Potential Conservation Opportunities from Fittings Redesign, Mainline Modification, and Pump Efficiency Improvement in Irrigation Systems of the Pacific Northwest

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POTENTIAL CONSERVATION
OPPORTUNITIES FROM
FITTINGS REDESIGN, MAINLINE
MODIFICATION, AND PUMP EFFICIENCY
IMPROVEMENT IN IRRIGATION
SYSTEMS OF THE PACIFIC NORTHWEST

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SUMMARY

This report documents research efforts to identify the potential energy savings and the costs per kWh saved from reducing head losses in fittings and mainlines, and improving pump efficiency in the sprinkler irrigation systems currently being used in the Pacific Northwest agricultural sector. These efforts are part of an overall project aimed at developing a computer model and data base that will allow for estimation of the potential energy savings and cost effectiveness of a number of conservation technologies that are available for use in irrigated agriculture. The research is being 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 improvements has been developed by Pacific Northwest Laboratory personnel and is the primary analytical tool utilized in this research. This model generates energy savings and cost per kWh saved estimates using engineering and economic input parameters for the various conservation measures that could potentially be implemented in irrigated agriculture. The objective of this report is to provide documentation on the input parameters that were provided to the model and the output results that were generated pertaining to three technologies known as fittings redesign, mainline modification, and pump efficiency improvement.

Fittings redesign involves the replacement of small, sharply angled fittings around irrigation pumps with larger, gradually angled fittings. The results of this study show that approximately 8.8 average megawatts (MW) of electricity could potentially be saved through implementation of fittings redesign on existing sprinkler acreages and, the cost of obtaining these savings would average less than 10 mills per kWh saved. Little variation in cost per kWh saved for fittings redesign was noted among subregions, between surface water and groundwater, or between center pivot and other sprinkler systems. In addition, approximately 2.3 average MW could be saved by the year 2003 through the use of fittings redesign on new sprinkler acreages. The costs

of savings on new acreages were estimated to be essentially zero because not enough evidence was found that properly designed fittings would cost more than improperly designed fittings on new acreages.

Mainline modification involves the installation of additional irrigation mainlines parallel to existing mainlines. The addition of another mainline reduces friction and resulting energy losses within an irrigation piping system. The results of the study illustrate that approximately 13.1 average MW of electricity could potentially be saved through mainline modification on existing sprinkler acreages, and the cost of obtaining these savings would average approximately 20 mills per kWh saved. Again, only a small amount of variation in cost per kWh saved was noted for mainline modification among subregions, between surface water and groundwater, or between center pivot and other sprinkler systems. The additional savings by the year 2003 for mainline modification on new sprinkler acreages were estimated to be approximately 4.3 average MW. The costs of obtaining these savings on new acreages will average approximately 10.5 mills per kWh saved.

A preliminary investigation of various methods of improving pump efficiencies was conducted. Based on this preliminary assessment, it was concluded that the most reliable method of improving pump efficiencies were improved pump selection and maintenance procedures that would generally require little capital expenditure on the part of irrigators. However, the various methods of improving pump efficiencies will require additional study before their costs and energy savings potentials can be adequately characterized.

CONCLUSIONS AND RECOMMENDATIONS

The major results of this study in terms of cost per kWh of savings and energy savings potential are presented in Summary Table 1. Note that although the potential energy savings for any single conservation technology are relatively small, when taken together the total savings for all technologies on existing acreages could be almost 22 average megawatts (MW), and the savings on new acreages in the year 2003 would exceed 6.5 average MWs. In the analysis, the energy-savings input parameters selected for use were generally in the low range of available estimates. Thus, the energy savings estimates shown in Summary Table 1 should be conservatively low, and the cost per kWh saved estimates should be conservatively high.

Although the head reductions resulting from fittings redesign will vary substantially from one pump to another, it appeared from data gathered during BPA-sponsored irrigation audits that 7 feet was a representative conservative estimate of the amount of pumping head that could be saved through fittings redesign. A capital cost of \$3.75 per acre was determined to be representative of the cost of implementing a fittings redesign on existing sprinkler irrigated acres. The incremental cost on new acres of using efficient fittings design was estimated to be zero, although it is possible that a small additional cost will be incurred in using efficiently designed fittings on new acres. It was also estimated that 34 percent of all fittings on existing acres would require no redesign because their design was already efficient. The potential energy savings estimates shown in Summary Table 1 are based on the remaining 66 percent of existing fittings.

Note that the average cost per kWh saved for fittings redesign is less than 10 mills over a 20-year system life for both existing center pivots and existing other sprinkler systems. It is estimated that virtually all of the potential energy savings from fittings redesign can be obtained for a cost less than or equal to 15 mills per kWh saved over a 20-year life.

Analysis of the audit data indicated that 13 feet was a representative conservative estimate of the amount of pumping head reduction that would be realized through mainline modification, although substantial variance around this representative level was again noted. A capital cost of \$15.00 per acre

SUMMARY TABLE 1. Major Results for Fittings Redesign,
Mainline Modification, and
Pump Efficiency Improvement^(a)

Conversion Alternative	Estimated Avg. Cost per kWh Saved on Existing Acres (Mills) ^(b)	Estimated Avg. Cost per kWh Saved on New Acres (Mills)	Estimated Savings Potential on Existing Acres (MW)	Estimated Savings Potential on New Acres (MW)
Fittings redesign on center pivot	9.2	0.0	2.5	.8
Fittings redesign on other sprinkler ^(c)	9.8	0.0	6.3	1.5
Mainline modification on center pivot	19.8	10.4	3.7	1.5
Mainline modification on other spinkler	21.1	11.2	9.4	2.8

- (a) Fittings redesign involves the purchase and installation of tapered cones, flanges, etc., so that head losses in fittings around the pump are reduced. Mainline modification involves purchase and installation of a parallel pipe adjacent to the existing mainline on the ground surface so that head losses in mainlines are reduced.
- (b) Assuming a 20-year system life.
- (c) Other sprinkler systems are defined as all non center-pivot sprinkler irrigation systems and include handmove, sideroll and solid set systems.

was selected to be representative of the cost of implementing a mainline modification on existing acres. This cost includes both the cost of materials for the new mainline and the cost of burying the additional mainline under the ground. A capital cost of \$6.75 per acre, which represented an incremental materials cost only, was used to represent the capital cost of implementing mainline modification on new sprinkler acres. It was estimated that 50 percent of all existing systems require no modification to be efficient and aggregate energy savings were estimated on the basis of the remaining 50 percent.

The cost per kWh saved for implementing the mainline modification selected for analysis in this study is estimated to average approximately 20.5 mills across all types of existing sprinkler systems and 10.8 mills across all types of new systems. Over 90 percent of the savings on existing systems from mainline modification can be obtained for a cost of 25 mills per kWh saved or less. Virtually all of the savings on new systems can be realized for a cost of 15 mills per kWh saved or less.

The analysis of pump efficiency improvements is complicated because of the multitude of factors that can affect pump efficiency and the multitude of actions that could potentially be undertaken to improve efficiency. It is believed that many of the actions could be undertaken at little or no cost to improve pump efficiency during the process of modifying pumps to convert to low pressure. These actions were not included in our quantitative analysis because it was felt these actions were a part of normal pump maintenance. Analysis of the replacement of surface water centrifugal pumps was also not included under pump efficiency improvements because such replacement was considered a necessary part of low pressure conversion.

Preliminary investigations of other methods of improving pump efficiencies, including replacement of groundwater turbine pumps and the use of variable speed pumps, were also undertaken. On the basis of these investigations, it was concluded that there is currently not enough information on pump efficiency improvements to develop reliable quantitative estimates of the potential energy savings that might result from such improvements and the costs of obtaining these savings.

Further investigation may reveal that cost-effective energy savings are available from pump efficiency improvements, but at this point in time, the savings appear to be too uncertain to incorporate in power supply resource forecasts.

