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# **A Sensitivity Analysis of Conservation Opportunities in the Irrigated Agriculture Sector of the Pacific Northwest**

**B. J. Harrer**

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**July 1985**

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Bonneville Power Administration  
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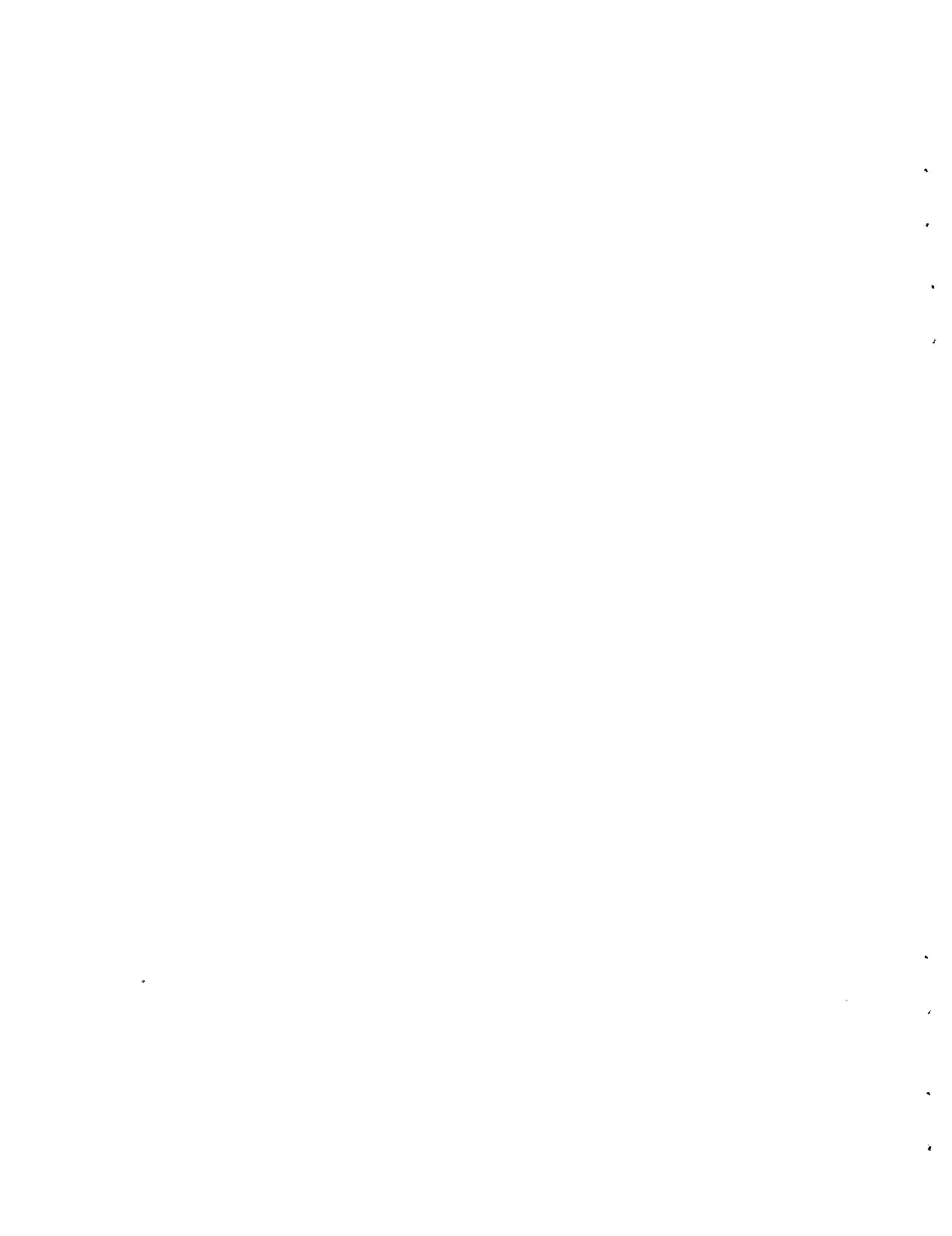
A SENSITIVITY ANALYSIS  
OF CONSERVATION OPPORTUNITIES  
IN THE IRRIGATED AGRICULTURE  
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## SUMMARY

This report summarizes the results of a sensitivity analysis of the cost effectiveness and energy-savings potential of conservation measures in the irrigation sector of the Pacific Northwest. This study is characterized as a sensitivity analysis because it examines the sensitivity of estimates of the cost effectiveness and energy-savings potential of conservation measures in the irrigation sector generated in a previous study (Harrer et al. 1985c) to changes in various types of input data parameters. These changes include reductions in purchase, installation and operating/maintenance costs for irrigation-sector conservation measures. Increases in the amounts of irrigation pumping head savings that would result from the use of the measures were also implemented in the sensitivity analysis.

The assumptions used in the sensitivity analysis cause the analysis to represent a "best-case" scenario for the amount of energy that can potentially be saved through the implementation of irrigation-sector conservation measures in the Pacific Northwest and the costs per kWh saved for obtaining these savings. Under these "best-case" assumptions, it is estimated that approximately 207 average megawatts of electricity can potentially be saved by the year 2003 through the implementation of low-pressure irrigation, pump fittings redesign, increases in mainline size, and improved irrigation scheduling on new and existing irrigated acres. The majority of these savings (70 percent) can be obtained for a cost of 20 mills per kWh saved or less.



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## 1.0 INTRODUCTION

The irrigated agriculture sector of the Pacific Northwest has been targeted by the Pacific Northwest Power Planning Council and the Bonneville Power Administration (BPA) as one of the areas where cost-effective electricity savings can potentially be obtained through the application of various types of conservation measures. In an earlier BPA-sponsored study of the costs and availability of these savings, a computer model known as the Irrigation Sector Energy Planning (ISEP) model was developed by Pacific Northwest Laboratory (PNL) personnel (Harrer et al. 1985c). Various types of data on the characteristics of conservation measures in the irrigation sector were input to the ISEP model, and output results were obtained that were subsequently incorporated in BPA planning activities.

A conservative approach was generally followed in performing the original study of the costs and energy-savings potential of conservation measures in the irrigation sector for BPA. That is, the cost input data on conservation measures provided to the ISEP model were in the high range of available estimates, and the energy savings input data were in the low range of available estimates. This conservative approach was requested by BPA so that the predicted levels of energy savings and their costs could be relied upon with a high degree of certainty.

After the results of the original study were developed, BPA requested that a sensitivity analysis of these results be performed using cost input data selected from the low range of available estimates and energy savings input data selected from the high range of available estimates. By providing estimates of the energy-savings potential and cost effectiveness of irrigation conservation measures under a "best-case" scenario, this analysis will provide an indication of the range in energy-savings potential and cost effectiveness of conservation measures in the irrigation sector. The purpose of this report is to describe the input data used in the sensitivity analysis and document the results of the analysis.

This report is divided into four sections. The second section provides a brief overview of the methodology employed in the ISEP model for evaluating the cost effectiveness and energy-savings potential of conservation measures in the

irrigation sector. In the third section, the input data used in both the original study of irrigation conservation measures and the sensitivity analysis are described. The final chapter presents a summary of the results of the sensitivity analysis and highlights the major differences between these results and those obtained in the original study.

## 2.0 RESULTS AND CONCLUSIONS

A summary of the results of the sensitivity analysis of conservation measures in the irrigation sector of the Pacific Northwest is presented in Table 2.1. These results indicate that the potential energy savings on new acres increase by only 8.6 average MW in going from the low range of energy savings estimates for conservation measures developed in the original study (Harrer et al. 1985c) to the high range of energy savings estimates. The potential energy savings on existing acres increase by 39.4 average MW compared to the original study by using the high range of energy savings estimates.

The impacts on the cost effectiveness of conservation measures from varying the energy savings and economic input data used to analyze the measures are generally more significant than the impacts on the energy-savings potential of the measures. The average leveled costs per kWh saved are reduced by more than 25 percent in the sensitivity analysis compared to the original study for all conservation measures except low-pressure irrigation on existing handmove and sideroll systems, and in many cases the reductions in costs per kWh saved approach 50 percent. Under the assumptions of the sensitivity analysis, all of the conservation measures in the irrigation sector, except improved scheduling, have average costs per kWh saved of less than 15 mills.

Results presented in Table 2.2 indicate that, under the assumptions of the sensitivity analysis, over 35 percent of the total potential energy savings on all acres in the irrigation sector can be obtained for a cost of 10 mills per kWh saved or less. Over 70 percent of all savings can be realized for 20 mills per kWh saved or less, and over 85 percent of total savings are available for a cost of 30 mills per kWh saved or less. Only 10 percent of the total potential savings would cost more than 50 mills per kWh saved to obtain.

Detailed measure-specific data on the results of the sensitivity analysis are presented in Appendix A. These numbers can be compared to data presented in Chapter 6.0 of the original study (Harrer et al. 1985c) to evaluate in detail the impacts on individual conservation measure cost effectiveness and energy-savings potential of using energy savings input data selected from the high range of available estimates and cost input data selected from the low range of available estimates.

