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# The Importance of Regional Analysis in Evaluating Agricultural Water Conservation Strategies

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**Abstract:** Water resources are essential for agricultural crop production, especially in semi-arid regions of the nation such as the Texas High Plains. In this region, agriculture is a major economic driver and is also the main water user while withdrawals continue to exceed the small recharge of the primary source of water, the Ogallala Aquifer. Agricultural water conservation strategies are being considered to limit the decline of scarce resources in the region. Potential water savings and associated implementation costs are typically the primary considerations in evaluating strategies. However, the inclusion of a regional economic analysis can change the acceptability of conservation strategies considered. This paper examines the impacts of including regional analysis in evaluating agricultural water conservation strategies in the Panhandle Water Planning Area of Texas.

## 1. Introduction

The Texas High Plains is a semi-arid region where the primary source of water is the Ogallala Aquifer. Withdrawals from this aquifer continue to exceed the slow rate of recharge, making water conservation an important issue for local stakeholders and planners. In this region, agriculture is the primary user of water, accounting for more than 90 percent of the total water use (Panhandle Regional Water Plan, 2016). Thus, most conservation plans have evaluated strategies/policies which have focused on the agricultural industry. At the same time, agriculture is a major economic driver, with cash receipts of $4.7 billion, contributing more than $8 billion to the regional economy (Amosson, Guerrero, and Dudensing, 2014).

Texas continues to operate under the common-law rule of capture, which has been the prevailing system of groundwater management for more than one hundred years (Potter, 2004). Rights to the water resource are recognized as belonging to landowners who could use the water under their land as they see fit, as long as that use is not wasteful or harmful. More recent legislation has allowed for more localized control of resources through the formation of groundwater management areas (GMAs) to facilitate joint planning between groundwater conservation districts (GCDs) within the area that share a common resource. In 2005, House Bill 1763 required that for the water resource they manage GMAs adopt desired future conditions (DFCs), which amount to quantifiable goals for the future state of the resource (Mace et al., 2006). The individual conservation districts are then charged with creating their own plans for meeting the applicable DFC.

Senate Bill 1 allowed for another type of group to form which encouraged the inclusion of stakeholder input into the water planning process (Texas Legislature, 2015). As a result, the Panhandle Water Planning Group (PWPG) was formed to develop a 50-year regional water plan for the Panhandle Water Planning Area (PWPA), which is a 21-county area in the

Texas High Plains. The PWPG recently developed a plan in which eight different agricultural strategies were evaluated, including irrigation scheduling, irrigation equipment changes, change in crop type, change in crop variety, conversion to dryland, soil management, advances in plant breeding for drought tolerance, and precipitation enhancement. In the initial analysis these strategies were primarily evaluated in terms of water savings and implementation costs (Panhandle Regional Water Plan, 2016). The objective of this study is to expand upon the previous analysis with the evaluation of regional economic impacts resulting from each of the strategies. This will prove beneficial in determining if providing this additional viewpoint can change the acceptability or ranking of the strategies being considered. This information will help the PWPG and local groundwater management districts develop policies to prolong the life of the Ogallala Aquifer while also considering the impacts to the regional economy.

## 2. Evaluation of strategies in the 2016 Panhandle Regional Water Plan

Water savings, implementation cost, savings from reduced pumping, and the impact in gross crop receipts were estimated for each of the eight proposed water management strategies evaluated in the Panhandle Regional Water Plan (2016). Baseline adoption rates for 2013 were estimated using secondary data sources, and future adoption rates by decade (2020–2070) were identified under the guidance of the PWPG Agriculture Committee. All strategies were evaluated over a 60-year planning horizon (2020–2079). The results are shown in Table 1.

