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Tailwater Recovery Systems for Irrigation: Benefit/Cost Analysis and Water Resource Conservation Technique in Northeast Arkansas

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Abstract

Water, one of the earth's most vital resources, is particularly significant in the Arkansas Delta agricultural landscape. While both surface and groundwater are extremely important, 94% of the 26.9 billion L (7.1 billion gal) of water pumped daily from the Alluvial Aquifer is used for agricultural purposes. This common property is subsequently being depleted and sustainable conservation methods are being pursued. State and federal incentive programs encourage the use of a tailwater recovery system in agricultural irrigation. With the use of a complete recovery system, benefits include not only government incentives for wetland habitat, but reduced groundwater use and decreased agricultural runoff entering receiving streams. Costs incurred to the farm manager include crop loss due to reservoir storage, additional ditch construction, and the cost of a lift pump. Use of these systems offers not only economic benefits associated with aquifer preservation but also ecological benefits including reduced nutrient and sediment loading to receiving streams concurrent with ecosystem services. The overall benefit/cost analysis of these systems shows that the economic benefits of using a tailwater recovery system exceed the cost. Other positive features include the ecological benefits of surface water protection and ecosystem services.

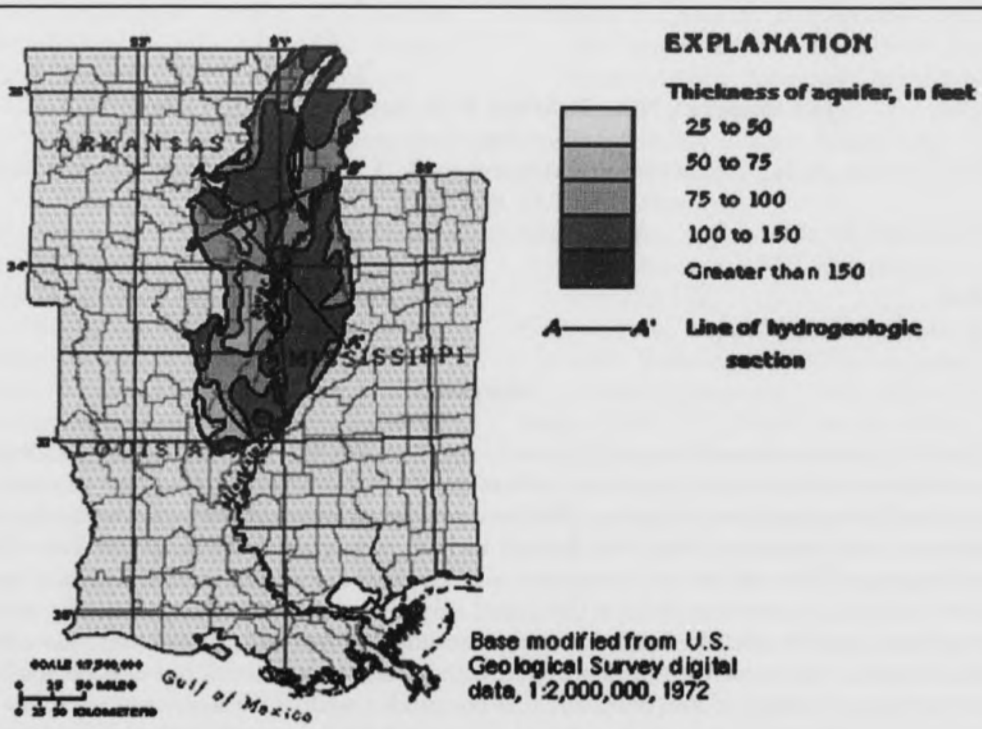
Introduction

Surface water uses in Arkansas include navigation for shipment of goods on the Arkansas and White rivers, withdrawal for public water supply, and discharge for municipality, industry and agricultural waste, and limited irrigation for agriculture (Arkansas Environmental Federation (AEF), 2003). Although there are a variety of uses for surface water, 73% of the total water used in the state is groundwater, making Arkansas the fourth largest user of groundwater in the nation (ASWCC, 2004). It should also be noted that two areas of the state have been declared critical with regard to groundwater, including a region of south-central Arkansas and an area in east-central Arkansas that are experiencing depletion of the Sparta Aquifer and the Sparta and Alluvial aquifers, respectively. Groundwater is also used by municipalities, as a drinking water source, as well as fire protection. In addition, industry is attracted to water rich areas and often uses large quantities of water in on-line processing and cooling.

