Energy Savings Potential from Energy-Conserving Irrigation Systems

November 1982

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ENERGY SAVINGS POTENTIAL FROM ENERGY-
CONSERVING IRRIGATION SYSTEMS

G. L. Wilfert
W. P. Patton
B. J. Harrer
M. A. Clark

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Pacific Northwest Laboratory
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PREFACE

The Agriculture and Food Processes Branch is a research, development, and demonstration program office within the Office of Industrial Programs, U.S. Department of Energy (DOE). In accordance with DOE goals, the Agriculture and Food Processes Branch is promoting both increased use of existing energy-saving irrigation technologies and the development of new technologies in the Energy Conservation in Irrigation Systems Program. This program has involved sharing with industry the development costs of projects having the potential to significantly reduce energy usage in irrigation systems.

Since 1977, the Pacific Northwest Laboratory (PNL), operated by the Battelle Memorial Institute, has been supporting the Agriculture and Food Processes Branch in its efforts to issue a program opportunity notice for the design and development of irrigation systems that reduce energy consumption without sacrificing agricultural productivity. Toward this end, PNL has technically and administratively monitored the contracts under the program opportunity notice. This report provides a national perspective of the energy savings potential from energy-conserving irrigation systems.

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EXECUTIVE SUMMARY

Annual energy savings up to 87 trillion Btu are made possible in the U.S. by adopting energy-conserving irrigation technologies in those markets where their use is cost effective. In addition, annual water savings of some 9.8 million acre-feet are possible through widespread adoption of energy-conserving technologies.

Energy for lifting irrigation water from surface-water and groundwater sources to agricultural crops is a critical input in the production of this nation's food and fiber. About 257 trillion Btu, the equivalent of 44 million barrels of oil, are consumed annually in pumping and applying irrigation water to over 50 million acres of cropland in the 17 leading irrigation states. Although irrigation of agricultural land is practiced in all 50 states, the 17 leading irrigation states contain over 90 percent of all irrigated land in the United States and use an even higher percentage of the total energy consumed to irrigate crops. In 1980, the cost of the energy consumed by irrigation pumping in the 17 states exceeded \$1.4 billion using statewide average fuel prices. Assuming that the total irrigated cropland in the United States remains at the same level as today, energy-conserving irrigation technologies similar to those discussed herein are expected to reduce the energy needed to pump irrigation water in the year 2000 by one third.

The objective of this report is to systematically compare, within a consistent framework, the technical and economic characteristics of energy-conserving irrigation systems with those of conventional irrigation systems and to determine total energy savings. Levelized annual costs of owning and operating both energy-conserving and conventional irrigation systems have been developed and compared for all 17 states to account for the differences in energy costs and irrigation conditions in each state. Market penetration of energy-conserving systems is assessed for those systems having lower levelized annual costs than conventional systems performing the same function. Annual energy savings have been computed by matching the energy savings per system with an assumed maximum market penetration of 100 percent in those markets where the levelized annual costs of energy-conserving systems are lower than the levelized annual costs of conventional systems.

The following energy-conserving technologies are compared to conventional irrigation systems:

- wells developed using surging and jetting techniques vs. conventional wells
- pump column, impeller and housing redesign vs. conventional pump designs
- electric powered variable-speed pumping vs. constant-speed pumping
- automated gated-pipe irrigation vs. conventional gated-pipe irrigation
- reduced-pressure center-pivot irrigation vs. conventional center-pivot irrigation
- low-energy precision application (LEPA) center-pivot and lateral-move irrigation vs. conventional center-pivot and lateral-move irrigation
- computerized and instrumented irrigation water scheduling vs. conventional scheduling.

To calculate the potential energy savings attainable by substituting energy-conserving irrigation systems for conventional systems, three items are determined: first, the computed total amount of energy currently used by irrigated agriculture; second, the energy that can technically be saved by substituting a conserving system for a conventional system; third, the market areas where each conserving system is likely to penetrate. Market penetration is assumed to be primarily an economic phenomenon. Penetration tends to occur when a conserving system provides irrigation water at a cost that is lower than that of conventional systems performing the same function.

The amount of energy used by alternative irrigation systems is calculated by using energy-use equations that relate the amount of energy consumed by an irrigation system to both technical and regional variables. Economic and regional characteristics of energy-conserving and conventional irrigation systems are used in the equations to estimate the energy consumed per acre.