**Table 1.** Estimated water savings and adoption percentage of water conservation strategies, 2013-2070.

| Strategy | Annual Water Savings (% of irrigation or ac-inch/ac) | 2013 Baseline Use | 2020 Adoption Goal | 2030 Adoption Goal | 2040 Adoption Goal | 2050 Adoption Goal | 2060 Adoption Goal | 2070 Adoption Goal |
|---|---|---|---|---|---|---|---|---|
| Irrigation scheduling | 10% | 20% | 35% | 50% | 75% | 85% | 90% | 95% |
| Irrigation equipment changes | Furrow to MESA/ LESA 3.5 | 87% | 90% | 91.5% | 93% | 94.5% | 96% | 98% |
| | MESA/LESA to LEPA/SDI 1.3 | 75% | 80% | 85% | 90% | 95% | 100% | 100% |
| Change in crop type | 7.8-8.6 | 10% | 15% | 20% | 25% | 30% | 35% | 40% |
| Change in crop variety | Corn 4.10; Sorghum 3.0 | 40% | 50% | 60% | 70% | 70% | 70% | 70% |
| Conversion to dryland | 13.9 | 0% | 2.5% | 5% | 5% | 5% | 5% | 5% |
| Soil management | 1.75 | 70% | 75% | 80% | 85% | 90% | 95% | 95% |
| Advances in plant breeding | Corn, cotton, and soybean 15% (2020-2030); 30% (2040-2079) | 0% | 50% | 75% | 85% | 95% | 95% | 95% |
| | Wheat and sorghum 12% (2030-2079) | 0% | 0% | 50% | 75% | 85% | 95% | 95% |
| Precipitation enhancement | 1.0 | 38% | 38% | 38% | 38% | 38% | 38% | 38% |

Implementation costs were defined as the costs that would be borne by producers and/or the government associated with implementing a strategy. The savings in pumping cost takes into the account the variable cost savings from the reduced irrigation, which was estimated to be $9.10 per acre-inch (Texas A&M AgriLife Crop and Livestock Budgets, 2014). The loss in gross receipts was estimated by strategy, where warranted.

An excess of 61 million acre feet of water was projected to be utilized for irrigation within the region over the 50-year planning horizon (2020–2070) without adoption of any new conservation strategies or increases in the implementation level of current strategies. Cumulative water savings, implementation cost, reduced pumping cost, and the change in gross receipts for each of the water conservation strategies and combinations of strategies are presented in Table 2.

**Table 2.** Estimated water savings, implementation costs, cost savings, and loss in producer gross receipts associated with potential water management strategies.

| Strategy | Water savings (ac-ft) | Implementation cost ($1,000) | Implementation cost per unit water saved ($/ac-ft) | Cost savings ($1,000) | Net cost per unit water saved ($/ac-ft) | Loss in gross receipts ($1,000) |
|---|---|---|---|---|---|---|
| Irrigation scheduling | 4,685,325 | $209,396 | $44.69 | $511,637 | ($64.51) | - |
| Irrigation equipment changes | 3,643,928 | $55,638 | $15.27 | $397,917 | ($93.93) | - |
| Change in crop type | 6,394,663 | $199,934 | $31.27 | - | $31.27 | $3,006,360 |
| Change in crop variety | 3,064,326 | $602,294 | $196.55 | - | $196.55 | $1,204,587 |
| Conversion to dryland | 4,156,337 | $145,226 | $34.94 | - | $34.94 | $2,805,477 |
| Soil management | 1,970,123 | ($34,989) | ($17.76) | $215,137 | ($126.99) | - |
| Advances in plant breeding | 13,821,966 | $113,322 | $8.20 | $1,509,359 | ($102.63) | - |
| Precipitation enhancement | 813,923 | $6,601 | $8.11 | $88,880 | ($101.09) | - |

Following is a brief summary of each water management strategy and the initial parameters used in the Panhandle Regional Water Plan (2016) to estimate water savings and implementation costs. These strategies are evaluated in this study in terms of impacts (both economic output and employment) to the regional economy.

