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Evaluating **Drainage Water Recycling** Decisions (EDWRD)

What Benefits Can You Gain from Drainage Water Recycling?
Compare the **irrigation** and **water quality** advantages you could gain with various sizes of water storage reservoir.

Photo Credit:
JKW Construction Ltd

About This Tool

A tool for exploring the potential irrigation and water quality benefits resulting from water storage reservoirs in tile-drained landscapes

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Purpose and Overview

This tool provides an estimate of the potential benefits that result from capturing drained agricultural water in various sizes of water storage reservoirs (e.g. pond, reservoir, storage tank, etc.) for reuse as irrigation, a practiced referred to as drainage water recycling. The benefits of drainage water recycling include (1) supplemental crop irrigation from the captured water, and (2) reduction of the discharge of nutrient-rich drainage water into downstream water bodies. See Questions and Answers About Drainage Water Recycling for the Midwest for more information on this practice.

The tool Evaluating Drainage Water Recycling Decisions (EDWRD) can be used by a variety of users to answer a range of different questions, for example:

- **Farmers** may use EDWRD to evaluate how large of an on-farm water reservoir they would need to provide a target level of irrigation.
- **Drainage contractors** and **engineers** can use it to get initial approximations of the size of reservoir needed to store a certain amount of drained water from agricultural areas.
- **Researchers** may use it to evaluate the potential for irrigation and nutrient reduction benefits at specific experimental sites using measured drain flow and climate data.
- **Conservation planners** and **crop consultants** can use it to quickly explore opportunities with farmers and landowners to improve crop production and enhance conservation benefits across a range of fields in their operations.
- **Policy makers** and **analysts** may use the Regional Analysis Tool to evaluate the potential impact, or areas of greatest opportunity for, new or pilot conservation programs focused on implementing agricultural best management practices.

Currently, EDWRD includes crop information only for corn and soybeans, the two dominant crops found within the U.S. Midwest. All data is currently reported as English units (inches, feet, acres, acre-feet, etc.).

In process, EDWRD links two water balances simultaneously on a daily time step, as shown in Figure 1: one for the water storage reservoir (left) and one for a cropped agricultural field (right).

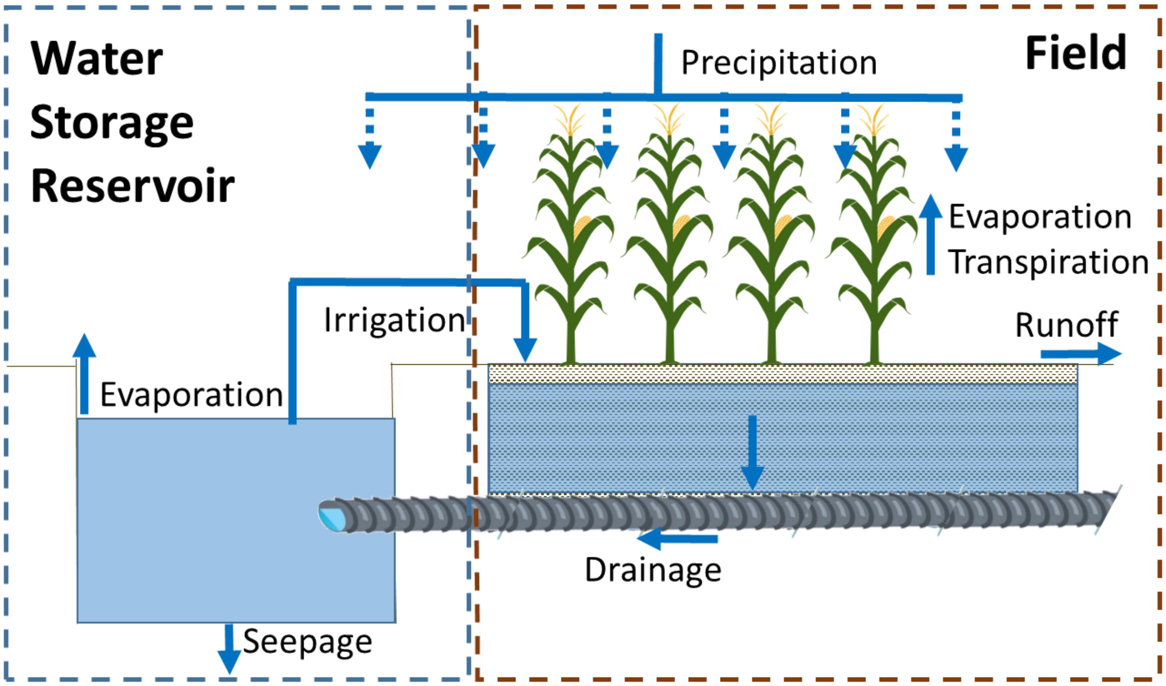

Figure 1. Two water balances calculated in EDWRD, connected through the precipitation, drainage, and irrigation