This information is then multiplied by the total acreage irrigated for each type of system in 1980, which results in the total energy used under conventional irrigation practices in each of the 17 states.

A conserving system's technical potential to save energy is estimated by comparing its per-acre energy consumption to that of a conventional system performing similar functions. The proportional change in energy used is calculated by dividing energy savings by energy used for the conventional system (see Appendix B).

Market penetration is determined by comparing the levelized costs of generic 160-acre conventional systems and energy-conserving irrigation systems. Market penetration for a conserving system is assumed to occur wherever its levelized costs are lower than those of a conventional system performing the same function. Levelized costs for each system varies across regions due to differences in physical, climatological, and economic characteristics.

Total potential energy savings from investments in energy-conserving technologies are estimated by multiplying proportional energy savings times total energy used in each market in which penetration of a conserving technology appears likely on economic grounds. In order to determine the maximum possible savings for any individual technology, these savings are aggregated over all markets where penetration is assumed to occur. Since these technologies will undoubtedly compete against each other for market shares, the maximum potential energy savings for each individual technology cannot legitimately be summed to estimate the aggregate energy potential for all technologies taken together. Summing the savings involves some double counting of energy savings. Thus, aggregate energy-savings potential is adjusted for double counting by assuming that only one conserving system in a given technology group will effectively penetrate the market. For example, either surged wells or jetted wells are assumed to penetrate the well market, but not both. Similarly, either computerized scheduling or instrumented scheduling will penetrate, etc. The energy savings for each technical area is summed to estimate potential aggregate energy savings, thereby eliminating the double-counting problems.

The major findings of the study include the following:

- The annual amount of money expended for irrigation energy in the top 17 states is around \$1.4 billion.
- Annual energy consumed in the 17 states amounts to about 257 trillion Btu.
- On the basis of the economic analysis, the following systems using energy-conserving technologies appear to have a high potential market penetration:
  - reduced-pressure center-pivot systems
  - LEPA center-pivot and lateral-move systems
  - surged and jetted wells
  - computerized scheduling
  - column and pump redesign
- The following systems appear, on economic grounds, to have limited potential for market penetration:
  - instrumented scheduling
  - radio controlled automated gated-pipe irrigation
  - electric powered variable-speed pumping
- The annual amount of energy (in trillion Btu) that can be saved by energy-conserving systems by the year 2000 within each area is listed below:

wells	13
pumps	11
sprinkler application systems	32
gravity application systems	3
scheduling systems	<u>28</u>
Total	87

- In addition to energy savings, the use of energy-conserving systems could reduce annual water use by nearly 10 million acre-feet.

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1.0 INTRODUCTION

Energy use in lifting irrigation water from surface and groundwater sources to agricultural crops is a critical factor in the production of food and fiber in the United States. The 1978 Census of Agriculture estimated that 29% of the agricultural products sold came from irrigated cropland. At that time, 18% of the nation's cropland was irrigated. Recent estimates place the nation's irrigated cropland at over 61 million acres, approximately 20% above the 1974 estimates (Brantwood Publications 1980). Although irrigation is practiced in all 50 states, the majority of irrigated cropland is located in the arid West. Some 270 trillion Btu, the equivalent of 46 million barrels of oil, are annually consumed in the pumping of irrigation water.

In recent years, national energy policy has emphasized conservation of renewable energy sources. Conservation efforts beyond those motivated by price have concentrated on: 1) advancing the displacement of scarce, nonrenewable energy sources with more plentiful or renewable sources, and 2) promoting more efficient use of energy. Past research suggests that substantial energy savings are possible through technological improvements in irrigation system equipment and improvements in water management.

Recently, the Office of Industrial Programs, Department of Energy, has had Federal responsibility for promoting research and development of conservation technology applicable to the agricultural sector. In 1978, the Agriculture and Food Process Branch, Office of Industrial Programs, initiated a program of energy conservation in irrigated agriculture to promote research in energy-saving irrigation system technologies (Department of Energy 1980). The program matched public funds with private research funds for ten development projects, each advancing a specific energy-conservation irrigation technology. The projects selected to receive funding were required to show significant energy conservation potential, as well as offering a high probability of economic viability within the next 5 to 10 years. When evaluating energy-saving systems, it is important to remember that if energy prices continue to rise as fast as they have in recent years, technologies considered too costly today may become feasible at some future date. The Energy Conservation in Irrigation

Program identified energy-saving irrigation technologies and techniques that required further development before being used on a wide scale.

