Report for 2001AR3661B: Economics of water management to sustain irrigated agriculture in eastern Arkansas watersheds

- Other Publications:
    - Wailes, E.J., K.B. Young, J. Smartt, P. Tacker, and J. Popp. 2001. Economics of on-farm reservoirs for Arkansas rice farms. In R.J. Norman and J.F. Meullenet (eds). B.R. Wells Rice Research Studies 2000. University of Arkansas Agricultural Experiment Station Research Series 485: 342-346.
    - Wailes, E.J., J. Popp, K.B. Young, and J. Smartt. 2002. Economics of on-farm reservoirs and other water conservation practices for Arkansas rice farms. In R.J. Norman (ed.). B.R. Wells Rice Research Studies 2001. University of Arkansas Agricultural Experiment Station Research Series (forthcoming): 313-319.
    - Wailes, E.J., K.B. Young, J. Smartt, and P. Tacker. 2002. Economic impacts on Arkansas rice from ground water depletion. In R.J. Norman (ed.). B.R. Wells Rice Research Studies 2001. University of Arkansas Agricultural Experiment Station Research Series (forthcoming): 348-379.

Report Follows:

Problem and Research Objectives:

Four million of a total 7.7 million acres of Arkansas harvested cropland are irrigated. Rice, cotton, and soybeans are the dominant irrigated crops. The annual farm value of this irrigated output is nearly $1.5 billion with an additional $2.5 billion added in the region from further processing. Excessive ground water use to irrigate these crops is resulting in ground water depletion and water quality problems, including both salinity and alkalinity, for agriculture production in eastern Arkansas watersheds. When the salinity or alkalinity of irrigation water exceeds certain levels, their transport and accumulation into the soils builds over time and damage to crop plants occurs and yields are reduced. In addition, sediment runoff degrades the surface waters flowing out of this region. Current ground water use in the irrigated cropping systems of eastern Arkansas is not sustainable.

On-farm reservoirs, tail-water recovery systems and access to surface waters have been identified as needed components to address these problems. However, producers and policy-makers need decision tools to help them investigate and understand the potential benefits and costs of investment and water management using on-farm reservoirs and other water conservation practices. Farmers in eastern Arkansas have developed a strong interest in alternatives to pumping ground water for irrigation, not only because of ground water depletion but also due to much higher energy prices. Without assistance in changing their irrigation systems, the common property ground water resource will be depleted, soil and water quality will deteriorate, and high-valued irrigated agriculture will decline.

The project investigated the economics of farm-level irrigation systems. It evaluated optimal investment in on-farm reservoirs, tail-water recovery systems and access to surface water. Best irrigation management practices in eastern Arkansas watersheds to conserve groundwater and sustain irrigated crop production were identified. Specific research objectives of this project included:

1) Evaluate the costs and benefits of on-farm reservoirs to achieve sustainable water and soil quality for irrigated agriculture in eastern Arkansas.

2) Evaluate water conservation practices to protect the depleting ground water supply. The research will assess the benefits and costs of new technologies including: 1) alternative irrigation delivery systems, 2) alternative irrigation water sources, and 3) alternative cultural practices, including shorter season crop varieties and earlier termination of irrigation application.

3) Develop a user-friendly decision tool for use by extension agents to assist farmers in evaluating the investment in on-farm reservoirs and irrigation management strategies.

Methodology:

The research methods of this proposal included a literature review, case studies of representative farms located in eastern Arkansas watersheds, and computer modeling and simulation to add water and soil quality attributes to the analysis. The MARORA (Modified Arkansas Off-stream Reservoir Analysis) model is a farm level irrigation management and investment simulation framework that evaluates the economics of multiple source (ground water and surface) water supplies for Arkansas rice and soybean farms under various farm resource conditions. The investment analysis determines the optimal size and use of the on-farm reservoir needed to maximize a 30-year time-stream of net returns to the farming operation. Current attempts to assess the impacts of water quality on the incentives to invest in on-farm reservoirs have been based on static assumptions about the yield impacts from using irrigated water with different salinity characteristics. The model was modified to incorporate water quality dimensions.

Two major enhancements have been made to the MARORA model to assess the water quality problem. The first allows the model to keep track of the soil contained in runoff water. The amount of soil lost and the amount of soil recovered in a tail-water recovery system (if a tail-water recovery system was specified), are recorded. The second enhancement allows the model to keep track of soil salt balances for six salts most commonly found in poor quality well water. Yearly deposits in kilograms per hectare are recorded for calcium, magnesium, sodium, potassium, sulfate, and chloride. The equations for determining silt loss and yearly salt balances were taken from "A Salt and Water Balance Model for a Silt Loam Soil Cropped to Rice and Soybean" J.T. Gilmour, J.A. Ferguson, B. R. Wells, Arkansas Water Resources Research Center, publication no. 82, 1981.