As the largest user of water in the state, agriculture is dependent upon this resource for the application of fertilizers and pesticides and the irrigation of standing crops. Water is also utilized as a physical herbicide in rice production, minimizing chemical application. Pimentel et al. (2000) reported that rice and soybeans are among the most water demanding crops, with rice requiring 1,910 L of water for each kg (228 gal/lb) produced and soybeans requiring 2,000 L of water for each kg produced (238 gal/lb).

The National Agriculture Statistics Service (NASS, 2003) states that Arkansas was the largest producer of rice in the United States, producing 4.35 billion kg (9.6 billion lb) in 2002. In this year, the state supported 5.91 million ha (14.6 million acres) of crop production with 1.50 million of those ha (3.7 million acres) under irrigation. Total irrigated acres in northeast Arkansas included 89,702 ha (221,658 acres) in Craighead County with 31,970 and 29.495 ha (79,000 and 63,000 acres) respectively in rice and irrigated soybean production. NASS reported a total of 47,100 irrigated ha (116,388 acres) for Greene County, with 24,848 and 20,235 ha (61,400 and 50,000 acres) in rice and irrigated soybean production. For the same year, Poinsett County supported 110,895 irrigated ha (274,028 acres) with 54,673 and 46,944 ha (135,100 and 116,000 acres) in rice and irrigated soybean production. This extensive production acreage in northeast Arkansas illustrates how water availability and fertile soils combine to make Arkansas the fourth largest user of groundwater in the nation (AEF, 2003).

The Mississippi River Valley Alluvial Aquifer is the surficial aquifer system located beneath the eastern one-third of Arkansas (Fig. 1). Large groundwater withdrawals from this aquifer have resulted in a long-term decline of



Base modified from U.S. Geological Survey digital data, 1:2,000,000, 1972

Modified from Ackerman, D.J., 1996, Hydrology of the Mississippi River Valley alluvial aquifer, south-central United States: U.S. Geological Survey Professional Paper 1416-D, 56 p.

Fig. 1. Location and thickness of the Mississippi River Valley Alluvial Aquifer as reported by USGS.

water levels in some areas and also have reduced the amount of water discharged into rivers. By the early 1980s, withdrawal for irrigation and aquaculture had dropped water levels in the Alluvial Aquifer below the stream bed of several rivers that have acted as long term drains from the aquifer (Renken, 1998). The configuration of the water table near rivers that incise the Mississippi River Valley Alluvial Aquifer is influenced by seasonal changes in river stage (USGS, 2002). During the winter and spring, greater stream flow characterizes the rivers as influent, recharging the aquifer and raising the water table. However, during the dryer seasons of summer and fall, stream flow is low, and groundwater from the aquifer is discharged into the river. These seasonal changes in water levels in the Alluvial Aquifer may be quite large. According to Renken (1998) the decline in water levels in the Mississippi River Valley Alluvial Aquifer from spring to fall, 1965, was greater than 3.05 meters (10 feet) in some areas. The seasonal influx makes the alluvial aquifer a renewable resource, albeit at a very sluggish rate. However, the natural recharge of this resource cannot compensate for the constant demands of groundwater withdrawals.

Approximately 26.9 billion L (7.1 billion gal) of groundwater per day were extracted in 2001 from the state's aquifers. Currently, the same volume of water is extracted daily from the Alluvial Aquifer for use in Arkansas, with 94% used by agriculture (Fig. 2) (ASWCC, 2004). Since 1996, the aquifer has fallen an average of 0.30 m (one ft) per year with Craighead County's five-year (1996-2001) decline equivalent to 1.12 m (3.69 ft). This county is flanked with a 1.84 and 1.23-m (6.03 and 4.05-ft) decline, respectively, in Poinsett and Greene counties for the same five-year period (ASWCC, 2004). In 2002 the Arkansas Water Resources Center reported that over the next 30-year period the Alluvial Aquifer would fall to critical levels, leaving most irrigated farms without operational wells. Groundwater use and uncertain aquifer levels in Arkansas have raised concern by state officials and policy makers, calling for conservation methods by the agricultural community and legislation encouraging alternate plans for water utilization. Government incentives and payback enticements are now available to encourage these management practices.

