An Integrated Assessment of Conservation Opportunities in the Irrigated Agriculture Sector of the Pacific Northwest Region

February 1985

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AN INTEGRATED ASSESSMENT
OF CONSERVATION OPPORTUNITIES
IN THE IRRIGATED AGRICULTURE
SECTOR OF THE PACIFIC NORTHWEST
REGION

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SUMMARY

This report documents research to identify the potential energy savings and cost per kWh saved for implementing currently available energy conservation measures in the irrigated agriculture sector of the Pacific Northwest. The report is the final documentation of a project to develop a model and data base that allow the cost-effectiveness and the energy-savings potential of conservation measures in the irrigation sector to be evaluated. The project is sponsored by the Bonneville Power Administration (BPA), Division of Conservation Planning, and is intended to aid BPA in its overall conservation planning efforts.

A computer model that simulates the energy consumption process of irrigation systems and estimates the levelized costs of undertaking conservation investments has been developed by Pacific Northwest Laboratory personnel and is the primary analytical tool used in this research. Using engineering and economic input parameters for the various conservation measures that could potentially be implemented in irrigated agriculture, the Irrigation Sector Energy Planning (ISEP) model generates estimates of energy savings and cost per kWh saved for the measures. All parameters input to the ISEP model are based upon empirical field data.

This report summarizes the theoretical framework of the ISEP model. It also presents information on the input data provided to the ISEP model and the output results obtained from the model for three types of irrigation conservation measures:

- o low-pressure irrigation
- o improved design of fittings and mainlines
- o improved irrigation scheduling.

The results provided by the ISEP model indicate that by the year 2003 a total of approximately 158.6 average MW of energy could potentially be saved in the Pacific Northwest irrigation sector by implementing the measures identified above on all sprinkler-irrigated acres. Approximately 130.4 average MW can be saved on acres currently irrigated by sprinkler, while an additional 28.2 average MW could be saved on new acres that are forecast to come under irrigation in the next 20 years. The largest share of the total savings (47 percent) is estimated to come from the use of low-pressure irrigation.

Over 60 percent of the total potential savings 158.6 average MW is estimated to be available for a cost per kWh saved of 20 mills or less and over 75 percent could be achieved for a cost of 30 mills or less. Savings from low-pressure irrigation and the redesign of fittings and mainlines will normally cost less than 20 mills per kWh saved. Almost all of the savings that are estimated to cost more than 30 mills per kWh saved to obtain are savings from improved irrigation scheduling on irrigated acres that use surface water and have low average pumping lifts. This implies that selectively targeting irrigation scheduling programs to situations where high pumping lifts exist may be necessary to obtain cost-effective energy savings from this measure.

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1.0 INTRODUCTION

In a plan recently adopted by the Pacific Northwest Power Planning Council, conservation was forecast to be the primary source of power for meeting the demands of the Pacific Northwest. Conservation in the irrigated agriculture sector is an important component of the overall conservation effort outlined in the Council's plan.

The Bonneville Power Administration (BPA) is expected to play a major role in implementing conservation programs in the region. In keeping with this role, BPA contracted with the Pacific Northwest Laboratory (PNL) to perform additional research on conservation in the irrigated agriculture sector. This report is the fourth report in a series of four that address the costs and energy-savings potential of various measures that could reduce the energy used for irrigation.

This report is intended to provide an integrated assessment of the costs and energy-savings potential of all conservation measures that appear to be immediately available for widespread use in the irrigation sector. These measures include low-pressure irrigation, improved irrigation scheduling, and redesign of fittings and mainlines. In low-pressure irrigation, water application devices on sprinkler irrigation systems operate at lower pressures than traditional sprinkler heads and, thus, reduce total pumping energy requirements. Improved irrigation scheduling entails the use of soil moisture data, weather data, and evapotranspiration models to reduce the amount of water applied to growing crops without reducing crop yields. The reduced water requirements from improved scheduling translate directly into reduced energy requirements. Redesign of fittings and modification of mainlines reduce irrigation energy use by reducing the friction losses produced within irrigation piping systems.

In conjunction with its planning efforts, BPA required that specific information on the energy-savings potential (in average MW) and the cost per kWh saved be developed for each conservation measure selected for analysis. To aid in this effort, a computer model of the irrigation energy consumption process was developed by PNL personnel. This model is referred to throughout this report as the ISEP (Irrigation Sector Energy Planning) model.

The report is divided into six chapters. Chapter 2.0 presents the major conclusions and recommendations of the study. Chapter 3.0 presents the theoretical components and framework of the ISEP model. The data selected for use in developing baseline¹ estimates of energy use in the irrigation sector are described in Chapter 4.0. In Chapter 5.0, technical descriptions of the four conservation measures and input data used in generating costs and energy savings estimates for the measures are presented. Finally, the ISEP model estimates of the energy savings and cost per kWh saved are presented for each of the conservation measures selected for study.

¹ Baseline estimates of irrigation energy use are estimates that do not incorporate the impacts of conservation measures on energy use. Thus, there is no assumed price-induced conservation. These estimates are used as a baseline for estimating conservation potential, not as a load forecast.

2.0 CONCLUSIONS AND RECOMMENDATIONS

The analysis described in this report is believed to be the most complete characterization of energy conservation opportunities in the irrigation sector of the Pacific Northwest that has been developed to date. A number of results and conclusions were derived that should be useful to BPA and others in planning energy conservation activities. Several recommendations pertaining to further research needs were also identified.

2.1 CONCLUSIONS

The major results concerning the energy savings potential and the cost per kWh saved for conservation measures in the irrigation sector are summarized in Table 2.1. Note that the estimated potential energy savings on existing acres are more than four times larger than on new acres, and that the total estimated potential energy savings by the year 2003 on both existing and new acres are approximately 158.6 average MW. The largest proportion of these energy savings is estimated to result from implementation of low-pressure irrigation, although the potential energy savings from improved irrigation scheduling are also relatively large.

The estimated average costs for implementing conservation measures in the irrigation sector are generally at or below 20 mills per kWh saved for all technologies except improved irrigation scheduling. On new acres, the estimated costs per kWh saved for implementing some conservation measures are zero, because available evidence indicates that it should cost no more to install a new irrigation system that incorporates low-pressure irrigation and redesigned fittings than to install an irrigation system that does not incorporate these measures.

It should be noted that the energy savings input data selected for use in this study were generally in the low range of available estimates and the cost input data were generally in the high range of available estimates. This conservative approach causes the estimates of energy savings for the measures to be low and the estimates of cost per kWh saved to be high.

TABLE 2.1. Summary of Estimated Results for Conservation Measures
in the Pacific Northwest Irrigation Sector

Measure	Total Potential Energy Savings (Avg. MW)		Average Levelized Cost Per kWh Saved (Mills)	
	New Acres ^(a)	Existing Acres ^(b)	New Acres ^(a)	Existing Acres ^(b)
Low-pressure irrigation on center-pivot	6.7	21.4	0.0	10.5
Low-pressure irrigation on handmove and sideroll	7.2	39.0	7.5	17.8
Fittings redesign on center-pivot	0.8	2.5	0.0	9.2
Fittings redesign on other sprinkler ^(c)	1.5	6.3	0.0	9.8
Mainline modification on center-pivot	1.5	3.8	10.4	19.8
Mainline modification on other sprinkler ^(c)	2.8	9.4	11.1	21.1
Improved scheduling on center-pivot	3.4 ^(d)	22.2 ^(d)	46.8 ^(e)	30.3 ^(e)
Improved scheduling on other sprinkler ^(c)	4.3 ^(d)	25.8 ^(d)	79.2 ^(e)	77.2 ^(e)
All Measures	28.2	130.4	---	---

(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.

Estimates of the total energy savings potential available in the irrigation sector are presented in Table 2.2 in 5-mill increments of cost per kWh saved. A comparison of estimates from Table 2.2 and Table 2.1 indicate that 58 percent of the total estimated energy savings on existing sprinkler irrigated acres (130.4 average MW) can be achieved for a cost of 20 mills or less per kWh saved. Approximately 76 percent can be realized for 30 mills or less per kWh saved. Costs to implement conservation measures on new acres are even lower, and 73 percent of the estimated savings can be realized for 20 mills per kWh saved or less.

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 (in Avg. MW)										
	0	5	10	15	20	25	30	35	40	45	50
Total Energy Savings Potential on Existing Acreages	0.0	0.0	14.9	47.4	75.0	93.6	98.6	103.0	107.7	108.0	109.9
Total Energy Savings Potential on New Acreages in 2003	9.0	9.0	17.4	20.1	20.6	21.2	21.8	22.2	22.8	22.9	23.2

Because of the relatively low estimated costs per kWh saved for implementing conservation measures in the irrigation sector, one might question why irrigators would not implement these measures without BPA involvement. However, the costs per kWh saved estimates shown in Table 2.1 were developed from a power planning standpoint. Two of the important assumptions used in developing the estimates are that all conservation measures except improved irrigation scheduling will have lifetimes of 20 years and that a three percent real cost of capital is appropriate for developing all cost estimates. These assumptions will generally not correspond to the payback and interest rate requirements imposed on irrigators by their lenders. Thus, while investments in conservation measures generally appear to be low cost from a power planning standpoint, irrigators may have different perspectives on the cost-effectiveness of such investments.

Although all of the results developed in this study are based upon the best available field data, the energy savings input assumptions associated with improved scheduling have not been proved through extensive field testing in the Pacific Northwest. Estimates of energy savings potential and cost per kWh saved for improved scheduling that could be developed using validated regional field data may differ from those shown here.

Estimates of the potential energy savings for all conservation measures on all irrigated acres for selected time periods in 1985, 1990, 1995, and 2000 are shown in Table 2.3. These estimates are significantly lower than energy savings estimates developed for the same time periods in an earlier preliminary study performed for the Pacific Northwest Power Planning Council (Harrer 1982).

TABLE 2.3. Estimated Potential Energy Saving in the Irrigation Sector in Selected Years (in Avg. MW)

	Year			
	<u>1985</u>	<u>1990</u>	<u>1995</u>	<u>2000</u>
Estimated Potential Energy Savings	132	141	149	155

The estimates developed in this study are believed to be more reliable than those developed in the earlier study. Differences between the energy savings estimates developed in the earlier study and those presented here can be attributed primarily to four factors:

- o The estimates developed in the earlier study were based on baseline¹ energy use estimates and forecasts that were much larger than those used in this study.
- o The earlier study did not incorporate acres on which conservation has already been achieved through implementation of conservation measures.

¹ Baseline estimates of irrigation energy use are estimates that do not incorporate the impacts of conservation measures on energy use. Thus, there is no assumed price-induced conservation. These estimates are used as a baseline for estimating conservation potential, not as a load forecast.

- o In generating its energy savings estimates, the analytical model used in the earlier study did not have the ability to account for interactive effects between conservation measures.
- o Several potential conservation measures that were included in the earlier study were omitted from this study because their technical reliability and feasibility have not yet been proven.

The earlier study worked from a 1980 baseline energy use estimate in the irrigation sector of over 750 average MW. This estimate grew to 869 average MW in 1985 and to 1079 average MW in 2000. These baseline estimates were not empirically validated using billing record data, and they were developed using data from the high-growth years of the 1970s. In contrast, the baseline estimates generated by BPA's irrigation load forecasting model, from which the conservation energy savings contained in this study were derived, are 521 average MW in 1980, 548 average MW in 1985, and 610 average MW in 2000. The baseline estimates used in this study are believed to be more representative of actual irrigation energy use than those used in the earlier study, primarily because they are based on data obtained from actual billing records.

A significant number of irrigators have already installed some of the conservation measures considered in this study. The estimated number of acres on which conservation measures are already being used is subtracted from acres eligible to receive the conservation measures. Thus, the total potential energy savings estimates in this study are reduced compared to the estimates derived in the earlier study, which did not account for savings already achieved.

Interactions between conservation measures cause the total potential energy savings available from all conservation measures to be less than the sum of the individual parts. The ISEP model developed in this study has the ability to account for these interactions, while the model used in the earlier study did not.

Finally, the conservation measures of Low-Energy Precision Application (LEPA) systems, pump efficiency improvements, and improved groundwater turbine pumps that were included in the earlier study are omitted from the current study because of concerns about their technical feasibility and reliability.

It is possible that successful field testing and analysis of these measures will allow them to be included in future estimates of conservation savings potential.

2.2 RECOMMENDATIONS

The estimates of costs per kWh saved and energy savings potential developed in this study are based upon extensive analyses of empirical irrigation system field data; they are believed to be the most reliable estimates that have been developed to date on conservation potential in the irrigation sector of the Pacific Northwest. However, in the course of the study, several areas have been identified that seem to warrant further research. Recommendations pertaining to these areas, in what is perceived to be their order of importance, are the following:

- o Efforts should be initiated to further field test and demonstrate the use of low-pressure irrigation on handmove and sideroll sprinkler systems.
- o More extensive systems and data bases should be developed to obtain reliable and up-to-date estimates of the number of acres on which conservation measures have already been implemented.
- o Further field testing and analytical research should be performed to evaluate the energy savings potential and cost-effectiveness of pumping plant efficiency improvements and LEPA systems.
- o Field testing and statistical analyses of the potential water and energy savings that will result from improved irrigation scheduling in the Pacific Northwest should be undertaken.
- o Efforts should continue to coordinate and integrate estimates from the conservation planning model with those from the load forecasting model.

The reliability of estimates of the costs and energy-savings potential of conservation in the irrigation sector of the Pacific Northwest will be improved by addressing the topics identified above.

3.0 IRRIGATION SECTOR ENERGY PLANNING MODEL THEORY AND STRUCTURE

The Irrigation Sector Energy Planning (ISEP) model developed in this study utilizes both engineering and economic principles to estimate the cost-effectiveness and energy-savings potential of energy conservation measures that could be implemented in the irrigated agriculture sector of the Pacific Northwest. The model incorporates three primary structural components:

- o and energy use estimation component
- o a levelized cost estimation component
- o a cost per kWh saved, energy savings potential and supply curve estimation component

A summary of the major procedural steps of the model is presented in Figure 3.1.

FIGURE 3.1. Major Procedural Steps Incorporated in the Irrigation Sector Energy Planning Model

3.1 ENERGY USE ESTIMATION

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, including earlier studies performed by the Bonneville Power Administration (Bonneville Power Administration 1983) and for the Department of Energy (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 the climatic conditions of the area being irrigated, the type of crop being grown, the soil type of the field where the crop is being grown, 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 head that has to be overcome to move the irrigation water from its source point to the field level
2. the amount of application head 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 ΔE = 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 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 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 conservation 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. In this case, 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 will order estimation of the energy savings potential of the individual 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 possibility exists that a conservation measure may not realize its full energy savings potential during the early years of its implementation period because the user of the measure is not familiar enough with it to use it at its maximum efficiency. The ability to include such a "slow start" possibility in the analysis of conservation measures is incorporated in the ISEP model. Also incorporated in the model is the ability to account for possible "technical deterioration" in the energy savings of a conservation measure as the measure becomes older.

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 Adj ΔE = 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

ΔE = 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 estimated price-induced conservation. Thus, the impact of the adjustment factor, Adj ΔE , on the energy savings estimates for the various conservation measures is small.

3.2 LEVELIZED COST ESTIMATION

In the ISEP model, the levelized cost per acre for an irrigation system is calculated using the following equation:

$$\text{LEV} = \left[I - \frac{\text{SV}}{(1+d)^N} \right] \left[\frac{d(1+d)^N}{(1+d)^N - 1} \right] + \left[\text{PVO\&M} \right] \left[\frac{d(1+d)^N}{(1+d)^N - 1} \right] \quad (3.4)$$

where LEV = levelized or discounted annual cost of an irrigation system

I = initial capital cost of an irrigation system

SV = salvage value (if any) of an irrigation system

d = real discount rate

N = total expected life for the irrigation system

PVOM = present value of total annual operation and maintenance for an irrigation system over its lifetime

The equation listed above deviates from many levelized cost equations in that annual operation and maintenance costs are converted to present value terms and then levelized 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.

