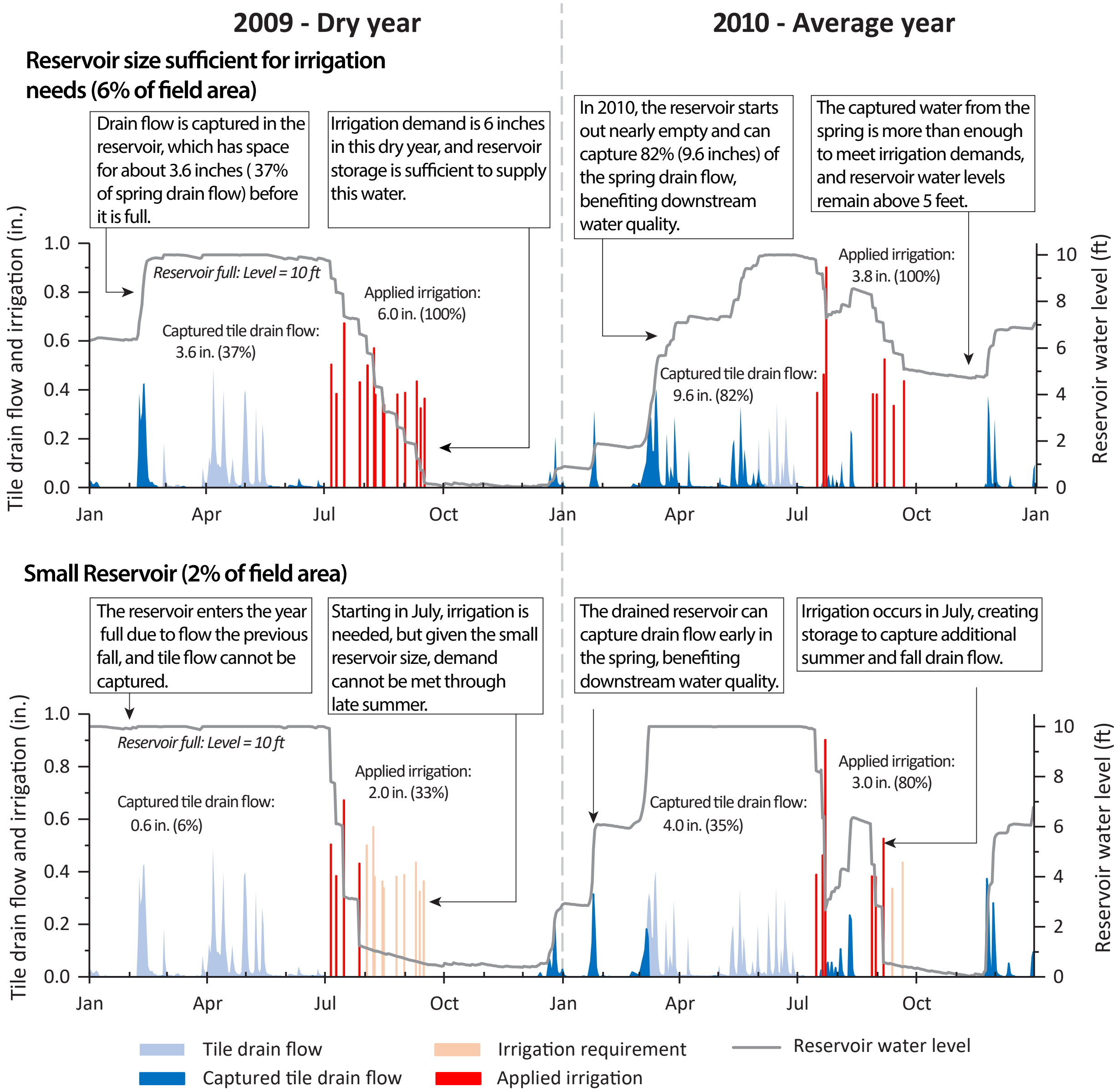
BOX 1. DRAINAGE WATER RECYCLING ACROSS THE SEASONS FOR TWO RESERVOIR SIZES

Drainage water recycling is a continued interplay of capturing drain flow in the reservoir when there is available storage volume, and irrigating crops when needed and water is available in the reservoir. The modeled results below show this complex interaction for a 2-year period, from 2009 (a dry year) through 2010 (an average year) for two reservoir sizes. In both graphs,

- Tile drain flow is shown in light blue and the portion that is captured by the reservoir is dark blue.
- Irrigation demand is light red while the portion met by irrigation water applied from the reservoir is dark red
- The water level in the reservoir is shown by the gray line, and uses the axis at the right.

The top graph shows the potential of a fairly large reservoir, 6% of field area and 10 feet deep. In addition to supplying all of the irrigation water needed by the crops in both years, it captures 37% of the drain flow and nutrients in 2009 and 82% in 2010.

The bottom graph shows the smaller potential benefits of a smaller reservoir, supplying 33% of the irrigation water needs in 2009 and 80% in 2010, and capturing 6% and 35% of drain flow and nutrients. This lower cost reservoir still provides a benefit to water quality and crop yield, although less than the larger reservoir.



CONCLUSION

Midwest crops suffer from both too much and too little water in most growing seasons, making drainage water recycling systems a potential solution in tile-drained fields. Based on this case study, a reservoir representing 6% of the field area at an average depth of 10 feet would hold enough water to irrigate crops in all but the most severe drought years. The reservoir could also reduce nitrogen and phosphorus loads reaching local waters by more than 35%.

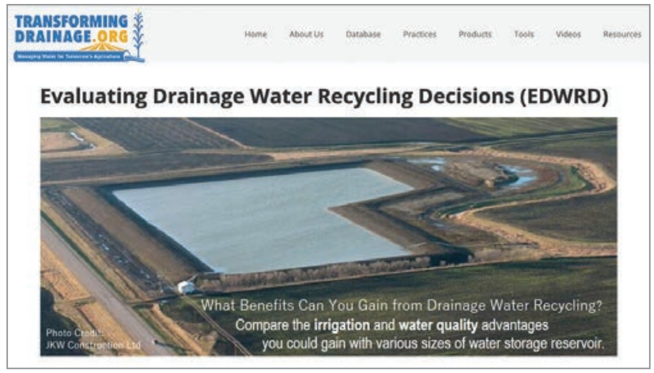
Drainage water recycling systems link irrigation and water quality, allowing agricultural producers to address their own crop production issues while improving their environmental stewardship.

FOR MORE INFORMATION

Questions and Answers about Drainage Water Recycling for the Midwest provides an introduction to the practice and what is currently known about drainage water recycling. https://transformingdrainage.org/ practices/drainage-water-recycling/

Drainage Water Recycling Videos: https://transformingdrainage.org/videos/

Evaluating Drainage Water Recycling Decisions (EDWRD) is a tool to estimate the potential water quality and irrigation benefits from drainage water recycling given various sizes of water storage. Based on user input about soil properties, field and reservoir sizes, and management, it uses a water balance approach to estimate how much drainage water can be captured, stored, and utilized for supplemental irrigation. https://transformingdrainage.org/tools/edwrd/



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Reinhart, B.D., Frankenberger, J.R., Hay, C.H. and Helmers, M.J., 2019. Simulated water quality and irrigation benefits from drainage water recycling at two tile-drained sites in the US Midwest. Agricultural Water Management, 223, p.105699. https://doi.org/10.1016/j.agwat.2019.105699

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Other drainage tools and resources can be found at https://conservationdrainage.net/resources/general-drainage-tools/.

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