The reuse of irrigation water from agricultural fields targeted for discharge into receiving streams is defined as tailwater recovery. Capture techniques vary according to source waters used; these include groundwater, surface

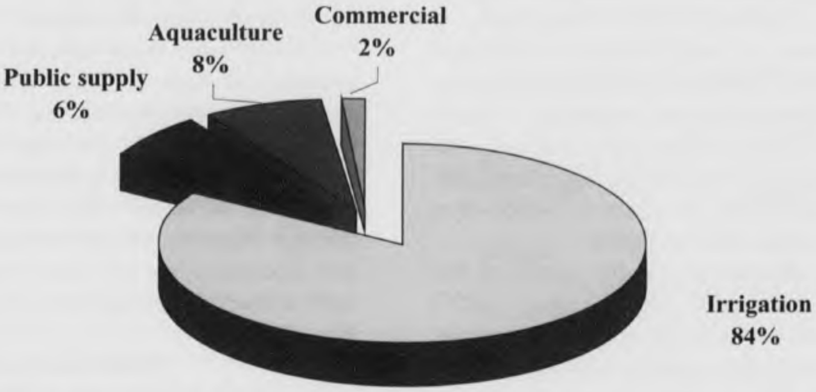


Fig 2. Groundwater use from the Mississippi River Valley Alluvial Aquifer during 1995 as reported by USGS.

water from rivers, streams, and runoff. Storage reservoirs hold water that is then utilized for irrigation. Irrigation water is then recaptured following release from flooded fields and redirected to the reservoir for future reuse. Rainfall runoff from surrounding watershed otherwise destined to be surface runoff can be stored for subsequent use in reservoirs. Water in each of these systems is utilized numerous times throughout a growing season with surplus collected during rainfall events. Conservation of this water and its concurrent non-release may be viewed as a benefit in both the agricultural and ecological realm.

Recent models have calculated economic benefits from reservoir storage of diverted surface water in critical groundwater areas of Arkansas, however, these studies failed to incorporate environmental benefits on production land and within downstream ecosystems (Wailes et al., 2000a, 2000b). The non-release of irrigation water into receiving streams conserves nutrients leached from the soil matrix in addition to sediment suspended in discharged irrigation water. Sediment is listed as the most common impairment of Arkansas' waterways, impairing 14% of rivers and streams in the state, and the US EPA (2000) cites agriculture as the leading source of contamination of the state's surface water.

Non-point source pollution is defined as contamination entering waterways without a defined point of discharge. Agricultural runoff is responsible for 25-36% of all non-point runoff into the country's streams and accounts for 90.5% of the total nitrogen contamination flowing into the Gulf of Mexico (Doering et al., 1999). Nutrient retention on agricultural fields benefits production land and results in decreased loading to receiving streams. Retained topsoil contains valuable organic matter resulting in increased fertility in production land concurrent with a decrease of sedimentation in receiving streams. Erosion not only results in soil loss from agriculture fields, but also produces negative effects in aquatic systems, such as light and visibility attenuation, coverage of spawning areas, clogging of gills, and transport of sediment-bound contaminants (US EPA, 2002). Turbidity caused by erosion is often associated with additional contaminants, such as nutrients, pathogens, and pesticides, causing further ecological impairment.

Loss of nutrients, topsoil, and pesticides from agricultural land results in economic losses for landowners in addition to reduced environmental quality for receiving streams. While on-farm impacts may be substantial, the ecosystem benefits of runoff control are generally considered to be much more significant. An ecosystem is defined as an ecological community functioning as a unit with its environment, and services provided by ecosystem protection include recreational and consumptive uses as well as aesthetic values associated with proximity to the resources. Contamination adversely affects ecosystem function and reduces the quality of freshwater resources and related ecosystems, thereby reducing the value of services provided by these systems (Crosson, 1986).

The use of tailwater recovery results in preservation of groundwater concurrent with environmental benefits. The Clean Water Action Plan, prepared by the USDA and the US EPA jointly and released by President Clinton in February, 1998, calls for states to deal with non-point source pollution problems. In this report, states are required to implement non-degradation policies, and the plan called for improved standards and criteria for defining water quality problems and methods for gauging progress. Seven priorities were listed in the plan: strengthening ambient water quality criteria, developing nutrient standards, developing specific standards for microbial pathogens, completing biocriteria for aquatic life, improving methods for measuring and achieving total maximum daily loads (TMDLs), considering possible criteria for sediment and flow characteristics, and finding ways to implement these standards and criteria throughout the United States (US EPA, 1998).