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

$$\begin{aligned} \text{LEV} &= \text{LEV}_1 - \text{LEV}_0 \\ &= \left[\left(I_1 - \frac{\text{SV}_1}{(1+d)^N} \right) \left(\frac{d(1+d)^N}{(1+d)^N - 1} \right) \right] - \left[\left(I_0 - \frac{\text{SV}_0}{(1+d)^M} \right) \left(\frac{d(1+d)^M}{(1+d)^M - 1} \right) \right] \\ &\quad + \left[\left(\text{PVOM}_1 \right) \left(\frac{d(1+d)^N}{(1+d)^N - 1} \right) \right] - \left[\left(\text{PVOM}_0 \right) \left(\frac{d(1+d)^N}{(1+d)^N - 1} \right) \right] \end{aligned} \quad (3.5)$$

where LEV = difference in the annual equivalent or levelized 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

3.3 COST PER KWH SAVED, ENERGY SAVINGS POTENTIAL, AND SUPPLY CURVE ESTIMATION

Estimates of the costs per kWh saved, energy-savings potential, and energy supply curves that show the potential energy savings in 5-mill increments of cost per kWh saved for conservation measures in the irrigation sector are the most important outputs of the ISEP model. The procedures used in developing these estimates are described below.

3.3.1 Cost Per kWh Saved Estimates

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

$$\text{Cost per kWh saved} = \frac{\Delta LEV}{\Delta E} \quad (3.6)$$

where ΔE = 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

ΔLEV = difference in annual equivalent or levelized 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 3.6, by type of crop being irrigated, water source used, and BPA sub-basin. 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 3.6. An example of the equations used in calculating the weighted average cost per kWh for conservation measures is the following:

$$\text{WAC}_{ik} = \frac{\sum_{j=1}^6 (C_{ijk} \times \text{ES}_{ijk})}{\sum_{j=1}^6 \text{ES}_{ijk}} \quad (3.7)$$

where WAC_{ik} = weighted average cost per kWh saved for an energy-conservation system in subregion i for water source k

C_{ijk} = cost per kWh saved for an energy-conservation system in subregion i for crop j and water source k

ES_{ijk} = potential energy savings in kWh for an energy-conservation system in subregion i for crop j and water source k

i = subregions 1 to 11

j = crops 1 to 6

k = surface water or groundwater

The above equation was used to calculate weighted averages of the cost per kWh saved by subregion and water source across all crops for all conservation measures except improved irrigation scheduling. Calculation of the average cost per kWh saved for improved scheduling was partitioned into water sensitive and non-water sensitive crops,¹ because of evidence that the market

¹ For purposes of this study, water sensitive crops are defined as potatoes, corn, and several other miscellaneous crops. Non-water sensitive crops are wheat, hay, orchard, and several other miscellaneous crops.

acceptance of improved scheduling was likely to proceed at a faster rate on water sensitive crops than on non-water sensitive crops (Merchant and Herman 1984).

3.3.2 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:

$$\begin{aligned} \text{Potential savings in average MW} &= \Delta E \times (\text{ACEL} - \text{ACCA}) / 1000 / 8760 \\ \text{for each conservation measure} & \end{aligned} \quad (3.8)$$

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

ΔE = 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 the implementation of 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 the measure. Thus, before potential energy savings estimates are calculated, the number of acres on which each conservation measure has been implemented is estimated and subtracted from the number of acres technically eligible for that conservation measure.

3.3.3 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. 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 3.8) that can be obtained for a specified level of cost per kWh saved (calculated by Equation 3.6).

4.0 BASELINE ENERGY USE AND ACREAGE DATA

Baseline energy use data refers to data that are used to produce the baseline energy demand estimates from which conservation estimates are calculated. These data include pumping lifts, irrigation system operating pressures, water application volumes, and pumping plant efficiencies. Acreage data refers to the current and future estimated number of acres under irrigation in the Pacific Northwest. Consistent with the BPA irrigation load and acreage forecasts, all data are disaggregated according to the geographic subregions illustrated in Figure 4.1.

In this chapter, the baseline energy use and acreage data used in deriving estimates of conservation potential in the irrigation sector of the Pacific Northwest are described. The methods used to develop this data are also identified.

4.1 BASELINE ENERGY USE DATA

The baseline energy use data of pumping lifts, irrigation system operating pressures, water application volumes, and pumping plant efficiencies are used in Equation 3.1 (described previously) to derive estimates of the per-acre irrigation system energy use on acres where no conservation actions have been undertaken. The data were selected for use in the study with three basic criteria in mind:

1. How well do the data reflect actual relationships known to exist for such factors as volume of water applied by crop, application pressures of the various irrigation systems, pumping lifts by subregion, etc.?
2. Are the data values based upon actual experiences reported in the fields rather than simulation modeling and other procedures that can be used to generate parameter values?
3. How closely do the energy use estimates derived by using the data reflect actual energy demand conditions?

In terms of energy conservation modeling objectives, the third criterion listed above would appear to be most important. Developing data on pumping

FIGURE 4.1. Irrigation Conservation Model Subregions

lifts, water application volumes, etc., that are representative of broad cross sections of irrigation systems and geographical subregions, such as those shown in Figure 4.1, is an imprecise process. However, if the values that are selected produce computed energy use estimates that are close to actual energy demand numbers, estimation of conservation potential has a valid empirical base from which to proceed.

All of the above criteria were used in selecting baseline energy use data from a number of different information sources. Actual energy demand and

irrigated acreage data were obtained from Northwest Economic Associates (NEA).¹ Energy use per acre estimates derived from Equation 3.1 were multiplied by the acreage data to generate aggregate baseline energy use estimates using the ISEP model.

When large discrepancies between the aggregate baseline energy use estimates calculated by the ISEP model and the actual energy demand numbers supplied by NEA were discovered, the baseline data values, such as pumping lifts, were adjusted in a direction that would cause the ISEP estimates to move closer to the NEA values. The goal was to obtain baseline energy use estimates from ISEP that were as close to actual values as possible, while still maintaining baseline data values that were within a realistic range.

4.1.1 Water Application Volumes

Aggregate data on actual per-acre volume of water delivered to farms are compiled by the Bureau of Reclamation (BREC).² These data were determined to be the best available source of aggregate geographic specific water application data. However, in order to use this data within the structure of the ISEP model, several modifications to the data were necessary.

The first modification involved compiling the data into the 11 subregions of the model. The BREC data are compiled by BREC project area. To obtain water volumes that are representative of the subregions, an average of BREC project volumes for the years 1979, 1980, and 1981 was first calculated. A weighted-average water application volume for each subregion was then calculated using water-volume and acreage data for all BREC projects contained within each subregion. BREC data corresponding to Subregion 1 were not available, so an average value for Subregion 1 was obtained from earlier data compiled in a previous study by King (King et al. 1977).

¹ Unpublished data supplied by Dave Ricks, analyst with Northwest Economic Associates, Vancouver, Washington, January 1984.

² Unpublished data supplied by the United States Bureau of Reclamation, Boise, Idaho, January 1984.

The average volumes calculated from the BREC data did not reflect differences in the efficiency of irrigation water application between sprinkler and gravity flow irrigation systems. However, these differences were reflected in earlier data developed by King (King et al. 1977). Using this data, ratios of water application volumes by gravity flow and sprinkler irrigation systems to water application volumes for all systems were calculated for each subregion. These ratios were then applied to the average water application volume estimates developed from the BREC data to obtain water application volumes by sprinkler and gravity flow irrigation systems.

Water application volumes by crop are also required for input to the ISEP model. Relationships between crops in the volume of water applied in the various subregions were computed using data from a previous study (NADP 1981) to calculate the ratio of water applied to each of the major crops to the average water applied to all crops. Crop water application data for Subregions 1 (Washington coast), 5 (Oregon coast) and 11 (Montana) were not available from the NEA data. Ratios for Subregions 1 and 5 were calculated from data in the King study. Averages of ratios for subregions 2-4 and 6-10 were used for Subregion 11. The calculated ratios were then applied to the average water application volume estimates developed from the BREC data to obtain representative figures for the water application volumes by crop and subregion.

One further adjustment was made in the water application data, based on the results of several test runs of the ISEP model. When the baseline energy use estimate for a subregion was not in close agreement with the NEA actual load number³ for the subregion, water application volumes in the subregion were adjusted. These adjustments were generally limited to less than 20 percent of the original water application volume estimates developed from the BREC data, meaning that most water application volumes used in the ISEP model deviate no more than 20 percent from the BREC data. Only for subregions 1 and 11, where good estimates of water application volumes were not available, were adjustments greater than 20 percent from the original BREC data implemented.

³ Unpublished data supplied by Dave Ricks, analyst with Northwest Economic Associates, Vancouver, Washington, January 1984.

The water application volumes that were finally selected to be included in the baseline data base are shown in Tables 4.1, 4.2 and 4.3. As a final check on the realism of the selected water application volumes, the computed volumes for subregions 3, 4, 6 and 10 were compared to volume data obtained from farm records for representative farms in each region. These farm-level data were compiled in a previous study (Harrer and Wilfert 1983). The volume data shown in Tables 4.1, 4.2, and 4.3 were found to be consistent with the farm-record data for the representative farms.

4.1.2 Total Dynamic Head

The two major components of the total dynamic head of an irrigation system are the pumping head required to move the water from its source to the field level and the application head required to distribute the water over the crop. Pumping heads are primarily determined by geography, while application heads are primarily determined by the irrigation system that is used.

Pumping Heads

Pumping heads, which are also referred to as pumping lifts, are very specific to the location at which irrigation is performed. Even within individual farms, pumping lifts among various irrigation pumping plants can vary significantly. Thus, defining a representative pumping lift for an area as broad as a BPA subregion is an imprecise process.

Data collected by Jack Houston at Washington State University⁴ on pumping lifts for 45 geographic areas within Washington, Oregon, and Idaho were the primary source of data for the pumping lifts used in this study. These data are believed to be the most current source of information on Pacific Northwest regional pumping lifts. They were developed by evaluating, through conversations with local irrigation experts in the various geographic areas, the accuracy of data developed previously by King (King et al. 1977). In some cases, the original King data were left intact, and in other cases, they were modified based upon what was thought to be better information.

⁴ Unpublished data supplied by Jack Houston, research assistant in the Washington State Department of Agricultural Economics, Pullman, Washington, January 1984.

TABLE 4.1. Selected Water Application Volumes for Center Pivot Systems by Subregion and Crop in Acre-Feet^(a)

Crop	Subregion Number										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0.4	1.7	2.1	1.7	0.8	2.1	1.8	1.8	1.6	1.9	1.5
Alfalfa	1.0	2.5	3.3	3.0	1.7	3.4	2.5	2.3	2.1	2.6	2.1
Potatoes	0.9	1.9	2.5	2.3	1.1	2.6	2.1	1.9	2.0	2.1	1.9
Corn	1.0	2.2	3.1	3.0	1.1	3.4	2.5	2.1	2.0	2.4	1.9
Orchard	1.0	2.6	3.3	3.0	1.2	3.4	2.5	2.0	2.1	2.4	2.0
Other	0.9	2.0	2.9	2.8	1.3	3.4	2.3	1.9	2.0	2.2	1.9

TABLE 4.2. Selected Water Application Volumes for Other Sprinkler Systems by Subregion and Crop in Acre-Feet^(a)

Crop	Subregion Number										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0.4	1.8	2.1	1.8	0.9	2.2	2.0	1.9	1.7	2.0	1.6
Alfalfa	1.0	2.6	3.4	3.0	1.7	3.5	2.7	2.5	2.3	2.7	2.2
Potatoes	0.9	2.0	2.6	2.5	1.2	2.7	2.2	2.0	2.2	2.2	2.0
Corn	1.0	2.4	3.3	3.1	1.2	3.5	2.7	1.8	2.1	2.5	2.0
Orchard	1.0	2.6	3.5	3.0	1.3	3.6	2.6	2.2	2.2	2.5	2.1
Other	0.9	2.4	3.0	2.8	1.4	3.5	2.4	2.1	2.2	2.3	2.0

TABLE 4.3. Selected Water Application Volumes for Gravity Flow Systems by Subregion and Crop in Acre-Feet^(a)

Crop	Subregion Number										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0.5	2.8	2.9	2.8	1.1	3.1	3.0	2.6	2.7	3.3	2.6
Alfalfa	2.8	4.0	5.8	5.8	3.0	5.9	5.2	4.9	4.7	5.2	4.6
Potatoes	1.9	3.0	5.8	5.2	2.0	5.0	3.0	4.1	3.6	3.7	3.5
Corn	2.3	3.4	5.6	5.6	1.7	5.3	3.1	3.8	3.3	4.4	3.2
Orchard	2.0	4.0	5.8	5.8	2.0	5.3	4.0	3.4	3.4	4.9	3.3
Other	2.0	3.5	5.5	5.4	2.0	5.4	4.0	4.1	3.5	4.2	3.4

(a) Sources: Basic data obtained from 1979, 1980, and 1981 Bureau of Reclamation records and allocated to systems and crops based on data developed by King (King et al. 1977) and Northwest Economic Associates.

To obtain representative pumping lifts for the 11 BPA subregions in Washington, Oregon and Idaho, the 45 subareas specified by Houston were first aggregated into their appropriate BPA subregions. Data on groundwater and surface water acreages in the 45 subareas were then used to calculate weighted-average pumping lifts for all BPA subregions except Western Montana. A representative pumping lift for the Western Montana subregion was obtained by assuming that pumping lifts in this subregion were similar to those in the Northern Idaho subregion (Subregion 9).

Modifications in the subregion pumping lift estimates were made when test runs of the ISEP model did not produce energy demand estimates that were in relatively close agreement with actual load numbers supplied by NEA. In most cases, modifications in the average lift numbers calculated from Houston's data were less than 25 percent of the original numbers. However, in some cases, larger modifications were required to produce energy use estimates that reflected actual loads. The pumping lifts selected for use in this study are shown in Table 4.4.

Application Heads

In the energy use equation, application heads are specified as the head required at the source point of the irrigation system. On a sprinkler system, this head must be large enough to operate all of the sprinklers of the irrigation system at their design pressure, including allowances for friction and elevation losses within the system.

Conversations with irrigation experts and review of previous studies (King et al. 1977) revealed that appropriate design pressures for conventional high-pressure center-pivot sprinkler heads are approximately 50 to 70 pounds per square inch (psi). Similar pressures for other types of sprinkler systems are 45 to 55 psi.⁵ Friction losses for a conventional center-pivot system would be in the range of 15 psi or 35 feet of head between the source point and the

⁵ Personal communication with Marvin Shearer, Department of Agricultural Engineering, Oregon State University, Corvallis, Oregon, March 1984.

TABLE 4.4. Selected Pumping Lifts in Feet for
Surface Water and Groundwater Irrigation^(a)

<u>Water Source</u>	<u>Subregion Number</u>										
	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>	<u>11</u>
Surface Water	5 ^(b)	30 ^(b)	10	36	14	185	18 ^(b)	12	19	10	7
Groundwater	25 ^(b)	210	346	205	40 ^(b)	200 ^(b)	105 ^(b)	40	120	190	90

^(a) Source: average lift estimates calculated based on unpublished data compiled by Jack Houston.

^(b) Modification of more than 25% of the original computed lift number was required to produce energy use numbers corresponding to actual loads.

end of the system.⁶ A similar value for other sprinkler systems would be 11 psi or 25 feet of head.

Elevation changes between the source point of an irrigation system and its design sprinklers are highly variable, depending upon the slope of the field. However, an appropriate average value would be approximately 10 to 12 feet.⁷

In general, gravity flow systems operate at very low pressures. In many cases, no pressure at all is required for a gravity flow system to operate. However, in some cases, a small amount of head is required to distribute water through a gravity flow system, especially when groundwater is the water source.

The estimated application heads that were selected for use in this study for the representative irrigation systems are shown in Table 4.5. Note that all operating pressure requirements have been converted to application head requirements using the conversion factor of 2.31 feet of head per psi.