RECOMMENDATIONS

The ability to obtain cost-effective energy savings from fittings redesign, mainline modification, and pump efficiency improvements will depend on the methods system auditors use to locate and estimate potential energy savings for each technology on specific irrigation systems. Thus, the following recommendation is given:

- o Efforts should be continued to ensure that BPA energy auditing procedures are as standardized as possible across utility districts.
- o Efforts should be continued to inform irrigators and irrigation equipment dealers of the benefits of energy efficient fittings, mainlines and pumps.

In addition, it is recommended that additional efforts be undertaken to characterize and quantify the potential energy savings available from pump efficiency improvements in the irrigation sector.

CONTENTS

SUMMARY	iii
CONCLUSIONS AND RECOMMENDATIONS	v
1.0 INTRODUCTION	1.1
2.0 TECHNOLOGY DESCRIPTION	2.1
2.1 Factors Influencing Energy Losses in Irrigation Fittings	2.1
2.2 Factors Influencing Energy Losses in Irrigation Mainlines	2.2
2.3 Irrigation Pump Efficiency	2.4
3.0 ALTERNATIVES CHOSEN FOR ANALYSIS AND ENERGY SAVINGS ASSUMPTIONS OF EACH ALTERNATIVE	3.1
3.1 Selected Alternatives	3.1
3.2 Energy Savings Input Assumptions	3.4
3.2.1 Fittings Redesign Estimates	3.4
3.2.2 Mainline Modification Estimates	3.6
3.2.3 Pump Efficiency Improvement Estimates	3.6
3.2.4 Input Parameters Selected For Use	3.8
4.0 COST INPUT ASSUMPTIONS	4.1
4.1 Costs of Fittings Redesign	4.1
4.2 Costs of Mainline Modification	4.2
4.3 Cost Inputs Selected for Use in this Study	4.4
4.4 Other Economic Inputs	4.4
5.0 TECHNICAL LIMITS ON MEASURE APPLICATION AND CONSERVATION ALREADY ACHIEVED	5.1
5.1 Technical Limits	5.1
5.2 Conservation Already Achieved	5.1
6.0 ESTIMATION OF RESULTS	6.1
6.1 Study Methodology	6.1
6.2 Cost per kWh Saved and Energy Savings Potential for Fittings Redesign	6.4
6.3 Cost per kWh Saved and Energy Savings Potential for Mainline Modification	6.10
6.4 Cost per kWh Saved Assuming a 3-Year Investment Life	6.18
REFERENCES	R.1

FIGURES

2.1	Four Potential Classifications of Irrigation Fittings Design Source: Hansen and Shearer, 1983	2.2
2.2	Illustration of the Trade-offs Between Capital and Power Costs in Irrigation Pipe Sizing	2.3
2.3	Illustration of Pump Curves and Efficiency Curves	2.6

TABLES

Summary Table 1. Major Results for Fittings Redesign, Mainline Modification, and Pump Efficiency Improvement		vi
3.1	Alternatives Selected for Use in Analyzing the Potential Energy Savings of Fittings Redesign, Mainline Modification, and Pump Efficiency Improvement	3.2
3.2	Average and Median Calculated Head Reductions from the Redesign of Pump Discharge Fittings on Centrifugal Pumps	3.5
3.3	Average and Median Calculated Head Reductions from the Redesign of Pump Discharge Fittings on Turbine Pumps	3.5
3.4	Average and Median Calculated Head Reductions from the Modification of Mainlines	3.7
3.5	Estimated Efficiency Changes for Groundwater Turbine Pumps	3.7
3.6	Input Parameters Selected for Use in Analyzing the Energy Savings Potential and Cost per kWh Saved for Various Technologies	3.9
4.1	Costs of Fittings Redesign Derived from BPA Pilot Program Records	4.2
4.2	Total Installed Costs of Mainline Modification Assuming 900 Feet of 6" PVC Pipe is Purchased	4.3
4.3	Cost Inputs Selected for Analyzing Fittings Redesign and Mainline Modification	4.5

5.1	Estimated Percentages of Irrigation Systems Where Fittings Redesign and Mainline Modification Were Not Recommended after Field Audits	5.3
5.2	Percent of Total Evaluations for Various Categories of Fittings Designs	5.3
5.3	Conservation Achieved by Fittings Redesign on Surface Water Center-Pivot Acres	5.5
5.4	Conservation Achieved by Fittings Redesign on Groundwater Center-Pivot Acres	5.5
5.5	Conservation Achieved by Fittings Redesign on Surface Water Other Sprinkler Acres	5.6
5.6	Conservation Achieved by Fittings Redesign on Groundwater Other Sprinkler Acres	5.6
5.7	Conservation Achieved with Mainline Modification on Surface Water Center-Pivot Acres	5.7
5.8	Conservation Achieved with Mainline Modification on Groundwater Center-Pivot Acres	5.7
5.9	Conservation Achieved with Mainline Modification on Surface Water Other Sprinkler Acres	5.8
5.10	Conservation Achieved with Mainline Modification on Groundwater Other Sprinkler Acres	5.8
6.1	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	6.5
6.2	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Fittings Redesign on Existing Center-Pivot Acres	6.6
6.3	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Fittings Redesign on All New Center-Pivot Acres	6.7
6.4	Estimated Energy Savings Potential in Average MW and Cost per kWh Saved in 1984 Mills for Fittings Redesign on Existing and New Handmove and Sideroll Acres	6.8
6.5	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Fittings Redesign on Existing Handmove and Sideroll Acres	6.9

6.6	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Fittings Redesign on New Handmove and Sideroll Acres	6.10
6.7	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	6.12
6.8	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on Existing Center-Pivot Acres	6.13
6.9	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on New Center-Pivot Acres	6.14
6.10	Estimated Energy Savings Potential in Average MW and Cost per kWh Saved in 1984 Mills for Mainline Modification on Existing and New Handmove and Sideroll Acres	6.15
6.11	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on Existing Handmove and Sideroll Acres	6.16
6.12	Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on All New Handmove and Sideroll Acres	6.17

1.0 INTRODUCTION

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

The Bonneville Power Administration (BPA) is expected to play a major role in the implementation of conservation programs in the region. In keeping with this role, BPA contracted with Pacific Northwest Laboratory to perform additional research on conservation in the irrigated-agriculture sector. This report is the third in a series of four that will address the costs and energy-savings potential of various technologies that could be used to reduce the energy used by irrigators in watering their crops.

This report is intended to provide information on the costs and energy-savings potential of technologies that are referred to as fittings redesign, mainline modification, and pump improvement. Fittings redesign and mainline modification reduce irrigation energy use by reducing the pumping heads that must be overcome in applying water to the crops. Pump efficiency improvements reduce energy use by increasing the efficiency of pumping plants in transforming electrical input energy into horsepower output energy.

In conjunction with its planning efforts, BPA required that specific information on the energy-savings potential (in average megawatts) and the cost per kilowatt-hour saved be developed for each conservation technology selected for analysis. To aid in this effort, a computer model of the irrigation energy consumption process was developed by PNL personnel. This report provides information on the data on fittings redesign, mainline modification and pump improvement that were input to the model and the output results that were obtained.

The report is divided into six chapters. Chapter 2.0 describes some of the technical issues and characteristics associated with fittings redesign, mainline modification and pump efficiency improvement used in analyzing each alternative. In Chapter 3.0, the energy savings input parameters that were used in our analysis of the three technologies are described. Cost input

parameters are identified in Chapter 4.0. Chapter 5.0 describes any technical limitations that may hinder the use of the technologies and also provides information on the amount of conservation that may have already been achieved through application of the technologies. Finally, the report concludes with a description of the potential energy savings estimates and cost per kWh saved estimates that were obtained in the study.

2.0 TECHNOLOGY DESCRIPTION

The efficiency of an irrigation pump in translating input energy to output energy and the design of the pipes and fittings through which irrigation water is transported are important determinants of the energy use of an irrigation system. In this chapter, a brief description of the factors that determine the energy efficiency of an irrigation pumping plant is presented. The factors that influence energy losses in the pipe fittings and mainlines of an irrigation system are also identified.