Recent legislation addressing these problems includes the 2002 Farm Bill, which established a new Conservation

Security Program (CSP) designed to conserve resources of concern (USDA, 2002). Soil and water conservation is enhanced by the adoption of land based construction practices. These practices conserve soil and water in addition to providing payments upon adoption of these management techniques. These efforts are defined with three tiers of participation, and 75% cost sharing is available for construction and utilization of grassed waterways, contour grass strips, filter strips, and wetlands.

During the Clinton administration, the goals of the President's Council on Sustainable Development (1997) were the management of agricultural activities to protect air, soil, and water quality and the conservation of wildlife habitat and biodiversity. These goals were intended to increase agriculture's long-term productivity and profitability as well as enhance human health and well-being. The integration of pollution prevention and natural resource conservation into agricultural production as well as global agricultural sustainability were primary policies developed by the Task Force. Concurrently, the Organization for Economic Cooperation and Development acknowledged that agricultural activities have both beneficial and harmful effects on the environment through changing the quality and quantity of soil and water (OECD, 1997). Natural resources indigenous to Arkansas, including surface water and fertile soils of agricultural production areas, should be managed in terms of global sustainability recommendations.

Cairns (1997) emphasized the relationships between management and sustainability of the planet's resources and the importance of monitoring these systems. Under the present legislation, farm managers are encouraged to conserve and improve these resources through soil preservation and water protection from runoff-associated contaminants by various government incentive programs (USDA, 2003). Cairns expressed concern for ecosystem health as the basis of sustainability and warned that sustainable use of the planet will be impossible unless human society pays closer attention to the delivery of ecosystem services. Society is often not aware of these services until the service is impaired and the results are evident. He reiterated three basic principles outlined by Arrow et al. (1995) concerning economics and the environment:

1. all economic activity ultimately depends upon the environmental resource base,
2. the environmental resource base is finite, and lastly,
3. imprudent use of the environmental resource base may irreversibly reduce the capacity for generating material production in the future.

According to Cairns (1997), a few ecological resources have received attention, such as timber and fisheries, while most services perceived as beneficial to human society have not. He called for the development of a field of non-market ecosystem services and insisted they be incorporated into the present economic system.

These ecosystem services have been included in a benefit/cost analysis of a tailwater recovery system for agricultural systems utilizing a reservoir-ditch-relift system for crop irrigation. The model included benefit/cost for agriculture as well as benefit/cost for ecosystems and their associated services. The following model was developed through interdisciplinary research of ecological, agricultural, and economic sources, and values for model parameters were obtained through peer-reviewed research.

Materials and Methods

A benefit/cost analysis model for tailwater recovery systems was developed utilizing a simple debit/credit model. Monetary values for various environmental benefits may be difficult to catalogue; however, many of these benefits have been previously identified and valuated. Government programs provide financial support for various types of environmentally beneficial actions by private citizens, giving landowners a financial incentive to improve environmental quality.

Constants and values are assigned to various functions used in the model. Functions related to pumps include:

1. amount gas for a well pumps (reflected as total number of acres)
2. efficiency factor between relift pump and well pump (a relift pump uses one third the gas of a well pump), and
3. government payback for relift pumps of 50% (pers. comm. Farm Bureau and Southern Ecological Services (SES, 2003)).

Functions related to dirt work include:

1. construction of reservoirs and ditches at 78 cents per cubic meter (60 cents per cubic yard) (pers. comm. SES, 2003),
2. government payback for dirt work at 30% (varies with county), and
3. conversion to wetland or natural habitat from farmland at $168 per hectare ($68 per acre) (Conservation Reserve Program (CRP), Wetlands Reserve Program (WRP), and Wildlife Incentives Program (WIP) (US EPA, 2002))

Functions related to water utilization include:

1. water usage for rice and soybeans of 6.08 million L per ha (two acre-ft per acre) of crop (Doering et al., 1999),
2. average growing season precipitation of 51 cm (20 inches) and evapotranspiration of 84 cm (33 inches),
3. annual groundwater safe yield (groundwater removal without onset of environmental damage is 23.3 million cubic m (18,901 acre-ft) (Doering et al., 1999)),
4. fertility saved or lost as percentage of growth (32% per year with loss as a function of total years farmed with/without soil conservation practices) (Trout, 1996; Sojka

et al., 1992), and

5. land inaccessible by irrigation (25% of the total ha with a tailwater recovery system (Knapp et al., 1998; Sun et al., 1992; Abdallah, 1990)).