## 2.1. Irrigation scheduling

Irrigation scheduling is the process of allocating irrigation water according to crop requirements based on meteorological demands and field conditions with the intent to manage and conserve water, control disease infestations, and maximize farm profit. With irrigation water becoming increasingly limited, proper and accurate scheduling is critical to ensure profitable agricultural production and conservation of the existing water resources. Soil water measurement-based methods, plant stress sensing-based methods, and weather-based methods are the common irrigation scheduling tools. The water savings from this strategy was assumed to be 10% of the water applied for each crop. The cost of irrigation scheduling varies depending on the level of service, equipment costs, and area served; however, an average cost of $5.00 per acre annually was used in the initial study.

## 2.2. Irrigation equipment changes

Current irrigation methods practiced in the Texas Panhandle include conventional furrow irrigation (CF), center pivot irrigation (MESA: Mid Elevation Spray Application, LESA: Low Elevation Spray Application, and LEPA: Low Elevation Precision Application) and subsurface drip irrigation (SDI).The average application efficiencies of CF, MESA, LESA, LEPA, and SDI are 60, 78, 88, 95, and 97%, respectively (Amosson et al., 2011). These efficiencies are the percentage of irrigation water applied that is used by the crop, with the remainder being lost to runoff, evaporation, or deep percolation. Switching from low efficiency irrigation systems to more efficient irrigation systems can help conserve groundwater. The water conservation strategy of changing irrigation equipment includes establishing new MESA/LESA systems in CF irrigated fields, for which the water savings was estimated to be 3.5 acre-inches per acre, and converting existing MESA/LESA to LEPA, saving an estimated 1.3 acre-inches per acre. Establishing a new system requires a major investment, while conversion of a center pivot using conversion kits is comparatively less expensive.

Although conversion can be costly, the cost can be partially offset by a decrease in pumping cost. The implementation cost was estimated using the costs associated with the irrigation equipment required for each of the systems. The total cost of applying one acre-inch of water per acre for intermediate water use for furrow, MESA, LESA, LEPA, and SDI is $12.26, $13.98, $13.60, $13.76, and $17.04, respectively (Amosson et al., 2011). These values were inflated to 2014 values using a price index for farm machinery (USDA, 2014). The assumed adoption percentage of the irrigation systems during each decade was used along with the acreage and average water use to estimate the amount of irrigation applied using these systems. These irrigation amounts were multiplied times the cost per acre-inch to get the total cost of irrigation. The difference in total costs between the baseline year and future decades was used as the implementation cost for this strategy.

## 2.3. Change in crop type

There is considerable variation in water requirements for different crops. Corn, cotton, wheat, and grain sorghum are the four major crops in the Panhandle region, accounting for about 90% of the irrigated acreage. Corn has one of the highest water requirements of any irrigated crop grown in the Texas High Plains because of a longer growing season than most other spring crops, which can adversely affect yield in limited moisture situations (Howell et al., 1996). Cotton, wheat, and grain sorghum can tolerate lower moisture availability and are more suited to deficit irrigation practices. Considerable amounts of irrigation water can be saved by shifting from high water use crops like corn to lower water use crops like cotton, wheat, or grain sorghum. Water savings were estimated to be 7.8 to 8.6 acre-inches per acre, depending on the crop.

The cost of implementing this water conservation strategy was estimated in terms of the reduced land values which reflect the water availability required to produce crops. The cost of adoption was estimated as the difference between the average land value for irrigated cropland with good water availability to support high-water use crops ($3,400 per acre) and that of irrigated cropland with fair water availability to support low water-use crops ($2,150 per acre) (ASFMRA, 2013). This per acre cost of adoption was then applied to the acreage of adoption to get the total implementation cost.

## 2.4. Change in crop variety

The evaporative demand for short season varieties can be significantly lower than that for long season varieties. Thus, converting from long season varieties to short season varieties of corn and grain sorghum can be a useful water conservation strategy. In addition, short season hybrids may be seeded earlier to possibly avoid insect threat and high evaporative demand periods, and producers have the potential of planting a third crop in two years either by planting a short season variety prior to or following a wheat crop (Howell et al., 1996). The water savings from adopting short season corn and short season grain sorghum were assumed to be 4.1 and 3.0 acre-inches per acre, respectively.