2.1 FACTORS INFLUENCING ENERGY LOSSES IN IRRIGATION FITTINGS

The design of pipe fittings in an irrigation system influences the amount of energy used in the irrigation system by affecting the amount of total dynamic head that is lost as water flows from an irrigation pump to the point of water application. The total dynamic head of a sprinkler irrigation system is determined by the amount of head required to operate those sprinklers located at the highest elevations and the longest distances from the irrigation pump. Head is lost as water flows around corners, through valves, and through any other obstructions that may keep water from flowing as freely as possible as it moves through the pipe system. Some head losses through pipe fittings are unavoidable, but to the degree that head losses within an irrigation piping system can be reduced, the total dynamic head needed at the pump for irrigation can also be reduced.

Although head losses can occur through any of the fittings within an irrigation system, the largest head losses through fittings generally occur near the pump because the velocity head of the irrigation system is largest at that point. If the suction and discharge fittings around a pump are small, change size abruptly, or change angles abruptly, the head losses occurring in the piping system may be increased significantly. In contrast, if the pipe fittings around the pump gradually increase in size, head losses can be reduced.

An illustration of four potential classifications of the design of pipe fittings around an irrigation pump is shown in Figure 2.1. This classification system was developed as part of an extensive study of a large number of irrigation pumping plants in Oregon (Hansen and Shearer 1983). This study

found that 63% of the pump fittings that were examined fell under the fair or poor classification. The potential reductions in total dynamic heads from changing the design of pump fittings from a poor to a good classification were estimated to range as high as 20 feet.

FIGURE 2.1. Four Potential Classifications of Irrigation Fittings Design
Source: Hansen and Shearer, 1983

The illustrations presented in Figure 2.1 provide a good summary description of the conservation technology of irrigation fittings redesign. By modifying current irrigation pump fittings so that they conform to the good or excellent designs shown in Figure 2.1, total dynamic head requirements can be reduced. If the irrigation pump is modified to conform to the reduced head requirements, energy savings can result.

2.2 FACTORS INFLUENCING ENERGY LOSSES IN IRRIGATION MAINLINES

In addition to fittings design, two other factors are important in determining energy losses in irrigation piping systems. These factors are the size of the pipes that are used in the system and the material from which the pipes are made.

In general, as the pipes within a piping system become larger, the energy losses within the piping system are reduced because the friction produced by flowing water is less in the larger pipes. The size of the mainline nearest the pump is particularly important in determining system energy losses because the head and flow rates are greater at this point in the system. However, the capital costs of larger pipes are greater than those of smaller pipes. The trade-offs between capital and power costs in the sizing of pipes are illustrated in Figure 2.2. Note that as pipe size increases, power costs decrease while capital costs increase. The objective is to size pipes so that the minimum level of capital and power costs is achieved over the life of a pipe.

FIGURE 2.2. Illustration of the Trade-offs Between Capital and Power Costs In Irrigation Pipe Sizing

Many of the irrigation pipes installed in the irrigation systems of the Pacific Northwest are smaller than would be considered to be optimal over the additional expected lifetime of the pipes. Increasing pipe sizes, particularly in the mainline pipes, has the potential to decrease the energy use of many irrigation systems.

The size of a mainline irrigation pipe can be increased without discarding the existing pipe by installing a "parallel" pipe. This parallel pipe is installed so that it runs parallel to the existing pipe, and fittings to bring together or split apart the two pipes are installed at required points in the system.

The material used in irrigation pipes influences irrigation system energy use because rough materials result in larger friction and energy losses than do smooth materials. Thus, a rusted iron pipe will have larger energy losses than a smooth PVC plastic pipe, even if the two pipes are equal in size. Advancements in the production technology for PVC pipes have caused them to be currently the most widely recommended type of pipe for use in irrigation systems.

2.3 IRRIGATION PUMP EFFICIENCY

A general definition of pump efficiency is the ratio of pump input energy to pump output energy, expressed as a percentage. Motor efficiency is the ratio of motor input energy to motor output energy, expressed as a percentage, and pumping plant efficiency is pump efficiency multiplied by motor efficiency.

The following factors have often been pinpointed as causes of low irrigation pump efficiency (Potato Grower of Idaho 1982).

1. worn pumps - A common example is excessive sand pumping, which wears the pump so that it wastes horsepower.
2. wrong pump for the job - Sometimes farmers use large pumps when smaller pumps would be more energy efficient and still do the same job.
3. low-pressure conversion without adapting the pump
4. using large single pumps rather than multiple smaller pumps
5. pumps in a multiple pump bank not built to operate at the same head.

Note that factors 2 through 5 listed above pertain to selecting and designing an irrigation pump so that it matches the pumping requirements of the irrigation system in which it is used. The field efficiency of any specific irrigation pump will depend in large part upon how closely to the pump's design

head and flow rate the pump is operated. The presumed advantage of variable speed pumps is that they allow for a closer matching of pump output with irrigation head and flow rate requirements. The relationship between the head and flow rate of a pump is commonly denoted as the pump curve. By transposing pump efficiency curves on a set of pump curves, an indication of the relationship between pumping heads, flow rates and efficiencies can be obtained.

A set of pump curves and efficiency curves for a vertical turbine pump is illustrated in Figure 2.3. Note from Figure 2.3 that, other factors remaining constant, an increase in pump efficiency as one moves to the right or a decrease in the total dynamic head will result in an increase in the gallons-per-minute pump flow rate.

The interactions between pumping head requirements, flow rates, and efficiencies have important implications for conducting irrigation conservation programs. These implications include the following:

- 1) Increasing the efficiency of an existing irrigation pump may not result in a decrease in total system energy use because an increase in the volume of water pumped may offset the efficiency change.
- 2) If a constant flow rate is to be maintained, then a pump must be modified when total dynamic head requirements are reduced.
- 3) Pump modifications to react to changes in total dynamic head requirements will often reduce pump efficiency.

The first point listed above implies that changes in water management practices (i.e., improved scheduling) will be necessary to realize significant reductions in energy use from increasing existing pump efficiencies (Shearer 1984). For example, an increase in pump efficiency from 70 to 75 percent along Curve A for the pump illustrated in Figure 2.3 will result in an increase in the flow rate from approximately 360 gpm to 440 gpm. If current irrigation schedules are not modified, this 80 gpm increase in flow rate will be wasted through excessive water application, and the savings from the efficiency increase could be offset.

FIGURE 2.3. Illustration of Pump Curves and Efficiency Curves

Because it is believed that maintaining a constant pump flow rate will normally be desirable when total dynamic head requirements are reduced, pump modifications are usually a necessary element in low-pressure conversion. The most common pump modification to react to a reduction in total dynamic head requirements is the trimming of impellers. On turbine pumps, another common procedure is to drop one or two stages of a pump where the stages are stacked in tandem.

Figure 2.3 can again be used to illustrate how a reduction in total dynamic head requirements for a pump can result in a reduction in pump efficiency. Suppose that the pump illustrated in Figure 2.3 was using a 6-3/8" x 7-3/16" diameter impeller (corresponding to Curve B in Figure 2.3) to pump 480 gpm at approximately 38 feet of total dynamic head. If the impellers of the pump are trimmed to a diameter of 5-3/4" x 6-1/2" to obtain a required head reduction from 38 to 25 feet and the flow rate is maintained at 480 gpm, the pump will be on Curve C. Note, however, that as a result of moving from Curve B to Curve C, pump efficiency declined because we moved from the envelope of the 75% efficiency curve to the envelope of the 70% efficiency curve.

In most cases, the reduction in pump efficiency from pump modifications related to reductions in total dynamic head requirements will be relatively

small.¹ However, it should be acknowledged that these efficiency decreases will occur and that they have the potential to slightly offset the energy use reductions that will be realized from decreasing total dynamic head requirements. On some pumps, the efficiency decreases could be large enough to offset a substantial amount of the savings from such actions as low-pressure conversion.