Functions related to waterway maintenance include:

1. required dirtwork each twenty years for removal of accumulated sediment (pers. comm. Farm Bureau and SES, 2003). (This work is ubiquitous with relift and well systems since feeder ditches in well systems must also be cleaned periodically).

Initial cost includes the equal expense of pump installation for wells and relift systems; however, gas consumption for relift pumps is 1/3 the gas of well pumps. Construction cost for ditch and reservoir structures is then calculated.

Included as benefits in the model are:

1. government financial payback programs for tailwater recovery systems (varies with county),
2. income from created wetlands (lease of hunting/fishing club), and
3. increased crop production from absence of cold-water crops phenomenon (decreased water temperature affects approximately 1% of crops).

Environmental benefits incorporated into the model are:

1. topsoil conservation, which reduces fertility loss and retains soil organic matter,
2. decreased nutrients to waterways--a product of ha and $75.19 (cost of fertility lost to river systems (Doering et al. 1999)),
3. monetary value of $6,178 per ha ($2,500 per surface acre)--assigned for ecological services of wetlands (estimated for various ecological services such as filtration of sediments and nutrients, wildlife habitat, and various other positive externalities of wetland ecosystem services (Doering et al., 1999; Cairns, 1997),
4. government incentive for wetland acres (CRP, WRP, and WIP)--valued as $168/ha/year ($68/surface acre/year) (pers. comm. Farm Bureau and SES, 2003), and
5. groundwater use; increased groundwater storage is the product of the difference in amount of safe groundwater yield and groundwater used multiplied by $0.46 per cubic m ($5.69/acre-ft) (cost of groundwater) (Doering et al., 1999).

Present value (Costs) are calculated as follows:

PV Cost of Well =
(CL + WC + GC + FL) / (1 + IR) ^ Year

Where
CL = Annual maintenance cost
WC = Well pump cost
GC = Annual gas cost
FL = Annual fertility loss
IR = Interest Rate
Year = number of years with current system

PV Cost of relift =
(CL + RC + GC + DD + DR + CLO) / (1 + IR) ^ Year

Where
CL = Annual maintenance cost
RC = Relift pump cost
GC = Annual gas cost
DD = Dirt work for ditches
DR = Dirt work for reservoirs
CLO = Annual crop loss to acres loss to reservoir
IR = Interest Rate
Year = number of years with current system

Present value (Benefit) are calculated as follows:

PV Benefit of well = (CSW) / (1 + IR) ^ Year

Where
CSW = Net Crop Sales for well
IR = Interest rate
Year = Number of years in current system

PV Benefit of relift =
(CSR + GSP + GSD + HC + CC + FS + DN + ES + WL + GS) / (1 + IR) ^ Year

Where
CSR = Net Crop Sales for relift
GSP = Government support for relift pump
GSD = Government support for dirt work
HC = Hunting club
CC = Crops saved from cold water damage
FS = Soil fertility saved
DN = Decreased nutrient into waterways
ES = Ecological services
WL = Wetland habitat
GS = Increased groundwater storage
IR = Interest rate
Year = Number of years in current system

Table 1 (The Present Value Benefit divided by the Present Value Cost) produces a ratio indicating a system with higher benefits than cost, thus resulting in an economically positive scenario. It should also be noted that the Internal Rate of Return (IRR) is also calculated for the model. The IRR is defined as the interest rate at which the

Table 1. Comparison of benefit/cost ratios of well and relift systems for tailwater recovery system in northeast Arkansas.

Interest Rate	Well B/C ratio	Relift B/C ratio
0.25	1.23	6.91
0.20	1.44	8.03
0.18	1.55	8.62
0.15	1.78	9.74
0.10	2.42	12.61
0.05	3.89	17.74

sum of present value benefits equals the sum of present value costs, thereby resulting in an increased economic rate of return.

Results

Modeled with a 25% interest rate, the B/C ratio of relift is approximately five times that of a well system (Table 1). With a lower interest rate the B/C ratio difference is even more pronounced with a ratio of 17.74 for relift and 3.89 for well systems. The B/C ratio difference remains approximately five times higher for the relift system than the well system, regardless of the interest rate.