The implementation cost was assumed to be the compensation needed to account for the loss in yield and profitability of employing the strategy. Howell et al. (1998) reported that the yield from short season hybrids was about 15% less than that from the full season hybrids. A partial budget analysis considering the loss in revenue versus the reduction in pumping cost, fertilizer, and harvest expense (Texas A&M AgriLife Crop and Livestock Budgets, 2014) resulted in approximately half of the revenue reduction being profit loss. Thus, the loss of producer gross receipts was estimated as 15% of the five-year average revenue (USDA, 2014), and the implementation cost was estimated to be half of that amount.

## 2.5. Conversion to dryland

The strategy of converting from irrigated crop production to dryland crop production would conserve the irrigation water normally used on irrigated acreage and may be a viable economic alternative for producers in the Panhandle who have marginally irrigated lands. The primary dryland crops grown in the area are winter wheat, grain sorghum, and cotton. Providing incentives across a region for conversion to dryland, identifying and adopting crops that perform well in the region under rain fed conditions, and developing higher yielding heat and drought-tolerant varieties are critical in implementing this strategy. The water savings from this strategy was estimated to be 13.9 acre-inches per acre; however, actual amounts will vary by the crop composition in a particular county or area.

The cost of implementing this water conservation strategy was evaluated in terms of reduced land values and was estimated as the difference between the average land value in the region for irrigated cropland ($2,900 per acre) and that of dryland ($750 per acre) (ASFMRA, 2013). This per acre cost of adoption was then multiplied by the assumed acreage of adoption to get the total implementation cost. In addition, the loss in gross receipts from the conversion of irrigated to dryland crop production was estimated.

## 2.6. Soil management

Effective soil management practices can increase the efficiency of both irrigation and rainfall events through increased soil infiltration, reduced runoff, reduced evaporative loss, and soil moisture conservation. Conservation tillage is defined as a practice that minimizes soil and water loss by maintaining a surface residue cover of more than 30 percent on the soil surface (CTIC, 2014). Different tillage practices such as minimum tillage, reduced tillage, no-till, ridge tillage, vertical tillage, and strip tillage are often interchangeably used with the term conservation tillage. In addition to reduced water loss, conservation tillage systems also have economic advantages through reduced machinery, fuel, and labor costs. The water savings from a soil management strategy was estimated to be 1.75 acre-inches per acre.

The implementation cost of soil management strategy was estimated as the difference between the cost of conventional tillage and conservation tillage. While a conventionally tilled field is typically disked once, chiseled once, and cultivated three times followed by two herbicide applications, conservation tillage consists of the field being chiseled once and cultivated two times with three herbicide applications. The cost of these field operations were calculated as $87.75 per acre for conventional and $85.16 per acre for conservation tillage (Texas A&M AgriLife Crop and Livestock Budgets, 2014; Texas Agricultural Custom Rates, 2013).

## 2.7. Advances in plant breeding

Plant breeding has played a major role in increasing crop productivity. In addition, varieties with higher water use efficiency and enhanced drought tolerance can lead to substantial water savings. The first wave of drought resistant varieties for corn, cotton, and soybeans are expected to be released by 2020 and reduce water use by 15 percent, followed by a second wave in 2040 that will improve drought and heat tolerance even more, reducing water use an additional 15 percent. It is also expected that drought tolerant varieties of wheat and grain sorghum will be available by 2030, reducing water use by 12 percent.

The implementation cost of this strategy includes the additional cost of drought resistant seed which was estimated at a dollar per acre for every one percent reduction in water use. These costs were then multiplied times the annual total acreage for corn, cotton, and soybeans affected by incorporation of this strategy.