4.1.3 Pumping Plant Efficiencies

A number of studies have been performed on the efficiencies of irrigation pumping plants. The Bonneville Power Administration tested a total of 615 pumps and estimated an average pump efficiency of approximately 55 percent for all pumps tested (BPA 1981). The results of this study also demonstrated that, in general, there is a positive relationship between pump efficiency and the size of an irrigation pump. Pumps larger than 75 horsepower were found to have average efficiencies ranging up to 61 percent, while smaller pumps generally had efficiencies below 54 percent.

In the King study (King 1977), pump efficiencies were reported as follows: 72-82 percent for large Bureau of Reclamation pumps, 65-75 percent for large private pumps, 54-65 percent for intermediate pumps, and 50-58 percent for small on-farm pumps.

⁶ Personal communication with Mike Monaghan, Nelson Irrigation, Walla Walla, Washington, December 1983.

⁷ Personal communication with Mike Monaghan, Nelson Irrigation, Walla Walla, Washington, December 1983.

TABLE 4.5. Estimated Operating Heads for Representative Irrigation Systems^(a)

System	Pressure Head at Sprinkler (Feet)	Friction Loss Head (Feet)	Elevation Loss Head (Feet)	Estimated Head at Source Point (Feet)
Center-Pivot	125 ^(b)	35 ^(c)	10	170
Other Sprinkler	115 ^(d)	25 ^(e)	10	150
Gravity Flow	--	--	3	3

- (a) Sources: Based on personal communications with several irrigation equipment experts including Marvin Shearer, Oregon State University, Corvallis, Oregon, and Mike Monaghan, Nelson Irrigation, Walla Walla, Washington. (b) Computed by multiplying an estimated operating pressure of approximately 54 psi by a conversion factor of 2.31 feet per psi. (c) Computed by multiplying frictional losses of approximately 15 psi by a conversion factor of 2.31 feet per psi. (d) Computed by multiplying an estimated operating pressure of approximately 50 psi by a conversion factor of 2.31 feet per psi. (e) Computed by multiplying frictional losses of approximately 11 psi by a conversion factor of 2.31 feet per psi.

Idaho Power Company in Boise, Idaho, operates a fairly extensive pump testing program for their farming customers. It is reported that tests performed in this program generally indicate irrigation pumping plant efficiencies averaging between 55 percent and 60 percent.⁸ In general, it was found that groundwater turbine pumps do not achieve as high an efficiency as surface water pumps.

Given the discrepancies in available estimates, it is difficult to define the best efficiency figure for this analysis. However, it is believed that the average efficiencies for large pumps should receive more weight than the efficiencies for small pumps in choosing an efficiency number, because large pumps consume a higher proportion of the total energy used in irrigation. For

⁸ Personal communication with Jim Worstell, Idaho Power Company, Boise, Idaho, January 1984.

example, it is reported that a large commercial farm using more than 100 million kWh annually has pump efficiencies in excess of 80 percent.⁹

It is also believed that there is justification for assuming that surface water pump efficiencies are slightly higher than groundwater pump efficiencies. In general, the irrigation pumps operating off the rivers and reservoirs of the Pacific Northwest are larger than the average groundwater pumps. In addition, surface water pumps appear to have less potential for water level fluctuations and sand and gravel pumping than do groundwater pumps.

Based upon the above considerations, the pump efficiencies shown in Table 4.6 were selected for use in this analysis. These pump efficiencies are within the range of all available estimates. The upper values in the feasible range were chosen for use in this study because large irrigation pumps with high efficiencies use a higher proportion of total irrigation energy than do smaller pumps with low efficiencies, as discussed previously.

TABLE 4.6. Selected Pumping Plant Efficiencies^{(a)(b)}

<u>Water Source</u>	<u>Pumping Plant Efficiency (%)</u>
Groundwater	59
Surface Water	60

(a) Includes consideration for efficiency losses in both the pump and the motor.

(b) Sources: The upper range of average values reported by BPA 1981, King 1977 and personal communication from Jim Worstell, Idaho Power Company 1984. The upper range was chosen because larger pumps with higher efficiencies use significantly more energy than smaller pumps with lower efficiencies.

⁹ Personal communication with Melvin Campbell, Irrigation Manager, U and I Incorporated, Kennewick, Washington, December 1983.

4.2 ACREAGE DATA

Most of the acreage data used in this study were obtained directly from results generated by BPA's irrigation acreage and load forecasting model.¹⁰ However, some refinements in this data were necessary before it could be used in the ISEP model to generate estimates of conservation potentials. These refinements and the acreage data provided by the BPA load forecasting model are described below.

4.2.1 Percentage of Total Sprinkler Acres Comprised by Center-Pivot Systems

BPA's irrigated acreage forecasts are divided only into sprinkler and gravity flow acres. However, for purposes of this study, it is necessary that sprinkler acres be further divided into center-pivot and other sprinkler acres. This division was performed using data compiled by Houston¹¹ as the primary data source. The center-pivot acres reported by Houston for 45 subareas were aggregated into the 11 BPA subregions in Washington, Oregon and Idaho, as were the total sprinkler acres. The percentages of total acres comprised by center-pivot acres in each subregion by crop and water source were then calculated. The calculated values are shown in Tables 4.7 and 4.8.

In Montana (subregion 11), percentages of total sprinkler acres comprised by center-pivot systems were estimated based on discussions with Larry King of Montana State University; agricultural extension agents in Broadwater, Jefferson, Beaverhead and Madison counties; and Montana Agricultural Statistics, 1983. Mr. King identified counties which have significant center-pivot acres; the extension agents estimated the percentages that center-pivot acres comprise of total sprinkler irrigation for various crops.

4.2.2 Percentage of Gravity Flow Systems Using Groundwater

The use of gravity flow irrigation systems on groundwater aquifers is very small in most areas of the Pacific Northwest. The only subregions in which

¹⁰ Unpublished data supplied by John Wilkens, Bonneville Power Administration, April 1984.

¹¹ Unpublished data supplied by Jack Houston, research assistant in the Washington State Department of Agricultural Economics, Pullman, Washington, January 1984.

TABLE 4.7. Estimated Percentages of Total Groundwater Sprinkler Acres Comprised by Center-Pivot Irrigation Systems^(a)

Crop	Subregion Number										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0	89	92	20	0	67	33	41	0	14	8
Alfalfa	0	48	78	10	4	55	63	53	0	17	9
Potatoes	0	95	95	20	0	95	15	64	0	16	4
Corn	0	100	100	0	0	100	0	100	0	100	0
Orchard	0	0	0	0	0	0	0	0	0	0	0
Other	0	23	9	0	0	0	0	0	0	22	11

(a) Source: Computed from unpublished data compiled by Jack Houston, Washington State University, Pullman, Washington.

TABLE 4.8. Estimated Percentages of Total Surface Water Sprinkler Acres Comprised by Center-Pivot Irrigation Systems^(a)

Crop	Subregion Number										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0	51	45	53	5	71	9	9	0	17	8
Alfalfa	0	10	41	23	2	34	10	9	0	16	9
Potatoes	0	95	84	57	14	71	25	57	0	18	4
Corn	0	100	100	0	5	100	0	0	0	100	0
Orchard	0	0	0	0	0	0	0	0	0	0	0
Other	0	10	28	0	0	0	0	0	0	6	11

(a) Source: Computed from unpublished data compiled by Jack Houston, Washington State University, Pullman, Washington.

gravity flow systems are used to distribute groundwater to any significant extent are Southern Idaho (subregion 10) and Western Montana (subregion 11). Estimated percentages of gravity flow irrigation systems using groundwater were computed from the data compiled by Houston¹² and were found to average approximately 10 percent of total gravity flow acres in subregion 10 and 4 percent of total gravity flow acreages in subregion 11. Percentages for all other subregions were found to be zero.

4.2.3 Irrigated Acres

The data on irrigated acres used in this study includes estimates of actual irrigated acres and estimates of future irrigated acres generated by BPA's irrigation acreage and load forecasting model. As described below, the estimates of actual irrigated acres were used to validate the levels of the energy use parameters selected for use in the study, while the load forecasting model estimates were used in developing estimates of current and future energy conservation potential in the irrigation sector.

Estimates of Actual Acres

Estimates of actual irrigated acres in each subregion were obtained from NEA for the year 1980.¹³ These estimates are shown in Table 4.9. The estimates shown in Table 4.9 were disaggregated into acres by crop using allocation percentages calculated from 1978 Census of Agriculture data (U.S. Department of Commerce 1978). The disaggregated acres estimates that were used in deriving the baseline energy use estimates are shown in Appendix Tables A.1, A.2 and A.3.

The estimates shown in Tables 4.9, A.1, A.2 and A.3 were used only in validating the levels of the energy use input data (water application volumes, pumping lifts, etc.) used in the study and were not used in developing

¹² Unpublished data supplied by Jack Houston, research assistant in the Washington State Department of Agricultural Economics, Pullman, Washington, January 1984.

¹³ Unpublished data supplied by Dave Ricks, analyst with Northwest Economic Associates, Vancouver, Washington, January 1984.

TABLE 4.9. Estimated Irrigated Acres by Subregion in 1980 (acres in thousands)

Subregion	Acres Served by Surface Water	Surface Water under Sprinkler	Acres Served by Groundwater	Total Acres Sprinkler Irrigated	Total Irrigated Acres in Production Area	Percent Sprinkler %
1	41.5	40.9	38.6	79.5	80.1	99
2	502.5	198.7	36.5	235.2	539.0	43
3	824.2	560.5	232.4	792.9	1056.6	75
4	63.1	59.5	74.2	133.7	137.3	97
5	249.0	205.8	61.9	267.7	310.9	86
6	198.3	166.6	43.7	210.3	242.0	87
7	468.2	121.8	58.7	180.5	526.9	34
8	564.4	121.4	72.2	193.6	636.6	30
9	218.1	51.9	80.0	131.9	298.1	44
10	2041.8	274.6	1189.2	1463.8	3231.0	45
11	627	372.6	23	395.6	650.0	54
Total	5798.1	2174.3	1910.4	4040.7	7708.5	52

(a) Groundwater was assumed to be supplied entirely to sprinkler irrigation systems except in Subregion 10, where 142,600 acres are flood irrigated from wells.

Source: Unpublished data supplied by Dave Ricks, Northwest Economic Associates, Vancouver, Washington.

conservation-potential estimates. That is, these acreage estimates were multiplied by energy use per acre estimates (generated using Equation 3.1) to obtain ISEP model estimates of the irrigation energy use in each subregion. The ISEP model energy use estimates were then compared to estimates of irrigation energy use in 1980 compiled from billing records.¹⁴ When the energy use estimates developed by the ISEP model were not in close agreement with the estimates compiled from the billing records, changes in the levels of the input data (pumping lifts, water application volumes, etc.) contained in the ISEP model were implemented. The process was continued until 1) the energy use estimate calculated by the ISEP model was within 10 percent of the billing record estimate in each subregion or 2) the energy use parameters for a subregion could not be modified further and still be in a realistic range. In this manner, the ISEP model parameters were validated using actual billing record data.

The estimated baseline energy use estimates derived by ISEP using the selected baseline data and the 1980 acreage estimates are shown in the first column of Table 4.10. Load numbers supplied by Ricks compiled from actual billing records are shown in the second column. Ratios of loads compiled from billing records to load estimates derived by ISEP are shown in the third column.

Note that, with the exception of subregion 11, all of the ISEP energy use estimates by subregion are within 10 percent of estimated actual loads for the corresponding subregion. It was not possible to reconcile differences between energy use estimates from ISEP and actual billing data for subregion 11 without altering the baseline input data by very large amounts. The discrepancy between the ISEP model estimate and actual billing data for subregion 11 is large and appears to indicate that the acreage estimates and billing record data for this subregion may have been defined over different geographic areas. Estimates of conservation potential in subregion 11 should not be relied upon because validation of the baseline input data for this subregion was not possible.

¹⁴ Unpublished data supplied by Dave Ricks, analyst with Northwest Economic Associates, Vancouver, Washington, January 1984.

TABLE 4.10. Baseline Energy Use Estimates Derived by the ISEP Model in MWh, Estimated Actual Load Numbers in MWh, and Ratios of Actual Loads to Baseline Estimates

Subregion Number	Baseline Energy Use Estimate Derived by ISEP Model (MWh)	Actual Estimated Load (MWh)	Ratio of Actual Load to Baseline Estimate
1	21,272.9	19,282.3	0.91
2	265,434.9	249,539.1	0.94
3	1,033,410.8	988,500.0	0.96
4	172,612.8	160,713.1	0.93
5	106,146.6	102,944.0	0.97
6	411,366.4	447,596.0	1.09
7	201,680.1	215,341.3	0.94
8	178,306.5	178,624.7	1.00
9	138,200.7	129,069.9	0.93
10	2,081,817.0	1,989,483.6	0.95
11	<u>275,149.9</u>	<u>72,987.0</u>	<u>0.23</u>
Total	4,885,398	4,554,081.0	0.93

- (a) Derived using the energy use equation and the baseline data on pumping lifts, water application volumes, etc., discussed previously.
 (b) Unpublished data supplied by Dave Ricks, Northwest Economic Associates, January 1984, and compiled from actual billing records.

The discrepancy between the ISEP model energy use estimate and billing record data for subregion 11 has an insignificant impact upon the validity of the ISEP model baseline energy use estimate for the total BPA service area. The ISEP model estimate obtained using 1980 acreage data for the total BPA service area is within 7 percent of the total load estimated from 1980 billing records.

Forecasting Model Acreage Estimates

Estimates of current (1984) and future irrigated acres, upon which estimates of the current and future conservation potential in the irrigation sector are based, were calculated directly from data obtained from BPA's

irrigation acreage and load forecasting model.¹⁵ Summaries of the data obtained from the load forecasting model are reported in Tables 4.11, 4.12 and 4.13. Also shown in the tables are annual compound growth rates for the acreage estimates calculated from the load forecasting model data. Note that, in general, relatively low annual growth rates in irrigation acres are forecast by the BPA forecasting model.

The procedure used to develop acreage estimates for this study was to apply the compound annual growth rates shown in the Tables 4.11 to 4.13 to the load forecasting model acreage estimates for 1985, 1990 and 2000. This procedure resulted in annual estimates of irrigated acres for the years 1984 to 2003. These annual estimates were then subdivided by crop using allocation percentages calculated from 1978 Census of Agriculture data (U.S. Department of Commerce 1978).

¹⁵ Unpublished data supplied by John Wilkens, Bonneville Power Administration, April 1984.

TABLE 4.11. Forecasts of Sprinkler-Irrigated (Surface Water) Acres in the Pacific Northwest^(a) and the Annual Compound Growth Rates Implicit in the Forecasts

Element	SUBREGION											Total
	1	2	3	4	5	6	7	8	9	10	11	
1985 Acreage Estimates (1000 Acres)	41	198	525	59	214	150	131	170	68	576	306	2438
1980-1985 Compound Growth Rate (%)	0	.3	.9	.6	.5	.3	0	7.6	.7	1.0	1.1	.2
1990 Acreage Estimates (1000 Acres)	41	200	569	61	212	152	131	155	55	621	308	2505
1985-1990 Compound Growth Rate (%)	0	0	1.6	.4	.6	1.4	0	.7	0	1.5	0	.5
2000 Acreage Estimates (1000 Acres)	41	193	744	73	205	160	131	126	57	643	294	2667
1990-2000 Compound Growth Rate (%)	0	-.4	2.7	1.8	-.3	.5	0	-2.0	0	.4	-.5	.6

(a) Source: Results from BPA's irrigation acreage and load forecasting model supplied by John Wilkens, Bonneville Power Administration, April 1984.

TABLE 4.12. Forecasts for Sprinkler-Irrigated (Groundwater) Acres in the Pacific Northwest^(a)
and the Annual Compound Growth Rates Implicit in the Forecasts

Element	SUBREGION											Total
	1	2	3	4	5	6	7	8	9	10	11	
1985 Acreage Estimates (1000 Acres)	38	110	300	76	71	60	60	56	25	994	5	1795
1980-1985 Compound Growth Rate (%)	0	0	0	.5	2.8	6.4	0	7.5	20	1.8	20	1.8
1990 Acreage Estimates (1000 Acres)	38	109	300	77	80	76	61	73	39	1063	11	1927
1985-1990 Compound Growth Rate (%)	0	0	0	0	2.4	4.8	0	5.4	9.3	1.4	18	1.4
2000 Acreage Estimates (1000 Acres)	35	115	300	83	117	82	67	74	37	1099	32	2041
1990-2000 Compound Growth Rate (%)	-.8	.5	0	.7	3.9	.8	.9	0	0	.3	11.3	1.2

(a) Source: Results from BPA's irrigation acreage and load forecasting model supplied by John Wilkens, Bonneville Power Administration, April 1984.