The present value benefits for a relift system are consistently higher using this analysis (Fig. 3). Included in the benefits are government incentives and reduction of operational costs of relift over well pumps, and also important ecological benefits. According to this model, a 400-ha farm (1,000 acre) will accrue an initial cost of $392,063 during construction and pump installation. Construction costs include a 51-ha (125-acre) reservoir and a ditch system sufficient for water movement. During the initial year, a benefit of $694,172 will be seen for the same system to give a Present Value (PV) Benefit-Cost of the relift system after the first year of $302,108. In the initial year, the PV Benefit-Cost for a well system will be $28,000. Accruing an initial cost of $32,000 for the well is offset by a $60,000 benefit, leaving the PV Benefit-Cost as $271,108 less than the PV Benefit-Cost for relift systems.

Overall B/C of a relift versus a well system calculates the net benefits for a relift to be greatest at the beginning of the accrual (Fig. 4). Although these values equilibrate over time, benefits of the relift system remain higher. A higher continuation of benefits of the relift system is seen primarily in the ecological services, decreased nutrients to the waterways, topsoil saved, and increased wetland habitat.

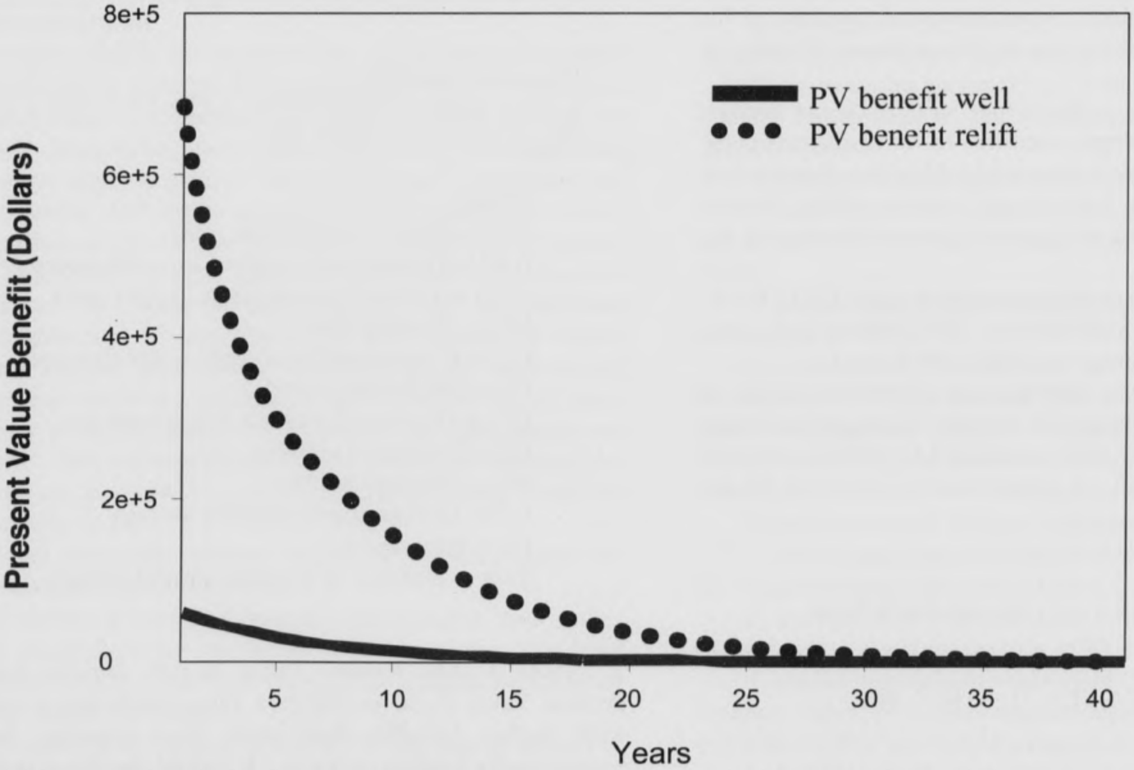


Fig. 3. Present value benefit of well and relift system versus time, calculated as B/C ratio for tailwater recovery system in northeast Arkansas.