Inputs Required

The required inputs needed to run EDWRD can be broken down into four main components which characterize the drainage water recycling system: the field, the water storage reservoir, the crop, and daily estimates of climate, drain flow, and ET. Inputs within each of these component areas are briefly listed here but described in more detail in the User Guide. Default values are provided for all field, reservoir, and crop inputs.

Field inputs include the amount of area being drained to the reservoir (Drained Area), the amount of area being irrigated with water from the reservoir (Irrigated Area), the target irrigation depth during a single irrigation event (Irrigation Depth) and the capacity of the soil profile within the field to store water (Available Water Capacity).

Water storage reservoir inputs include fields which define a range of reservoir sizes (i.e. volumes) that are evaluated by given a set of field, crop, and climate conditions. This range is defined by a minimum and maximum reservoir volume (Smallest Water Storage Volume, Largest Water Storage Volume) and an interval value which describes at which values between the minimum and maximum reservoir volumes to include in the evaluation (Water Storage Volume Increment). The final inputs describe the average water storage depth within the reservoir (Avg. Water Storage Depth) and set in the initial water depth with in the reservoir at the start of the analysis (Depth of Water on First Day of Simulation).

Crop inputs define the dates for when the crop is planted and harvested (Crop Start, Crop End) as well as the end of key growth periods for crop development within the growing season (Initial, Dev, Mid, Late). Additional inputs for the crop include the crop coefficient values which describe crop water use within each of the crop growth periods ($K_{c,initial}$, $K_{c,mid}$, $K_{c,end}$) and a measure of the maximum amount of much soil water can be depleted before the crop begins to experience water stress (Depletion Factor).

Daily climate and water data are the final required inputs. These may be uploaded as a .csv file with the following column order and units:

- Year (YYYY), Month (MO), Day (DY), Precipitation (in.), Drain flow (in.), Surface Runoff (in.), Evaporation (in.), Reference ET (in.)

It is important to note that “Evaporation” refers to open water evaporation and “Reference ET” refers to the grass-based (i.e. short crop) reference ET. Understanding that some of these inputs can be difficult to measure, a set of model simulated data is provided for use in running EDWRD.

Regional gridded input data

EDWRD is pre-populated with gridded, model simulated data from the Variable Infiltration Capacity (VIC) model that can be used as input for analysis (Lee, 2017). VIC is a macro-scale, semi-distributed hydrologic model that uses climate data and a suite of physical- and process-based algorithms to land-atmosphere energy fluxes and water balances at 1/8th degree grid-cell resolution (Liang et al., 1994). Daily data for 30 years (January 1, 1981 to December 31, 2009) are provided for all grid cells in the Midwest containing somewhat poorly, poorly, or very poorly drained cropland. : These model simulations provide an estimate for drain flow and surface runoff at these locations. However, due to the variability of soils within grid cells they may only be considered an approximate estimate.

- Subsurface tile drain flow (mm per drained area)
- Precipitation (mm)
- Open water evaporation (mm)
- Surface runoff (mm)
- Reference ET, grass-based (mm)

In addition to these daily data, the soil series name and estimated tile drainage system depth (m below surface) and spacing (m) are provided. These estimated tile drainage characteristics are based on the estimated saturated hydraulic conductivity of the dominant poorly drained soil series and recommendations in *Soils and Water Conservation Engineering,* 7th edition. If a restrictive layer was present and was shallower than the recommended tile drain depth, tile drain depth was set to 0.2 m above the restrictive layer depth.