## 2.8. Precipitation enhancement

Precipitation enhancement, commonly known as cloud seeding or weather modification, is a process in which clouds are inoculated with condensation agents such as silver iodide to enhance rainfall formation (Encyclopedia Britannica, 2014). Cloud seeding is currently conducted in almost one-fifth of the land area of Texas, covering about 31 million acres. In 2012, the weather modification programs in Texas conducted 162 missions, treating 353 thunderstorms. Analysis showed that the treated storms lived 40% longer, covered 47% more area, and produced 124% more rain than the untreated storms. The estimated increase in water availability was 1,517,266 acre-feet at a cost of $11/acre-foot (TDLR, 2014). Precipitation enhancement can help conserve groundwater by reducing the irrigation requirement. It can also increase reservoir levels and could have positive impact on dryland farms and ranches. Water savings were estimated to be one acre-inch per acre for all irrigated acreage.

The strategy of precipitation enhancement has only been adopted by the counties in the Panhandle Groundwater Conservation District (PGCD). The cost of adoption of this strategy per acre feet of water saved was estimated with the help of personnel from the PGCD as \$6.28 in a previous water plan. This value was adjusted to 2014 dollars (USDA, 2014), and thus the implementation cost was estimated to be \$8.11 per acre-foot.

## 3. Conceptual Framework

Regional economics served as the framework for this study. In particular, input-output analysis was the method employed to quantify economic impacts of alternative water conservation strategies. This type of analysis portrays the economy in terms of a circular flow of income between producers and consumers. Identification of these economic flows and interdependence allows assessment of the effects of strategies on the economy. Water conservation strategies cause producers to change their inputs to production. That change will have an effect on other economic sectors related directly and indirectly to agricultural production.

Three main parts of input-output analysis include the transactions table, technical coefficients, and multipliers. The transactions table is the building block underlying input-output analysis. This table captures the production flows between the industries, or sectors, in a region's economy. The figure in the $i^{th}$ row and $j^{th}$ column represents the amount that sector $i$ delivered to sector $j$ in a particular time period. The values that appear in the column for a processing sector are essentially the inputs, or factors of production, that an industry requires to produce output.

Technical coefficients are derived from the transactions table. These coefficients represent the amount of inputs required from each industry $i$ for the production of one dollar worth of output for a certain industry $j$. The demand for a portion of output from industry $i$ ($X_i$) by industry $j$ is a function of the level of production in $X_j$. This relationship can be shown as follows:

$$X_{ij} = a_{ij}X_j \tag{1}$$

where $X_{ij}$ is the demand for output from industry $i$ by industry $j$ and $a_{ij}$ represents the technical coefficients. The technical coefficients ($a_{ij}$) are calculated by dividing the column entry of a processing sector by the adjusted gross output. The resulting equation for technical coefficients is the formula:

$$a_{ij} = \frac{x_{ij}}{x_j} \tag{2}$$

The technical coefficients can be used to determine the amount of output that is necessary from an industry to fulfill the direct demand from purchasing industries. The table of coefficients represents only the direct effects of a change in output in one industry on the other industries in the economy that supply its inputs (Miernyk, 1965).

The purpose of input-output analysis is to determine how a change in final demand affects gross output. Technical coefficients provide a means for linking final demand to gross output. The Leontief inverse (1928), or multiplier matrix, is necessary to calculate the total addition to output from a change in final demand. Multiplier effects are captured by solving a system of equations in matrix form. The set of equations for all industries in the economy can be represented as follows:

$$X - AX = Y \tag{3}$$

where $X$ is an **n x 1** vector of gross output, $Y$ is an **n x 1** vector of final demand, and $A$ is an **n x n** matrix of input coefficients ($a_{ij}$) with $n$ sectors in the economy. With the use of the identity matrix, equation 3 can be simplified to the following:

$$(I - A)X = Y \tag{4}$$

The inverse of $(I - A)$ can be used to express gross output as a function of final demand:

$$X = (I - A)^{-1}Y \tag{5}$$

The matrix $(I - A)^{-1}$ is known as the Leontief inverse, or the multiplier matrix. An exogenous shock to final demand in an economy is then multiplied by the Leontief inverse to obtain the new level of gross output (Richardson, 1972).