TABLE 2.1. Summary of the Results of a Sensitivity Analysis of Conservation Measures in the Pacific Northwest Irrigation Sector

2.2

Measure	Total Potential Energy Savings (Avg. MW)		Average Levelized Cost Per kWh Saved (Mills)	
	New Acres <sup>(a)</sup>	Existing Acres <sup>(b)</sup>	New Acres <sup>(a)</sup>	Existing Acres <sup>(b)</sup>
Low-pressure irrigation on center pivot	7.8	25.1	0.0	6.4
Low-pressure irrigation on handmove and sideroll	7.2	39.0	5.9	14.6
Fittings redesign on center pivot	1.3	4.3	0.0	4.3
Fittings redesign on other sprinkler <sup>(c)</sup>	2.6	10.9	0.0	4.6
Mainline modification on center pivot	2.0	5.2	6.4	12.4
Mainline modification on other sprinkler <sup>(c)</sup>	3.9	13.0	6.8	13.2
Improved scheduling on center pivot	4.1 <sup>(d)</sup>	27.7 <sup>(d)</sup>	36.4 <sup>(e)</sup>	22.3 <sup>(e)</sup>
Improved scheduling on other sprinkler <sup>(c)</sup>	7.4 <sup>(d)</sup>	44.6 <sup>(d)</sup>	42.2 <sup>(e)</sup>	41.0 <sup>(e)</sup>
All Measures	36.8	169.8	---	---

(a) All estimates shown for new acres are for the end of the forecast period (2003).

(b) All estimates shown for existing acres are for the beginning of the forecast period (1984).

(c) Other sprinkler includes acres irrigated by handmove, sideroll, and solid-set sprinklers.

(d) Savings estimates shown here represent the sum of savings on water sensitive and non-water sensitive crop acres.

(e) Significant differences were found between groundwater and surface water acres in cost per kWh saved for improved scheduling.

2.3

TABLE 2.2. Estimated Total Energy-Savings Potential in the Irrigation Sector in 5-Mill Increments of Cost Per kWh Saved

	Levelized Cost Per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
Total Energy Savings Potential (Avg. MW) on Existing Acres	0.0	15.6	51.8	97.1	120.6	135.9	146.9	147.8	148.8	150.1	152.2
Total Energy Savings Potential (Avg. MW) on New Acres in 2003	15.2	15.2	24.3	25.2	26.8	28.8	30.4	30.7	31.2	31.9	33.2



### 3.0 OVERVIEW OF ISEP MODEL METHODOLOGY

The ISEP model developed by PNL personnel to estimate the cost effectiveness and energy-savings potential of conservation measures in irrigated agriculture combines both engineering and economic principles. It simulates the energy-use process of irrigation systems, uses a leveled costing routine to derive estimates of the annual costs of investments in conservation measures, and then combines the two steps to estimate a cost per kWh saved for conservation investments. The energy savings estimates are aggregated in 5-mill increments of cost per kWh saved to develop supply curves for conservation measures in the irrigation sector. The major features of the model are described in this section.

The kWh electrical energy use of an irrigation system is estimated in the ISEP model using the following equation:

$$E = \frac{V \times H \times 1.024}{PPE} \quad (3.1)$$

where  $E$  = annual electrical energy use per acre in kWh for an irrigation system

$V$  = volume of water applied annually through the irrigation system in acre feet

$H$  = total dynamic head of the irrigation system in feet

$PPE$  = efficiency of the pumping plant in converting energy input into energy output

The above equation is a reduced form of a standard equation that represents the relationship between the amount of irrigation water moved and the energy required to move it. The use of the above equation to calculate the electrical energy demand of an irrigation system is supported by a number of other studies (e.g., Bonneville Power Administration 1983 and Patton et al. 1982).

The volume of water applied ( $V$ ) that is input into the energy demand equation represents the actual amount of water that is distributed through an irrigation system. It is a function of a number of different factors,

including climatic conditions, crop type, soil type, and the efficiency of the water application system. The total dynamic head of an irrigation system is the sum of:

1. the amount of pumping lift that has to be overcome to move the irrigation water from its source point to field level
2. the amount of pressure required to operate the irrigation system at its design pressure.

The efficiency of a pumping plant is a function of both the efficiency of the motor used to drive the pump and the efficiency of the pump itself. The product from multiplying the two efficiencies represents the overall pumping plant efficiency.

In the context of Equation 3.1, energy conservation measures decrease the energy use of an irrigation system by either reducing  $H$ , reducing  $V$ , or increasing PPE. It follows then that the impact of an energy conservation measure upon the energy use per acre for irrigation can be estimated using the following general equation:

$$\Delta E = \frac{V_0 \times H_0 \times 1.024}{PPE_0} - \frac{V_1 \times H_1 \times 1.024}{PPE_1} \quad (3.2)$$

where  $\Delta E$  = difference in kWh energy use per acre between an irrigation system that incorporates an energy conservation measure and one that does not incorporate an energy conservation measure

$V_0$ ,  $H_0$ ,  $PPE_0$  = volume of water applied, total dynamic head, and pumping-plant efficiency of an irrigation system before a conservation measure is implemented

$V_1$ ,  $H_1$ ,  $PPE_1$  = volume of water applied, total dynamic head, and pumping-plant efficiency of an irrigation system after a conservation measure is implemented

To avoid over-estimation of the potential energy savings that will result from implementation of conservation measures, it is important to account for interactions between individual conservation measures that cause the total energy savings resulting from implementation of several measures to be less

than the sum of the savings for the individual measures. For example, suppose that a conservation measure that reduces V is implemented on an irrigation system after a conservation measure that reduces H. To avoid double counting of conservation-measure energy savings, the estimated energy savings for the conservation measure that reduces V should be estimated based upon the reduced H that was achieved using the previously implemented conservation measure.

The ISEP model has the ability to incorporate the interactive effects of individual conservation measures through a model-user specified implementation priority system. This priority system orders estimation of the energy-saving potential of conservation measures so that the potential energy savings estimates for each measure are based upon an irrigation system that incorporates all previously implemented conservation measures.

The per-acre energy savings estimates calculated using Equation 3.2 are also adjusted to account for any inconsistencies between the total energy use estimates of the ISEP model and BPA's irrigation load forecasts. This adjustment is performed using the following equation:

$$\text{Adj } \Delta E = \Delta E \times \text{Ratio} \quad (3.3)$$

where  $\text{Adj } \Delta E$  = adjusted difference in kWh energy use per acre between an irrigation system that incorporates an energy conservation measure and one that does not incorporate an energy conservation measure

$\Delta E$  = as defined in Equation 3.2

Ratio = ratio of the total regional energy use estimate from BPA's load forecasting model to the total regional energy use estimate calculated by ISEP, minus estimated price-induced conservation from BPA's load forecasting model

In general, the total energy use estimates from BPA's load forecasting model were within 10 percent of those calculated by ISEP, minus the load forecasting model's estimate of price-induced conservation. Thus, the impact of the adjustment factor,  $\text{Adj } \Delta E$ , on the energy savings estimates for the various conservation measures is small.

### 3.1 LEVELIZED COST ESTIMATION

The impact of a conservation measure on irrigation system costs per acre is estimated in the model using the following general equation:

$$\begin{aligned}\Delta LEV &= LEV_1 - LEV_0 \\ &= \left[ \left( I_1 - \frac{SV_1}{(1+d)^n} \right) \left( \frac{d(1+d)^n}{(1+d)^n - 1} \right) \right] - \left[ \left( I_0 - \frac{SV_0}{(1+d)^m} \right) \left( \frac{d(1+d)^m}{(1+d)^m - 1} \right) \right] \\ &\quad + \left[ \left( PVOM_1 \right) \left( \frac{d(1+d)^n}{(1+d)^n - 1} \right) \right] - \left[ \left( PVOM_0 \right) \left( \frac{d(1+d)^m}{(1+d)^m - 1} \right) \right] \quad (3.4)\end{aligned}$$

where  $\Delta LEV$  = difference in the annual equivalent or leveled cost between an irrigation system without implementation of a conservation measure and a system with implementation of a conservation measure

$I_1$  = initial capital cost of investing in an irrigation system that incorporates a conservation measure

$SV_1$  = salvage value for equipment installed as part of implementing a conservation measure

$d$  = discount rate used for converting present initial capital costs to annual equivalent (levelized) costs

$n$  = system life for a conservation measure

$I_0$  = initial capital cost of investing in an irrigation system that does not incorporate a conservation measure

$SV_0$  = salvage value for equipment of an irrigation system before implementation of a conservation measure

$m$  = system life for an irrigation system before implementation of a conservation measure

$PVOM_1$  = present value of operation and maintenance costs for an irrigation system that incorporates a conservation measure

$PVOM_0$  = present value of operation and maintenance costs for an irrigation system that does not incorporate a conservation measure

The equation listed above deviates from many leveled cost equations in that annual operation and maintenance costs are converted to present value terms and then leveled over the expected life of the irrigation system. This feature was incorporated in the calculation procedures to account for the possibility of annual operation and maintenance expenses varying over the life of the irrigation system.

### 3.2 COST PER KWH SAVED ESTIMATES

Once the impact of a conservation measure on irrigation system leveled cost and energy use per acre has been calculated, the cost per kWh saved for the conservation measure is calculated using the following equation:

$$\text{Cost per kWh saved} = \frac{\Delta \text{LEV}}{\Delta E} \quad (3.5)$$

where  $\Delta E$  = difference in kWh energy use between an irrigation system that incorporates an energy conservation measure and one that does not incorporate an energy conservation measure

$\Delta \text{LEV}$  = difference in annual equivalent or leveled cost between an irrigation system with a conservation measure and a system without a conservation measure

Cost per kWh saved estimates for each conservation measure are developed using Equation 3.5, by type of crop being irrigated, water source used, and EPA subregion. In order to develop more aggregate estimates of cost per kWh saved, a series of equations was developed to calculate weighted averages of the estimates obtained from Equation 3.5.