An additional problem that may be encountered in modifying pumps is that there is a finite limit to the amount that an impeller of a pump can be trimmed back. Thus, particularly on some centrifugal pumps for which dropping a stage is not possible, the only option may be replacing the pump when a large reduction in total dynamic head is required.

Because of advancements in the state of the art in pump manufacturing, replacement of existing irrigation pumps to react to changes in total dynamic head requirements will normally result in an increase in irrigation pump efficiency.² However, the cost effectiveness of pump replacement based solely upon potential increases in pump efficiency is questionable. Unless the potential efficiency increases are large, the decision to replace a pump will normally need to be based on considerations other than potential improvements in pump efficiency.

¹ Based on analysis of unpublished data supplied by Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

² Personal communication with Don Mulkey, Stadeler Pump, Silverton, Oregon, and Byron Wood, Hansen Irrigation, Idaho Falls, Idaho, February 1984.

3.0 ALTERNATIVES CHOSEN FOR ANALYSIS AND ENERGY SAVINGS ASSUMPTIONS OF EACH ALTERNATIVE

The specific types of actions that should be undertaken to improve fittings and mainline design or improve pump efficiencies will depend upon the specific characteristics of individual irrigation systems. The alternatives described in this chapter and the energy savings assumptions associated with each alternative were selected for use because they appear to be most representative of currently available results from field audits that were conducted under the BPA Irrigation Pilot Program and other available field data.

3.1 SELECTED ALTERNATIVES

The alternatives selected for use in this analysis are shown in Table 3.1. Note that the general heading of fittings redesign will include an analysis of redesign of discharge fittings around the pump only. The situations in which the redesign of irrigation suction fittings around the pump is recommended for energy savings seem to be rare, according to available field data.¹ The redesign of fittings that are not located around the pump is not included for analysis because of what appears to be the small energy savings potential of such redesign and the lack of available field data on what the level of these savings might be.

The installation of a 6-inch PVC mainline pipe parallel to the existing mainline pipe was chosen for analysis under the general heading of mainline modification only because it was the most common modification recommended in a relatively large number of audits of irrigation systems in one utility service area.² The installation of an 8-inch PVC parallel mainline was also frequently recommended.

¹ Based on analysis of unpublished irrigation system audit data supplied by Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

² Unpublished data on irrigation system audits obtained from Big Bend Electric, Ritzville, Washington, February 1984.

TABLE 3.1. Alternatives Selected For Use In Analyzing
The Potential Energy Savings of Fittings Redesign,
Mainline Modification, and Pump Efficiency
Improvement

<u>Type of Measure</u>	<u>Selected Alternative</u>
Fittings Redesign	Replacement of fair or poor design of discharge fittings at the pump with good or excellent design of discharge fittings ^(a)
Mainline Modification	Installation of a 6-inch PVC mainline pipe parallel to the existing mainline pipe
Pump Efficiency Improvement	No alternative selected

(a) For illustrations of poor, fair, good, and excellent fittings design, refer to Figure 2.1.

Note that under the heading of pump efficiency improvement, no alternative was selected for quantitative analysis. The decision to exclude pump efficiency improvements from the current analysis was based on the following considerations:

- o Not enough information could be obtained to justify the development of quantitative estimates of the potential savings that could result from various alternative methods of improving pump efficiencies and the costs of obtaining these savings.
- o Although available records indicate that replacing a centrifugal surface water pump will increase pump efficiency, such pumps are usually replaced because the pump's impeller can not be trimmed far enough to operate at the lower head requirements of low-pressure irrigation; thus, pump replacement should be considered to be an element of low pressure conversion rather than an efficiency improvement.

Some of the methods of improving irrigation pump efficiencies, including the replacement of worn pump impellers, pump flow-rate adjustments, and improved pump maintenance procedures are well known. In general, these methods require little capital expenditure as long as access to the pump can be gained. In addition, there may be other, more costly methods of improving pump efficiencies, such as the replacement of fixed speed pumps with variable speed pumps, that could potentially produce significant energy savings.

Although various alternatives for improving pump efficiencies seem to be available, it was not possible to develop a reliable basis for developing quantitative estimates of the potential energy savings and cost per kWh saved for any of these alternatives within the scope of this study. Additional investigation will hopefully be able to develop reliable estimates of the quantitative conservation potential of pump efficiency improvements.

In analyzing available records from audits conducted under the BPA program,³ it was found that in 85 percent of the cases where centrifugal pump replacement was recommended, such replacement was required to adapt to the lower total dynamic head requirements resulting from low pressure conversion, fittings redesign and mainline modification. Thus, centrifugal pump replacement was considered to be a cost element of low-pressure conversion rather than an element of pump efficiency improvement. Replacement of centrifugal pumps will result in an improvement in pump efficiency, but this improvement is merely a side benefit in situations where pump replacement is required to adapt to lower total dynamic head requirements.

3.2 ENERGY SAVINGS INPUT ASSUMPTIONS

Field data from audits conducted under the BPA conservation program in 1983⁴ and data from a previous study of pump efficiency and fittings design (Hansen and Shearer 1983) were the only sources of relevant information that could be located pertaining to the potential energy savings of the conservation measures described in this report. Thus, all energy savings input assumptions for fittings redesign and mainline modification will be based upon estimates calculated from the data developed by these two sources.

3.2.1 Fittings Redesign Estimates

Calculated averages and medians for the head reductions that could occur from the redesign of pump discharge fittings are shown in Tables 3.2 and 3.3. Note that, except for Utility District 1, the differences in head reductions between centrifugal and turbine pumps are relatively small. Note also that in almost all cases, the calculated median head reductions are significantly below the average head reductions. This results from the presence of a few large estimated head reductions that cause the average value to be inflated.

³ Based on analysis of unpublished irrigation system audit data supplied by Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

⁴ Based on analysis of unpublished irrigation system audit data supplied by Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

TABLE 3.2. Average and Median Calculated Head Reductions From The Redesign of Pump Discharge Fittings on Centrifugal Pumps^(a)

<u>Utility District Number</u>	<u>Number of Pumps</u>	<u>Average Head Reductions (ft.)^(b)</u>	<u>Median Head Reduction (ft.)^(b)</u>
1	51	13.0	2.9
2	17	12.0	5.4
3	24	4.3	3.75
4	6	4.0	3.4
6	1	8	8
All Districts	1	10.1	NC ^(c)

TABLE 3.3. Average and Median Calculated Head Reductions From The Redesign of Pump Discharge Fittings on Turbine Pumps

<u>Utility District Number</u>	<u>Number of Pumps</u>	<u>Average Head Reductions (ft.)^(b)</u>	<u>Median Head Reduction (ft.)^(b)</u>
1	10	31.8	3.4
2	11	12.6	2.6
3	5	8.6	2.6
4	1	8.8	8.8
5	1	1.2	1.2
6	5	3.9	3
All Districts	33	16.0	NC ^(c)

(a) Source: Unpublished data from the BPA audit program supplied by Terry Henderson.

(b) Average and medians calculated for those pumps on which redesigned discharge fittings were recommended and exclude those pumps where redesigned fittings were not recommended.

(c) NC = not calculated.

In an extensive study of pumping plants in Oregon (Hansen and Shearer 1983) it was determined that the head reductions from the redesign of pump fittings should generally range from 5 to 15 feet. Except for turbine pumps in Utility District 1, the estimates calculated from the field audit program data and presented in Tables 3.2 and 3.3 are within the 5 to 15 feet range.

3.2.2 Mainline Modification Estimates

Calculated averages and medians for the head reductions that could occur from modifying irrigation system mainlines are presented in Table 3.4. Note, again, that the median head reductions are generally lower than the average head reductions.

3.2.3 Pump Efficiency Improvement Estimates

Although pump efficiency improvements were not included in the quantitative estimation procedures performed in this study, a preliminary analysis of the efficiency improvements that could potentially be obtained from replacing groundwater turbine pumps was conducted.