## 4. Methods and data

The results of the water management strategies evaluated in the Panhandle Regional Water Plan (2016), Table 2, were used as the basis to determine the impact of the strategies on the regional economy of the PWPA. If these strategies are implemented, the direct impacts would ripple through the economy, creating additional indirect and induced impacts. The level of these impacts depends upon the magnitude of the water-use reductions and the relative economic importance and composition of the affected agricultural sector(s) in the region.

Many studies have quantified the economic contribution of industries or the economic impact of policies or alternative scenarios on a region with the input-output IMPLAN (IMpact analysis for PLANning) model (Guerrero et al., 2011; IMPLAN Group, LLC, 2009; Watson et al., 2015; Whited, 2010). The IMPLAN regional economic model was used in this study to examine of how producers linked directly and indirectly to crop production and other affected sectors are impacted by the various management strategies.

Each strategy was reviewed to determine the economic sectors that would be affected with implementation, with the results shown in Table 3. It was determined that IMPLAN sectors 19 (support activities for agriculture), 115 (petroleum refineries), 417 (equipment repair and maintenance), and 6001 (proprietary income) were affected for the strategies of irrigation scheduling, soil management, advances in plant breeding, and precipitation enhancement. In each of these scenarios, the implementation cost was applied as either a positive or negative direct impact to sector 19, depending on if there was increased or decreased spending in the regional economy as a result of the strategy. For example, additional scheduling tools and/or services would need to be purchased in the irrigation scheduling scenario, resulting in more spending and a positive impact to the regional economy.

**Table 3.** Direct impact to affected IMPLAN sectors.

| Strategy | IMPLAN Sector | | | | | |
|---|---|---|---|---|---|---|
| | 19 | 115 | 203 | 417 | 6001 | Loss in gross receipts |
| Irrigation scheduling | $209,396 | ($306,982) | | ($204,655) | $302,241 | |
| Irrigation equipment changes | | | $55,638 | | ($55,638) | |
| Change in crop type | | | | | | $3,006,360 |
| Change in crop variety | | | | | | $1,204,587 |
| Conversion to dryland | | | | | | $2,805,477 |
| Soil management | ($34,989) | ($129,082) | | ($86,055) | $250,126 | |
| Advances in plant breeding | $113,322 | ($905,615) | | ($603,743) | $1,396,037 | |
| Precipitation enhancement | $6,601 | ($53,328) | | ($35,552) | $82,279 | |

Next, the cost savings from reduced water pumpage was applied to sectors 115 and 417 to account for reduced fuel use and lower maintenance and repair. The proportion of the cost savings was applied to these two sectors according to the irrigation system costs reported by Amosson et al. (2011). Reduced pumping costs are considered a negative impact to the regional economy because there will be fewer dollars flowing through the economy. Proprietary income (6001) was also determined to be affected by these strategies. The direct impact to producer income was calculated as the net effect of implementation cost and cost savings from reduced water pumping. The strategy of irrigation equipment changes was determined to affect IMPLAN sector 203 (farm machinery manufacturing). Thus, the implementation cost for this strategy was applied to sector 203, which included both the fixed and variable costs per acre-inch of water pumped. The implementation cost was also considered as a reduction in proprietary income (6001).

The IMPLAN model allows the incorporation of user-supplied data throughout the model building process, which makes the model flexible and enhances the accuracy of results. The IMPLAN Group suggests that researchers input region-specific averages, since agricultural production costs within the model are calculated on a national average (Olson and Lindall, 2004). Analysis-By-Parts (ABP) is a method which can be used to tailor input-output modeling to local conditions (IMPLAN Group, LLC, 2015). In this study, ABP was used where the Panhandle Regional Water Plan indicated a loss in producer gross receipts, which included the change in crop variety, change in crop type, and conversion to dryland scenarios (Table 3). Thus, specific crop production costs were included for irrigated crops under these strategies in order to get more detailed and region-specific results (Amosson et al., 2013).