Algorithms

Water Storage Reservoir

The daily water volume in the reservoir is estimated based on the following equation:

$$V_i = V_{i-1} + P_i + D_i - I_i - SP_i - E_i$$

where V_{i-1} is the volume of water in the reservoir on the previous day, P_i is the precipitation volume over the surface area of the pond on day *i*, D_i is the volume of tile drain flow entering the reservoir from the drained field on day *i*, I_i is the daily amount of water withdrawn from the reservoir for irrigation purposes, and SP_i and E_i are daily losses due to seepage through bottom soil layers and open water evaporation from the reservoir, respectively. Daily values of reservoir volume range between zero, representing a completely drained reservoir, or V_m , representing an reservoir that is completely full. The flows of water (i.e. inflows and outflows) are aggregated on a daily time step and uniformly distributed across the reservoir.

Outflows

Reservoir outflows include irrigation withdrawals, seepage loss, and evaporation from the pond surface. The irrigation methodology is described in the Soil Water Balance section. Both seepage loss and evaporation from the surface of the reservoir may vary based on physical dimensions of the reservoir. In addition, seepage for a specific reservoir may also vary based on soil properties or seepage control practices such as amendments or special liners. In order to simplify calculations across a variety of conditions, calculations of daily reservoir volumes are based on an reservoir defined by a constant area with an average depth. A daily seepage rate is assumed (0.9 mm/day) based on USDA-Natural Resources Conservation Service (NRCS) design standards for waste storage lagoons (USDA Natural Resources Conservation Service 2008). Daily estimates of open water evaporation are a required input for EDWRD and can be obtained using daily pan evaporation measurements or simulated data.

Inflows

The two primary water inflows to the reservoir, precipitation and drain flow are both required input data within EDWRD and can be measured or simulated using various climate and hydrologic models.

Field Soil Water Balance

Soil water is described by a simple single-layer bucket model with the overall capacity, total available water (TAW), defined by:

$$TAW = rz * (\theta_{fc} - \theta_{wp})$$

where *rz* is equal to the root zone of the soil profile and θ_{fc} and θ_{wp} are the average volumetric soil water contents at field capacity and wilting plant, respectively, for the root zone. Daily soil water within this bucket is tracked as part of a water budget based on the total amount of water depletion (i.e. water use/loss from the profile) following the equation:

$$Z_i = Z_{i-1} - (P_i - RO_i) - I_i + ET_{c,adj} + dp_i$$

where Z_{i-1} is the soil water depletion of the previous day, P_i and RO_i are precipitation and runoff on day *i*, I_i is the daily amount of water applied to the field as irrigation, $ET_{c,adj,i}$ is crop evapotranspiration on day *i* and adjusted for water-stresses, and dp_i are losses of excess soil water. Conditions where Z_i=0 indicate when soil water conditions are at field capacity. As with the relationships described for the reservoir, soil water flows are aggregated on a daily time step and uniformly distributed across the soil profile.

Soil Water Balance: Outflows

Soil water is depleted from the profile through drainage, *dp*, or crop water use, *ET*. Drainage is calculated only when inflows (precipitation or irrigation) are added to a profile that exceeds field capacity. In this case, the bucket which defines the capacity of the soil profile to store water is already full, so excess water is assumed to be removed through drainage.

Evapotranspiration by the crop is calculated following the FAO crop coefficient method (Allen et al. 1998).

$$ET_{c,i} = ET_{o,i} * K_c$$

where $ET_{o,i}$is the amount of evapotranspiration from a grass-based reference crop on day *i* and $K_c$is a coefficient value describe by the ratio of evapotranspiration between a specific crop of interest and the reference crop.

Considering that as the soil water profile becomes drier (i.e. the bucket is drained), water becomes more tightly held by the soil. As a result, there is a point at which the availability of soil water is not able to fully meet the evapotranspirative demand of the crop. At this point crop water stress begins to occur and the overall daily amount of ET is reduced. In order to calculate ET that is adjusted for water-stresses, $ET_{c,adj}$, the amount of readily available water, RAW, is calculated based on a daily water depletion fraction, p_i.

$$p_i = p_{tab} + 0.04(5 - ET_{c,i})$$
$$RAW_i = TAW * p_i$$

where p_{tab} is the crop-specific soil water depletion fraction in Allen et al. (1998). Periods of high ET result in lower p values, which in turn reduce the value of RAW and reflect a greater sensitivity to crop water stress. If soil water depletion, Z_i, exceeds RAW_i, then a water stress coefficient, K_s, is calculated and used to calculate $ET_{c,adj}$.

```
$if\ Z_i > RAW_i\ then$
    $K_s = \frac{TAW - Z_i}{TAW - RAW_i}$
    $ET_{c,adj} = ET_{o,i} * K_c * K_s$
$if Z_i \leq RAW_i\ then$
    $K_s = 1$
    $ET_{c,adj} = ET_{o,i} * K_c * K_s = ET_{o,i} * K_c = ET_{c,i}$
```

If the difference between Z_i and RAW_i is small, then the value of K_s is closer to 1 and any reduction in ET is small. As this difference increases, $K_s$descreases toward 0 and the reduction in ET becomes greater.