### 3.3 POTENTIAL ENERGY SAVINGS ESTIMATES

Estimates of the potential energy savings that could result from implementation of conservation measures in the regional irrigation sector are calculated in the ISEP model using the following equation:

$$\text{Potential savings in average MW} = \Delta E \times (\text{ACEL} - \text{ACCA})/1000/8760 \quad (3.6)$$

where ACEL = new and existing acreage eligible to utilize a conservation measure (i.e., not limited by technical considerations)

ACCA = acreage on which a conservation measure has already been implemented

$\Delta E$  = as defined in Equation 3.2

1000, 8760 = factors for converting kWh savings to average MW of savings

Two limiting factors are placed on the acres that are used to calculate aggregate potential energy savings in the model. The first limit is that technical constraints to implementing a conservation measure on specific types of acres are accounted for. Possible examples of technical constraints are soils that are too heavy or fields that have too much slope to allow for the use of a specific conservation measure. The second limit on acres involves accounting for the number of acres on which a conservation measure has already been implemented. For power planning purposes, acres on which a conservation measure has already been implemented should not be included in estimating the potential energy savings that are still available from the use of this measure. Thus, before potential energy savings estimates are calculated, the estimated number of acres on which each conservation measure has been implemented is subtracted from the number of acres technically eligible for each measure.

### 3.4 SUPPLY CURVE ESTIMATES

A supply curve for a conservation measure represents the amount of potential energy savings available from the measure at a given price per kWh saved at a given point in time. In the ISEP model, potential energy savings estimates in a supply curve are defined for 5-mill increments of cost per kWh saved. That is, for each 5-mill increase in the cost per kWh saved for a conservation measure up to a maximum of 50 mills per kWh, an estimate of the potential energy savings in average MW for the measure is developed. The supply curve estimates are calculated in ISEP simply by aggregating all of the estimated energy savings for a conservation measure (calculated by Equation 3.6) that can be obtained for a specified level of cost per kWh saved (calculated by Equation 3.5).

#### 4.0 INPUT DATA FOR CONSERVATION MEASURE ANALYSES

The conservation measures selected for analysis as to their cost effectiveness and energy-savings potential in the Pacific Northwest irrigation sector include:

- o low-pressure irrigation on center-pivot and handmove/sideroll sprinkler systems
- o fittings redesign on all types of sprinkler systems
- o mainline modification on all types of sprinkler systems
- o improved irrigation scheduling on all types of sprinkler systems.

Low-pressure irrigation reduces irrigation energy use by requiring lower application pressures for water distribution than traditional high-pressure sprinkler application systems. Thus, the total dynamic head ( $H$ ) is reduced by the use of low-pressure irrigation. Fittings redesign and mainline modification reduce friction losses within a sprinkler irrigation piping system and, thus, also serve to reduce total dynamic head ( $H$ ) requirements for irrigation. Improved irrigation scheduling reduces the water application volumes ( $V$ ) required for irrigation. More detailed descriptions of these conservation measures are presented in other reports for those desiring additional information (Harrer and Lezberg 1984a, Harrer and Wilfert 1985a, Harrer and Lezberg 1985b, and Harrer et al. 1985c).

The input data used in the original study for BPA (Harrer et al. 1985c) of the conservation measures listed above are shown in Tables 4.1 through 4.4. The data were obtained from estimates provided by various published and unpublished sources. These estimates are all based upon actual field experience with the various conservation measures, and most of the estimates were obtained from sources located within the Pacific Northwest region. The energy-use data selected for the original study and shown in Tables 4.1 and 4.2 were generally in the low range of available estimates while the selected economic data (shown in Tables 4.3 and 4.4) were generally in the high range of available estimates.

The input data selected for use in the sensitivity analysis were derived from the same information sources as the data used in the original study.

TABLE 4.1. Energy-Use Input Data Selected for Analyzing Conservation Measures on Center-Pivot Irrigation Systems

<u>Conservation Measure</u>	<u>Total Application Head (feet) Before Measure Implemented</u>	<u>Total Application Head (feet) After Measure Implemented</u>	<u>Volume of Water Applied Before Measure Implemented</u>	<u>Volume of Water Applied After Measure Implemented</u>
Low-Pressure Irrigation	170 <sup>(a)</sup>	110 <sup>(b)</sup>	100% of baseline <sup>(c)</sup>	100% of baseline
Fittings Redesign	110 <sup>(d)</sup>	103 <sup>(e)</sup>	100% of baseline	100% of baseline
Mainline Modification	103 <sup>(f)</sup>	90 <sup>(g)</sup>	100% of baseline	100% of baseline
Improved Scheduling	90 <sup>(h)</sup>	90	100% of baseline	88% of baseline <sup>(i)</sup> on orchard 80% of baseline on potatoes 78% of baseline on all other crops

4.2

- (a) Assumes a design operating pressure of 54 psi (125 feet of head) for high-pressure sprinkler head, 35 feet of frictional head loss, and 10 feet of elevation head loss.
- (b) Assumes a design operating pressure of 28 psi (65 feet of head) for a low-pressure spray application head, 35 feet of frictional head loss, and 10 feet of elevation head loss, and is derived from analyzing data obtained from numerous published and unpublished sources including personal communications with Mike Monaghan, Merlin Jensen and Bruce Hurtado.
- (c) Baseline water application volumes are estimates of current water application amounts by subregion and crop and were obtained by analyzing historical data from the United States Bureau of Reclamation.
- (d) Assumes low-pressure irrigation already has been implemented.
- (e) Assumes implementation of fittings redesign will reduce total dynamic head by an average of approximately 7 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson and results developed by Shearer (Shearer 1983).
- (f) Assumes fittings redesign has already been implemented.
- (g) Assumes implementation of mainline modification will reduce total dynamic head by an average of approximately 13 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson.
- (h) Assumes all other conservation measures have been implemented.
- (i) Assumes improved irrigation scheduling will reduce water application volumes by 12% on orchard crops, 20% on potatoes, 22% on all other crops and is derived from analysis of the results of numerous field studies (including Lord 1981 and Green 1982) and personal communication with various experts on irrigation scheduling, including Fred Ziari.

TABLE 4.2. Energy-Use Input Data Selected for Analyzing Conservation Measures on Other Sprinkler Irrigation Systems

Conservation Measure	Total Application Head (feet) Before Measure Implemented	Total Application Head (feet) After Measure Implemented	Volume of Water Applied Before Measure Implemented	Volume of Water Applied After Measure Implemented
Low-Pressure Irrigation	150 <sup>(a)</sup>	115 <sup>(b)</sup>	100% of baseline <sup>(c)</sup>	100% of baseline
Fittings Redesign	115 <sup>(d)</sup>	108 <sup>(e)</sup>	100% of baseline	100% of baseline
Mainline Modification	108 <sup>(f)</sup>	95 <sup>(g)</sup>	100% of baseline	100% of baseline
Improved Scheduling	95 <sup>(h)</sup>	95	100% of baseline	93% of baseline <sup>(i)</sup> on orchard 89% of baseline on potatoes 88% of baseline on all other crops

(a) Assumes a design operating pressure of 50 psi (115 feet of head) for a high-pressure impact sprinkler head, 25 feet of frictional head loss, and 10 feet of elevation head.

(b) Assumes a design operating pressure of 35 psi (80 feet of head) for a low-pressure impact application head, 25 feet of frictional head loss, and 10 feet of elevation head loss, and is derived from analyzing data obtained from numerous published and unpublished sources including personal communications with Dennis Kincaid and Carl Bronson.

(c) Baseline water application volumes are estimates of current water application amounts by subregion and crop and were obtained by analyzing historical data from the United States Bureau of Reclamation.

(d) Assumes low-pressure irrigation has already been implemented.

(e) Assumes implementation of fittings redesign will reduce total dynamic head by an average of approximately 7 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson and results developed by Shearer (Shearer 1983).

(f) Assumes fittings redesign has already been implemented.

(g) Assumes implementation of mainline modification will reduce total dynamic head by an average of approximately 13 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson.

(h) Assumes all other conservation measures have been implemented.

(i) Assumes improved scheduling will reduce water application volumes by 7% on orchard crops, 11% on potatoes, and 12% on all other crops, and is derived by arbitrarily reducing scheduling effectiveness estimates obtained in several field studies (including Lord 1981 and Green 1982) and personal communication with various experts on irrigation scheduling, including Fred Ziai.

TABLE 4.3. Economic Parameters Used in Analyzing Conservation Measure Implementation on Existing Acres

	Conservation Measure				
	Low-Pressure Irrigation on Center-Pivot	Low-Pressure Irrigation on Handmove/Sideroll	Fittings Redesign	Mainline Modification	Improved Scheduling
Purchase and Installation Cost per Acre (\$1984) <sup>(a)</sup>	\$31 on surface water \$42 on groundwater	\$15 on surface water \$26 on groundwater	\$3.75 on both surface and groundwater	\$15.00 on both surface and groundwater	\$0
Incremental Operation and Maintenance Cost per Acre (\$1984) <sup>(b)</sup>	0	1	0	0	6
Expected Lifetime of Measure (years) <sup>(c)</sup>	20	20	20	20	NA
Real Discount Rate (%) <sup>(d)</sup>	3	3	3	3	3

- (a) All purchase and installation costs include the costs of installing low-pressure single spray heads on center-pivot systems, low-pressure impact heads on handmove and sideroll systems (end-guns on center-pivots, where necessary), and performing any required pump modifications, including pump replacement (where necessary). Fittings redesign costs include both labor and material costs. Mainline modification includes the cost of burying the mainline. (Sources of purchase and installation cost data include personal communications with Bruce Hurtado, Mike Monaghan and Jeff Raleigh for low-pressure irrigation; BPA Pilot Program records for fittings redesign; and personal communication with Byron Wood and Don Mulkey for mainline modification).
- (b) Incremental operation and maintenance costs for low-pressure irrigation on handmove and sideroll systems is associated with the use of offsetting. Incremental O&M costs for improved scheduling are based on an annual per-acre charge for all scheduling services and were obtained by analyzing data from several sources including personal communications with Joe Lord and Umatilla Electric Co-op representatives.
- (c) No justification was found for specifying expected measure lives of less than 20 years for any of the conservation measures. Measure life is not applicable for improved scheduling because its cost is based upon an annual per-acre charge.
- (d) Specified by BPA for conservation measure cost analyses.