## 5. Results

Results from the Panhandle Regional Water Plan (2016) will be summarized first, in Table 2, followed by the results of the extended analysis of the impact on the regional economy in Table 4. Results from the initial plan indicate that the one strategy yielding the largest water savings is the adoption of drought resistant varieties of corn, cotton, sorghum, soybeans and wheat, which are being developed with the aid of advances in plant breeding. This strategy is estimated to have the potential to save 13.8 million ac-ft. (cumulative savings), which is 22.6 percent of the total irrigation water pumped over the 60-year planning horizon and is significantly more than the other strategies evaluated. The cumulative effectiveness of the remaining strategies in millions of ac-ft. are as follows: change in crop type (6.4), irrigation scheduling (4.7), conversion to dryland (4.2), irrigation equipment (3.6), change in crop variety (3.1), soil management (2.0), and precipitation enhancement (0.8).

**Table 4.** Estimated water savings and regional economic impact associated with potential water management strategies.

| Strategy | Water savings (ac-ft) | Regional economic impact ($1,000) | Regional impact per unit water saved ($/ac-ft) | Annual employment impact (jobs) |
|---|---|---|---|---|
| Irrigation scheduling | 4,685,325 | ($60,689) | ($13) | 106 |
| Irrigation equipment changes | 3,643,928 | $35,847 | $8 | - |
| Change in crop type | 6,394,663 | ($3,747,287) | ($800) | -490 |
| Change in crop variety | 3,064,326 | ($1,498,366) | ($320) | -199 |
| Conversion to dryland | 4,156,337 | ($3,546,404) | ($757) | -478 |
| Soil management | 1,970,123 | ($153,948) | ($33) | -11 |
| Advances in plant breeding | 13,821,966 | ($873,470) | ($186) | 35 |
| Precipitation enhancement | 813,923 | ($41,568) | ($9) | 5 |

Implementation cost can be a critical barrier to the adoption or rate of adoption of water conservation strategies. The estimated cost of implementing the various strategies expressed in $/ac-ft. of water savings varies considerably. The cost of implementing soil management is actually negative, suggesting producers would save money by utilizing soil conservation techniques (-$17.76 per ac-ft.). Precipitation enhancement, advances in plant breeding, and irrigation equipment are the next three most cost effective strategies at $8.11, $8.20, and $15.27 per ac-ft., respectively. The remaining strategies where implementation cost were identified include change in crop type, conversion to dryland, and irrigation scheduling, which have implementation costs estimated at $31.27, $34.94 and $44.69 per ac-ft., respectively.

Water savings generated by conservation strategies not only help meet regional goals for water conservation but have a direct benefit to producers through reduced pumping costs. Savings in pumping cost exceed the estimated cost of implementation for five of the strategies, leading to a negative net cost per acre-foot of water saved. These strategies are: soil management (-$126.99), advances in plant breeding (-$102.63), precipitation enhancement (-$101.09), irrigation equipment (-$93.93), and irrigation scheduling (-$64.51). This suggests these strategies may be readily adopted if the implementation cost can be overcome. The remaining three strategies, change in crop variety, conversion to dryland, and change in crop type, have a positive net cost to implementation, indicating that more significant monetary enticements will be necessary to encourage adoption of these strategies.

The impact on the regional economy should be a major consideration in prioritizing strategies to be implemented. In this study, the impacts of the eight water conservation strategies were measured by applying the direct change in costs, income, or gross receipts to the affected economic sectors. The economic indicators reported include the impact on regional economic output and employment. In addition, the impact on regional economic output was divided by the amount of water savings in order to determine the regional economic impact per acre-inch of water saved.