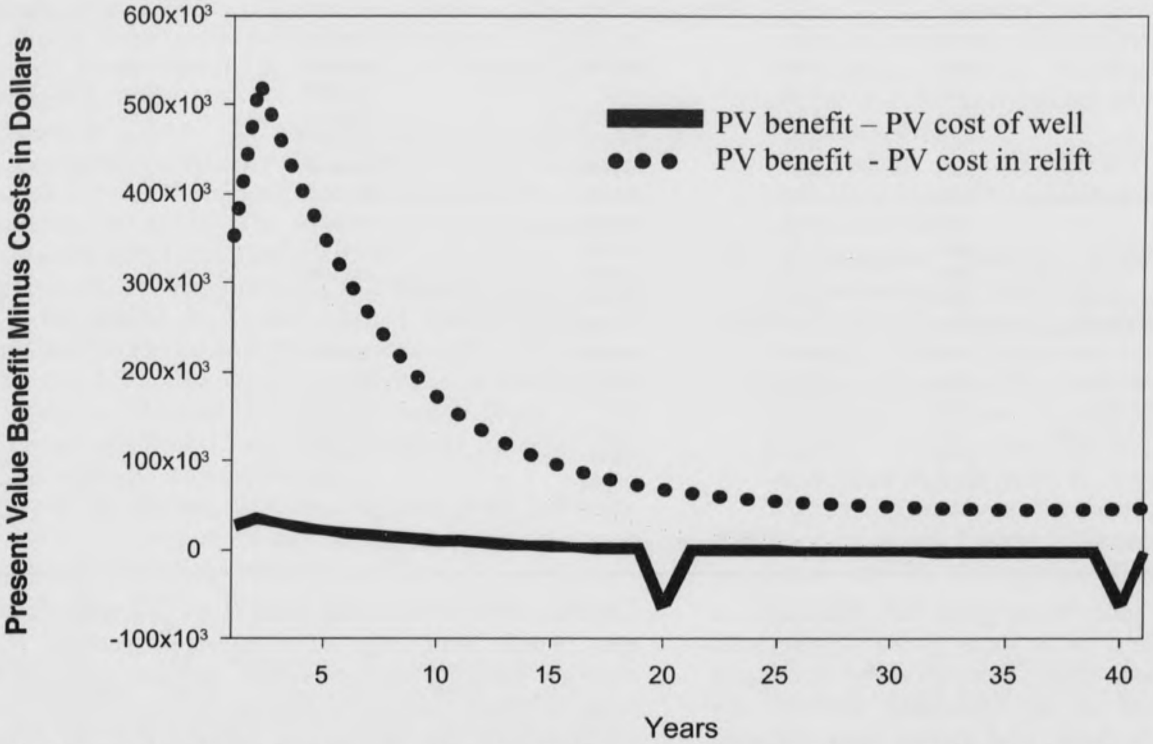


Fig. 4. Present value benefit minus cost of well and relift versus time, calculated as B/C ratio for tailwater recovery system in northeast Arkansas.

These ecological benefits are accrued as economical benefits and are illustrated throughout the 40 years of the model.

For all scenarios modeled, the B/C Ratio is much greater for the tailwater recovery system with the exclusion of environmental services (Table 1). The B/C Ratio in this situation is almost equal (relift = 1.50 and well = 1.55). These situations are illustrated with a constant interest rate of 0.18 and varying farm sizes (Appendix 1). A 40-ha (100-acre) farm results in a B/C Ratio of 19.05 for relift and 1.01 for well systems. Without crop subsidies, a 400-ha (1,000-acre) farm may result in a B/C Ratio of 10.07 for relift and 4.67 for a well system. The calculated IRR for a relift system is greater than 1.00, while the calculated IRR for the well system is 0.3467.

Discussion

The problems associated with over exploitation of common property such as groundwater have been voiced in economic publications such as Tragedy of the Commons by Garrett Hardin (1968). Hardin envisioned economic misfortune concurrent with the overuse of common resources and proposed that responsible parties must curtail unequal usage of the common resource. Resources slow to replenish, such as groundwater, must be used at a sustainable rate to ensure continued existence and maintenance. To remain a sustainable resource, groundwater usage rate must not exceed recharge rate. With agriculture utilizing approximately 25.3 billion L (6.7 billion gal) of groundwater per day, it is by far the largest stakeholder in this common resource. Hardin suggested that the commons could be privatized or kept as public property to which rights to entry and use could be allocated. Feeny et al. (1990) suggested that self-management is better than government regulation options. Therefore, the communal property utilized so heavily by agriculture should become self-managed to avoid depletion of common property. The self-management strategy illustrated in this model is found to be of economic benefit for the agricultural society as well as a self-management tool.