TABLE 4.13. Forecasts for Gravity-Irrigated Acres in the Pacific Northwest^(a)
and the Annual Compound Growth Rates Implicit in the Forecasts

Element	SUBREGION											Total
	1	2	3	4	5	6	7	8	9	10	11	
1985 Acreage Estimates (1000 Acres)	0	211	256	1	39	32	299	377	145	1800	205	3365
1980-1985 Compound Growth Rate (%)	-20	3.5	.4	-19.7	-1.9	0	.13	4.8	2.5	1.3	-1.4	1.2
1990 Acreage Estimates (1000 Acres)	0	211	261	1	42	32	301	396	145	1776	204	3369
1985-1990 Compound Growth Rate (%)	0	0	.4	0	1.5	0	.1	1.0	0	0	0	0
2000 Acreage Estimates (1000 Acres)	1	211	281	2	43	32	310	440	146	1742	209	3417
1990-2000 Compound Growth Rate (%)	1.0	0	.7	7.2	0	0	.3	1.0	0	-.2	.2	.1

(a) Source: Results from BPA's irrigation acreage and load forecasting model supplied by John Wilkens, Bonneville Power Administration, April 1984.

5.0 CONSERVATION MEASURE DESCRIPTIONS

In this chapter, the technical and economic characteristics of the irrigation conservation measures that were analyzed in this study are described. The chapter begins with brief descriptions of the technical characteristics of each of the conservation measures. Then, the economic and energy-use data for each measure that were input to the ISEP model are identified. Finally, the chapter concludes with descriptions of technical limits to the implementation of the various conservation measures and identifies acres on which the various conservation measures may have already been implemented.

5.1 CONSERVATION MEASURE TECHNICAL DESCRIPTIONS

The conservation measures that were identified to be available for immediate use in the irrigation sector of the Pacific Northwest are the following:

- o low-pressure irrigation
- o improved design of pipe fittings and mainlines
- o improved irrigation scheduling
- o pump efficiency improvements.

The first three conservation measures listed above were selected for analysis using the ISEP model. For reasons explained below, pump efficiency improvements were not incorporated in the analysis. The technical characteristics of each of the measures will be described in turn.

5.1.1 Low-Pressure Irrigation

The basic principle behind low-pressure irrigation is that crops can be successfully irrigated using sprinkler or spray application devices designed to operate at lower pressures than traditional impact sprinkler devices. The application devices used in low-pressure irrigation can be divided into three major types--low-pressure spray heads, low-pressure impact sprinklers and drop-tubes.

Low-pressure spray heads appear to be the most popular low-pressure application devices on center-pivot systems. An illustration of a low-pressure spray application device is presented in Figure 5.1. Low-pressure spray heads are typically designed to operate in a pressure range of 20 to 35 psi.

Spray application devices can be mounted on top of a center-pivot lateral, on tubes below a center-pivot lateral (Figure 5.2), or on booms extended from the lateral (Figure 5.3). The principal advantage of mounting the spray devices below the lateral is that less irrigation water is used because evaporation losses and wind drift are reduced. The primary advantage of spray booms is that they reduce the potential for water runoff by increasing the field surface area over which water is applied at any point in a center-pivot's rotation. Irrigators who have used low-pressure spray center pivots of any type generally report that water runoff is not impacted significantly by conversion from high pressure to low pressure. Empirical field studies have shown that the potential for water runoff may actually be decreased when low-pressure application devices are used (Longley 1984).

FIGURE 5.1. Low-Pressure Spray Applicator

FIGURE 5.2. Illustration of a Spray Application Head Mounted on a Drop-Tube

FIGURE 5.3. Illustration of Spray Boom System

Low-pressure impact sprinklers are similar in design to the high-pressure impact sprinklers that have traditionally been used in irrigation. The major difference is that low-pressure impact sprinklers are designed to operate at a pressure of 35 to 45 psi compared to the 50 to 60 psi of high-pressure impact sprinklers.

Low-pressure impact sprinklers can be the preferred alternative for low-pressure irrigation in certain situations. An example is a situation in which an irrigator has a large integrated irrigation system with several laterals operating off one irrigation pump. Because the required pressure at the pump is determined by the pressure needed at the distant laterals, the laterals closest to the pump need not achieve the same pressure levels as those that are distant from the pump. The sprinklers closest to the pump can often be operated at pressures above 35 psi without increasing total irrigation system energy use.

Low-pressure impact sprinklers are the only low-pressure alternative for handmove and sideroll sprinkler irrigation systems. Conversion to low pressure on these systems has not proved to be nearly as popular as for center pivots because of concerns about inadequate water coverage that could result from the smaller throw diameter of low-pressure sprinklers. However, field studies have shown that by using an irrigation management technique known as offsetting,¹ water coverage from using low-pressure impact sprinklers on handmove or sideroll irrigation systems can be raised to the level of high-pressure impact sprinklers (Kincaid 1982; Shearer 1983). In addition, throw diameters of low-pressure impact sprinklers are normally sufficient to provide adequate water distribution without the use of offsetting, 50-foot irrigation lateral spacings are used.

An illustration of a type of drop-tube system is presented in Figure 5.4. These systems are designed to operate at very low pressures of from 10 to 25 psi. Field studies of the LEPA drop-tube system in Texas found that use of the

¹ Offsetting involves varying the location of an irrigation lateral every other trip across a field so that no areas of the field are left continuously unirrigated.

FIGURE 5.4. Illustration of a Furrow Drop-Tube System and Its Emitter

system would result in large savings of both water and energy (Lyle and Bordovsky 1981). However, drop-tube systems are untested for use in the Pacific Northwest, and many irrigation experts have reservations about the technical feasibility of using such systems in the region. Because of technical uncertainties surrounding drop-tube systems, they were excluded from analysis in this study but may be incorporated again at some future date if the uncertainties are resolved.

An important element of using low-pressure irrigation to reduce energy usage is that the irrigation pump be properly designed for the pressure requirements of low-pressure application. Thus, when conversion from high-

pressure to low-pressure irrigation is undertaken, it will normally be necessary to modify or replace the irrigation pump that was used for high-pressure irrigation. Common modifications of pumps to adapt to low pressure include the trimming of pump impellers on centrifugal and turbine pumps and reducing the number of pump bowls on turbine pumps.

5.1.2 Fittings and Mainline Redesign

The fittings of an irrigation system include the valves, elbow joints and other components used to connect the irrigation pump to the pipes of the system and to connect the pipes within the system to each other. The mainline is the name given to the primary water supply pipe of an irrigation system. Energy is lost from friction that is produced as water flows through fittings and mainlines. Such energy losses can never be eliminated, but they can be reduced through more efficient design.

Fittings redesign involves replacement of valves and elbows that are too small or change abruptly in size and direction with larger, more tapered fittings. The largest energy savings associated with fittings redesign will normally occur from modification of the fittings directly connected to the irrigation pump. Four ratings of the energy efficiency of irrigation fittings design are illustrated in Figure 5.5. The objective of an energy conservation program that incorporates fittings redesign is to modify irrigation fittings so that they conform to the good or excellent configurations shown in Figure 5.5.

Mainline redesign involves a simple increase in the size of the irrigation system mainline, which results in a decrease in frictional energy losses. This redesign can normally be accomplished most economically by installing a second mainline pipe parallel to the existing mainline pipe.

5.1.3 Improved Scheduling

A simple description of improved scheduling is that it involves improving the timing and amounts of irrigation water applications so that water usage is reduced (with no change in yields) and/or crop yields are increased. From an energy savings standpoint, the reduction in water usage is the most important aspect of improved scheduling, because decreased water application requirements translate directly into decreased pumping energy requirements.

CLASSIFICATION	FITTING DESCRIPTION
EXCELLENT
GOOD
FAIR
POOR

FIGURE 5.5. Four Types of Fittings Classifications

Numerous field tests have demonstrated that improvements in the traditional "rule-of-thumb" irrigation scheduling methods used by irrigators are possible (Lord and Gartung 1981; Green 1982). Improved irrigation scheduling requires frequent collection of soil moisture and weather data and the use of this data in some type of crop evapotranspiration model that will estimate both the optimal timing and amounts of water applications.

In order for improved irrigation scheduling to be successful in reducing water use and/or increasing crop yields, investments must be made to acquire soil moisture monitoring devices (the most common is the neutron probe), weather data collection stations, and evapotranspiration models. However, probably the most important element of a successful irrigation scheduling program is the commitment and expertise of the individuals that collect the soil moisture and weather data and develop the irrigation scheduling recommendations. The labor- and knowledge-intensive nature of improved irrigation scheduling tends to favor contracting with private consultants to perform irrigation scheduling activities. These private consultants assess irrigators a per-acre charge for providing scheduling services. To date, most

of the success in the development of private irrigation scheduling services has been achieved in California, where water and energy prices are higher than they are in the Pacific Northwest.

5.1.4 Pump Efficiency Improvements

The efficiency of an irrigation pump can be defined as the ratio of the energy output from a pump to the energy input to the pump. There are numerous causes of low pump efficiencies, including worn pump components, improper matching of a pump with irrigation system flow requirements, using a single large pump rather than multiple smaller pumps, and pumps taking in air.

The causes of low pump efficiencies are so numerous that it is difficult to specify a generic problem for analysis. In particular, it is difficult to determine, on any type of generic basis, whether pump efficiencies can be improved merely by undertaking simple pump maintenance procedures or whether more costly actions such as pump replacement are required. Pump testing programs are conducted by several utilities and government agencies in the Pacific Northwest. These programs provide information on the levels of pump efficiencies and likely causes of low pump efficiencies. However, quantitative information on the improvements in pump efficiencies that will result from undertaking any specific actions to modify irrigation pumping plants are generally not readily available.

Variable-speed pumps have the potential to reduce the energy used by irrigation pumping plants. The advantage of these pumps is that the irrigation head that they provide can be matched with the head required by the irrigation application system at any point in time, while constant-speed pumps often provide more head than is required for operation of the irrigation system in certain periods of the irrigation season.

The potential for using pump efficiency improvements and variable-speed pumps to save energy in the irrigation sector of the Pacific Northwest was investigated in this study by examining pump testing data and contacting irrigators and other knowledgeable experts. Based upon this work, it was concluded that developing reliable quantitative estimates of the cost per kWh saved and energy-savings potential for these conservation measures was beyond the scope of the study because of a lack of available field data required to

develop such estimates. Certainly, energy savings are available from implementation of pump efficiency improvements and variable-speed pumps in specific irrigation situations, and the fact that the energy-savings potential of these conservation measures cannot be reliably quantified at this time should not preclude further analysis of them in the future.

5.2 CONSERVATION MEASURE ENERGY USE INPUT DATA

As reported in Chapter 3, irrigation conservation measures will reduce the energy used in irrigation by either decreasing the head (i.e., pressure) requirements of an irrigation system, decreasing the volume of water applied through the irrigation system, or increasing the efficiency of the pump used in lifting and pressurizing the irrigation water. In addition, the energy savings that will be achieved through implementation of irrigation energy conservation measures will be affected by the interactions that occur among the various measures.

To incorporate the impacts of conservation-measure interactions into its energy savings estimates, the ISEP model uses a priority system for implementation of conservation measures. This system requires the model user to specify the order of conservation-measure implementation prior to undertaking model operation. The implementation order that was determined to be appropriate for use in this study is shown in Table 5.1.

TABLE 5.1. Conservation Measure Implementation Priorities
Selected for Use in This Study

<u>Conservation Measure</u>	<u>Implementation Priority</u>
Low-pressure irrigation	1
Fittings redesign	2
Mainline modification	3
Improved scheduling	4

The implementation order shown in Table 5.1 was selected primarily on the basis of the nature of the conservation actions that irrigators are currently known to have undertaken or are aware of. Certainly, the current level of awareness of low-pressure irrigation on the part of irrigators is much higher

than for the other three measures, and thus, it appears likely that low-pressure irrigation will be implemented more quickly than the other measures. Fittings redesign and mainline modification are relatively easy to implement once irrigators are aware of the availability of the measures, but awareness of these measures is much lower than for low-pressure irrigation. Improved irrigation scheduling is likely to be the conservation measure that will be most difficult for irrigators to accept. Thus, it was assigned the lowest implementation priority number among the conservation measures that were selected for use in this analysis.

The conservation measure energy use input data that were selected for use in analyzing conservation potential on center-pivot systems in this study are presented in Table 5.2. The input data selected for analyzing handmove and sideroll systems are shown in Table 5.3.

The reasons for the selection of the data values shown in Tables 5.2 and 5.3 are explained in detail in individual reports that were developed during this project, and thus detailed explanation is not repeated here (Harrer and Lezberg 1984, Harrer and Lezberg 1985, and Harrer and Wilfert 1985). However, all of the data selected for use in the study are based upon estimates obtained from either empirical field studies or experts who are actively working in the irrigation equipment industry. The selected energy use input data are generally in the low range of available estimates, because of BPA's desire to be conservative in forecasting the energy-savings potential of conservation measures.

Two major differences between the energy savings input data selected for center-pivot systems and the energy savings input data selected for handmove and sideroll systems were incorporated in the study. The first major difference is that the reduction in application head from converting to low pressure is smaller for handmove and sideroll systems than for center-pivot systems. This occurs because application heads of high-pressure handmove and sideroll systems are generally smaller than that of high-pressure center-pivot systems and because it is generally not possible to reduce the operating pressures of impact sprinklers on handmove and sideroll systems below 35 psi and still ensure adequate water distribution. The other major difference is

TABLE 5.2. Energy-Use Data Selected for Analyzing 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 ^(a)	110 ^(b)	100% of baseline ^(c)	100% of baseline
Fittings Redesign	110 ^(d)	103 ^(e)	100% of baseline	100% of baseline
Mainline Modification	103 ^(f)	90 ^(g)	100% of baseline	100% of baseline
Improved Scheduling	90 ^(h)	90	100% of baseline	88% of baseline ⁽ⁱ⁾ on orchard 80% of baseline on potatoes 78% of baseline on all other crops

(a) Source: Table 4.5.

(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 provided in Table 3.1.

(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).

TABLE 5.3. Energy-Use Input Data Selected for Analyzing Conservation Measures on Handmove and Sideroll 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 ^(a)	115 ^(b)	100% of baseline ^(c)	100% of baseline
Fittings Redesign	115 ^(d)	108 ^(e)	100% of baseline	100% of baseline
Mainline Modification	108 ^(f)	95 ^(g)	100% of baseline	100% of baseline
Improved Scheduling	95 ^(h)	95	100% of baseline	93% of baseline ⁽ⁱ⁾ on orchard 89% of baseline on potatoes 88% of baseline on all other crops

(a) Source: Table 4.5.

(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 provided in Table 4.2.

(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).

that the water savings that will be achieved using improved scheduling are assumed to be smaller for handmove and sideroll systems than for center-pivot systems. This difference is not indicated in the results of available field studies, but an expert who has extensive experience in managing irrigation scheduling programs stated that it was likely that improved scheduling would be less effective on handmove and sideroll systems.²

No information was identified that would justify the use of quantitative estimates of "slow start" or "technical deterioration" of the energy savings associated with any of the conservation measures. Thus, the energy savings input data shown in Tables 5.2 and 5.3 are applied in all years of the conservation measures' expected lifetimes.

5.3 CONSERVATION MEASURE ECONOMIC INPUT DATA

Conservation measure economic input data include the initial purchase and installation costs for each measure, the operation and maintenance costs of each measure, the expected life of each measure, and the discount rate used in the study. The latter two parameters are designated as economic input data because they are used in estimating the levelized cost for each measure.