Replacement of groundwater turbine pumps or dropping a stage on such pumps will potentially increase the efficiency of groundwater pumping plants in two ways. First, the new pump will likely be more efficient than the old pump because of advancements in the state-of-the-art of pump technology, or because the old pump was not maintained properly.⁵ Second, the possible efficiency losses associated with impeller trimming will be avoided.

Estimates of the increases in efficiency that were predicted in the BPA audit program to occur when a groundwater turbine pump is replaced or a stage is dropped are presented in Table 3.5. Also shown in Table 3.5 are estimates of the potential decrease in pump efficiency that will occur when the impeller of a turbine pump is trimmed. Note from Table 3.5 that pump replacement or dropping a stage has a relatively significant positive impact on pump efficiency. However, two problems were incurred in attempting to incorporate

⁵ Based on information supplied by Dick Skreen and Gary Spencer, Cornell Pump Co., Portland, Oregon, 1984.

TABLE 3.4. Average and Median Calculated Head Reductions from the Modification of Mainlines^(a)

Utility District Number	Number of Pumps	Average Head Reductions (ft.) ^(b)	Median Head Reduction (ft.) ^(b)
1	50	19.1	12.9
2	20	17.2	12.6
3	16	17.2	18.2
4	3	31.9	25.1
5	3	4.2	3.5
6	4	8.5	7.9
All Districts	96	17.9	NC ^(c)

(a) Source: Unpublished data from the BPA audit program supplied by Terry Henderson.

(b) Average and medians calculated for those pumps on which mainline modifications were recommended and exclude those pumps where redesigned fittings were not recommended.

(c) NC = not calculated.

TABLE 3.5. Estimated Efficiency Changes for Groundwater Turbine Pumps^(a)

Utility District Number	Estimated Efficiency Change if Pump Replaced or Stage Dropped (Percentage Points)	Estimated Efficiency Change if Impeller Trimmed (Percentage Points)
1	+4.58	+0.83
2	+9.0	-4.04
3	+7.5	-0.88
4	+1	0
5	NR ^(b)	-1
6	+3.75	-2.4
All Districts	+6.83	-1.6

(a) Source: Unpublished data from the BPA audit program supplied by Terry Henderson.

(b) NR = None Recommended

this impact in our quantitative analysis. First, the impacts on pump efficiency from replacing a turbine pump could not be explicitly separated from the impacts of dropping a stage because of data constraints. A second and more important problem is that it could not be determined whether the predicted positive impact on pump efficiency from pump replacement resulted from poor maintenance procedures on existing pumps or from increases in the state-of-the-art in pump design. Additional research is required before groundwater pump replacement is considered a reliable conservation resource.

3.2.4 Input Parameters Selected For Use

The input parameters selected for use in quantitatively analyzing the technologies of fittings redesign and mainline modification are shown in Table 3.6. In examining the head reduction values selected for fittings redesign and mainline modification, it can be seen that the selected values are conservative compared to the average values shown in Tables 3.3 and 3.4. Conservative values were selected for the following reasons:

- o The median values for head reductions from the two technologies are significantly less than the average values and thus, the majority of systems will not achieve the average values.
- o It is believed to be unrealistic to expect that representative operating pressures for center pivots at the pivot pad can be reduced much below 90 feet (39 psi) or that operating pressures for other sprinkler systems at the source point can be reduced much below 95 feet (41 psi) unless furrow drop tubes or spray booms are used.

Although the values shown in Table 3.6 were arbitrarily selected, it is believed that they are based on the most representative data that is currently available.

TABLE 3.6. Input Parameters Selected For Use In Analyzing
The Energy Savings Potential and Cost Per kWh Saved
For Various Technologies

Measure	Assumed Net Reduction in Head (Feet)
Fittings Redesign	7 (a)
Mainline Modification	13 (b)

-
- (a) Results in an estimated operating head of 103 feet for low pressure center pivots and 108 feet for all other sprinkler systems after implementation of the fittings redesign.
 - (b) Results in an estimated operating head of 90 feet for low pressure center pivots and 95 feet for all other sprinkler systems after implementation of mainline modifications.

4.0 COST INPUT ASSUMPTIONS

The costs of implementing fittings redesign and mainline modification will vary significantly depending upon the specific situations in which they are implemented. In this chapter, representative cost numbers are presented. However, the variance around these representative numbers from one farm to another will likely be significant. All costs associated with the conservation technologies of fittings redesign and mainline modification are designated as initial capital costs, because no justification was found for assuming that the use of these technologies would affect irrigation operation and maintenance costs. The economic input parameters, including technology life, that were used to convert the technologies' initial capital costs to levelized annual costs are described in the final section of this chapter.

4.1 COSTS OF FITTINGS REDESIGN

It is believed that cost records from the actual implementation of fittings redesign are the most appropriate data source for deriving representative costs for fittings redesign. A significant proportion of the cost of redesigning pump discharge fittings are the labor costs associated with disassembling the existing fittings alignment and reassembling the more efficient design. Thus, the costs of the materials (flanges, cones, etc.) used in the fittings redesign will not accurately reflect the costs of implementing the redesign.

The only actual records on the costs of implementing fittings redesign that could be located were from BPA's Irrigation Conservation Pilot Program.¹ Unfortunately, only five observations were available where the costs of fittings redesign could be explicitly separated from other costs. Costs per acre for fittings redesign on these five pumps were calculated and are shown in Table 4.1. The data presented in Table 4.1 demonstrates the substantial variation in costs inherent in fittings redesign. The high costs per acre for

¹ Unpublished data on the costs of irrigation system modifications supplied by Steve Levy, Bonneville Power Administration, Portland, Oregon.

pumps four and five can be attributed primarily to the relatively small number of acres (63 and 105 respectively) served by these pumps. Obviously, economies of scale are present in fittings redesign because the

TABLE 4.1. Costs of Fittings Redesign Derived from BPA Pilot Program Records^(a)

<u>Pump Number</u>	<u>Total Cost (\$)</u>	<u>Cost Per Acre (\$)</u>
1	250.00	0.51
2	48.74	0.60
3	6500.00	3.39
4	635.46	10.09
5	1463.40	13.81

(a) Source: Unpublished data supplied by Steve Levy, Bonneville Power Administration

fittings of large pumps generally require no more labor to redesign than small pumps, but the number of acres irrigated by large pumps is greater.

4.2 COSTS OF MAINLINE MODIFICATION

The difficulty of defining a representative cost for installing a parallel mainline is compounded by the fact that the length of the mainline can vary from a few feet to a few thousand feet. The approach taken in this study was to derive a mainline length that corresponds to the assumed level of head savings used in the study and to estimate costs accordingly.

Based upon a detailed analysis of irrigation system audit records,² it's estimated that an average of approximately 1.46 feet of head can be saved per

² Unpublished data on irrigation system audits obtained from Big Bend Electric, Ritzville, Washington, February 1984.

hundred feet of 6-inch PVC parallel mainline pipe that is installed. Under the assumption that 13 feet of head will be saved by mainline modification, approximately 900 feet of 6-inch PVC parallel mainline would be required to obtain this amount of head savings ($13/1.46 \times 100$). Thus, all cost estimates for mainline modification will be based on the assumption of 900 feet of 6-inch PVC pipe.

Estimates of the cost of 900 feet of 6-inch PVC pipe were obtained from various sources and are shown in Table 4.2. Note that if a representative diameter, length and material can be defined for the pipe used in mainline modification the variation in costs is not large. The costs shown in Table 4.2 represent costs of purchase, delivery and burial of the mainline pipe. Burial costs are normally 30 to 50 percent of the total installed costs of a mainline pipe, but were considered to be a necessary element of mainline modification to insure that the additional mainline would be used for its intended purpose over its expected lifetime.

TABLE 4.2. Total Installed Costs of Mainline Modification
Assuming 900 Feet of 6" PVC Pipe is Purchased

<u>Source</u>	<u>Total Cost (\$)</u>	<u>Cost per Acre (\$)^(a)</u>
Byron Wood Hansen Irrigation Idaho Falls, Idaho	2133	13.33
Don Mulkey Stadeler Pump Silverton, Oregon	2628	16.43
Ted Hilton Irrigation Specialists Pasco, Washington	1803	11.27
Jeff Raleigh Warrington Irrigation Warrington, Oregon	2133	13.33

(a) Assuming 160 acres.