Soil loss in runoff

Soil loss in rice and soybean fields depend on the time of the year and more specifically the state of the field. When fields are fallow, but spring field operations are likely (week 14 to week 22), the concentration of soil in the runoff water is 1660 ppm (milligrams per liter). At all other times during the fallow season, concentration is set at 1050 ppm.. During soybean season soil concentration in runoff is set to 1860 ppm. For rice, soil loss is set to zero when fields are flooded. Thus the accounting for soil loss consists of keeping track of the runoff amounts and the seasonal soil loss concentrations for each crop.

Soil loss (in milligrams/liter) = seasonal soil loss concentration x runoff volume (in liters)

Soil salt balance

Keeping track of soil salt balances is more complex. The user interface is modified to allow the user to input well and surface water salt concentrations for calcium, magnesium, sodium, potassium, sulfate, and chloride. These salts are added to the soil via infiltration of irrigation water. Removal is facilitated in various ways. During runoff events, salts are removed based on the concentration of salts in the runoff water. Additional salts are lost via erosion. When infiltration proceeds beyond the soil profile, salts are again lost. And finally, salts are removed via crop uptake. The methodology for tracking salt additions and removals is outlined in the following paragraphs taken from the Gilmour, Ferguson, and Wells publication referenced above.

Runoff water salt concentrations

When cumulative runoff following removal of rice floodwater is less than or equal to 10 cm, the following equation is used.

$$RWAT = WAT \times EXP(D \times CUMROFF + E)$$

Where,
RWAT is runoff water concentration (meq/l),
WAT is irrigation water concentration (meq/l),
CUMROFF is cumulative runoff (cm), and
D and E are constants.

The values for D for Ca, Mg, Na, K, SO4, and Cl are -0.28, -0.27,-0.23, -0.12, -0.44, and -0.35 (cm/l), respectively. The values for E for Ca, Mg, Na, and K are -1.00, -0.45, 0.20, 0.80, respectively. The E values for SO4 and Cl are related to irrigation water concentration (WAT) and are computed using the equation below.

$$E = F \times WAT + G$$

Where:
F and G are constants equal to –2.43 and 3.44 respectively.

When cumulative runoff following rice floodwater removal is greater than 10 cm, runoff water concentrations are assigned constant values using the equations above where,

CUMROFF = 10 cm.

Runoff water salt concentration during runoff from soybean irrigation is assumed to be equal to the irrigation water quality.

Losses from erosion

Erosion losses are tied to the soil loss concentration values described in the paragraph above describing soil loss as demonstrated in the following equation.

SEROS = SOIL x DROFF x PPM x 10 to the minus 7

Where,
SEROS is erosion salt loss in kg/ha,
SOIL is the soil salt concentration constants for Ca, Mg, Na, K, SO4, and Cl which are 1280, 160, 100, 70, 55, and 0, respectively
DROFF is runoff depth in cm and PPM was runoff soil concentration as described in the soil loss paragraph above.

Salt additions and removals in water

When salt is added to the soil via infiltration of irrigation water or removed from the soil during runoff, the following equation was used to compute salt added or removed.

$$SALT = K1 \times DEPTH \times CONC$$

Where,
SALT is the amount of salt in kg/ha,
DEPTH is the depth of water in cm,
CONC is the concentration in the water in meq/l, and
K1 is a conversion factor of 2.0, 1.2, 2.3, 3.9, 4.8, and 3.5 for Ca, Mg, Na, K, SO4, and Cl, respectively.

Concentration was calculated as follows:

$$C2 = (C1 \times D1 + WAT \times DIRR) / (D1 + DRAIN + DIRR - DE)$$

Where,
C2 is the new concentration,
C1 is the old concentration,
WAT is the irrigation water concentration,
D1 is the original water depth,
DIRR is the depth of irrigation water,
DRAIN is the depth of rainfall, and
DE is the depth of water lost to evapotranspiration.

Crop Uptake

Crop uptake of salts is described by the following equation:

$$RCROP = YIELD \times SEED/100$$

Where,
RCROP is crop uptake in kg/ha,
YIELD is grain yield in kg/ha, and
SEED is percent of salt in the grain.

The values for percent salt in the grains for rice are 0.017, 0.122, 0.129, 0.351, 0.346, 0.257 for Ca, Mg, Na, K, SO4, and Cl, respectively. The values for percent of salt in the beans for soybean are 0.142, 0.216, 0.548, 1.648, 0.535, 0.126 for Ca, Mg, Na, K, SO4, and Cl, respectively.