The economic input data that were selected for use in this study are presented in Tables 5.4 and 5.5. Again, detailed explanations on how these input data were selected are presented in other reports and are not repeated here (Harrer and Lezberg 1984, Harrer and Lezberg 1985, and Harrer and Wilfert 1985). All of the input data were derived by analyzing estimates from either BPA Pilot Program results or experts who are actively working in the irrigation industry. All economic data were converted to a cost-per-acre basis so that they are compatible with the energy-use input data. In an effort to be conservative, the cost parameters selected for use in the study are generally in the high range of the estimates that were obtained.

² Personal communication with Marvin Shearer, agricultural extension agent, Department of Agricultural Engineering, Oregon State University, March 1984.

TABLE 5.4. Economic Input Data 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) ^(a)	\$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) ^(b)	0	1	0	0	6
Expected Lifetime of Measure (years) ^(c)	20	20	20	20	NA
Real Discount Rate (%) ^(d)	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 5.5. Economic Input Data 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) ^(a)	\$0	\$0	\$0	\$8.25	\$0
Incremental Operation and Maintenance Cost per Acre (\$1984) ^(b)	0	1	0	0	6
Expected Lifetime of Measure (years) ^(c)	20	20	20	20	NA
Real Discount Rate (%) ^(d)	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.

The cost per acre for low-pressure irrigation when surface water is used is lower than for groundwater primarily because of the additional costs of pump pulling that will be incurred in converting to low pressure on acres irrigated with groundwater. The cost per acre for surface water acres incorporates the costs that will be incurred in replacing surface water irrigation pumps when their impellers cannot be trimmed far enough to convert to low pressure. According to BPA irrigation system audit records, pump replacement will likely be necessary on 40 percent to 50 percent of the surface water acres that are converted to low pressure.³

No information was found that indicated converting to low pressure on center pivots, redesigning fittings, or modifying mainlines would result in any increase in irrigation system operation and maintenance costs. A small increase of one dollar per acre in operation and maintenance costs from using low-pressure irrigation on handmove and sideroll acres was specified because of the need to use offsetting to ensure adequate water distribution on such systems. The costs of improved scheduling are specified strictly as incremental operation and maintenance costs because a per-acre payment to consultants to provide scheduling services currently appears to be the most likely form of future irrigation scheduling arrangements.

The expected life of all conservation measures except improved scheduling is specified as 20 years because no justification was found for arguing that low-pressure irrigation equipment, fittings redesign, or mainline modification would not last 20 years. The real discount rate selected for use in the study is specified by BPA for all constant dollar cost analyses.

Note from Table 5.5 that only for mainline modification is any cost associated with purchasing and installing conservation measures on new acres. All experts contacted stated that the costs of low-pressure irrigation systems on new acres would not be any higher than the costs of high-pressure irrigation systems, except where spray booms would be required to use low-pressure irrigation. The costs of purchasing and installing energy-efficient fittings

³ Based on unpublished data from irrigation system audits obtained from Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

designs should also not differ significantly from the costs associated with less efficient fittings, although a significant amount of uncertainty is associated with the cost estimates for efficient fittings on new acres because most experts were unfamiliar with what equipment components would be required for such fittings. Additional costs would be incurred in purchasing a larger mainline, but the costs of installing a larger mainline should be the same as those of a smaller mainline. Thus, the mainline modification cost input data on new acres is for additional materials only and does not incorporate the cost of burying the mainline. Operation and maintenance costs and expected life of conservation measures on new acres are estimated to be equal to those on existing acres.

5.4 TECHNICAL LIMITATIONS ON CONSERVATION MEASURE IMPLEMENTATION

No technical limitations on the implementation of the conservation measures selected for analysis in this study were incorporated in the estimation procedure. This does not imply that implementation of the conservation measures will not be limited by technical factors in specific situations. What is implied is that not enough evidence could be obtained to justify the broad exclusion of any of the conservation measures because of technical factors.

Several technical constraints that are commonly believed to be associated with each conservation measure were evaluated to determine their validity. A common assumption is that low-pressure irrigation cannot be used on heavy clay soils or on steeply sloped fields because of the water runoff problems that would be created. Our analysis indicates that low-pressure irrigation can be used anywhere that high-pressure irrigation can be used, although in some situations, low-pressure spray booms may be necessary to keep water runoff at acceptable levels. One empirical field study found that water runoff problems associated with low-pressure irrigation were actually less severe than those associated with high-pressure irrigation (Longley 1984).

A common technical limitation that is thought to apply to improved irrigation scheduling is that it cannot be used in conjunction with integrated surface water delivery systems because such scheduling is not compatible with

the timed sequential nature of water deliveries in such systems. Our analysis indicates that the use of improved irrigation scheduling will require increased skill and attention on the part of the managers of integrated water delivery systems. However, the problems caused by the use of improved scheduling in integrated surface water delivery systems should not be insurmountable. Experience in California with such problems verifies this conclusion (Lyford and Schild 1981).

5.5 ACRES ON WHICH CONSERVATION MEASURES HAVE BEEN IMPLEMENTED

As stated previously, acres on which conservation measures have already been implemented should not be incorporated in estimating the potential energy savings that are available from conservation measures. However, developing accurate estimates of acres on which conservation measures have been implemented requires extensive data gathering and analysis using surveys or other methods. Developing and conducting detailed surveys of the conservation measure implementation that has occurred to date in the irrigation sector was beyond the scope of this study. Consequently, the acreage data described in this chapter should be regarded as rough estimates from which more detailed estimates can eventually be developed.

5.5.1 Low-Pressure Irrigation Acres

Estimates of the number of center-pivot acres on which low-pressure irrigation has been implemented are shown in Tables 5.6 and 5.7. These estimates were developed using the following equation:

$$ACI_{ijk} = AC_{ijk} \times CF_{ij} \quad (5.1)$$

where ACI_{ijk} = estimated acres on which low-pressure irrigation has been implemented for crop i and subregion j using water source k

AC_{ijk} = estimated acres of crop i irrigated with sprinklers in subregion j using water source k (presented in Tables A.1 and A.2)

CF_{ij} = conversion factor for calculating center-pivot acres on which low-pressure irrigation has been implemented for crop i and subregion j

i = wheat, alfalfa, potatoes, corn, orchard and other

TABLE 5.6. Estimates of Center-Pivot Acres Using Groundwater
on Which Conservation Has Been Achieved from
Implementation of Low-Pressure Irrigation

Region	Crop					
	Wheat	Alfalfa	Potatoes	Corn	Orchard	Other
1	0	0	0	0	0	0
2	1,009	879	44	735	0	324
3	21,476	14,517	8,411	7,165	0	1,471
4	1,694	708	0	0	0	0
5	0	172	0	80	0	0
6	3,824	3,139	2,931	483	0	0
7	1,075	6,030	80	0	0	0
8	1,205	6,540	301	18	0	0
9	0	0	0	0	0	0
10	19,856	19,207	7,831	1,520	0	11,889
11	83	383	2	0	0	2

TABLE 5.7. Estimates of Center-Pivot Acres Using Surface Water
on Which Conservation Has Been Achieved from
Implementation of Low-Pressure Irrigation

Region	Crop					
	Wheat	Alfalfa	Potatoes	Corn	Orchard	Other
1	0	0	0	0	0	0
2	3,155	985	240	4,002	0	755
3	25,384	18,463	17,945	17,281	0	10,880
4	3,615	1,287	0	0	0	0
5	114	286	21	457	0	0
6	15,446	7,365	8,352	1,841	0	0
7	611	2,020	281	0	0	0
8	452	1,888	454	0	0	0
9	0	0	0	0	0	0
10	6,333	4,714	2,302	399	0	858
11	1,338	6,205	27	0	0	39

j = subregions 1 to 11

k = surface water and groundwater

The conversion factor for each crop and subregion was calculated by the following equation:

$$CF_{ij} = (\%LF_j)(\%CLF_j)(\%CP_{ijk}) + (\%SF_j)(\%CSF_j)(\%CP_{ijk}) \quad (5.2)$$

where CF_{ij} = as defined above

$\%LF_j$ = percentage of all irrigated acres comprised by farms greater than 2000 acres in each subregion j

$\%CLF_j$ = percentage of center-pivot acres on large farms assumed to be converted to low pressure in each subregion j

$\%CP_{ijk}$ = percentage of total sprinkler-irrigated acres that use center-pivot irrigation systems for crop i, in subregion j using water source k

$\%SF_j$ = percentage of all irrigated acres comprised by farms less than 2000 acres in each subregion j

$\%CSF_j$ = percentage of center-pivot acres on small farms assumed to be converted to low pressure in each subregion j

i, j, k = as defined above

The percentages of farms greater than and less than 2000 acres that were used in the above equation were derived from data from the 1978 Census of Agriculture (U.S. Department of Commerce 1978). The percentages of center-pivot acres on large farms that were assumed to have been converted to low-pressure irrigation were 30 percent in subregions 2, 4, 7, 8, 9, and 11, and 60 percent in all other subregions. The percentages of center-pivot acres on small farms that had been converted to low pressure were assumed to be 20 percent in all subregions except subregion 10, where it was assumed to be 30 percent. The rationale behind these assumptions is explained in a related report (Harrer and Lezberg 1984) and is not repeated here.

Based on conversations with irrigation experts, conversions to low pressure of handmove and sideroll sprinkler acres appear to be limited almost exclusively to Southern Idaho (subregion 10). Thus, handmove and sideroll

acres that have already been converted to low-pressure irrigation were estimated based on an assumption that 20 percent of the eligible acres in subregion 10 have been converted to low pressure and no acres have been converted in any of the other subregions.

5.5.2 Fittings Redesign and Mainline Modification Acres

Some of the fittings that are used in irrigation pumping plants already conform to the good and excellent design categories illustrated in Figure 5.5. Records from BPA-sponsored irrigation system energy audits indicate that fittings redesign is not necessary in about 32 percent of existing irrigation pumping systems.⁴ Another study (Hansen and Shearer 1983) found that about 37 percent of irrigation pumping plants in Oregon have fittings designs that conform to the good and excellent configurations shown in Figure 5.5. These results were used in developing estimates of the acreages on which fittings redesign has already been implemented. It was assumed in this study that 34 percent of all existing sprinkler-irrigated acres should be excluded from estimating the potential energy savings for fittings redesign because correct fittings design on these acres had already been implemented. Thus, estimates of the number of acres on which fittings redesigns have been implemented were calculated by multiplying the existing sprinkler acreage estimates shown in Tables A.1 and A.2 by 0.34.

The BPA irrigation system audits records were the only readily available source of data on the percentage of acres where mainline modification has been implemented. These records indicate that mainline modification is not necessary on approximately 50 percent of all pumping plants because the mainline is already sized correctly.⁵ This estimate was used directly in developing estimates of the number of acres on which conservation has already been achieved through mainline modification. These estimates were calculated

⁴ Based on unpublished data from irrigation system audits obtained from Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

⁵ Based on unpublished data from irrigation system audits obtained from Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

by multiplying 0.5 by estimates of all existing sprinkler acres (shown in Tables A.1 and A.2).

5.5.3 Improved Scheduling Acres

Discussions with irrigation experts and reviews of available public reports indicate that the use of scientific irrigation scheduling is generally not widespread in the Pacific Northwest (Merchant and Herman 1984). However, such scheduling is more prevalent in some subregions and for some crops than it is for others. Our analysis indicated that the estimates shown in Table 5.8 and 5.9 were likely to be representative of the percentages of acres on which improved scheduling is already being used. These percentages were multiplied by acreage estimates for center-pivot and other sprinkler irrigation systems to derive estimates of the number of acres on which improved scheduling has already been implemented.

TABLE 5.8. Assumed Levels of Conservation Achieved Through Improved Scheduling on Center-Pivot Acres (% of total center-pivot acres)

<u>Region</u>	<u>Crop</u>					
	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	0	0	20	15	NA ^(a)	10
2	0	0	20	15	NA	10
3	5	5	40	25	NA	20
4	0	0	20	15	NA	10
5	0	0	20	15	NA	10
6	5	5	40	25	NA	20
7	0	0	20	15	NA	10
8	0	0	20	15	NA	10
9	0	0	20	15	NA	10
10	5	5	50	25	NA	30
11	0	0	20	15	NA	10

(a) NA = Not Applicable because of the small number of orchard acres irrigated with center pivots.

TABLE 5.9. Assumed Levels of Conservation Achieved Through Improved Scheduling on Other Sprinkler Acres^(a)
(% of total other sprinkler acres)

Region	Crop					
	Wheat	Alfalfa	Potatoes	Corn	Orchard	Other
1	0	0	10	5	15	5
2	0	0	10	5	15	5
3	5	5	20	10	30	10
4	0	0	10	5	15	5
5	0	0	10	5	15	5
6	5	5	20	10	30	10
7	0	0	10	5	15	5
8	0	0	10	5	15	5
9	0	0	10	5	15	5
10	5	5	25	10	30	15
11	0	0	10	5	15	5

(a) Other sprinkler acres include acres irrigated by handmove, sideroll and solid-set sprinkler systems.

6.0 ESTIMATION RESULTS

This chapter contains estimation results from the ISEP model for each of the irrigation conservation technologies incorporated in this study. These results represent the cost per kWh saved and the total estimated energy savings potential for each technology in the Pacific Northwest region.

6.1 LOW-PRESSURE IRRIGATION RESULTS

Estimates of the average cost per kWh saved (in 1984 mills) and the energy savings potential (in average MW) in each subregion for low-pressure irrigation on existing and new center-pivot acreages are shown in Table 6.1. The estimates shown for existing acres are for the current year (1984), while the estimates for new acres are for the final year of the forecasting period (2003).

The total estimated potential energy savings for low-pressure irrigation on existing center-pivot acres are over 21 average MW, and over 70 percent of this total is available in subregion 3 (the Columbia Basin of Washington) and subregion 10 (Southern Idaho). The estimated average cost per kWh saved for low-pressure irrigation on existing center-pivot acres is approximately 10.5 mills, and differences in cost per kWh saved between surface water acres and groundwater acres are not large.

The total estimated potential energy savings for low-pressure irrigation on new center-pivot acres is approximately 6.7 average MW, and over 60 percent of this potential is estimated to be available in subregion 3. The estimated cost per kWh saved for low-pressure irrigation on new center-pivot acres is zero in all cases because no evidence was found that it would cost any more to install a low-pressure center pivot on new acres than a high-pressure center pivot.

Estimates of the energy available at 5-mill increments of cost per kWh saved from implementing low-pressure irrigation on existing center-pivot acres are shown in Table 6.2. Note from Table 6.2 that all of the potential savings for this conservation measure can be obtained for a cost of 20 mills per kWh saved or less. Estimates of the additional energy supplies at each cost increment that could be obtained from low-pressure irrigation on new center-pivot acres are presented in Table 6.3.

TABLE 6.1. 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	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	NCP ^(a)	0.75	4.84	0.25	0.04	1.05	0.23	0.33	NCP	2.46	0.41	10.36
	Ground	NCP	0.92	4.59	0.14	0.01	0.63	0.57	0.43	NCP	3.74	NCP	11.03
	Total	NCP	1.67	9.43	0.39	0.05	1.68	0.80	0.76	NCP	6.20	0.41	21.38
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	10.66	7.99	10.62	17.37	8.37	9.38	10.07	NCP	9.62	10.88	8.92
	Ground	NCP	13.81	10.91	13.92	17.00	10.72	12.09	13.17	NCP	12.65	NCP	11.93
	Average	NCP	12.39	9.41	11.78	17.28	9.25	11.31	11.82	NCP	11.45	10.88	10.47
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NCP	NCP	4.23	0.12	NCP	0.16	NCP	NCP	NCP	0.40	NCP	4.91
	Ground	NCP	0.06	NCP	0.02	0.01	0.47	0.12	0.27	NCP	0.72	0.08	1.75
	Total	NCP	0.06	4.23	0.14	0.01	0.63	0.12	0.27	NCP	1.12	0.08	6.66
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 6.2. 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	0.00	6.98	10.34	10.36	10.36	10.36	10.36	10.36	10.36	10.36
	Groundwater	0.00	2.76	9.89	11.02	11.02	11.02	11.02	11.02	11.02	11.02
	Total	0.00	9.74	20.23	21.38	21.38	21.38	21.38	21.38	21.38	21.38

TABLE 6.3. 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	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
1986	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
1987	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
1988	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
1989	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77	1.77
1990	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10	2.10
1991	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41
1992	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69
1993	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
1994	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33	3.33
1995	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66
1996	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
1997	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35
1998	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70	4.70
1999	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08	5.08
2000	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50	5.50
2001	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89	5.89
2002	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26	6.26
2003	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66

Estimates of the maximum estimated energy savings potential in average MW and the average cost per kWh saved for implementing low-pressure irrigation on existing and new handmove and sideroll sprinkler acres are shown in Table 6.4. The potential energy savings of approximately 42 average MW for this conservation measure on existing acres are the largest among all of the conservation measures selected for study. Over 50 percent of the total potential is estimated to be available in subregions 3 and 10, and approximately 35 percent of the total is available in subregion 10 alone. The average cost of achieving these savings is estimated to be approximately 18 mills per kWh saved, and differences in cost per kWh saved between surface water and groundwater acres are relatively small.