4.3 COST INPUTS SELECTED FOR USE IN THIS STUDY

The cost inputs selected for use in this study are shown in Table 4.3. Although all the estimates were arbitrarily selected, they are within the range of those presented in Tables 4.1 and 4.2. An assumption concerning field size was necessary to break down all costs to a cost-per-acre basis. A field size of 160 acres appeared to be a representative average for the number of acres that the technologies should be allocated over.

4.4 OTHER ECONOMIC INPUTS

Other inputs that are important in evaluating the economics of the technologies are the assumed life for each technology and the discount rate used in converting initial capital costs to levelized annual costs. In accordance with BPA procedures, a real discount rate of three percent is used in all analyses.

There appears to be no basis for arguing that fittings redesigns and mainline modifications will not achieve lifetimes of 20 years. These are hardware modifications that should require little maintenance to achieve these lifetimes.

TABLE 4.3. Cost Inputs Selected for Analyzing Fittings
Redesign and Mainline Modification

<u>Technology</u>	<u>Capital Cost Per Field (\$)</u>	<u>Capital Cost Per Acre (\$)</u> ^(a)
Fittings Redesign ^(b)	600	3.75
Mainline Modification ^(c)	2400	15.00

(a) All costs per acre based on an assumption of a 160-acre field.

(b) Includes all labor and materials necessary to transform a poor or fair fittings design to a good or excellent fittings design. Refer to Figure 2.1 for illustrations of the four types of fittings designs.

(c) Based on 900 feet of 6" PVC pipe.

5.0 TECHNICAL LIMITS ON MEASURE APPLICATION AND CONSERVATION ALREADY ACHIEVED

The purpose of this chapter is to provide information on acreage that should be excluded from estimates of potential energy savings because of technical limits or achieved conservation. For the technologies of fittings redesign and mainline modification, achieved conservation will be the most important element of the discussion.

5.1 TECHNICAL LIMITS

There appears to be no absolute technical limits to the use of fittings redesign and mainline modification. The use of these technologies is possible in all situations. However, the use of these technologies will not be appropriate in all situations because, in many cases, little or no energy savings will be achieved by implementing the technologies.

The fittings around some irrigation pumps in the Pacific Northwest are already designed efficiently. An even higher percentage of the irrigation mainlines in the region are large enough that increasing their size would result in only a very small amount of energy savings.

Conceptually, situations where efficient design has already been accomplished should be thought of as acreages on which conservation has already been achieved. No further significant reductions in energy use are possible through improved designs, because the designs are already almost as efficient as they can be.

5.2 CONSERVATION ALREADY ACHIEVED

The number of fittings and mainlines that are already designed efficiently in any given area will depend on a number of factors including:

- o the age of the existing irrigation systems in the area
- o the expertise of the irrigation dealer who originally sold and installed the pumps, fittings, and mainlines in the area
- o the expertise of the irrigators who purchased the systems.

Obviously, without a statistically valid sample, estimates of the number of irrigation systems that are already designed efficiently will necessarily be very rough. However, two sources of empirical field data are available for use in developing these estimates.

The first source of data was developed in the course of conducting audits under BPA's Irrigation Pilot Program.¹ The second source is a study of irrigation pumping plants conducted by personnel at Oregon State University (Hansen and Shearer 1983).

As a part of the audits conducted under the BPA audit program, trained auditors evaluate the potential head reductions or pump efficiency increases that could occur from fittings redesign, mainline modification, and pump replacement and/or dropping a stage. Based on the results of these evaluations, recommendations are developed on whether each conservation technology should be implemented. Data on these recommendations were analyzed to calculate the percentages of systems for which implementation of fittings redesign and mainline modification were not recommended. The results of these calculations are shown in Table 5.1.

Note from Table 5.1 that situations where mainline modifications were not recommended were generally much more frequent than situations where fittings redesigns were not recommended. The number of acres where mainlines are sized appropriately is greater than the number of acres where fittings are designed properly.

Summarized results from the study of Oregon pumping plants (Hansen and Shearer 1983) are shown in Table 5.2. Note from Table 5.2 that approximately 37 percent of the fittings evaluated in the study were rated good or excellent. This number is very similar to that presented in Table 5.1 where, in 32 percent of all system audits, fittings redesigns were not recommended.

On the basis of the close agreement between the results of the two field data sources, it was concluded that averages of the two studies could be used to estimate the acreages that should be excluded from further analysis because

¹ Unpublished data from irrigation system audits obtained from Terry Henderson, Consulting Engineer, Umatilla, Oregon, February 1984.

TABLE 5.1. Estimated Percentages of Irrigation Systems Where Fittings Redesign and Mainline Modification Were Not Recommended after Field Audits^(a)

<u>Utility District Number</u>	<u>% Where Fittings Redesign Not Recommended</u>	<u>% Where Main-Modification Not Recommended</u>
1	35	47
2	33	52
3	3	47
4	42	75
5	89	67
6	0	33
All Districts	32	50

(a) Field audits conducted under the BPA Conservation Pilot Program; percentage estimates calculated from data supplied by Terry Henderson.

TABLE 5.2. Percent of Total Evaluations for Various Categories of Fittings Designs^(a)

<u>Fittings Design Rating (% of Total)</u>			
<u>Poor</u>	<u>Fair</u>	<u>Good</u>	<u>Excellent</u>
<u>8</u>	<u>55</u>	<u>22</u>	<u>15</u>

(a) Source: Efficiency Performance Criteria For Irrigation Systems (Hansen and Shearer 1983).

the designs of the systems used to irrigate these acreages are already efficient. It was also concluded that there is not enough information to assume that the acreages on which conservation has already been achieved should vary by subregion, crop, or irrigation system. Thus, 34% of all acreages were excluded from the analysis of the energy savings potential for fittings redesign and 50% of all acreages were excluded for mainline modifications. The acreages on which conservation has already been achieved that were estimated using these percentages are shown in Tables 5.3 to 5.10.

TABLE 5.3 Conservation Achieved by Fittings Redesign
on Surface Water Center-Pivot Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	0	0	0	0	0	0
2	5,065	1,594	385	6,418	0	1,223
3	26,242	19,064	18,569	17,914	0	11,259
4	4,149	1,480	0	0	0	0
5	161	389	29	388	0	0
6	12,347	5,913	6,676	1,473	0	0
7	813	2,642	373	0	0	0
8	602	2,511	612	0	0	0
9	0	0	0	0	0	0
10	5,904	4,422	2,168	373	0	796
11	1,490	3,127	32	0	0	44

TABLE 5.4 Conservation Achieved by Fittings Redesign
on Groundwater Center-Pivot Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	0	0	0	0	0	0
2	1,624	1,406	71	1,179	0	516
3	22,245	15,039	8,707	7,428	0	1,500
4	1,953	802	0	0	0	0
5	0	234	0	117	0	0
6	3,056	2,509	2,343	386	0	0
7	1,436	8,022	108	0	0	0
8	1,630	8,795	407	24	0	0
9	0	0	0	0	0	0
10	18,532	17,906	7,345	1,423	0	11,117
11	92	434	0	0	0	0

TABLE 5.5 Conservation Achieved by Fittings Redesign
on Surface Water Other Sprinkler Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	58	9,804	473	1,279	1,057	1,252
2	4,866	14,349	20	0	22,632	11,005
3	32,073	27,435	3,537	0	5,527	28,952
4	3,680	4,953	0	20	2,569	3,379
5	3,058	19,063	181	12,557	6,507	27,499
6	5,043	11,477	2,727	0	6,118	4,928
7	8,215	23,779	1,118	4	41	4,431
8	6,085	25,391	461	41	1,981	3,674
9	4,588	11,293	547	18	71	1,129
10	28,827	23,214	9,876	0	5,415	12,462
11	17,139	75,038	757	493	197	351