TABLE 4.4. Economic Parameters Used in Analyzing Conservation Measure Implementation on New Acres

	Conservation Measure				
	Low-Pressure Irrigation on Center-Pivot	Low-Pressure Irrigation on Handmove/Sideroll	Fittings Redesign	Mainline Modification	Improved Scheduling
Purchase and Installation Cost per Acre (\$1984) <sup>(a)</sup>	0	0	0	8.25	0
Incremental Operation and Maintenance Cost per Acre (\$1984) <sup>(b)</sup>	0	1	0	0	6
Expected Lifetime of Measure (years) <sup>(c)</sup>	20	20	20	20	NA
Real Discount Rate (%) <sup>(d)</sup>	3	3	3	3	3

(a) No additional equipment purchase and installation costs were found to be associated with any of the conservation measures except mainline modification and improved irrigation scheduling. Estimated cost for mainline modification is based upon the cost of purchasing the additional mainline materials only and does not include the cost of burying the mainline.

(b) All incremental operation and maintenance costs on new acres are estimated to be equal to those on existing acres.

(c) Measure life on new acres is estimated to be equal to those on existing acres.

(d) Specified by BPA for conservation measure cost analyses.

However, the selected energy savings input data were taken from the high range of available estimates, and the selected economic input data were taken from the low range of available estimates. The data selected for use in the sensitivity analysis are shown in Table 4.5 through 4.8.

Note from Table 4.5 that the reduction in total application head resulting from implementation of low-pressure irrigation on center pivots was increased by 10 feet (approximately 4 psi) in the sensitivity analysis. A representative total application head of 100 feet corresponds to an application pressure for low-pressure single-spray application heads of approximately 24 psi or 55 feet of head. The total application head for low-pressure irrigation (presented in Table 4.6) is unchanged from that used in the original study because design application pressures below 35 psi will generally not provide acceptable water distribution uniformity on such systems, according to available studies (e.g., Kincaid 1982).

The reduction in total application head resulting from implementation of fittings redesign was increased by 5 feet in the sensitivity analysis for both center-pivot and other sprinkler systems. The head reduction for mainline modification was also increased by 5 feet on both systems.

Water volume reductions resulting from improved irrigation scheduling on center pivots were increased by 2 percentage points on orchard crops and 8 percentage points on all other crops in the sensitivity analysis. Water volume reductions for improved scheduling on other sprinkler systems were increased by 5 percentage points on orchard crops, 9 percentage points on potatoes and 10 percentage points on all other crops. These increases restored the water volume reductions for improved scheduling on other sprinkler systems to the levels used for center pivots in the original study.

All purchase and installation costs for the conservation measures were reduced in the sensitivity analysis. Conservation measure incremental operation and maintenance costs were also reduced. The costs selected for use in the sensitivity analysis are all within the low end of the range of available estimates.

TABLE 4.5. Energy-Use Input Data for a Sensitivity Analysis of Conservation Measures on Center-Pivot Irrigation Systems

Conservation Measure	Total Application Head (feet) Before Measure Implemented	Total Application Head (feet) After Measure Implemented	Volume of Water Applied Before Measure Implemented	Volume of Water Applied After Measure Implemented
Low-Pressure Irrigation	170 <sup>(a)</sup>	100 <sup>(b)</sup>	100% of baseline <sup>(c)</sup>	100% of baseline
Fittings Redesign	100 <sup>(d)</sup>	88 <sup>(e)</sup>	100% of baseline	100% of baseline
Mainline Modification	88 <sup>(f)</sup>	70 <sup>(g)</sup>	100% of baseline	100% of baseline
Improved Scheduling	70 <sup>(h)</sup>	70	100% of baseline	86% of baseline <sup>(i)</sup> on orchard 72% of baseline on potatoes 70% of baseline on all other crops

(a) Assumes a design operating pressure of 54 psi (125 feet of head) for a high-pressure sprinkler head, 35 feet of frictional head loss, and 10 feet of elevation head loss.

(b) Assumes a design operating pressure of 24 psi (55 feet of head) for a low-pressure spray application head, 35 feet of frictional head loss, and 10 feet of elevation head loss, and is derived from analyzing data obtained from numerous published and unpublished sources, including personal communication with Mike Monaghan, Merlin Jensen and Bruce Hurtado.

(c) Baseline water application volumes are estimates of current water application amounts by subregion and crop and were obtained by analyzing historical data from the United States Bureau of Reclamation.

(d) Assumes low-pressure irrigation already has been implemented.

(e) Assumes implementation of fittings redesign will reduce total dynamic head by an average of approximately 12 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson and results developed by Shearer (Shearer 1983).

(f) Assumes fittings redesign has already been implemented.

(g) Assumes implementation of mainline modification will reduce total dynamic head by an average of approximately 18 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson.

(h) Assumes all other conservation measures have been implemented.

(i) Assumes improved irrigation scheduling will reduce water application volumes by 14% on orchard crops, 28% on potatoes, 30% on all other crops, and is derived from analysis of the results of numerous field studies (including Lord 1981 and Green 1982) and personal communication with various experts on irrigation scheduling, including Fred Ziari.

TABLE 4.6. Energy-Use Data for a Sensitivity Analysis of Conservation Measures on Other Sprinkler Irrigation Systems

Conservation Measure	Total Application Head (feet) Before Measure Implemented	Total Application Head (feet) After Measure Implemented	Volume of Water Applied Before Measure Implemented	Volume of Water Applied After Measure Implemented
Low-Pressure Irrigation	150 <sup>(a)</sup>	115 <sup>(b)</sup>	100% of baseline <sup>(c)</sup>	100% of baseline
Fittings Redesign	115 <sup>(d)</sup>	103 <sup>(e)</sup>	100% of baseline	100% of baseline
Mainline Modification	103 <sup>(f)</sup>	85 <sup>(g)</sup>	100% of baseline	100% of baseline
Improved Scheduling	85 <sup>(h)</sup>	B5	100% of baseline	88% of baseline <sup>(i)</sup> on orchard 80% of baseline on potatoes 78% of baseline on all other crops

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(a) Assumes a design operating pressure of 50 psi (115 feet of head) for a high-pressure sprinkler head, 25 feet of frictional head loss, and 10 feet of elevation head loss.

(b) Assumes a design operating pressure of 35 psi (80 feet of head) for a low-pressure impact application head, 25 feet of frictional head loss, and 10 feet of elevation head loss, and is derived from analyzing data obtained from numerous published and unpublished sources, including personal communication with Dennis Kincaid and Carl Bronson.

(c) Baseline water application volumes are estimates of current water application amounts by subregion and crop and were obtained by analyzing historical data from the United States Bureau of Reclamation.

(d) Assumes low-pressure irrigation has already been implemented.

(e) Assumes implementation of fittings redesign will reduce total dynamic head by an average of approximately 12 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson and results developed by Shearer (Shearer 1983).

(f) Assumes fittings redesign has already been implemented.

(g) Assumes implementation of mainline modification will reduce total dynamic head by an average of approximately 18 feet and is derived from an analysis of BPA irrigation system audit records supplied by Terry Henderson.

(h) Assumes all other conservation measures have been implemented.

(i) Assumes improved scheduling will reduce water application volumes by 12% on orchard crops, 20% on potatoes, and 22% on all other crops, and is derived from field studies (including Lord 1981 and Green 1982) and personal communication with various experts on irrigation scheduling, including Fred Ziari.

TABLE 4.7. Economic Parameters for a Sensitivity Analysis of Conservation Measure Implementation on Existing Acres

	Conservation Measure				
	Low-Pressure Irrigation on Center-Pivot	Low-Pressure Irrigation on Handmove/Sideroll	Fittings Redesign	Mainline Modification	Improved Scheduling
Purchase and Installation Cost per Acre (\$1984) <sup>(a)</sup>	22.75 on surface water 29.50 on groundwater	13.50 on surface 21.50 on groundwater	3.00 on both surface and groundwater	13.00 on both surface and groundwater	0
Incremental Operation and Maintenance Cost per Acre (\$1984) <sup>(b)</sup>	0	0.80	0	0	5.50
Expected Lifetime of Measure (years) <sup>(c)</sup>	20	20	20	20	NA
Real Discount Rate (%) <sup>(d)</sup>	3	3	3	3	3

(a) All purchase and installation costs include the costs of installing low-pressure single spray heads on center-pivot systems, low-pressure impact heads on handmove and sideroll systems (end-guns on center-pivots, where necessary), and performing any required pump modifications, including pump replacement (where necessary). Fittings redesign costs include both labor and material costs. Mainline modification includes the cost of burying the mainline. (Sources of purchase and installation cost data include personal communications with Bruce Hurtado, Mike Monaghan and Jeff Raleigh for low-pressure irrigation; BPA Pilot Program records for fittings redesign; and personal communication with Byron Wood and Don Mulkey for mainline modification).

(b) Incremental operation and maintenance costs for low-pressure irrigation on handmove and sideroll systems is associated with the use of offsetting. Incremental O&M costs for improved scheduling are based on an annual per-acre charge for all scheduling services and were obtained by analyzing data from several sources including personal communications with Joe Lord and Umatilla Electric Co-op representatives.