Results of the regional economic analysis of water management strategies are given in Table 4. Results indicate that the strategy which will benefit and/or sustain the regional economy is irrigation equipment changes, with a positive impact to economic output of $8 per acre-foot of water saved and no change in employment. This is followed by precipitation enhancement, which has a small economic impact of -$9 per acre-foot but supports 5 additional jobs annually. Irrigation also has a relatively small economic impact of -$13 per acre-foot and supports an additional 106 jobs annually due to the support for irrigation scheduling tools. The soil management strategy has a regional economic impact of -$33 per acre-foot with a decline of 11 jobs annually.

The remaining strategies result in much larger negative impacts to the regional economy, which indicates that the regional economy will not be sustained and some businesses may not remain viable. Advances in plant breeding are expected to have an economic impact of -$186 per acre-foot. On the other hand, this strategy supports an additional 35 jobs annually due to more research and manpower required to develop more productive and drought-tolerant varieties. A change in crop variety from a long to short season crop results in an economic impact of -$320 and a decrease of 200 jobs annually. The conversion of irrigated to dryland farming and the change in crop type strategy both have very high costs to the regional economy at -$757 and -$800 per acre foot and an annual loss of 478 and 490 jobs, respectively.

## 6. Conclusions

Prioritizing and implementing the eight irrigation conservation strategies will depend on the individual irrigator and regional support for the strategy. If emphasis is placed on a strategy that will result in the largest water savings, the advance in plant breeding would be a fitting strategy. For this strategy, the implementation cost is minimal and producers will actually benefit from the cost savings from reduced water pumpage, resulting in a negative net cost per acre-foot of water saved. On the other hand, there is a negative regional economic impact of -$186 per acre-foot.

If regional planners are instead considering a strategy that has little to no implementation cost, the soil management strategy may be the best fit. This strategy actually has both a negative implementation cost and is projected to save producers pumping costs, resulting in the lowest net cost (which is negative) per acre-foot of water saved. However, while this strategy may benefit producers, there is a negative impact to the regional economy due to the decrease in dollars flowing through the agricultural input sectors. This impact is -$33 per acre-foot of water saved.

While conserving water is important, many regional planners may be reluctant to implement a policy or strategy that will negatively affect the regional economy and the number of jobs available in their region. The best case scenario would be to implement a policy that not only conserved water but also had a positive impact to the economy. The strategy analyzed in the strategy that has the best outcome for the regional economy is irrigation equipment changes. This strategy has a relatively low implementation cost and also a negative net cost per acre-foot of water saved. In addition, the regional economy will benefit from the additional purchases of new irrigation systems resulting from switching from furrow to MESA or LESA and switching from MESA or LESA to LEPA or SDI. It is projected that the impact to the regional economy from this strategy is a positive $8 per acre-foot of water saved.

Many studies of alternative water conservation strategies or policy scenarios emphasize the resulting impact on agricultural producers. The goal often times is to help producers maximize profit by utilizing the optimal amount of water given availability and the costs and receipts of different cropping options. However, it is just as important to consider the effects on local businesses and jobs. Producers rely on local agribusinesses to help supply inputs for production. If the regional economy suffers, those businesses may not be there to support the agricultural needs. Agricultural economists studying policy alternatives and regional planners should consider regional economic impacts in their planning efforts to ensure that the economy remains viable.

There were a few limitations to this study which should be mentioned. First, the associated water savings with these strategies are "potential" water savings. In the absence of water use constraints, most of the strategies considered will simply increase gross receipts. In fact, the improved water use efficiencies generated from some of these strategies may actually increase the depletion rate of the Ogallala Aquifer. In addition, precipitation enhancement is not a strategy that a producer can implement. It has to be funded and implemented by a group such as a water district. Currently, only the Panhandle Groundwater Conservation District practices precipitation enhancement. At this time, none of the other water districts have any plans to adopt precipitation enhancement; therefore, estimated water savings may be overestimated depending on location.

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