TABLE 5.6. Conservation Achieved by Fittings Redesign
on Groundwater Other Sprinkler Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	55	9,252	446	1,207	814	1,181
2	201	1,523	0	0	4,158	1,730
3	1,934	4,242	458	0	2,292	15,172
4	7,810	7,220	0	25	3,204	4,213
5	968	5,617	63	3,777	1,957	8,271
6	1,505	2,053	123	0	1,605	1,293
7	2,915	4,711	611	0	20	2,136
8	2,346	7,799	229	0	1,178	2,185
9	7,072	17,408	843	27	109	1,741
10	113,842	87,424	38,559	0	20,639	39,413
11	1,058	4,391	47	30	12	22

TABLE 5.7. Conservation Achieved with Mainline Modification
on Surface Water Center-Pivot Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	0	0	0	0	0	0
2	7,449	2,345	566	9,439	0	1,799
3	38,591	28,036	27,308	26,344	0	16,557
4	6,102	2,176	0	0	0	0
5	237	572	43	571	0	0
6	18,157	8,695	9,818	2,166	0	0
7	1,195	3,886	548	0	0	0
8	885	3,693	899	0	0	0
9	0	0	0	0	0	0
10	8,683	6,503	3,188	549	0	1,170
11	2,192	4,598	47	0	0	64

TABLE 5.8 Conservation Achieved with Mainline Modification
on Groundwater Center-Pivot Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	0	0	0	0	0	0
2	2,388	2,068	104	1,734	0	760
3	32,713	22,115	12,805	10,923	0	2,206
4	2,871	1,180	0	0	0	0
5	0	344	0	172	0	0
6	4,495	3,690	3,445	568	0	0
7	2,112	11,792	159	0	0	0
8	2,397	12,934	599	36	0	0
9	0	0	0	0	0	0
10	27,254	26,332	10,801	0	0	16,348
11	135	639	3	0	0	4

TABLE 5.9 Conservation Achieved with Mainline Modification
on Surface Water Other Sprinkler Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	86	14,417	696	1,882	1,554	1,840
2	7,156	21,102	30	0	16,783	16,185
3	47,166	40,345	5,202	0	8,128	42,576
4	5,412	7,285	0	30	3,779	4,969
5	4,497	28,034	265	18,465	9,570	40,440
6	7,416	16,878	4,010	0	8,996	7,747
7	12,081	34,969	1,645	6	61	6,517
8	8,949	37,340	679	60	2,914	5,403
9	6,747	16,608	805	26	104	1,661
10	42,393	34,139	14,524	0	7,964	18,327
11	25,205	110,350	1,113	725	290	516

TABLE 5.10 Conservation Achieved with Mainline Modification
on Groundwater Other Sprinkler Acres

<u>Region</u>	<u>Wheat</u>	<u>Alfalfa</u>	<u>Potatoes</u>	<u>Corn</u>	<u>Orchard</u>	<u>Other</u>
1	81	13,607	656	1,775	1,197	1,737
2	295	2,240	5	0	6,114	2,544
3	2,845	6,236	674	0	338	22,312
4	11,486	10,618	0	37	4,712	6,195
5	1,424	1,424	8,260	93	6,554	2,879
6	2,214	3,018	182	0	2,360	1,901
7	4,282	6,929	898	3	30	3,140
8	3,450	11,469	337	0	1,733	3,213
9	10,400	25,600	1,240	40	160	2,560
10	117,414	128,565	56,705	0	30,351	57,961
11	1,555	6,457	69	45	18	32

6.0 ESTIMATION OF RESULTS

As stated in the introduction of this report, the primary objective of this study is to develop cost and energy savings information on fittings redesign and mainline modification that BPA can use in its conservation program planning efforts. In this chapter a brief discussion of the methodology used in this study and the results derived using this methodology are presented.

6.1 STUDY METHODOLOGY

To facilitate understanding of the results of this study, a brief discussion of the methodology employed in deriving our results is presented. Those wishing further detail on the computer model used in the estimation procedure should refer to other documents to be generated during this research effort (Harrer 1984a and Harrer 1984b).

In general, the kWh electrical energy use of an irrigation system can be estimated using the following equation:

$$E = \frac{V \times H \times 1.024}{PPE}$$

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 way in which fittings redesign and mainline modification reduce irrigation system energy use is by reducing the amount of head (H) that is required for lifting and applying water to the crop. Pump efficiency improvements can potentially reduce energy use by increasing the value of PPE. The difference in energy use for fittings redesign and mainline modifications is calculated by the following:

$$\Delta E = \frac{V \times H_0 \times 1.024}{PPE} - \frac{V \times H_1 \times 1.024}{PPE}$$

where ΔE = difference in annual energy use per acre in kWh between an irrigation system with properly designed mainlines or fittings and an irrigation system with improperly designed mainlines or fittings

H_0 = total head requirements of an irrigation system with improperly designed mainlines or fittings

H_1 = total head requirements of an irrigation system with properly designed mainlines or fittings

To determine a cost per kWh saved using annual energy savings as the denominator, all costs must be converted to an annual equivalent or levelized cost basis. The equation used in this study for estimating the differences between the levelized costs of fittings redesign and mainline modification was the following:

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

where ΔLEV = difference in the annual equivalent or levelized cost between an irrigation system without implementation of a conservation technology and a system with implementation of a conservation technology

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

- SV_1 = salvage value for equipment installed as part of implementing a conservation technology
- d = discount rate used for converting present initial capital costs to annual equivalent (levelized) costs
- n = system life for a conservation technology
- I_0 = initial capital cost of investing in an irrigation system that does not incorporate a conservation technology
- SV_0 = salvage value for equipment of an irrigation system before implementation of a conservation technology
- m = system life for an irrigation system before implementation of a conservation technology
- OM_1 = operation and maintenance costs for an irrigation system that incorporates a conservation technology
- OM_0 = operation and maintenance costs for an irrigation system that does not incorporate a conservation technology.

Often, some of the parameters in the above equation are zero. For example, the initial capital costs for irrigation systems that do not incorporate a conservation technology on existing acreages are sunk costs and thus, would be zero at the time implementing a conservation technology is being considered.

Once the differences in annual kWh usage and annual levelized cost per acre are calculated, the cost per kWh saved is calculated by the following:

$$\text{Cost per kWh saved} = \frac{\Delta LEV}{\Delta E}$$

The aggregate potential energy savings in average MW for fittings redesign, mainline modification, and pump efficiency improvement are estimated by the following:

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

where ACEL = acreage eligible to utilize conservation technology
(i.e., not limited by technical considerations)

ACCA = acres eligible to use a conservation technology where the
conservation technology has already been implemented
1000, 8760 = factors for converting kWh savings to average MW of savings

6.2 COST PER kWh SAVED AND ENERGY SAVINGS POTENTIAL FOR FITTINGS REDESIGN

Estimates of the average cost per kWh saved by subregion for implementing fittings redesign and the potential energy savings that could be realized from such implementation on existing and new center-pivot acres are shown in Table 6.1. Note from Table 6.1 that the estimated total energy savings from redesigning fittings on center-pivot acres are relatively small. However, over a 20-year life, the cost of obtaining these savings would average less than 10 mills per kWh saved for both surface water and groundwater on existing acres. On new acres, the costs are estimated to be zero, because no additional capital or operating costs are estimated to be associated with using efficient fitting designs on new acres.

The estimated cumulative energy savings and acreages impacted in five mill cost increments for fittings redesign on existing acres are shown in Table 6.2. Note from Table 6.2 that all of the estimated energy savings from fittings redesign can be obtained for a cost of 15 mills per kWh saved or less and that approximately 64 percent of the savings can be obtained for a cost of 10 mills per kWh saved or less. The estimated cumulative energy savings in five mill cost increments on new center-pivot acres are shown in Table 6.3. Because the incremental costs of fittings redesign on new acres are assumed to be zero, all potential savings on new acres can be realized for no cost.