(c) No justification was found for specifying expected measure lives of less than 20 years for any of the conservation measures. Measure life is not applicable for improved scheduling because its cost is based upon an annual per-acre charge.

(d) Specified by BPA for conservation measure cost analyses.

TABLE 4.8. Economic Parameters for a Sensitivity Analysis of Conservation Measure Implementation on New Acres

	Conservation Measure				
	Low-Pressure Irrigation on Center-Pivot	Low-Pressure Irrigation on Handmove/Sideroll	Fittings Redesign	Mainline Modification	Improved Scheduling
Purchase and Installation Cost per Acre (\$1984) <sup>(a)</sup>	0	0	0	7.00	0
Incremental Operation and Maintenance Cost per Acre (\$1984) <sup>(b)</sup>	0	0.80	0	0	5.50
Expected Lifetime of Measure (years) <sup>(c)</sup>	20	20	20	20	NA
Real Discount Rate (%) <sup>(d)</sup>	3	3	3	3	3

(a) No additional equipment purchase and installation costs were found to be associated with any of the conservation measures except mainline modification and improved irrigation scheduling. Estimated cost for mainline modification is based upon the cost of purchasing the additional mainline materials only and does not include the cost of burying the mainline.

(b) All incremental operation and maintenance costs on new acres are estimated to be equal to those on existing acres.

(c) Measure life on new acres is estimated to be equal to those on existing acres.

(d) Specified by BPA for conservation measure cost analyses.

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## APPENDIX A

**TABLE A.1. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Low-Pressure Irrigation on Existing and New Center-Pivot Acres**

	Water Source	Subregion										BPA Service Area	
		1	2	3	4	5	6	7	8	9	10		
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	NCP <sup>(a)</sup>	0.88	5.64	0.29	0.05	1.22	0.27	0.38	NCP	2.87	0.48	12.08
	Ground	NCP	1.07	5.36	0.16	0.01	0.73	0.67	0.50	NCP	4.36	0.00	12.86
	Total	NCP	1.95	11.00	0.45	0.06	1.95	0.94	0.88	NCP	7.23	0.48	24.94
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	6.70	5.03	6.68	10.92	5.27	5.90	6.34	NCP	6.05	6.84	5.61
	Ground	NCP	8.32	6.57	8.38	10.23	6.46	7.28	7.93	NCP	7.62	NCP	7.18
	Average	NCP	7.59	5.78	7.28	10.77	5.71	6.88	7.24	NCP	7.00	6.84	6.42
Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NCP	4.93	0.14	NCP	0.19	NCP	NCP	NCP	0.47	NCP	5.73	
	Ground	NCP	0.07	0.00	0.03	0.02	0.55	0.13	0.31	NCP	0.84	0.09	2.04
	Total	NCP	0.07	4.93	0.17	0.02	0.74	0.13	0.31	NCP	1.31	0.09	7.77
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Ground	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(a) No center-pivot acres for this subregion and water source.

**TABLE A.2. Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Low-Pressure Irrigation on Existing Center-Pivot Acres**

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	3.94	12.06	12.08	12.08	12.08	12.08	12.08	12.08	12.08	12.08
	Groundwater	0.00	12.46	12.86	12.86	12.86	12.86	12.86	12.86	12.86	12.86
	Total	3.94	24.52	24.94	24.94	24.94	24.94	24.94	24.94	24.94	24.94

TABLE A.3. Estimated Cumulative Energy Savings  
Potential (Avg. MW) in 5-Mill  
Increments of Cost per kWh Saved  
for Low-Pressure Irrigation  
on New Center-Pivot Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
1986	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
1987	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23	1.23
1988	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
1989	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06	2.06
1990	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
1991	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81
1992	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14	3.14
1993	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51	3.51
1994	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89	3.89
1995	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27	4.27
1996	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68	4.68
1997	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08
1998	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49	5.49
1999	5.93	5.93	5.93	5.93	5.93	5.93	5.93	5.93	5.93	5.93	5.93
2000	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41	6.41
2001	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87	6.87
2002	7.30	7.30	7.30	7.30	7.30	7.30	7.30	7.30	7.30	7.30	7.30
2003	7.76	7.76	7.76	7.76	7.76	7.76	7.76	7.76	7.76	7.76	7.76

**TABLE A.4. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Low-Pressure Irrigation on Existing and New Handmove and Sideroll Acres**

	Water Source	Subregion										BPA Service Area	
		1	2	3	4	5	6	7	8	9	10		
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	0.25	1.43	4.72	0.57	1.75	1.29	1.85	2.50	0.94	5.77	3.67	24.74
	Ground	0.23	0.53	1.77	0.93	0.58	0.38	0.47	0.40	0.29	8.59	0.05	14.22
	Total	0.48	1.96	6.49	1.50	2.33	1.67	2.32	2.90	1.23	14.36	3.72	38.96
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	31.02	12.68	10.78	11.83	20.82	9.43	12.17	12.97	14.28	13.29	14.63	13.24
	Ground	40.10	16.03	12.98	15.96	26.98	12.27	16.28	17.07	18.47	17.23	18.92	17.07
	Average	35.43	13.58	11.38	14.40	22.34	10.11	13.01	13.56	15.27	15.65	14.69	14.64
Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NOS <sup>(a)</sup>	NOS	2.66	0.19	NOS	1.10	NOS	NOS	NOS	0.91	NOS	3.86
	Ground	NOS	0.03	NOS	0.11	0.52	0.19	0.07	0.17	0.22	1.50	0.50	3.31
	Total	NOS	0.03	2.66	0.30	0.52	0.29	0.07	0.17	0.22	2.41	0.50	7.17
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	5.05	5.54	NOS	4.42	NOS	NOS	NOS	6.23	NOS	13.24
	Ground	NOS	5.71	NOS	5.69	9.61	4.37	5.80	6.08	6.58	6.14	6.74	17.07
	Average	NOS	5.71	5.05	5.60	9.61	4.39	5.80	6.08	6.58	6.17	6.74	14.64

(a) No other sprinkler acres for this subregion and water source.

TABLE A.5. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost  
Per kWh Saved for Low-Pressure Irrigation on Existing Handmove and Sideroll Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	3.28	19.31	23.61	24.51	24.51	24.78	24.78	24.78	24.78
	Groundwater	0.00	0.00	6.13	13.12	13.75	13.99	14.04	14.22	14.27	14.27
	Total	0.00	3.28	25.44	36.73	38.26	38.50	38.82	39.00	39.05	39.05

TABLE A.6. Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Low-Pressure Irrigation on  
 New Handmove and Sideroll Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.09	0.55	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
1986	0.00	0.16	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1987	0.00	1.26	1.44	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
1988	0.00	0.35	1.90	1.94	1.94	1.94	1.94	1.94	1.94	1.94	1.94
1989	0.00	0.43	2.39	2.43	2.43	2.43	2.43	2.43	2.43	2.43	2.43
1990	0.00	0.54	2.78	2.83	2.83	2.83	2.83	2.83	2.83	2.83	2.83
1991	0.00	0.66	3.04	3.10	3.10	3.10	3.10	3.10	3.10	3.10	3.10
1992	0.00	0.78	3.29	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36
1993	0.00	0.92	3.54	3.63	3.63	3.63	3.63	3.63	3.63	3.63	3.63
1994	0.00	1.06	3.85	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
1995	0.00	1.19	4.14	4.26	4.26	4.26	4.26	4.26	4.26	4.26	4.26
1996	0.00	1.33	4.48	4.62	4.62	4.62	4.62	4.62	4.62	4.62	4.62
1997	0.00	1.46	4.86	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01
1998	0.00	1.61	5.11	5.29	5.29	5.29	5.29	5.29	5.29	5.29	5.29
1999	0.00	1.76	5.49	5.68	5.68	5.68	5.68	5.68	5.68	5.68	5.68
2000	0.00	1.92	5.87	6.07	6.07	6.07	6.07	6.07	6.07	6.07	6.07
2001	0.00	2.08	6.24	6.46	6.46	6.46	6.46	6.46	6.46	6.46	6.46
2002	0.00	2.24	6.59	6.84	6.84	6.84	6.84	6.84	6.84	6.84	6.84
2003	0.00	2.40	6.96	7.22	7.22	7.22	7.22	7.22	7.22	7.22	7.22

TABLE A.7. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Fittings Redesign on Existing and New Center-Pivot Acres

	Water Source	Subregion										BPA Service Area	
		1	2	3	4	5	6	7	8	9	10		
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	NCP <sup>(a)</sup>	0.12	0.95	0.04	NCP	0.25	0.04	0.06	NCP	0.50	0.10	2.06
	Ground	NCP	0.18	0.91	0.03	NCP	0.14	0.10	0.07	NCP	0.76	0.00	2.19
	Total	NCP	0.30	1.86	0.07	NCP	0.39	0.14	0.13	NCP	1.26	0.10	4.25
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	5.16	3.87	5.14	8.49	4.05	4.54	4.87	NCP	4.66	5.21	4.31
	Ground	NCP	4.93	3.90	4.97	6.07	3.83	4.32	4.71	NCP	4.52	NCP	4.26
	Average	NCP	5.03	3.88	5.08	7.97	3.97	4.38	4.79	NCP	4.58	5.21	4.28
Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NCP	0.85	0.03	0.00	0.04	0.00	0.00	0.00	NCP	0.08	0.00	1.00
	Ground	NCP	0.01	0.00	0.00	0.00	0.09	0.02	0.05	NCP	0.14	0.02	0.33
	Total	NCP	0.01	0.85	0.03	0.00	0.13	0.02	0.05	NCP	0.22	0.02	1.33
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Ground	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(a) No center-pivot acres for this subregion and water source.