The total potential energy savings for low-pressure irrigation on new handmove and sideroll acres in 2003 are estimated to be approximately 7.2 average MW. The estimated costs of obtaining these savings average approximately 7.5 mills per kWh saved.

Estimates of total potential energy savings by 5-mill cost increment for low-pressure irrigation on existing and new handmove and sideroll acres are shown in Tables 6.5 and 6.6. The estimates imply that approximately 73 percent of the total potential savings on existing acreages can be obtained for a cost of less than 20 mills per kWh saved, and 93 percent of the savings can be obtained for a cost of less than 25 mills per kWh saved. Virtually all of the potential energy savings on new acres can be obtained for a cost of less than 15 mills per kWh saved.

6.2 FITTINGS REDESIGN RESULTS

Estimates of the total potential energy savings and cost per kWh saved by subregion for fittings redesign on existing and new center-pivot acres are shown in Table 6.7. These estimates imply that the total potential energy savings for this conservation technology on center-pivot acres are relatively small (approximately 3.2 average MW on existing and new acres combined) and that most of the savings (75 percent) are available in subregions 3 and 10. However, the costs of obtaining these savings average less than 10 mills per kWh saved on existing acres and zero on new acres.

TABLE 6.4. 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	11	
Energy Savings on Existing Acres in 1984 (Avg. 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	36.41	14.88	12.70	13.91	25.15	11.42	14.34	15.45	16.80	15.64	17.22	15.82
	Ground	48.91	19.57	15.92	19.52	33.97	15.62	19.97	20.89	22.60	21.10	23.16	21.13
	Average	42.51	16.16	13.58	17.40	27.34	12.37	15.49	16.20	18.17	18.91	17.29	17.76
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NOS ^(a)	NOS	2.66	0.19	NOS	0.10	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	6.32	6.93	NOS	5.69	NOS	NOS	NOS	7.79	NOS	6.68
	Ground	NOS	7.12	NOS	7.11	12.36	5.69	7.27	7.60	8.23	7.60	8.23	8.42
	Average	NOS	7.12	6.32	6.99	12.36	5.69	7.27	7.60	8.23	7.72	8.23	7.48

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

TABLE 6.5. 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	0.00	11.76	22.01	23.38	24.44	24.44	24.75	24.75	24.75
	Groundwater	0.00	0.00	0.80	6.53	12.99	13.62	13.87	13.88	13.98	14.19
	Total	0.00	0.00	12.56	28.54	36.37	38.06	38.31	38.63	38.73	38.94

TABLE 6.6. 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	0.00	0.51	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
1986	0.00	0.00	0.92	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1987	0.00	0.00	1.35	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
1988	0.00	0.00	1.80	1.90	1.90	1.90	1.90	1.90	1.90	1.90	1.90
1989	0.00	0.00	2.25	2.39	2.39	2.39	2.39	2.39	2.39	2.39	2.39
1990	0.00	0.00	2.61	2.78	2.78	2.78	2.78	2.78	2.78	2.78	2.78
1991	0.00	0.00	2.86	3.05	3.05	3.05	3.05	3.05	3.05	3.05	3.05
1992	0.00	0.00	3.08	3.30	3.31	3.31	3.31	3.31	3.31	3.31	3.31
1993	0.00	0.00	3.34	3.59	3.59	3.59	3.59	3.59	3.59	3.59	3.59
1994	0.00	0.00	3.63	3.91	3.91	3.91	3.91	3.91	3.91	3.91	3.91
1995	0.00	0.00	3.90	4.21	4.22	4.22	4.22	4.22	4.22	4.22	4.22
1996	0.00	0.00	4.22	4.56	4.57	4.57	4.57	4.57	4.57	4.57	4.57
1997	0.00	0.00	4.58	4.96	4.96	4.96	4.96	4.96	4.96	4.96	4.96
1998	0.00	0.00	4.81	5.23	5.23	5.23	5.23	5.23	5.23	5.23	5.23
1999	0.00	0.00	5.16	5.62	5.62	5.62	5.62	5.62	5.62	5.62	5.62
2000	0.00	0.00	5.52	6.01	6.01	6.01	6.01	6.01	6.01	6.01	6.01
2001	0.00	0.00	5.86	6.40	6.40	6.40	6.40	6.40	6.40	6.40	6.40
2002	0.00	0.00	6.20	6.78	6.78	6.78	6.78	6.78	6.78	6.78	6.78
2003	0.00	0.00	6.54	7.17	7.17	7.17	7.17	7.17	7.17	7.17	7.17

TABLE 6.7. 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	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	NCP ^(a)	0.07	0.56	0.03	NCP	0.14	0.02	0.04	NCP	0.29	0.06	1.20
	Ground	NCP	0.10	0.53	0.01	NCP	0.08	0.06	0.04	NCP	0.45	NCP	1.27
	Total	NCP	0.17	1.09	0.04	NCP	0.22	0.08	0.08	NCP	0.74	0.06	2.47
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	11.05	8.29	11.02	18.19	8.69	9.73	10.45	NCP	9.98	11.17	9.23
	Ground	NCP	10.57	8.35	10.64	13.00	8.21	9.25	10.10	NCP	9.69	NCP	9.12
	Average	NCP	10.77	8.32	10.88	17.08	8.51	9.39	10.26	NCP	9.80	11.17	9.17
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NCP	NCP	0.49	0.02	NCP	0.02	NCP	NCP	NCP	0.05	NCP	0.57
	Ground	NCP	0.01	NCP	NCP	NCP	0.06	0.01	0.03	NCP	0.08	0.01	0.20
	Total	NCP	0.01	0.49	0.02	NCP	0.08	0.01	0.03	NCP	0.13	0.01	0.77
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.

Estimates of the potential energy savings by 5-mill cost increment for fittings redesign on existing and new center-pivot acres are shown in Tables 6.8 and 6.9. The estimates indicate that all of the potential energy savings on both types of acres can be obtained for a cost of 20 mills per kWh saved or less.

The estimated total potential energy savings and average cost per kWh saved on new and existing other sprinkler acres for fittings redesign are presented in Table 6.10. Because of the larger number of other sprinkler acres compared to center-pivot acres, the potential energy savings for fittings redesign on handmove and sideroll acres are significantly larger (7.83 average MW on existing and new acres combined) than on center-pivot acres. Over 40 percent of the total estimated potential savings is available in subregion 10 alone. The costs per kWh saved for fittings redesign again average less than 10 mills.

The estimated potential energy savings by 5-mill cost increment for fittings redesign on existing and new other sprinkler acres are shown in Tables 6.11 and 6.12. On other sprinkler acres, it is estimated that all of the energy savings from fittings redesign can be obtained for a cost of 25 mills per kWh saved or less and that 99 percent can be obtained for 20 mills per kWh saved or less.

6.3 MAINLINE MODIFICATION RESULTS

Estimates of the total potential energy savings that could result from mainline modification on existing and new center-pivot acres and the costs per kWh saved for achieving these savings are shown in Table 6.13. The total estimated potential savings from mainline modification on existing and new acres combined is approximately 5.2 average MW, and about 48 percent of these savings are estimated to be available in subregion 3 alone. The average cost per kWh saved is estimated to be approximately 19.8 mills on existing center-pivot acres and 10.4 mills on new acres.

Estimates shown in Table 6.14 show that all of the potential energy savings from mainline modification on existing center-pivot acres can be obtained for a cost of 30 mills per kWh saved or less, and 90 percent of the savings should be available for 25 mills per kWh saved or less. Estimates

TABLE 6.8. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost per kWh Saved for Fittings Redesign on Existing Center-Pivot Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.76	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
	Groundwater	0.00	0.82	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
	Total	0.00	1.58	2.49	2.49	2.49	2.49	2.49	2.49	2.49	2.49

TABLE 6.9. 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	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
1986	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
1987	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1988	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
1989	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
1990	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
1991	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
1992	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
1993	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
1994	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
1995	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
1996	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
1997	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.51
1998	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
1999	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
2000	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
2001	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
2002	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73
2003	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77

TABLE 6.10. 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	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	0.03	0.36	0.60	0.09	0.25	0.20	0.26	0.39	0.14	1.10	0.48	3.90
	Ground	0.03	0.20	0.28	0.15	0.10	0.08	0.07	0.04	NOS	1.48	NOS	2.43
	Total	0.06	0.56	0.88	0.24	0.35	0.28	0.33	0.43	0.14	2.58	0.48	6.33
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	22.83	9.01	7.95	8.48	15.89	6.96	9.01	9.72	10.54	9.80	10.82	9.86
	Ground	22.45	8.73	7.25	8.69	15.54	6.89	9.17	9.58	10.46	9.75	NOS	9.64
	Average	22.65	8.91	7.73	8.61	15.78	6.94	9.04	9.71	10.54	9.77	10.82	9.78
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NOS ^(a)	NOS	0.54	0.05	NOS	0.03	NOS	NOS	NOS	0.19	NOS	0.81
	Ground	NOS	0.01	0.00	0.03	0.11	0.05	0.01	0.03	0.04	0.31	0.10	0.69
	Total	NOS	0.01	0.54	0.08	0.11	0.08	0.01	0.03	0.04	0.50	0.10	1.50
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 6.11. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Fittings Redesign on Existing Other Sprinkler Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	2.22	3.72	3.88	3.92	3.92	3.92	3.92	3.92	3.92
	Groundwater	0.00	1.38	2.30	2.36	2.40	2.40	2.40	2.40	2.40	2.40
	Total	0.00	3.60	6.02	6.24	6.32	6.32	6.32	6.32	6.32	6.32

TABLE 6.12. 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	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
1986	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
1987	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
1988	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
1989	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
1990	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59
1991	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64	0.64
1992	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
1993	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
1994	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
1995	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89	0.89
1996	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97	0.97
1997	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04
1998	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
1999	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19	1.19
2000	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
2001	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35
2002	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
2003	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51	1.51

TABLE 6.13. 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	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	NCP ^(a)	0.10	0.75	0.04	0.01	0.19	0.04	0.06	NCP	0.50	0.09	1.78
	Ground	NCP	0.18	0.82	0.02	NCP	0.12	0.08	0.05	NCP	0.69	NCP	1.96
	Total	NCP	0.28	1.57	0.06	0.01	0.31	0.12	0.11	NCP	1.19	0.09	3.74
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	23.80	17.85	23.73	39.51	18.71	20.95	22.50	NCP	21.46	23.92	20.05
	Ground	NCP	22.77	17.98	22.92	28.02	17.68	19.93	21.84	NCP	20.75	NCP	19.61
	Average	NCP	23.14	17.92	23.44	37.15	18.30	20.23	22.19	NCP	21.05	23.92	19.82
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NCP	NCP	0.92	0.03	NCP	0.03	NCP	NCP	NCP	0.09	NCP	1.07
	Ground	NCP	0.01	NCP	NCP	NCP	0.10	0.03	0.06	NCP	0.16	0.02	0.38
	Total	NCP	0.01	0.92	0.03	NCP	0.13	0.03	0.06	NCP	0.25	0.02	1.45
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	9.41	10.05	NCP	8.25	NCP	NCP	NCP	11.61	NCP	10.08
	Ground	NCP	10.34	NCP	10.29	18.58	8.16	10.86	11.35	12.28	11.44	12.59	11.23
	Average	NCP	10.34	9.41	10.14	18.58	8.19	10.86	11.35	12.28	11.51	12.59	10.38

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

presented in Table 6.15 imply that almost all (99 percent) of the potential energy savings from mainline modification on new center-pivot acres can be obtained for a cost of 15 mills per kWh saved or less.

TABLE 6.14. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Mainline Modification on Existing Center-Pivot Acres

Year	Water Source	Cost Per kWh Saved									
		5	10	15	20	25	30	35	40	45	50
1984	Surface Water	0.00	0.00	0.26	0.88	1.56	1.76	1.77	1.77	1.77	1.77
	Groundwater	0.00	0.00	0.33	1.25	1.78	1.97	1.97	1.97	1.97	1.97
	Total	0.00	0.00	0.59	2.13	3.34	3.73	3.74	3.74	3.74	3.74

TABLE 6.15. 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	0.00	0.03	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1986	0.00	0.00	0.04	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
1987	0.00	0.00	0.07	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
1988	0.00	0.00	0.09	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
1989	0.00	0.00	0.11	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
1990	0.00	0.00	0.13	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
1991	0.00	0.00	0.16	0.51	0.53	0.53	0.53	0.53	0.53	0.53	0.53
1992	0.00	0.00	0.19	0.58	0.57	0.57	0.57	0.57	0.57	0.57	0.57
1993	0.00	0.00	0.24	0.64	0.65	0.65	0.65	0.65	0.65	0.65	0.65
1994	0.00	0.00	0.27	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
1995	0.00	0.00	0.30	0.77	0.78	0.78	0.78	0.78	0.78	0.78	0.78
1996	0.00	0.00	0.34	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
1997	0.00	0.00	0.37	0.93	0.95	0.95	0.95	0.95	0.95	0.95	0.95
1998	0.00	0.00	0.41	1.00	1.02	1.02	1.02	1.02	1.02	1.02	1.02
1999	0.00	0.00	0.45	1.09	1.10	1.10	1.10	1.10	1.10	1.10	1.10
2000	0.00	0.00	0.49	1.16	1.19	1.19	1.19	1.19	1.19	1.19	1.19
2001	0.00	0.00	0.54	1.25	1.28	1.28	1.28	1.28	1.28	1.28	1.28
2002	0.00	0.00	0.58	1.33	1.35	1.35	1.35	1.35	1.35	1.35	1.35
2003	0.00	0.00	0.62	1.42	1.44	1.44	1.44	1.44	1.44	1.44	1.44

The estimated potential energy savings and average costs per kWh saved for mainline modification on existing and new other sprinkler acres are presented in Table 6.16. The combined potential energy savings on existing and new other sprinkler acres of approximately 12.2 average MW is significantly larger than the estimate developed for center-pivot acres. A large part of these savings (41%) is available in subregion 10. The average costs of 21.1 mills per kWh saved on existing other sprinkler acres and 11.1 mills on new acres are only slightly higher than for center-pivot acres.

Estimates of the potential energy savings by 5-mill cost increment for mainline modification on existing other sprinkler acres (shown in Table 6.17) indicate that 93 percent of the total potential energy savings for mainline modification can be obtained for a cost of 30 mills per kWh saved or less. On new other sprinkler acres, estimates presented in Table 6.18 imply that virtually all of the energy savings (98 percent) can be obtained for a cost of 20 mills per kWh saved or less.

6.4 IMPROVED SCHEDULING RESULTS

Estimates of the total potential energy savings and costs per kWh saved for improved irrigation scheduling on existing and new center-pivot water-sensitive crop acres are presented in Table 6.19. Note that of the 6.7 average MW of potential energy savings that are estimated to be available on existing water sensitive crop acres in the region, over 70 percent are on groundwater acres. The average cost per kWh saved of approximately 21 mills on groundwater acres is also substantially less than the average cost of about 58 mills per kWh saved on surface water acres. The differences in energy savings potential and costs between groundwater and surface water acres are caused by the generally higher pumping lifts of groundwater irrigation. Low-cost energy savings are available from improved irrigation scheduling on center pivots, but, in order for them to be realized, it is necessary that the scheduling be implemented on acres with high pumping lifts.