This report is one of a three-part series of reports which analyze the technologies^(a), cost savings^(b) and energy-savings potential of energy-conserving irrigation systems. The cost-savings analysis indicated that application of economic energy-conserving technologies to irrigated agriculture can provide significant reductions in the costs of irrigation. Cost savings vary depending on the regional pumping costs per unit of water and the amount of water required. The purpose of this report is to identify the expected energy savings of energy-conserving irrigation systems by the year 2000.

(a) Harrer et al. Ten Irrigation Technologies for Conserving Energy 1982. Pacific Northwest Laboratory, Richland, Washington.

(b) Patton et al. Potential Cost Savings from Investments in Energy-Conserving Irrigation Systems 1982. Pacific Northwest Laboratory, Richland, Washington.

2.0 CONCLUSIONS AND RECOMMENDATIONS

To determine where market penetration of the energy-conserving irrigation technologies is likely to occur, levelized costs of owning and operating new energy-conserving systems are compared to those of conventional systems. The levelized annual costs for these systems vary across regions because of differences in irrigating conditions in each state. Market penetration of conserving systems is probable for those systems that have lower levelized costs than conventional systems and perform the same function. This market penetration information is used to calculate the annual energy savings by the year 2000 that could result from energy-conserving irrigation systems.

2.1 CONCLUSIONS

The estimated annual energy savings by 2000 of 90 trillion Btu resulting from the adoption of energy-conserving technologies is significant in terms of its contribution to national goals of promoting energy independence and maintaining a viable agricultural sector. Annual energy savings of 90 trillion Btu are equivalent to 15.5 million barrels of oil, which is \$543 million at \$35 a barrel. For an individual farmer, the energy-cost savings of using any of the energy-conserving technologies analyzed in this study could return any additional capital and operating/maintenance costs that are incurred.

In addition to the 90 trillion Btu savings, additional energy and water savings are possible from using the conserving systems. Use of the energy-conserving technologies will result in energy savings greater than those projected in this analysis when the energy-saving technologies are used when additional land is brought under irrigation, or if they penetrate into markets not directly corresponding to each technology (the replacement of sideroll sprinklers by LEPA, for example). Use of LEPA, computerized scheduling, and automated gated-pipe systems could save an estimated 9.8 million acre feet of water, which could be as important as the energy savings from the use of these technologies. In some cases, savings in water costs could allow the use of these technologies to be cost effective in markets where they are not cost effective when based on energy-cost savings alone.

Based on the analysis conducted in this report, the replacement of conventional center-pivot and lateral-move systems with the LEPA system could result in energy savings up to of 40 trillion Btu, the greatest among the technologies under study. Computerized irrigation scheduling would result in savings of 27 trillion Btu, while replacement of conventional center pivots with reduced pressure sprinklers on center pivots (rather than replacement by LEPA) would result in savings up to 26 trillion Btu. Use of either surging or jetting well development methods could result in energy savings of approximately 18 trillion Btu, and the redesigned pumps and columns will save approximately 12 trillion Btu. The energy savings of the other three technologies, variable-speed pumping, radio-controlled automated gated-pipe systems, and instrumented scheduling systems, will be small (less than six trillion Btu in total) primarily because the high initial costs of these systems will not allow them to be adopted except in extremely high energy-cost or water-cost markets.

A number of characteristics will determine how quickly the technologies under study in this analysis penetrate their respective markets. These characteristics include relative profitability, riskiness, initial investment costs, compatibility with existing irrigation methods, ease of communication, complexity, and divisibility. Also, potential changes in crop yields will effect the rate of adoption. However, there has been no consideration of changes in total crop yield that might occur by adoption of these technologies, primarily because such changes are likely to be very site specific.

Based on a ranking of the technologies with respect to these characteristics, reduced-pressure center-pivot systems will penetrate their respective markets and produce energy savings the fastest, followed by computerized scheduling and LEPA, well development techniques, and redesigned pumps and columns. The other technologies will penetrate slowly because of both economic and technical factors.