**TABLE A.8.** Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Fittings Redesign on Existing Center-Pivot Acres

TABLE A.9. Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Fittings Redesign on  
 New Center-Pivot Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
1986	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
1987	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
1988	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
1989	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
1990	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
1991	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
1992	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
1993	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
1994	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
1995	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
1996	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
1997	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
1998	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94
1999	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
2000	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
2001	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
2002	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26
2003	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33	1.33

TABLE A.10. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Fittings Redesign on Existing and New Other Sprinkler Acres

	Water Source	Subregion										BPA Service Area	
		1	2	3	4	5	6	7	8	9	10		
A 10	Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	0.06	0.62	1.04	0.16	0.43	0.35	0.45	0.66	0.24	1.89	0.83 6.73
		Ground	0.05	0.33	0.47	0.26	0.18	0.13	0.11	0.07	NOS	2.54	NOS 4.14
		Total	0.11	0.95	1.51	0.42	0.61	0.48	0.56	0.73	0.24	4.43	0.83 10.87
A 10	Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	10.66	4.21	3.71	3.96	7.42	3.25	4.20	4.54	4.92	4.57	5.05 4.60
		Ground	10.48	4.07	3.38	4.06	7.25	3.21	4.28	4.47	4.87	4.55	NOS 4.50
		Average	10.57	4.16	3.61	4.02	7.37	3.24	4.22	4.53	4.92	4.56	5.05 4.56
A 10	Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NOS <sup>(a)</sup>	NOS	0.92	0.08	NOS	0.05	NOS	NOS	NOS	0.33	NOS 1.38
		Ground	NOS	0.02	NOS	0.05	0.19	0.09	0.03	0.06	0.08	0.54	0.17 1.23
		Total	NOS	0.02	0.92	0.13	0.19	0.14	0.03	0.06	0.08	0.87	0.17 2.61
A 10	Cost Per kWh Saved on New Acres (1984 Mills)	Surface	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 0.00
		Ground	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 0.00
		Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00 0.00

(a) No other sprinkler acres for this subregion and water source.

**TABLE A.11.** Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Fittings Redesign on Existing Other Sprinkler Acres

**TABLE A.12. Estimated Cumulative Energy Savings  
Potential (Avg. MW) in 5-Mill  
Increments of Cost per kWh Saved  
for Fittings Redesign on New  
Other Sprinkler Acres**

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1986	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
1987	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52	0.52
1988	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
1989	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
1990	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01	1.01
1991	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
1992	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
1993	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.30
1994	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
1995	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
1996	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
1997	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
1998	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
1999	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04	2.04
2000	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18	2.18
2001	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33	2.33
2002	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
2003	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60	2.60

TABLE A.13. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Mainline Modification on Existing and New Center-Pivot Acres

	Water Source	Subregion										BPA Service Area		
		1	2	3	4	5	6	7	8	9	10			
A.13	Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	NCP <sup>(a)</sup>	0.14	1.04	0.05	0.01	0.27	0.05	0.08	NCP	0.70	0.13	2.47
		Ground	NCP	0.25	1.14	0.03	0.00	0.17	0.12	0.07	NCP	0.95	0.00	2.73
		Total	NCP	0.39	2.18	0.08	0.01	0.44	0.17	0.15	NCP	1.65	0.13	5.20
	Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	14.90	11.17	14.85	24.73	11.71	13.11	14.08	NCP	13.43	14.97	12.55
		Ground	NCP	14.25	11.26	14.35	17.54	11.07	12.47	13.67	NCP	12.99	NCP	12.28
		Average	NCP	14.49	11.22	14.67	23.25	11.46	12.66	13.89	NCP	13.17	14.97	12.41
	Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NCP	NCP	1.27	0.04	NCP	0.05	NCP	NCP	NCP	0.12	NCP	1.48
		Ground	NCP	0.02	NCP	0.00	NCP	0.14	0.03	0.08	NCP	0.22	0.02	0.51
		Total	NCP	0.02	1.27	0.04	NCP	0.19	0.03	0.08	NCP	0.34	0.02	1.99
	Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	6.01	8.00	NCP	6.30	NCP	NCP	NCP	7.27	NCP	6.17
		Ground	NCP	7.67	NCP	7.72	9.44	5.96	6.72	7.30	NCP	7.09	8.05	6.88
		Average	NCP	7.67	6.01	7.95	9.44	6.05	6.72	7.30	NCP	7.15	8.05	6.36

(a) No center-pivot acres for this subregion and water source.

**TABLE A.14.** Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Mainline Modification on Existing Center-Pivot Acres

<u>Year</u>	<u>Water Source</u>	<u>Cost Per kWh Saved</u>									
		<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>	<u>30</u>	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>
1984	Surface Water	0.00	0.58	2.15	2.44	2.45	2.46	2.46	2.46	2.46	2.46
	Groundwater	0.00	0.65	2.46	2.72	2.72	2.72	2.72	2.72	2.72	2.72
	Total	0.00	1.23	4.61	5.16	5.17	5.18	5.18	5.18	5.18	5.18

TABLE A.15. Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Mainline Modification  
 on New Center-Pivot Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.02	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
1986	0.00	0.04	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
1987	0.00	0.05	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
1988	0.00	0.07	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
1989	0.00	0.09	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
1990	0.00	0.10	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
1991	0.00	0.13	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
1992	0.00	0.15	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
1993	0.00	0.16	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
1994	0.00	0.19	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1995	0.00	0.20	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
1996	0.00	0.23	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
1997	0.00	0.25	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31	1.31
1998	0.00	0.28	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40	1.40
1999	0.00	0.30	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52	1.52
2000	0.00	0.32	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
2001	0.00	0.35	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
2002	0.00	0.37	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87	1.87
2003	0.00	0.39	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99

TABLE A.16. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Mainline Modification on Existing and New Other Sprinkler Acres

	Water Source	Subregion										BPA Service Area		
		1	2	3	4	5	6	7	8	9	10			
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	0.07	0.76	1.13	0.17	0.50	0.37	0.52	0.86	0.30	2.55	0.94	8.17	
	Ground	0.06	0.48	0.60	0.30	0.23	0.17	0.13	0.05	0.00	2.83	0.00	4.85	
	Total	0.13	1.24	1.73	0.47	0.73	0.54	0.65	0.91	0.30	5.38	0.94	13.02	
A 96	Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	30.78	12.11	10.71	11.44	21.42	9.39	12.15	13.14	14.21	13.22	14.60	13.32
		Ground	30.27	11.77	9.74	11.71	20.85	9.28	12.36	12.91	14.16	13.24	NOS	13.05
		Average	30.53	11.98	10.37	11.61	21.22	9.36	12.19	13.12	14.21	13.23	14.60	13.22
	Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NOS <sup>(a)</sup>	NOS	1.39	0.12	NOS	0.07	NOS	NOS	NOS	0.49	NOS	2.07
		Ground	NOS	0.04	NOS	0.07	0.29	0.13	0.04	0.09	0.11	0.81	0.26	1.84
		Total	NOS	0.04	1.39	0.19	0.29	0.20	0.04	0.09	0.11	1.30	0.26	3.91
	Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	5.77	6.16	NOS	5.05	NOS	NOS	NOS	7.11	NOS	6.09
		Ground	NOS	6.34	NOS	6.31	11.39	5.00	6.66	6.95	7.53	7.01	7.71	7.64
		Average	NOS	6.34	5.77	6.21	11.39	5.02	6.66	6.95	7.53	7.05	7.71	6.82

(a) No other sprinkler acres for this subregion and water source.

**TABLE A.17. Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Mainline Modification on Existing Other Sprinkler Acres**

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.76	6.18	7.79	8.03	8.11	8.19	8.19	8.19	8.19
	Groundwater	0.00	0.86	4.32	4.47	4.61	4.66	4.67	4.67	4.67	4.67
	Total	0.00	1.62	10.50	12.26	12.64	12.77	12.86	12.86	12.86	12.86

**TABLE A.18. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on New Other Sprinkler Acres**

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.04	0.29	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
1986	0.00	0.06	0.51	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
1987	0.00	0.09	0.75	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
1988	0.00	0.13	1.01	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
1989	0.00	0.15	1.26	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.29
1990	0.00	0.19	1.47	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51
1991	0.00	0.22	1.61	1.66	1.66	1.66	1.66	1.66	1.66	1.66	1.66
1992	0.00	0.26	1.73	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
1993	0.00	0.30	1.87	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
1994	0.00	0.34	2.03	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
1995	0.00	0.38	2.18	2.28	2.28	2.28	2.28	2.28	2.28	2.28	2.28
1996	0.00	0.43	1.36	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
1997	0.00	0.46	2.56	1.69	1.69	1.69	1.69	1.69	1.69	1.69	1.69
1998	0.00	0.50	2.70	2.84	2.84	2.84	2.84	2.84	2.84	2.84	2.84
1999	0.00	0.55	2.90	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
2000	0.00	0.59	3.09	3.26	3.26	3.26	3.26	3.26	3.26	3.26	3.26
2001	0.00	0.64	3.29	3.48	3.48	3.48	3.48	3.48	3.48	3.48	3.48
2002	0.00	0.69	3.47	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
2003	0.00	0.73	3.67	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90

**TABLE A.19. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Improved Scheduling on Existing and New Center-Pivot Water-Sensitive Crop<sup>(a)</sup> Acres**