Soil Water Balance: Inflows

The primary inflow to the soil water balance is the amount of precipitation that is infiltrated into the soil profile. This is commonly referred to as effective precipitation and can be calculated by subtracting surface runoff from the precipitation amount.

Supplemental irrigation, supplied from the reservoir, is an additional inflow to the soil water balance and is calculated based on a target irrigation amount, crop evapotranspiration, readily available water, and storage capacity of the reservoir. As described above, whenever soil water depletion exceeds readily available water, a soil water deficit exists. If this deficit occurs then a user-defined target irrigation amount, t, is applied within the water availability constraints of the reservoir. A minimum irrigation application depth of 0.25” is applied to avoid unrealistically low irrigation applications.

```
$if\ (Z_i > RAW_i)\ then$
    $if\ t\ > V_i\ then$
        $I_i\ =\ max(V_i, 0.25")$
    $else\ I_i\ = t$
```

Note that the addition of soil water through capillary rise is not explicitly described within EDWRD.

Outputs

EDWRD includes graphical output from both water balances described above. Results are reported at three different levels of aggregation. The first level of output shows results for all water storage reservoir sizes across all years. The second level of output shows results for a single reservoir size across all years. The third level of output shows results for a single reservoir size for a single year. At all levels, output graphs include both the mean line as well as a shaded range defined by the adding to and subtracting from the mean a single standard deviation.

EDWRD also includes a Regional Analysis Tool which completes the describe algorithms for locations across the entire U.S. Midwest using climate and water data from the regional gridded dataset described above and a subset of user-specified reservoir and soil water storage conditions. The output from the Regional Analysis Tool are briefly described below. More details on using the Regional Analysis Tool can be found in the User Guide.

Water captured and stored in the reservoir

The reservoir of a drainage water recycling system provides the opportunity for both water quantity and quality benefits as a function of the amount of drainage from the field is captured and stored. To estimate the portion of daily drainage,D_i, that is captured (C_i) or discharged to the outlet (B_i), a relationship between D_i and the available storage capacity, ($V_{max} - V_i$), in the reservoir is evaluated on days where D_i> 0. This relationship can be described as:

```
$if\ D_i \geq (V_{max} - V_i)\ then$
    $C_i = (V_{max} - V_i);\ B_i = D_i - C_i$
$else\ if\ \ D_i < (V_{max} - V_i)\ \ then$
    $C_i = D_i;\ B_i = 0$
```

EDWRD reports the amount of drainage that is captured,C_i, as part of its first level of output, as well as drainage, D_i, and the water depth within the reservoir as part of its second and third level output.

An additional output, percent of drain flow captured ($\%C$), is provided on an annual basis as part of the Regional Analysis Tool. This value is calculated annually as follows:

$$C = \left(\frac{\sum C_i}{\sum D_i}\right) \times 100$$

Irrigation Benefits

The amount of supplemental irrigation supplied from the reservoir of the drainage water recycling system is a key output for crop production potential but can also be seen as a water quality benefit as this provides the opportunity for the capture of additional drain flow throughout the year and creates an opportunity for increased plant uptake of nutrients that would have otherwise been lost downstream. The amount of irrigation, I_i, supplied to the crop is reported at all levels of output.

To better evaluate results regarding the ability of various sizes of reservoir to provide supplemental irrigation, estimates of annual applied irrigation are divided by a hypothetical maximum that assumes a limitless supply of water during that given year, I_u. This metric, termed irrigation sufficiency (S), represents the percent of the maximum desired irrigation that can be met by the reservoir and is calculated on an annual basis.

$$S = \left(\frac{I_i}{I_u}\right) \times 100$$

where I_i is the estimated amount of irrigation supplied by the reservoir of given volume on day i and I_u is the daily amount of irrigation supplied given a limitless water supply across the same time period.

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