The energy savings potential on new surface water acres is larger than that on groundwater acres because of the larger number of new surface water acres that are forecast to come into existence in the next 20 years. However, the cost per kWh saved on new groundwater acres of approximately 27 mills is

TABLE 6.16. Estimated Energy Savings Potential in Average MW and Cost per kWh 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	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	0.05	0.55	0.81	0.13	0.36	0.27	0.38	0.62	0.22	1.84	0.68	5.91
	Ground	0.05	0.34	0.44	0.21	0.17	0.12	0.09	0.04	0.00	2.04	0.00	3.50
	Total	0.10	0.89	1.25	0.34	0.53	0.39	0.47	0.66	0.22	3.88	0.68	9.41
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	49.18	19.34	17.12	18.27	34.22	15.01	19.40	20.99	22.71	21.11	23.33	21.28
	Ground	48.35	18.81	15.56	18.72	33.31	14.83	19.74	20.63	22.64	21.15	NOS	20.85
	Average	48.78	19.14	16.57	18.55	33.90	14.96	19.47	20.97	22.71	21.13	23.33	21.11
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NOS ^(a)	NOS	1.00	0.09	NOS	0.05	NOS	NOS	NOS	0.36	NOS	1.50
	Ground	NOS	0.03	NOS	0.05	0.21	0.10	0.03	0.06	0.08	0.58	0.18	1.32
	Total	NOS	0.03	1.00	0.14	0.21	0.15	0.03	0.06	0.08	0.94	0.18	2.82
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	9.41	10.05	NOS	8.25	NOS	NOS	NOS	11.61	NOS	9.94
	Ground	NOS	10.34	NOS	10.29	18.58	8.16	10.86	11.35	12.28	11.44	12.59	12.46
	Average	NOS	10.34	9.41	10.14	18.58	8.19	10.86	11.35	12.28	11.51	12.59	11.12

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

TABLE 6.17. 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	0.00	0.55	2.76	5.18	5.52	5.77	5.80	5.86	5.90
	Groundwater	0.00	0.00	0.25	1.67	3.12	3.23	3.31	3.33	3.33	3.37
	Total	0.00	0.00	0.80	4.43	8.30	8.75	9.08	9.13	9.19	9.27

TABLE 6.18. 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	0.00	0.07	0.20	0.21	0.22	0.22	0.22	0.22	0.22	0.22
1986	0.00	0.00	0.14	0.36	0.38	0.39	0.39	0.39	0.39	0.39	0.39
1987	0.00	0.00	0.21	0.53	0.56	0.56	0.56	0.56	0.56	0.56	0.56
1988	0.00	0.00	0.28	0.70	0.74	0.75	0.75	0.75	0.75	0.75	0.75
1989	0.00	0.00	0.35	0.94	0.99	0.99	0.99	0.99	0.99	0.99	0.99
1990	0.00	0.00	0.41	1.03	1.09	1.10	1.10	1.10	1.10	1.10	1.10
1991	0.00	0.00	0.48	1.13	1.18	1.20	1.20	1.20	1.20	1.20	1.20
1992	0.00	0.00	0.53	1.21	1.28	1.29	1.29	1.29	1.29	1.29	1.29
1993	0.00	0.00	0.60	1.31	1.39	1.41	1.41	1.41	1.41	1.41	1.41
1994	0.00	0.00	0.67	1.42	1.51	1.53	1.53	1.53	1.53	1.53	1.53
1995	0.00	0.00	0.73	1.52	1.62	1.65	1.65	1.65	1.65	1.65	1.65
1996	0.00	0.00	0.80	1.65	1.74	1.77	1.77	1.77	1.77	1.77	1.77
1997	0.00	0.00	0.89	1.79	1.91	1.94	1.94	1.94	1.94	1.94	1.94
1998	0.00	0.00	0.93	1.88	2.02	2.05	2.05	2.05	2.05	2.05	2.05
1999	0.00	0.00	1.01	2.02	2.17	2.20	2.20	2.20	2.20	2.20	2.20
2000	0.00	0.00	1.09	2.17	2.32	2.36	2.36	2.36	2.36	2.36	2.36
2001	0.00	0.00	1.17	2.30	2.45	2.50	2.50	2.50	2.50	2.50	2.50
2002	0.00	0.00	1.24	2.43	2.61	2.65	2.65	2.65	2.65	2.65	2.65
2003	0.00	0.00	1.32	2.56	2.76	2.81	2.81	2.81	2.81	2.81	2.81

TABLE 6.19. 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^(a) Acres

	Water Source	Subregion											BPA Service Area
		1	2	3	4	5	6	7	8	9	10	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	NCP ^(b)	0.19	0.84	0.00	0.01	0.36	0.01	0.02	0.00	0.41	0.00	1.84
	Ground	NCP	0.33	2.31	0.00	0.00	0.22	0.00	0.03	0.00	1.99	0.00	4.88
	Total	NCP	0.52	3.15	0.00	0.01	0.58	0.01	0.05	0.00	2.40	0.00	6.72
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	65.75	61.78	NCP	149.50	23.88	82.63	96.70	NCP	74.69	97.72	58.43
	Ground	NCP	26.05	14.25	NCP	NCP	22.82	45.00	63.63	NCP	25.88	51.38	20.55
	Average	NCP	40.50	26.96	NCP	149.50	23.48	70.00	74.68	NCP	34.25	96.45	30.92
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NCP	0.00	0.70	0.00	0.00	0.05	0.00	0.00	0.00	0.06	0.00	0.81
	Ground	NCP	0.02	0.00	0.00	0.00	0.15	0.00	0.02	0.00	0.33	0.00	0.52
	Total	NCP	0.02	0.70	0.00	0.00	0.20	0.00	0.02	0.00	0.39	0.00	1.33
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	62.90	NCP	NCP	24.29	NCP	NCP	NCP	75.50	NCP	61.55
	Ground	NCP	26.05	NCP	NCP	NCP	23.01	44.99	64.31	NCP	26.48	51.74	26.59
	Average	NCP	26.05	62.90	NCP	NCP	23.32	44.99	64.31	NCP	34.44	51.74	47.92

(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.

substantially less than the 61.6 mills estimated for surface water acres. Note also that the estimates of average costs per kWh saved on both new groundwater and new surface water acres are higher than corresponding estimates on existing acres. Improved scheduling is the only conservation measure studied for which average costs on new acres were higher than those on existing acres.

Estimates of the total energy savings potential by 5-mill cost increment on existing and new center-pivot water sensitive crop acres are shown in Tables 6.20 and 6.21. The estimates shown in Table 6.20 imply that approximately 80 percent of the total energy-savings potential on existing center-pivot acres can be obtained for a cost of 30 mills per kWh saved or less. However, about 20 percent of the total potential savings would cost more than 50 mills per kWh saved. Again, this demonstrates the importance of carefully targeting improved scheduling to those situations in which the potential energy savings are largest (i.e., pumping plants with high lifts and high water application levels).

Primarily because of the preponderance of surface water acres among the new irrigated acres that are forecast to be developed in the next 20 years, the estimates presented in Table 6.21 indicate that only 41 percent of the total potential energy savings on new acres can be obtained for a cost of 30 mills per kWh saved or less. Only 48 percent of the potential energy savings from improved irrigation scheduling on new center-pivot water sensitive crop acres can be realized for a cost of 50 mills per kWh saved or less.

TABLE 6.20. 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^(a) 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	0.11	0.11	0.36	0.36	0.36	0.36	0.36
	Groundwater	0.00	0.00	0.00	2.35	4.05	4.63	5.85	4.85	4.84	4.85
	Total	0.00	0.00	1.38	2.46	4.16	5.21	5.21	5.21	5.21	5.21

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

TABLE 6.21. 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^(a) 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	0.00	0.05	0.06	0.07	0.07	0.07	0.07
1986	0.00	0.00	0.00	0.00	0.01	0.09	0.10	0.12	0.12	0.12	0.12
1987	0.00	0.00	0.00	0.00	0.01	0.13	0.15	0.17	0.17	0.17	0.17
1988	0.00	0.00	0.00	0.00	0.01	0.17	0.20	0.23	0.23	0.23	0.23
1989	0.00	0.00	0.00	0.00	0.02	0.21	0.25	0.28	0.28	0.28	0.28
1990	0.00	0.00	0.00	0.00	0.02	0.23	0.27	0.30	0.30	0.30	0.30
1991	0.00	0.00	0.00	0.00	0.02	0.24	0.28	0.32	0.32	0.32	0.32
1992	0.00	0.00	0.00	0.00	0.02	0.25	0.30	0.34	0.34	0.34	0.34
1993	0.00	0.00	0.00	0.00	0.02	0.26	0.32	0.36	0.36	0.36	0.36
1994	0.00	0.00	0.00	0.00	0.02	0.27	0.33	0.37	0.37	0.37	0.37
1995	0.00	0.00	0.00	0.00	0.03	0.29	0.34	0.38	0.38	0.38	0.38
1996	0.00	0.00	0.00	0.00	0.04	0.30	0.37	0.41	0.41	0.41	0.41
1997	0.00	0.00	0.00	0.00	0.04	0.31	0.38	0.42	0.42	0.42	0.42
1998	0.00	0.00	0.00	0.00	0.04	0.32	0.39	0.44	0.44	0.44	0.44
1999	0.00	0.00	0.00	0.00	0.04	0.34	0.42	0.47	0.47	0.47	0.47
2000	0.00	0.00	0.00	0.00	0.04	0.35	0.44	0.50	0.50	0.50	0.50
2001	0.00	0.00	0.00	0.00	0.04	0.36	0.46	0.52	0.52	0.52	0.52
2002	0.00	0.00	0.00	0.00	0.04	0.37	0.48	0.54	0.54	0.54	0.54
2003	0.00	0.00	0.00	0.00	0.04	0.38	0.49	0.55	0.55	0.55	0.55

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

Estimates of the total potential energy savings and costs per kWh saved for improved scheduling on existing and new center-pivot non-water sensitive crop acres are shown in Table 6.22. The estimated costs per kWh saved on non-water sensitive crops do not differ significantly from those of water sensitive crops, but the estimated total potential energy savings on non-water sensitive crops are larger. Again, the estimated costs per kWh saved on new acres are higher than on existing acres.

Estimates of the total energy savings by 5-mill cost increment for improved irrigation scheduling on non-water sensitive center-pivot crop acres are presented in Tables 6.23 and 6.24. The estimates in Table 6.23 imply that almost 70 percent of the total energy savings from improved scheduling on existing acres can be realized for 30 mills per kWh saved or less. However, over 20 percent of the savings on existing acres are estimated to cost more than 50 mills per kWh saved. The estimates shown in Table 6.24 indicate that only 35 percent of the total savings on new acres can be obtained for 30 mills per kWh saved or less and more than 50 percent of the total savings would cost more than 50 mills per kWh saved.

Estimates presented in Table 6.25 indicate that only 4.2 average MW of energy savings could be realized from implementing improved irrigation scheduling on existing other sprinkler water sensitive crop acres. However, under the assumptions of this study, the costs per kWh saved for obtaining these savings are relatively high. Only in the case of groundwater acres in subregion 3 would the costs per kWh saved be less than 25 mills, and the estimated average cost on surface water acres is over 133 mills. The potential energy savings of only 0.7 average MW on new acres could also be obtained only at relatively high average costs of approximately 107 mills per kWh saved on surface water acres and 76 mills on groundwater acres.

Estimates shown in Table 6.26 indicate that approximately 20 percent of the total potential energy savings from improved irrigation scheduling on existing other sprinkler acres can be obtained for a cost of 30 mills per kWh saved or less. Less than 45 percent of the total potential savings can be realized for a cost of 50 mills per kWh saved or less. Estimates shown in Table 6.27 imply that no savings can be realized from improved irrigation scheduling on new other sprinkler water sensitive crop acres for a cost of 25

TABLE 6.22. 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^(a) Acres

	Water Source	Subregion											BPA Service Area
		1	2	3	4	5	6	7	8	9	10	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	NCP ^(b)	0.19	1.36	0.17	0.01	1.27	0.11	0.13	NCP	0.56	0.20	4.00
	Ground	NCP	0.74	6.39	0.21	0.01	0.64	0.54	0.26	NCP	2.69	0.01	11.49
	Total	NCP	0.93	7.75	0.38	0.02	1.91	0.65	0.39	NCP	3.25	0.21	15.49
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	NCP	74.73	64.72	66.23	114.03	24.58	67.55	75.81	NCP	77.47	88.05	56.02
	Ground	NCP	27.03	14.84	27.32	75.81	21.51	35.89	58.00	NCP	26.72	46.65	21.03
	Average	NCP	36.92	23.57	44.64	98.43	23.55	41.26	63.81	NCP	35.50	87.04	30.07
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NCP	0.00	0.82	0.06	0.00	0.11	0.00	0.00	0.00	0.08	0.00	1.07
	Ground	NCP	0.05	0.00	0.02	0.01	0.34	0.08	0.11	0.00	0.40	0.05	1.06
	Total	NCP	0.05	0.82	0.08	0.01	0.45	0.08	0.11	0.00	0.48	0.05	2.13
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NCP	NCP	64.59	66.23	NCP	24.58	NCP	NCP	NCP	77.47	NCP	61.62
	Ground	NCP	27.03	NCP	27.32	75.81	21.51	35.89	58.00	NCP	26.74	46.66	30.33
	Average	NCP	27.03	64.59	54.14	75.81	22.26	35.89	58.00	NCP	35.36	46.66	46.03

(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 6.23. 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^(a) 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	0.56	0.56	1.27	1.27	1.27	1.27	1.34
	Groundwater	0.00	0.00	3.35	6.85	8.61	9.20	11.14	11.14	11.15	11.21
	Total	0.00	0.00	3.35	7.41	9.17	10.47	12.41	12.41	12.42	12.55

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

TABLE 6.24. 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^(a) 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	0.05	0.08	0.10	0.10	0.10	0.10
1986	0.00	0.00	0.00	0.00	0.05	0.10	0.14	0.18	0.18	0.18	0.18
1987	0.00	0.00	0.00	0.00	0.07	0.14	0.22	0.27	0.27	0.27	0.27
1988	0.00	0.00	0.00	0.00	0.10	0.19	0.29	0.36	0.36	0.36	0.36
1989	0.00	0.00	0.00	0.00	0.12	0.23	0.35	0.44	0.44	0.44	0.44
1990	0.00	0.00	0.00	0.00	0.15	0.26	0.40	0.50	0.50	0.51	0.51
1991	0.00	0.00	0.00	0.00	0.16	0.28	0.44	0.55	0.55	0.55	0.56
1992	0.00	0.00	0.00	0.00	0.17	0.29	0.45	0.56	0.56	0.57	0.58
1993	0.00	0.00	0.00	0.00	0.17	0.31	0.47	0.60	0.60	0.62	0.62
1994	0.00	0.00	0.00	0.00	0.17	0.31	0.49	0.63	0.63	0.64	0.65
1995	0.00	0.00	0.00	0.00	0.18	0.33	0.52	0.67	0.67	0.68	0.69
1996	0.00	0.00	0.00	0.00	0.20	0.36	0.55	0.71	0.71	0.73	0.73
1997	0.00	0.00	0.00	0.00	0.20	0.36	0.56	0.73	0.73	0.75	0.76
1998	0.00	0.00	0.00	0.00	0.21	0.38	0.59	0.78	0.78	0.80	0.81
1999	0.00	0.00	0.00	0.00	0.23	0.41	0.63	0.83	0.83	0.85	0.86
2000	0.00	0.00	0.00	0.00	0.23	0.43	0.66	0.89	0.89	0.92	0.92
2001	0.00	0.00	0.00	0.00	0.23	0.44	0.70	0.93	0.93	0.97	0.98
2002	0.00	0.00	0.00	0.00	0.24	0.46	0.71	0.96	0.96	1.00	1.00
2003	0.00	0.00	0.00	0.00	0.25	0.48	0.74	0.99	0.99	1.04	1.05

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

TABLE 6.25. Estimated Energy Savings Potential in Average MW and Cost per kWh Saved in 1984 Mills for Improved Scheduling on Existing and New Other Sprinkler^(a) Water Sensitive Crop^(b) Acres

	Water Source	Subregion											8PA Service Area
		1	2	3	4	5	6	7	8	9	10	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	0.01	0.08	0.08	0.04	0.25	0.11	0.06	0.09	0.02	0.46	0.02	1.22
	Ground	0.02	0.12	0.82	0.11	0.10	0.06	0.05	0.02	0.01	1.67	0.00	2.98
	Total	0.03	0.20	0.90	0.15	0.35	0.17	0.11	0.11	0.03	2.13	0.02	4.20
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	332.68	104.12	99.16	85.05	219.66	31.87	121.12	150.92	129.90	139.71	160.20	133.87
	Ground	272.27	42.00	23.47	36.52	174.82	31.09	67.63	110.66	67.37	50.80	86.17	47.91
	Average	301.55	70.46	41.09	48.96	206.84	31.64	97.08	144.59	111.18	70.29	159.10	76.14
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NOS ^(c)	0.18	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.07	0.00	0.28
	Ground	NOS	0.00	0.01	0.09	0.03	0.01	0.01	0.01	0.01	0.29	0.00	0.46
	Total	NOS	0.18	0.02	0.09	0.05	0.01	0.01	0.01	0.01	0.36	0.00	0.74
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	103.33	85.05	NOS	37.67	NOS	NOS	NOS	139.91	NOS	106.70
	Ground	NOS	42.00	NOS	36.52	174.82	31.21	67.78	110.78	67.73	51.02	86.85	75.61
	Average	NOS	42.00	103.33	59.59	174.82	33.70	67.78	110.78	67.73	67.87	86.85	87.27

(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 potatoes, corn and other miscellaneous crops.