Estimates of the potential energy savings in average MWs and the costs per kWh saved in mills for fittings redesign on other sprinkler (i.e. non center-pivot) acres are shown in Table 6.4. The potential energy savings of implementing fittings redesign on other sprinkler acres are higher than for center pivot acres because of the larger number of acres that could potentially be involved. The differences in average cost per kWh saved for fittings redesign on other sprinkler acres versus fittings redesign on center pivot acres are generally not significant. However, the results presented in Table 6.5 illustrate that more variance in cost per kWh saved would be associated with fittings redesign on other sprinkler acres, because a small amount of the

TABLE 6.1. 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 Acreages in 1984 (Ave. MW)	Surface	NCP	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 Acreages (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 Acreages in 2003 (Ave. MW)	Surface	NCP	NCP	0.49	0.01	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	0.01	NCP	0.08	0.01	0.03	NCP	0.13	0.01	0.77
Cost Per kWh Saved on New Acreages (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

TABLE 6.2. Estimated Cumulative Energy Savings Potential (Ave. 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 6.3. Estimated Cumulative Energy Savings
Potential (Ave. MW) in 5-Mill
Increments of Cost per kWh Saved
for Fittings Redesign on All^(a)
New Center-Pivot Acres

Year	Cost per kWh Saved									
	0	5	10	15	20	25	30	35	40	50
1985	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
1987	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
1989	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
1991	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
1993	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
1995	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
1997	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
1999	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
2001	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
2003	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77

TABLE 6.4. Estimated Energy Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Fittings Redesign on Existing and New Handmove and Sideroll Acres

		<u>Subregion</u>											<u>BPA Service Area</u>
	<u>Water Source</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>	
Energy Savings on Existing Acreages in 1984 (Ave. 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 Acreages (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 Acreages in 2003 (Ave. MW)	Surface	NOS	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 Acreages (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

TABLE 6.5. Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost Per kWh Saved for Fittings Redesign on Existing Handmove and Sideroll Acres

<u>Year</u>	<u>Water Source</u>	<u>Cost Per kWh Saved</u>									
		<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>	<u>30</u>	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>
1984	Surface Water	0.00	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

savings could not be obtained for a cost of less than 20 to 25 mills per kWh saved. Approximately 55 percent of the savings can be obtained for a cost of 10 mills per kWh saved or less. Estimates of the potential cumulative energy savings in five-mill cost increments for fittings redesign on new other sprinkler acres are shown in Table 6.6.

6.3 COST PER kWh SAVED AND ENERGY SAVINGS POTENTIAL FOR MAINLINE MODIFICATION

The costs per kWh saved in mills and the estimated aggregate energy savings in average MW for mainline modification on existing and new center-pivot acres are shown in Table 6.7. The assumed level of average head reduction for mainline modification is higher than that of fittings redesign, while the acres on which mainline modification should be implemented are lower. The combined effects of the two factors produce slightly higher estimates of gross energy savings potential for mainline modification compared to fittings redesign.

The average cost per kWh saved over a 20-year life for mainline modification on center pivots is approximately 20 mills on existing acres and 10 mills on new acres. The costs on existing acres are higher because the cost of mainline burial is included, while costs on new acres are for additional materials only. Data presented in Table 6.8 demonstrates that almost all of the savings from mainline modification on existing center-pivot acres can be obtained for 25 mills per kWh saved or less. Estimates shown in Table 6.9 illustrate that all of the potential savings for mainline modification on new center-pivot acres can be obtained for 15 mills per kWh saved or less.

Estimates presented in Table 6.10 demonstrate that approximately 9.4 average MW can potentially be saved through mainline modification on existing other sprinkler acres. The estimated costs of these savings would average approximately 21 mills per kWh saved over a 20-year life. The potential savings on new acres are estimated to be over 2.5 average MWs and the average cost per kWh saved for obtaining these savings is about 11 mills. Information presented in Table 6.11 demonstrates that approximately 95 percent of the savings from mainline modification on existing other sprinkler acres can be obtained for a cost of 25 mills per kWh saved or less. Estimates presented in Table 6.12 indicate that almost all of the potential savings on new other sprinkler acres can be obtained for 15 mills per kWh saved or less.

TABLE 6.6. Estimated Cumulative Energy Savings
Potential (Ave. MW) in 5-Mill
Increments of Cost per kWh Saved
for Fittings Redesign on
New Handmove and Sideroll 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 6.7. 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 Acreages in 1984 (Ave. MW)	Surface	NCP	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 Acreages (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 Acreages in 2003 (Ave. 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 Acreages (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

TABLE 6.8. Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost Per kWh Saved for Mainline Modification on Existing Center-Pivot Acres

<u>Year</u>	<u>Water Source</u>	<u>Cost Per kWh Saved</u>									
		<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>	<u>30</u>	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>
1984	Surface Water	0.00	0.00	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	3.73	3.73	3.73	3.73

TABLE 6.9. Estimated Cumulative Energy Savings
Potential (Ave. 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

TABLE 6.10. Estimated Energy Savings Potential in Average MW and Cost Per kWh Saved in 1984 Mills for Mainline Modification on Existing and New Handmove and Sideroll Acres

		Subregion											BPA Service Area
		Water Source	1	2	3	4	5	6	7	8	9	10	11
Energy Savings on Existing Acreages in 1984 (Ave. 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 Acreages (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 Acreages in 2003 (Ave. MW)	Surface	NOS	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 Acreages (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

TABLE 6.11. Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost Per kWh Saved for Mainline Modification on Existing Handmove and Sideroll Acres

<u>Year</u>	<u>Water Source</u>	<u>Cost Per kWh Saved</u>									
		<u>5</u>	<u>10</u>	<u>15</u>	<u>20</u>	<u>25</u>	<u>30</u>	<u>35</u>	<u>40</u>	<u>45</u>	<u>50</u>
1984	Surface Water	0.00	0.00	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 6.12. Estimated Cumulative Energy Savings Potential (Ave. MW) in 5-Mill Increments of Cost per kWh Saved for Mainline Modification on All^(a) 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	0.07	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

6.4 COST PER kWh SAVED ASSUMING A 3-YEAR INVESTMENT LIFE

Although the costs for energy that could potentially be obtained from fittings redesign and mainline modification appear relatively low, all of the estimates presented in Tables 6.1 to 6.12 are based on an assumption of a 20-year conservation measure life. Normally, an irrigator can not wait 20 years for a conservation measure to return its investment costs, but instead is constrained to a 2 or 3-year payback period.

To test the impacts of a 3-year payback requirement on the cost-effectiveness of fittings redesign and mainline modification, the ISEP model was operated using the same input data as were used in all previous analyses except that 3-year conservation measure lives were assumed. The ISEP model results indicate that the average cost of fittings redesign, assuming a 3-year measure life, would be approximately 45 mills per kWh saved, while the average cost of mainline modification would exceed 60 mills per kWh saved. Under the assumptions of this analysis, fittings redesign and mainline modification would generally not be cost-effective at current power rates if a 3-year payback on investment is required.

REFERENCES

- Hansen, Hugh J. and Marvin N. Shearer. 1983. Energy Performance Criteria for Irrigation Systems. WRR1-90. Water Resources Research Institute. Oregon State University. Corvallis, Oregon.
- Harrer, B. J. 1984a. An Integrated Assessment of Conservation Opportunities in the Irrigated Agriculture Sector of the Pacific Northwest Region. Report prepared for the Bonneville Power Administration, Office of Conservation Planning, under Contract D1813-41812.
- Harrer, B. J. 1984b. A Users' Manual for an Irrigation Conservation Planning Model. Report prepared for the Bonneville Power Administration, Office of Conservation Planning, under Contract D1813-41812.
- Potato Grower of Idaho. 1982. "Is Your Pump Efficient?" Volume II Number 2. February, 1982. Idaho Falls, Idaho.
- Shearer, Marvin N. 1984. Opportunities for Energy Savings in Irrigation. Agriculture Extension Service. Oregon State University.

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