2.2 RECOMMENDATIONS

The technologies under study in this analysis span a wide range of developments. Some are already being used, to some degree, in commercial

applications, while others are still in the early research and development stage. Thus, appropriate future actions will differ with respect to each technology. However, it is believed that appropriate future actions to accelerate acceptance of energy-conserving technologies should concentrate on further research and development programs, demonstration programs, and information dissemination programs, rather than on subsidy and other types of programs which will distort irrigation industry markets.

No further actions are recommended with respect to development or demonstration of variable-speed pumps or instrumented scheduling. The costs of these technologies appear to be too high and the benefits too low for them to make a significant contribution in the near term to either agricultural production or energy conservation.

No further publicly funded actions with respect to reduced-pressure center-pivot systems are recommended. These systems are already being marketed by the private sector, and any further public efforts will represent a duplication of effort.

Two of the technologies, automated gated pipe and the redesigned pump and impeller, appear to warrant further research and development. It was demonstrated in this analysis that the costs and benefits of the automated gated-pipe system as developed at Kansas State were unfavorable with respect to adoption of this system. However, it is believed that a similar system using hard wiring rather than radio controls would be easier for the farmer to operate and would cost substantially less. In addition, development and mass production of components of a gated-pipe system specifically adapted for irrigation purposes would improve the reliability and reduce the costs of the gated-pipe system substantially. Research and development of this simpler and more reliable automated gated-pipe system is recommended.

The economics and adoption of the redesigned pump and column arrangement were demonstrated to be favorable. However, some technical questions have been raised regarding the durability of the redesigned pump's packer in supporting the hanging weight of the pump, especially in deep wells. Further technical research and development of this system appears to be warranted.

Limited demonstration programs using the LEPA system, computerized scheduling, and well development techniques are recommended. Based on both economics and energy savings, the LEPA system appears to hold the most promise of any of the technologies that were developed. However, it represents a significant change in design and in farming practices from a conventional center pivot. It is believed that a demonstration program would be very helpful in reducing farmers' resistance towards adoption of this new design and in convincing them that use of LEPA will not adversely affect crop yields.

Computerized scheduling is already being used in limited commercial applications. However, farmers generally believe the risks of underwatering, by using computerized scheduling methods, are greater than the risks of overwatering by using conventional scheduling methods. Successful demonstration of computerized scheduling in areas besides California would be helpful in alleviating farmers' concerns regarding the risks of using this new technology and in verifying that the use of computerized scheduling will not reduce crop yields.

The economic and energy-saving benefits of well development techniques were successfully demonstrated on an unconsolidated aquifer in Minnesota. However, the results of such a study in other geographic areas, where different well characteristics exist, would add credibility for local farmers. The application of the techniques developed in the well development study to other well sites is recommended.

Finally, information dissemination with respect to all of the projects, and especially those with significant energy-saving and economic potential, should be undertaken. An information dissemination program, with target groups such as farmers, irrigation manufacturers, and well drillers, could be undertaken for relatively low cost compared to the costs of developing and testing the technologies, which have already been incurred. If the information and conclusions regarding the energy- and water-conserving technologies are not widely disseminated to parties in the private sector who are able to act on it, the information developed as a result of these projects will be underutilized.

3.0 ENERGY USE PATTERNS

The following section discusses the approach used to calculate the amount of energy consumed annually in the 17 largest irrigation states. The amount of energy required to pump an acre-foot of irrigation water varies widely across states because of regional differences in several factors effecting energy consumption. These factors include: 1) the proportion of water obtained from ground and surface sources, 2) the amount of lift required to deliver water from its source to the field, 3) the operating pressures required by application systems, 4) the volume of water pumped, and 5) the pump, power unit and well efficiencies. Several data sources containing information on these factors were reviewed in order to obtain the most up-to-date and accurate data and information available. In several cases, judgment decisions were necessarily made on certain data sources used in our calculation. Energy-use equations relating the amount of energy expended in irrigation to the above factors were developed and used to estimate the amount of energy consumed in each of the 17 largest irrigation states.