	Water Source	Subregion											BPA Service Area	
		1	2	3	4	5	6	7	8	9	10	11		
A.19	Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	NCP <sup>(b)</sup>	0.22	0.93	0.00	0.01	0.47	0.01	0.02	0.00	0.45	0.00	2.11
		Ground	NCP	0.42	3.03	0.00	0.00	0.28	0.00	0.04	0.00	2.53	0.00	6.30
		Total	NCP	0.64	3.96	0.00	0.01	0.75	0.01	0.06	0.00	2.98	0.00	8.41
	Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	52.98	51.49	NCP	124.30	16.99	66.40	78.76	NCP	62.45	81.51	46.96
		Ground	NCP	18.75	9.93	NCP	NCP	16.14	32.83	50.32	NCP	18.69	38.25	14.58
		Average	NCP	30.32	19.66	NCP	124.30	16.67	54.39	59.64	NCP	25.32	80.18	22.67
	Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NCP	0.00	0.77	0.00	0.00	0.06	0.00	0.00	0.00	0.07	0.00	0.90
		Ground	NCP	0.03	0.00	0.00	0.00	0.20	0.00	0.02	0.00	0.41	0.00	0.66
		Total	NCP	0.03	0.77	0.00	0.00	0.26	0.00	0.02	0.00	0.48	0.00	1.56
	Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	52.34	NCP	NCP	17.26	NCP	NCP	NCP	63.05	NCP	50.71
		Ground	NCP	18.74	NCP	NCP	NCP	16.27	32.82	50.79	NCP	19.08	38.54	19.09
		Average	NCP	18.74	52.34	NCP	NCP	16.50	32.82	50.79	NCP	25.37	38.54	37.33

(a) For purposes of this study, water-sensitive crops are defined as potatoes, corn and other miscellaneous crops.

(b) No center-pivot acres for this subregion and water source.

TABLE A.20. Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Center-Pivot Water-Sensitive Crop<sup>(a)</sup> Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.00	0.13	0.47	0.47	0.47	0.47	0.47	0.47	1.10
	Groundwater	0.00	1.80	3.09	5.92	6.27	6.27	6.27	6.27	6.27	6.31
	Total	0.00	1.80	3.22	6.39	6.74	6.74	6.74	6.74	6.74	7.41

(a) For purposes of this study, water-sensitive crops are defined as potatoes, corn, and other miscellaneous crops.

TABLE A.21. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost per kWh Saved for Improved Scheduling on New Center-Pivot Water-Sensitive Crop<sup>(a)</sup> Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.00	0.00	0.01	0.07	0.08	0.08	0.08	0.08	0.08	0.10
1986	0.00	0.00	0.00	0.01	0.13	0.15	0.15	0.15	0.15	0.15	0.18
1987	0.00	0.00	0.00	0.01	0.20	0.22	0.22	0.22	0.22	0.22	0.27
1988	0.00	0.00	0.00	0.02	0.25	0.29	0.29	0.29	0.29	0.29	0.36
1989	0.00	0.00	0.00	0.02	0.31	0.36	0.36	0.36	0.36	0.36	0.44
1990	0.00	0.00	0.00	0.03	0.34	0.39	0.39	0.39	0.39	0.39	0.49
1991	0.00	0.00	0.00	0.03	0.37	0.42	0.42	0.42	0.42	0.42	0.54
1992	0.00	0.00	0.00	0.03	0.38	0.43	0.43	0.43	0.43	0.43	0.58
1993	0.00	0.00	0.00	0.03	0.40	0.45	0.45	0.45	0.45	0.45	0.63
1994	0.00	0.00	0.00	0.04	0.42	0.48	0.48	0.48	0.48	0.48	0.68
1995	0.00	0.00	0.00	0.04	0.44	0.49	0.49	0.49	0.49	0.49	0.73
1996	0.00	0.00	0.00	0.04	0.47	0.53	0.53	0.53	0.53	0.53	0.79
1997	0.00	0.00	0.00	0.04	0.48	0.55	0.55	0.55	0.55	0.55	0.84
1998	0.00	0.00	0.00	0.04	0.50	0.56	0.56	0.56	0.56	0.56	0.89
1999	0.00	0.00	0.00	0.04	0.54	0.61	0.61	0.61	0.61	0.61	0.96
2000	0.00	0.00	0.00	0.04	0.56	0.64	0.64	0.64	0.64	0.64	1.03
2001	0.00	0.00	0.00	0.05	0.59	0.67	0.67	0.67	0.67	0.67	1.10
2002	0.00	0.00	0.00	0.05	0.60	0.68	0.68	0.68	0.68	0.68	1.15
2003	0.00	0.00	0.00	0.05	0.62	0.70	0.70	0.70	0.70	0.70	1.20

(a) For purposes of this study, water-sensitive crops are defined as potatoes, corn and other miscellaneous crops.

TABLE A.22. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Improved Scheduling on Existing and New Center-Pivot Non-Water-Sensitive Crop<sup>(a)</sup> Acres

	Water Source	Subregion										BPA Service Area	
		1	2	3	4	5	6	7	8	9	10		
A.22	Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	NCP <sup>(b)</sup>	0.22	1.48	0.20	0.01	0.61	0.12	0.14	NCP	0.61	0.22 4.61
		Ground	NCP	0.94	8.32	0.26	0.01	0.81	0.67	0.30	NCP	3.40	0.01 14.72
		Total	NCP	1.16	9.80	0.46	0.02	2.42	0.79	0.44	NCP	4.01	0.23 19.33
	Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	60.28	54.38	52.92	94.90	17.82	55.73	63.39	NCP	65.10	74.56 44.62
		Ground	NCP	19.47	10.45	19.70	60.22	15.33	26.88	46.08	NCP	19.35	35.28 15.04
		Average	NCP	27.20	17.09	33.65	80.36	17.05	31.40	51.53	NCP	26.33	73.49 22.09
	Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NCP	0.00	0.90	0.06	0.00	0.14	0.00	0.00	NCP	0.09	NCP 1.19
		Ground	NCP	0.06	0.00	0.03	0.01	0.42	0.10	0.13	NCP	0.51	0.06 1.32
		Total	NCP	0.06	0.90	0.09	0.01	0.56	0.10	0.13	NCP	0.60	0.06 2.51
	Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	54.28	59.92	NCP	17.82	NCP	NCP	NCP	65.10	NCP 50.82
		Ground	NCP	19.47	NCP	19.70	60.22	15.53	26.88	46.08	NCP	19.36	35.28 22.25
		Average	NCP	19.47	54.28	41.86	60.22	16.09	26.88	46.08	NCP	26.21	35.28 35.75

(a) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard and other miscellaneous crops.

(b) No center-pivot acres for this subregion and water source.

TABLE A.23. Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Center-Pivot Non-Water-Sensitive Crop<sup>(a)</sup> Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.00	0.70	0.70	1.61	1.61	1.61	1.68	2.39	2.61
	Groundwater	0.00	4.36	8.89	11.80	13.73	14.32	14.33	14.40	14.67	14.67
	Total	0.00	4.36	9.59	12.50	15.34	15.93	15.94	16.08	17.06	17.28

(a) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard, and other miscellaneous crops.

TABLE A.24. Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Improved Scheduling on  
 Center-Pivot Non-Water-Sensitive  
 Crop<sup>(a)</sup> Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.00	0.00	0.03	0.10	0.13	0.13	0.13	0.13	0.16	0.17
1986	0.00	0.00	0.00	0.06	0.18	0.23	0.23	0.23	0.23	0.29	0.30
1987	0.00	0.00	0.00	0.09	0.26	0.34	0.34	0.34	0.34	0.43	0.44
1988	0.00	0.00	0.00	0.12	0.35	0.45	0.45	0.45	0.45	0.57	0.59
1989	0.00	0.00	0.00	0.15	0.43	0.55	0.55	0.56	0.56	0.61	0.72
1990	0.00	0.00	0.00	0.18	0.50	0.62	0.62	0.63	0.65	0.82	0.84
1991	0.00	0.00	0.00	0.20	0.52	0.66	0.68	0.69	0.71	0.91	0.93
1992	0.00	0.00	0.00	0.21	0.54	0.69	0.71	0.73	0.73	0.95	0.99
1993	0.00	0.00	0.00	0.22	0.57	0.74	0.76	0.78	0.78	1.04	1.08
1994	0.00	0.00	0.00	0.22	0.58	0.77	0.79	0.81	0.83	1.10	1.15
1995	0.00	0.00	0.00	0.24	0.62	0.81	0.85	0.87	0.89	1.18	1.24
1996	0.00	0.00	0.00	0.26	0.66	0.86	0.90	0.92	0.94	1.26	1.33
1997	0.00	0.00	0.00	0.26	0.67	0.88	0.93	0.96	0.97	1.33	1.41
1998	0.00	0.00	0.00	0.27	0.70	0.92	0.98	1.01	1.04	1.42	1.49
1999	0.00	0.00	0.00	0.29	0.74	0.98	1.04	1.08	1.10	1.51	1.60
2000	0.00	0.00	0.00	0.29	0.77	1.05	1.12	1.15	1.18	1.62	1.72
2001	0.00	0.00	0.00	0.30	0.80	1.11	1.18	1.23	1.26	1.73	1.83
2002	0.00	0.00	0.00	0.31	0.82	1.13	1.21	1.26	1.29	1.79	1.90
2003	0.00	0.00	0.00	0.32	0.85	1.17	1.26	1.31	1.34	1.88	1.99

(a) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard and other miscellaneous crops.