Water Quality Effects on Rice Yield

The original MARORA model was programmed to use reservoir water first for irrigation – using well water only if the reservoir water was insufficient or if the reservoir water was totally depleted. This version of the model uses well and reservoir water in a ratio that minimizes the effects of salts found in either the well or reservoir water. The EC level of the water is monitored for the first 40 days after rice emergence and yield reductions are assessed as follows: if the average EC value during this time is above 1200 micro mhos then the yield is reduced 20%. Yield reductions of 30% and 45% are assessed for EC values over 2000 and 3000 respectively. Running the model in non-optimization mode provides information on the predicted effects of a given combination of well and/or reservoir water on the rice yield. Running the model in optimization mode predicts an optimal size reservoir that will maximize profits by minimizing the yield loss associated with poor quality irrigation water. (EC values for both well and reservoir water can be input directly as one of the input parameters or can be calculated from the salt values for Ca, Mg, Na, K, SO4 and CL for both well and reservoir waters entered in meq/l). Yield reductions are based on research by J.T. Gilmour, "Water Quality in Rice Production", Rice Research Studies 2000, Research series 485, Arkansas Agricultural Experiment Station, August 2000, pp.171-177.

Principal Findings and Significance:

An on-farm reservoir is estimated to be not profitable in the good ground water situation as a water conservation practice because of the relatively low pumping cost for ground water and loss of valuable cropland for reservoir construction. The NPV per acre on the 320-acre tract is $2,145 with the baseline irrigation efficiency, $2,157 with underground pipe, and $2,639 to $2,696 with both underground pipe and land leveling in the good ground water situation. Sedimentation reductions do not pose a sufficient benefit to support construction of a reservoir.

NPV per acre is $1,456 in the poor ground water situation with no government cost share for an on-farm reservoir of 640 acre feet capacity covering 70 cropland acres with the low 45 percent soybeans/50 percent for rice baseline irrigation efficiency. This NPV is 68 percent of the NPV in the good ground water situation. NPV per acre increases to $1,598 with underground pipe, and to a level of $2,099 to $2,170 when both underground pipe and land leveling are combined with a reservoir. The required optimal reservoir size declines from 640 acre-feet at the baseline efficiency level to as low as 480 acre-feet as irrigation efficiency is increased. The underground pipe and field leveling improvements save up to 16 acres of valuable cropland.

A benefit-cost analysis of these three conservation practices shows that all are profitable at full cost without the cost share by the government except for on-farm reservoirs in the good ground water situation. NPV per acre without a reservoir at the baseline efficiency level is only $629 in the poor ground water situation and is increased by $1,269 per acre with a reservoir. The return on the reservoir investment with poor ground water is high. The rate of return is 187 percent based on a per acre $1,269 return and a per acre reservoir cost of $442 with no government cost share. With a 65 percent government cost share, the rate of return is 719 percent.

Water Quality

Water with an EC level over 1200 micro mhos is known to damage rice seedlings and reduce yields. In addition to model assumptions discussed above, results were based on the assumption that the well water was plentiful but of poor quality (50 feet saturated depth of water table with 0.5 foot decline per year; well water EC of 1800 micro mhos and reservoir water EC of 500 micro mhos). Simulations were run to show the effects on average yearly income assuming; crop yield reductions of 10, 15, 20, 25, and 30 percent without a reservoir; and with a reservoir of 200 acre-feet providing sufficient water to mix with the well water in a 1 to 1 ratio to bring the EC level down below 1200. A base simulation assuming plentiful high quality well water was also included as a benchmark.

Maturity Date

An additional analysis was conducted to measure the irrigation conservation benefits of earlier maturing rice varieties. The shorter the maturation process the less irrigation water needed. Shorter season rice varieties can provide conservation benefits in terms of requiring a smaller size reservoir to meet optimal investment and less water for irrigation use over the growing season. The optimal reservoir size can be reduced by 50 acre-feet capacity (5 surface acres) as maturity date is reduced by 25 days. Annual income for the 320 acres is estimated to increase on average by $170 per day reduction in maturity date of rice and soybeans.

Significance of findings

The results of this study show a high economic return from on-farm reservoirs when ground water is limited and also high returns to other water conservation practices under alternative ground water supply conditions. On-farm reservoirs are estimated to be highly profitable when ground water is depleted and are essential to maintain irrigation unless other surface water access is available. Underground pipe and land leveling are profitable for both good and poor ground water supply conditions as long as irrigation is sustainable. On-farm reservoirs can be economic in good ground water situations if ground water quality is a problem. The significant ground water depletion problem that is occurring in rice production areas of Arkansas can be addressed through the use of the MARORA models by assisting producers to make sound financial investments to improve water conservation and sustain rice production. The MARORA model has been enhanced to account for sedimentation loss and salt accumulation and damage. The model demonstrates that on-farm reservoirs can be a valuable investment to address water quality issues.