3.1 CALCULATING ENERGY USE

The amount of energy required to move a quantity of water can generally be computed from the following formula:

$$E_{iswf} = \frac{V_{iswf} \times H_{iswf} \times 2.718 \times 10^6 \text{ lbs/acre-ft}}{PE \times PUE_f \times 777.9 \text{ ft-lb/Btu}} \quad (1)$$

where:

E_{iswf} = quantity of energy consumed by irrigation system i , in state s , using water source w , and fuel f (Btu)

V_{iswf} = volume of water pumped by irrigation system i , in state s , from water source w , using fuel f (acre-ft)

H_{iswf} = total operating head for irrigation system i , in state s , using water source w , and fuel f (ft)

PE = average pump efficiency

PUE_f = power unit efficiency for fuel f.

Total operating head is measured in feet and defined as the force exerted by a column of water H feet in height. Total head (H_{iswf}) is the sum of well head (H_{iswf}^w), pumping head (H_{iswf}^p), and application head (H_{iswf}^a). Well head is zero for a system using surface water.

$$H_{iswf} = H_{iswf}^w + H_{iswf}^p + H_{iswf}^a \quad (2)$$

Well head is defined as the amount of head required to overcome drawdown in a well. Drawdown is the vertical difference (in feet) between the static and dynamic water level in a well. The actual amount of drawdown in a well (DDA) depends on the efficiency of the well; an efficient well has less drawdown. The drawdown efficiency of a well is measured as the ratio of the theoretical amount of drawdown (DDT) to actual drawdown. Well head is, therefore, equal to actual drawdown and can be computed by dividing theoretical drawdown by well drawdown efficiency (WE).

$$H_{iswf}^w = DDA = DDT/WE \quad (3)$$

The amount of pumping head is equal to the vertical distance in feet between the static water level and field level. Ground water generally requires more pumping head than surface water since it must usually be lifted a greater distance.

$$H_{iswf}^p = D \quad (4)$$

where:

D_{sw} = vertical distance between static water level and field in state s, for water source w (ft).

Application head is the amount of head necessary to pressurize an application system. Gravity flow application systems typically have lower operating pressures than sprinkler systems, so that sprinkler systems tend to consume more energy to apply a given quantity of water, but apply water more

uniformly, which results in less actual water use. Application head can be calculated by converting system operating pressure from psi to feet. This is accomplished by multiplying operating pressure times the factor 2.31 ft/psi.

$$H_{iswf}^a = OP_i \times 2.31 \text{ ft/psi} \quad (5)$$

where:

OP_i = operating pressure for application system i(psi).

The amount of energy consumed by an irrigation system is related to the total operating head, efficiency of energy use, and amount of water applied (which is related to application and distribution efficiency). High head, low energy efficiencies and high water use translate into high levels of energy use. Equations 1 through 5 illustrate the relationships between energy use, water volume, head and efficiencies. It is clear from these equations that energy can be saved by pumping less water or by increasing pump and power unit efficiencies. Lowering the amount of head, through improvements in well drawdown efficiency or reductions in application system pressure requirements, also conserves energy. These and other options for reducing energy consumption in irrigation are examined in projects promoted under the Energy Conservation in Irrigated Agriculture Program.

The basic formula in Equation (1) is used with regional information about the following:

- 1) irrigated acreage
- 2) proportion of water from ground and surface sources
- 3) proportion of irrigation systems powered by various energy sources
- 4) proportion of irrigation accounted for by different application systems
- 5) the average volume of water applied by different application systems.

It is combined with technical information on conventional irrigation systems to estimate total energy use for irrigation in the 17 largest irrigation states. This process involves first estimating the annual volume of water applied in each state by irrigation system, water source, and fuel type. Water

calculated by using Equation (6) with the five variables listed above. This water volume value from Equation (6) is substituted into Equation (1) to calculate regional energy use patterns.

$$V_{iswf} = A_s \times S_w \times I_i \times F_f \times VOL_{is} \quad (6)$$

where:

A_s = irrigated acreage in state s (acres)

I_i = proportion of irrigated acreage using application system i

F_f = proportion of power units using fuel f

VOL_{is} = average volume of water applied by system i, in state s (acre-feet/acre).