TABLE A.25. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Improved Scheduling in Existing and New Other Sprinkler<sup>(a)</sup> Water-Sensitive Crop<sup>(b)</sup> Acres

	Water Source	Subregion										BPA Service Area
		1	2	3	4	5	6	7	8	9	10	
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	0.02	0.14	0.14	0.07	0.41	0.19	0.10	0.14	0.04	0.76	0.03
	Ground	0.03	0.22	1.46	0.20	0.17	0.10	0.08	0.03	0.02	2.92	0.00
	Total	0.05	0.36	1.60	0.27	0.58	0.29	0.18	0.17	0.06	3.68	0.03
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	185.09	56.59	54.80	46.04	120.93	16.53	66.59	83.30	71.46	77.57	89.18
	Ground	148.72	21.71	12.01	18.89	94.41	16.11	35.69	59.80	35.44	26.46	45.70
	Average	166.18	37.26	21.40	25.61	113.24	16.40	52.38	79.54	60.33	37.11	88.50
Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NOS <sup>(c)</sup>	0.00	0.30	0.02	0.00	0.03	0.00	0.00	0.00	0.11	0.00
	Ground	NOS	0.01	0.00	0.03	0.16	0.06	0.01	0.01	0.02	0.52	0.01
	Total	NOS	0.01	0.30	0.05	0.16	0.09	0.01	0.01	0.02	0.63	0.01
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	57.18	46.04	NOS	19.60	NOS	NOS	NOS	77.69	NOS
	Ground	NOS	21.71	NOS	18.89	94.41	16.17	35.77	59.90	35.65	26.57	46.10
	Average	NOS	21.71	57.18	31.49	94.41	17.49	35.77	59.90	35.65	35.77	46.10

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.

(b) For purposes of this study, water-sensitive crops are defined as potatoes, corn and other miscellaneous crops.

(c) No other sprinkler acres for this subregion and water source.

TABLE A.26. Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Other Sprinkler<sup>(a)</sup> Water-Sensitive Crop<sup>(b)</sup> Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.00	0.00	0.21	0.21	0.21	0.21	0.21	0.21	0.21
	Groundwater	0.00	0.00	1.40	1.76	3.16	4.91	4.97	4.98	5.01	5.01
	Total	0.00	0.00	1.40	1.97	3.37	5.12	5.18	5.19	5.22	5.22

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.

(b) For purposes of this study, water-sensitive crops are defined as potatoes, corn, and other miscellaneous crops.

TABLE A.27. Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Improved Scheduling on  
 New Other Sprinkler<sup>(a)</sup> Water-  
 Sensitive Crop<sup>(b)</sup> Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.08	0.08	0.08	0.08
1986	0.00	0.00	0.00	0.00	0.01	0.06	0.14	0.14	0.14	0.15	0.15
1987	0.00	0.00	0.00	0.00	0.02	0.09	0.20	0.20	0.21	0.21	0.21
1988	0.00	0.00	0.00	0.00	0.02	0.12	0.27	0.28	0.28	0.28	0.28
1989	0.00	0.00	0.00	0.00	0.03	0.15	0.33	0.34	0.35	0.35	0.35
1990	0.00	0.00	0.00	0.00	0.04	0.16	0.34	0.36	0.37	0.37	0.37
1991	0.00	0.00	0.00	0.00	0.04	0.17	0.37	0.38	0.39	0.39	0.39
1992	0.00	0.00	0.00	0.00	0.05	0.18	0.38	0.39	0.40	0.40	0.40
1993	0.00	0.00	0.00	0.00	0.06	0.19	0.40	0.41	0.42	0.43	0.43
1994	0.00	0.00	0.00	0.00	0.06	0.20	0.42	0.43	0.44	0.45	0.45
1995	0.00	0.00	0.00	0.00	0.06	0.22	0.44	0.46	0.47	0.47	0.48
1996	0.00	0.00	0.00	0.00	0.06	0.23	0.47	0.49	0.50	0.50	0.50
1997	0.00	0.00	0.00	0.00	0.07	0.24	0.49	0.51	0.52	0.52	0.53
1998	0.00	0.00	0.00	0.00	0.07	0.24	0.51	0.52	0.53	0.54	0.54
1999	0.00	0.00	0.00	0.00	0.08	0.27	0.55	0.57	0.58	0.58	0.59
2000	0.00	0.00	0.00	0.00	0.09	0.29	0.59	0.61	0.62	0.62	0.63
2001	0.00	0.00	0.00	0.00	0.09	0.30	0.61	0.63	0.64	0.64	0.65
2002	0.00	0.00	0.00	0.00	0.09	0.32	0.64	0.65	0.66	0.67	0.67
2003	0.00	0.00	0.00	0.00	0.10	0.33	0.65	0.67	0.68	0.69	0.69

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.  
 (b) For purposes of this study, water-sensitive crops are defined as potatoes, corn and other miscellaneous crops.

TABLE A.28. Estimated Energy-Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Improved Scheduling on Existing and New Other Sprinkler<sup>(a)</sup> Non-Water-Sensitive Crop<sup>(b)</sup> Acres

	Water Source	Subregion										BPA Service Area
		1	2	3	4	5	6	7	8	9	10	
Energy Savings on Existing Acres in 1984 (Ave. MW)	Surface	0.12	1.23	2.12	0.42	0.72	1.99	1.13	1.38	0.57	3.13	2.09
	Ground	0.13	1.28	2.82	1.64	0.28	0.64	0.49	0.28	0.35	14.46	0.05
	Total	0.25	2.51	4.94	2.06	1.00	2.63	1.62	1.66	0.92	17.59	2.14
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	182.67	70.40	60.98	54.70	113.26	20.12	60.35	68.02	70.56	71.34	81.56
	Ground	146.23	28.39	12.43	22.86	87.60	19.37	33.28	52.56	35.19	24.25	42.14
	Average	163.25	48.98	33.26	29.41	105.91	19.94	52.14	65.40	57.22	32.52	80.58
Energy Savings on New Acres in 2003 (Ave. MW)	Surface	NOS <sup>(c)</sup>	0.00	1.25	0.14	0.00	0.17	0.00	0.00	0.00	0.45	0.00
	Ground	NOS	0.08	0.00	0.20	0.27	0.35	0.07	0.12	0.27	2.16	0.54
	Total	NOS	0.08	1.25	0.34	0.27	0.52	0.07	0.12	0.27	2.61	0.54
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	60.91	54.70	NOS	20.19	NOS	NOS	NOS	71.34	NOS
	Ground	NOS	28.57	NOS	22.99	88.51	19.68	33.28	52.65	35.20	24.31	42.16
	Average	NOS	28.57	60.91	36.06	88.51	19.84	33.28	52.65	35.20	32.43	42.16

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.

(b) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard and other miscellaneous crops.

(c) No other sprinkler acres for this subregion and water source.

**TABLE A.29.** Estimated Cumulative Energy-Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Other Sprinkler<sup>(a)</sup> Non-Water-Sensitive Crop<sup>(b)</sup> Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.00	0.00	1.37	1.37	1.99	1.99	1.99	2.20	3.19
	Groundwater	0.00	0.00	2.33	4.19	13.00	20.59	21.08	21.72	21.72	21.93
	Total	0.00	0.00	2.33	5.56	14.37	22.58	23.07	23.71	23.92	25.12

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.

(b) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard and other miscellaneous crops.

**TABLE A.30.** Estimated Cumulative Energy Savings  
 Potential (Avg. MW) in 5-Mill  
 Increments of Cost per kWh Saved  
 for Improved Scheduling on  
 New Other Sprinkler<sup>(a)</sup> Non-Water-  
 Sensitive Crop<sup>(b)</sup> Acres

Year	Cost per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1985	0.00	0.00	0.00	0.00	0.03	0.20	0.34	0.39	0.40	0.42	0.45
1986	0.00	0.00	0.00	0.00	0.05	0.35	0.60	0.68	0.70	0.73	0.78
1987	0.00	0.00	0.00	0.00	0.08	0.52	0.87	0.99	1.02	1.07	1.16
1988	0.00	0.00	0.00	0.00	0.12	0.68	1.16	1.31	1.36	1.41	1.53
1989	0.00	0.00	0.00	0.00	0.14	0.85	1.43	1.63	1.69	1.75	1.89
1990	0.00	0.00	0.00	0.00	0.18	0.90	1.51	1.75	1.83	1.91	2.10
1991	0.00	0.00	0.00	0.00	0.21	0.98	1.64	1.88	1.97	2.07	2.29
1992	0.00	0.00	0.00	0.00	0.22	1.01	1.70	1.94	2.05	2.14	2.39
1993	0.00	0.00	0.00	0.00	0.24	1.07	1.81	2.05	2.18	2.28	2.56
1994	0.00	0.00	0.00	0.00	0.25	1.13	1.90	2.14	2.30	2.41	2.72
1995	0.00	0.00	0.00	0.00	0.28	1.19	1.99	2.24	2.42	2.54	2.89
1996	0.00	0.00	0.00	0.00	0.30	1.26	2.12	2.37	2.57	2.68	3.07
1997	0.00	0.00	0.00	0.00	0.31	1.32	2.22	2.48	2.71	2.83	3.25
1998	0.00	0.00	0.00	0.00	0.33	1.36	2.19	2.55	2.81	2.94	3.40
1999	0.00	0.00	0.00	0.00	0.35	1.46	2.47	2.71	3.02	3.15	3.64
2000	0.00	0.00	0.00	0.00	0.38	1.57	2.66	2.89	3.24	3.37	3.91
2001	0.00	0.00	0.00	0.00	0.41	1.64	2.76	3.00	3.40	3.54	4.11
2002	0.00	0.00	0.00	0.00	0.42	1.68	2.85	3.08	3.53	3.67	4.29
2003	0.00	0.00	0.00	0.00	0.44	1.74	2.94	3.18	3.67	3.82	4.48

(a) Other sprinkler irrigation systems are handmove, sideroll, and solid-set systems.  
 (b) For purposes of this study, non-water-sensitive crops are defined as wheat, hay, orchard and other miscellaneous crops.

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