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

TABLE 6.26. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Other Sprinkler^(a) Water Sensitive Crop^(b) 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	0.00	0.00	0.00	0.12	0.12	0.12	0.12
	Groundwater	0.00	0.00	0.00	0.00	0.78	0.87	0.87	0.98	1.23	1.78
	Total	0.00	0.00	0.00	0.00	0.78	0.87	0.99	1.10	1.35	1.90

(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 6.27. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost per kWh Saved for Improved Scheduling on New Other Sprinkler^(a) Water Sensitive Crop^(b) 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	0.00	0.00	0.00	0.00	0.00	0.00	0.02
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.03
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.05
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.06
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.08
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.09
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.10
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.03	0.10
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.03	0.11
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.03	0.03	0.12
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.05	0.12
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.05	0.13
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.04	0.05	0.13
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.04	0.05	0.14
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05	0.05	0.16
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05	0.06	0.17
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05	0.06	0.17
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05	0.06	0.18
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.04	0.05	0.06	0.18

(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 potatoes, corn and other miscellaneous crops.

mills per kWh saved or less. Only 24 percent of the total potential savings could be realized for a cost of 50 mills per kWh saved or less.

Estimates of the total energy savings potential and average costs per kWh saved for improved scheduling on existing and new non-water sensitive crop acres are presented in Table 6.28. Although the total estimated energy savings potential for improved scheduling in the BPA service area exceeds 25 average MW, the costs of obtaining these savings are relatively high on both new and existing other sprinkler acres. This result is further illustrated by information shown in Tables 6.29 and 6.30 which indicates that less than 40 percent of the potential energy savings on existing other sprinkler non-water sensitive crop acres and less than 30 percent of the savings on new acres can be obtained for 50 mills per kWh saved or less.

It should be recognized that the potential water and energy savings from the use of improved scheduling have not been extensively demonstrated through field testing in the Pacific Northwest, particularly on other sprinkler acres. Conservative estimates of these savings were used in this study. The possibility exists that further research will demonstrate that improved scheduling is more cost-effective and has higher potential energy savings than the results presented in this report indicate. In addition, if improved scheduling is selectively implemented on high-lift pumping plants, cost-effective energy savings should be available on a large number of sprinkler irrigated acres.

6.5 SUMMARY OF RESULTS

A summary of the total potential energy savings and average cost per kWh saved for all conservation measures on all acres is presented in Table 6.31. By the end of the forecasting period in 2003, it is estimated that approximately 159 average MW of energy savings could be realized through implementation of the conservation measures selected for analysis in this study. The average costs for implementing these measures are all near 20 mills per kWh saved or less, except for improved irrigation scheduling where estimated costs are higher.

Estimates of the total energy-savings potential by 5-mill cost increment for all conservation measures on all acres are shown in Table 6.32. The

TABLE 6.28. Estimated Energy Savings Potential in Average MW and Cost per kWh Saved in 1984 Mills for Improved Scheduling on Existing and New Other Sprinkler^(a) Non-Water Sensitive Crop^(b) Acres

	Water Source	Subregion											BPA Service Area
		1	2	3	4	5	6	7	8	9	10	11	
Energy Savings on Existing Acres in 1984 (Avg. MW)	Surface	0.07	0.75	1.28	0.25	0.43	1.14	0.67	0.83	0.34	1.89	1.26	8.91
	Ground	0.08	0.74	1.58	0.93	0.17	0.37	0.28	0.16	0.20	8.17	0.03	12.71
	Total	0.15	1.49	2.86	1.18	0.60	1.51	0.95	0.99	0.54	10.06	1.29	21.62
Cost Per kWh Saved on Existing Acres (1984 Mills)	Surface	327.62	126.45	109.95	100.09	204.64	38.34	110.02	123.33	128.74	129.06	147.12	119.51
	Ground	267.22	53.19	24.16	43.89	161.43	37.01	63.23	97.33	67.11	46.79	79.72	48.18
	Average	295.71	89.87	62.56	55.91	192.43	38.02	96.23	118.99	106.13	62.04	145.52	77.41
Energy Savings on New Acres in 2003 (Avg. MW)	Surface	NOS ^(c)	0.00	0.76	0.08	0.00	0.10	0.00	0.00	0.00	0.27	0.00	1.21
	Ground	NOS	0.05	0.00	0.11	0.16	0.20	0.04	0.07	0.15	1.22	0.31	2.31
	Total	NOS	0.05	0.76	0.19	0.16	0.30	0.04	0.07	0.15	1.49	0.31	3.52
Cost Per kWh Saved on New Acres (1984 Mills)	Surface	NOS	NOS	109.84	100.09	NOS	38.50	NOS	NOS	NOS	129.06	NOS	107.86
	Ground	NOS	53.48	NOS	44.10	163.02	37.50	63.24	97.50	67.12	46.90	79.76	61.59
	Average	NOS	53.48	109.84	67.82	163.02	37.82	63.24	97.50	67.12	61.85	79.76	77.42

(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 6.29. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for Improved Scheduling on Existing Other Sprinkler^(a) Non-Water Sensitive Crop^(b) 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	0.00	0.00	0.00	0.77	0.77	0.77	0.77
	Groundwater	0.00	0.00	0.00	0.00	1.30	1.52	2.24	6.47	6.60	7.40
	Total	0.00	0.00	0.00	0.00	1.30	1.52	3.01	7.24	7.37	8.17

(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 6.30. Estimated Cumulative Energy Savings
Potential (Avg. MW) in 5-Mill
Increments of Cost per kWh Saved
for Improved Scheduling on
New Other Sprinkler^(a) Non-Water
Sensitive Crop^(b) 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	0.00	0.00	0.02	0.02	0.09	0.09	0.12
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.16	0.16	0.21
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.05	0.24	0.24	0.31
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.06	0.32	0.32	0.40
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.08	0.39	0.39	0.50
1990	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.10	0.42	0.42	0.54
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.12	0.46	0.46	0.59
1992	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.12	0.47	0.47	0.60
1993	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.13	0.50	0.50	0.64
1994	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.14	0.53	0.53	0.67
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.15	0.56	0.57	0.71
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.16	0.60	0.61	0.76
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.17	0.63	0.63	0.78
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.17	0.64	0.64	0.80
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.19	0.69	0.70	0.87
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.20	0.75	0.76	0.94
2001	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.22	0.79	0.79	0.97
2002	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.22	0.80	0.80	0.99
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.23	0.83	0.84	1.03

(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 6.31. Summary of Estimation Results for Conservation Measures in the Pacific Northwest Irrigation Sector

Measure	Total Potential Energy Savings (Avg. MW)		Average Cost Per kWh Saved (Mills)	
	New Acres ^(a)	Existing Acres ^(b)	New Acres ^(a)	Existing Acres ^(b)
Low-pressure irrigation on center-pivot	6.7	21.4	0.0	10.5
Low-pressure irrigation ^(c) on other sprinkler	7.2	39.0	7.5	17.8
Fittings redesign on center-pivot	0.8	2.5	0.0	9.2
Fittings redesign on other sprinkler	1.5	6.3	0.0	9.8
Mainline modification on center-pivot	1.5	3.8	10.4	19.8
Mainline modification on other sprinkler	2.8	9.4	11.1	21.1
Improved scheduling on center-pivot	3.4 ^(d)	22.2 ^(d)	46.8 ^(e)	30.3 ^(e)
Improved scheduling on other sprinkler	4.3 ^(d)	25.8 ^(d)	79.2 ^(e)	77.2 ^(e)
All Measures	28.2	130.4	---	---

(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) Includes primarily handmove and sideroll sprinkler acres.

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

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

TABLE 6.32. Estimated Cumulative Energy Savings Potential (Avg. MW) in 5-Mill Increments of Cost Per kWh Saved for All Conservation Measures on All Acres

Year	Cost Per kWh Saved										
	0	5	10	15	20	25	30	35	40	45	50
1984	0.0	0.0	15.30	47.41	75.07	93.60	98.59	102.95	107.66	108.07	109.96
1985	0.54	0.55	16.42	48.69	76.34	94.91	99.95	104.33	109.11	109.51	111.45
1986	0.99	1.01	17.38	49.86	77.56	96.21	101.29	105.71	110.54	110.95	112.92
1987	1.48	1.51	18.40	51.03	78.78	97.49	102.63	107.07	111.96	112.38	114.38
1988	1.98	2.01	19.46	52.33	80.15	98.94	104.13	108.61	113.57	113.99	116.02
1989	2.48	2.52	20.50	53.56	81.42	100.27	105.50	110.00	115.02	115.44	117.51
1990	2.95	3.00	21.45	54.78	82.76	101.68	106.98	111.50	116.55	116.96	119.05
1991	3.34	3.40	22.20	55.63	83.64	102.59	107.91	112.47	117.54	117.96	120.06
1992	3.71	3.77	22.91	56.48	84.57	103.57	108.90	113.48	118.57	118.99	121.11
1993	4.11	4.18	23.68	57.39	85.52	104.56	109.92	114.52	119.63	120.06	122.19
1994	4.55	4.62	24.53	58.36	86.52	105.59	110.97	115.59	120.73	121.16	123.30
1995	4.97	5.05	25.34	59.31	87.54	106.65	112.05	116.71	121.86	122.30	124.45
1996	5.44	5.52	26.25	60.35	88.61	107.75	113.18	117.85	123.03	123.47	125.64
1997	5.91	5.99	27.19	61.46	89.75	108.92	114.36	119.06	124.27	124.71	126.89
1998	6.36	6.44	27.97	62.37	90.71	109.92	115.38	120.11	125.33	125.78	127.97
1999	6.90	6.95	28.94	63.46	91.80	111.02	116.51	121.26	126.52	126.97	129.17
2000	7.40	7.50	29.92	64.49	92.78	111.99	117.48	122.26	127.55	128.00	130.22
2001	7.93	8.03	30.89	65.60	93.91	113.13	118.65	123.45	128.76	129.22	131.45
2002	8.43	8.53	31.85	66.70	95.05	114.29	119.83	124.64	129.97	130.44	132.68
2003	8.95	9.05	32.82	67.81	96.17	115.42	120.97	125.81	131.15	131.62	133.87

estimates shown for 1984 represent potential savings on existing acres, while the estimates for all other years are a combination of existing and new acres.

From the estimates presented in Table 6.32, the following major conclusions can be drawn:

- o Over 60 percent of the total estimated potential energy savings in the irrigation sector can be realized for a cost of 20 mills per kWh saved or less.
- o Over 75 percent of the total estimated potential energy savings in the irrigation sector can be realized for a cost of 30 mills per kWh saved or less.
- o Approximately 85 percent of the total estimated potential energy savings in the irrigation sector can be obtained for a cost of 50 mills per kWh saved or less.

It should be recognized that the conservation-measure cost estimates presented here were developed using expected lifetimes of 20 years for all conservation measures except improved irrigation scheduling and a 3 percent real discount rate. The payback period imposed by farm lenders for irrigators undertaking conservation investments will usually be much shorter than 20 years. In addition, current real interest rates on farm loans are more than twice the 3 percent level used in this analysis. Thus, while conservation investments in the irrigation sector may be cost-effective from a power planning standpoint, they may not be cost-effective from an irrigator's standpoint.

To test the impacts of farm lending requirements on conservation measure cost-effectiveness, estimates of the cost per kWh saved for low-pressure irrigation on center pivots were developed using an assumed 3-year payback period. The results of this analysis are presented in another report and are not repeated in detail here (Harrer and Lezberg 1984). The major implication of these results is that a 3-year payback requirement would raise the costs for low-pressure irrigation on center pivots to a range of 25 to 30 mills per kWh saved. This cost level is close to the prices that irrigators are currently paying for electricity. Thus, farm lending requirements can substantially reduce the cost effectiveness of conservation investments by irrigators.

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Appendix A

TABLE A.1. Estimated Groundwater Sprinkler Acres in 1980

Crop	Subregion										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	162	5,366	71,114	28,715	2,847	13,416	12,797	11,696	20,800	389,335	4,347
Alfalfa	27,213	8,614	56,706	23,596	17,208	13,416	37,451	48,807	51,200	309,794	18,239
Potatoes	1,312	219	26,958	0	186	7,254	2,113	1,872	2,480	135,011	184
Corn	3,551	3,468	21,846	74	11,452	1,136	6	72	80	4,186	46
Orchard	2,394	12,228	6,740	9,423	5,757	4,720	59	3,466	320	60,703	115
Other	3,474	6,606	49,036	12,391	24,327	3,802	6,281	6,426	5,120	148,617	92

TABLE A.2. Estimated Surface Water Sprinkler Acres in 1980

Crop	Subregion										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	172	29,209	171,513	23,027	9,467	51,146	26,552	19,667	13,494	102,151	70,421
Alfalfa	28,834	46,893	136,762	18,921	57,212	51,146	77,708	82,066	33,216	81,282	295,472
Potatoes	1,391	1,192	65,018	0	617	27,656	4,385	3,156	1,609	35,423	2,981
Corn	3,763	18,877	52,687	60	38,073	4,332	12	121	52	1,098	745
Orchard	3,108	66,565	16,255	7,557	19,139	17,993	122	5,827	208	15,927	1,863
Other	3,681	35,965	118,266	9,937	80,879	14,494	13,033	10,805	3,322	38,993	1,490

TABLE A.3. Estimated Gravity Flow Acres in 1980

Crop	Subregion										
	1	2	3	4	5	6	7	8	9	10	11
Wheat	0	44,659	80,692	1,393	1,987	9,732	75,515	71,766	43,212	710,445	48,034
Alfalfa	423	71,697	64,343	1,445	12,010	9,732	221,003	299,468	106,368	565,301	201,537
Potatoes	20	1,823	30,589	0	130	5,262	12,470	11,518	5,152	246,364	2,032
Corn	55	28,861	24,788	0	7,992	824	35	443	166	639	508
Orchard	46	101,773	7,647	457	4,018	3,424	346	21,264	665	110,768	1,271
Other	54	54,988	55,641	601	16,978	2,758	37,065	39,427	10,637	271,191	1,017

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