Ecological resources are commonly overlooked by present day economists, and services provided by a healthy ecosystem often go unnoticed until after their disappearance. The services may be too numerous to mention, and many times they cannot be measured by common parameters. Cairns (1998) stated that technology has raised production, resulting in reliable supplies of basic environmental services such as water, but these common resources are not always equitably shared. According to Dasgupta (1990) all economic activity is based ultimately on resources found in nature. Even raw labor is a produced good, manufactured by natural resources such as nutrients, air, and the water we drink; therefore all commodities are traceable to natural resources. The cycling of nutrients,

Variable	Farm size (acre)	Interest	PVBenefit - PVCost well	PVBenefit - PVCost relift	BCR well	BCR relift
10000 acre farm	10000	0.18	1544703	27316313	1.64	8.62
1000 acre farm	1000	0.18	140970	3453215	1.55	7.23
100 acre	100	0.18	597	1060905	1.01	19.05
Without groundwater	1000	0.18	140970	2789232	1.55	7.16
Without wetland revenues	1000	0.18	140970	3396989	1.55	8.50
Without ecological services	1000	0.18	140970	1386098	1.55	4.06
Without nutrient decrease into waterway	1000	0.18	140970	2960774	1.55	7.54
Without fertilizer savings	1000	0.18	140970	3441656	1.55	8.60
Saving from old crop damage	1000	0.18	140970	3447975	1.55	8.61
Without hunting club	1000	0.18	140970	3354976	1.55	8.41
Without goverment support for dirt	1000	0.18	140970	3343226	1.55	8.38
Without goverment support for pump	1000	0.18	140970	3445715	1.55	8.61
No environmental services	1000	0.18	140970	229675	1.55	1.50
Only groundwater savings no other	1000	0.18	140970	893657	1.55	2.97
Only ecological services no other	1000	0.18	140970	2296792	1.55	6.07
Environmental services and just crop	1000	0.18	140970	2512039	1.55	6.54
Only environmental services	1000	0.18	140970	2184575	1.55	5.82
With crop subsides	1000	0.18	926884	4108143	4.67	10.07

Appendix 1. modeled benefits of relift system versus well for irrigation at interest rate of 0.18.

primary production, and biodiversity are examples of ecosystem services, and to produce goods of economic value, society ultimately utilizes these services. Ecological resource is the base of all economic activity; the environmental base is finite, and misuse may decrease future production of these systems (Cairns, 1997).

Tailwater recovery systems utilizing the capture of surface runoff offer conservation of groundwater as a primary benefit. Savings of this slowly renewable resource are dependent upon the source water for the relift reservoir. The capture and storage of surface water runoff offers the highest groundwater savings due to the minimization of groundwater pumpage for irrigation use. With this option, the farm manager may utilize runoff or stream flow available adjacent to production acreage. The geomorphology of the surrounding area may result in the inaccessibility of surface runoff for reservoir storage, therefore farm managers may be forced to use groundwater to fill reservoirs of relift systems. This alternative will save subsequent groundwater extractions throughout the growing season. Resource savings with these systems will vary from a high of 6.1 million L/ha/yr (651,706 gal/acre/yr) (one acre-ft = 1.23 million L = 325,853 gal) for surface water utilization to 4.1 million L/ha/yr (436,643 gal/acre/yr) if groundwater is utilized for initial reservoir storage. In the latter scenarios, all fields are assumed to be flooded three times during the growing season with complete release of water after final flooding.

Tailwater recovery systems, although offering numerous environmental and economical benefits, may not be suitable for every farm system. In areas where the geomorphology may inhibit the capture and storage of surface runoff, the use of groundwater or stream water reuse may be applicable. Many smaller farms may not have the acreage necessary for benefits to be realized from the construction of such systems. In these cases, adjoining farms of smaller acreage may benefit from cooperative tailwater recovery plans. Whether utilizing surface runoff capture, groundwater reuse, or stream water for a tailwater recovery system, many environmental and economical benefits may be realized through the prudent use and protection of Arkansas' most valuable resources.

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