The proportional split between groundwater and surface water, shown in Table 1, was obtained from data reported in the 1969 Census of Agriculture (Department of Commerce 1969). The data have not, to the best of our knowledge, been reported in subsequent editions of the census. The proportion of water from ground sources varies widely from a low of 4.6% in Montana to a high of 93.7% in Kansas. Since pumping energy represents a significant fraction of the energy used by irrigation systems, states using a high proportion of water from ground-water sources tend to use more energy per unit of irrigation water delivered than other states. Similarly, states with deeper groundwater sources tend to require more energy than those with shallow groundwater sources. The amount of acreage irrigated from groundwater and surface-water sources is indicated in Table 2. This table is estimated by multiplying total 1980 irrigated acreage in each state times the proportion of groundwater and surface water in Table 1. Acreage figures for 1980 and the proportion of irrigation by application system and power unit type were obtained from an annual survey of irrigation (Brantwood Publications 1980).

Table 2 shows that the acreage irrigated in the 17 largest irrigation states comprises over 90% of all irrigated land in the United States. California, Texas and Nebraska have, by far, the largest amounts of irrigated

acreage in the nation. These 17 states use an even greater proportion of the total amount of energy consumed by domestic irrigated agriculture than is reflected in their proportion of irrigated acreage because they are located in semi-arid to arid regions. In most of the 17 states, irrigation is used continually during crop production, whereas other states irrigate only when there is insufficient rainfall. Since these 17 states consume the majority of the energy used to irrigate crops in the United States, the remaining states were not included in this analysis.

TABLE 1. Proportion of Groundwater and Surface Water Used for Irrigation by State, 1969 Census of Agriculture

<u>State</u>	<u>Surface (%)</u>	<u>Ground (%)</u>
Arizona	47.7	52.3
Arkansas	17.4	82.6
California	60.9	39.1
Colorado	72.4	27.6
Florida	54.2	45.8
Idaho	76.6	23.4
Kansas	6.3	93.7
Montana	95.4	4.6
Nebraska	25.2	74.8
Nevada	77.8	22.2
New Mexico	31.4	68.6
Oklahoma	14.1	85.9
Oregon	87.6	12.4
Texas	22.3	77.7
Utah	83.9	16.1
Washington	84.2	15.8
Wyoming	94.8	5.2

Source: Dvoskin and Heady 1976, p. 4, Figure 2.

TABLE 2. Acres Irrigated by State and Water Source in 1980

<u>State</u>	<u>Ground Water^(a)</u>	<u>Surface Water^(a)</u>	<u>Total^(b)</u>
Arizona	600,142	547,358	1,147,500
Arkansas	1,361,661	286,839	1,648,500
California	3,870,509	6,028,491	9,899,000
Colorado	836,280	2,193,720	3,030,000
Florida	1,046,896	1,238,904	2,285,800
Idaho	933,075	3,054,425	3,987,500
Kansas	3,361,956	226,044	3,588,000
Montana	142,600	2,957,400	3,100,000
Nebraska	5,569,010	1,876,190	7,445,200
Nevada	289,510	1,014,590	1,304,100
New Mexico	850,434	389,266	1,239,700
Oklahoma	803,337	131,863	935,200
Oregon	245,309	1,732,991	1,978,300
Texas	8,799,300	200,700	9,000,000
Utah	193,720	1,009,509	1,203,228
Washington	290,404	1,547,596	1,838,000
Wyoming	<u>100,760</u>	<u>1,836,940</u>	<u>1,937,700</u>
17 State Total	<u>29,294,903</u>	<u>26,272,826</u>	<u>55,567,728</u>
U.S. Total			61,148,376

(a) Based on proportions from 1969 census.

(b) Based on an annual survey conducted by Brantwood Publications.

Table 3 shows the average lift required for ground and surface-water sources in the 17 states. Pumping lift figures for groundwater include well head and pumping head. Average lift for surface water ranges from a low of 1 foot in Arizona to a high of 60 feet in Montana, while groundwater lift ranges from 60 feet in Arkansas to 375 feet in Arizona.

The amount of energy consumed in irrigation is affected by the average volume of water applied. Table 4 shows the average amount of water applied per

TABLE 3. Average Pumping Lift by State (feet)

<u>State</u>	<u>Groundwater</u> ^(a)	<u>Surface Water</u>
Arizona	375	1
Arkansas	60	15
California	110	10
Colorado	120	10
Florida	95	6
Idaho	266	11
Kansas	180	15
Montana	100	60
Nebraska	100	20
Nevada	100	20
New Mexico	250	5
Oklahoma	200	16
Oregon	266	11
Texas	200	40
Utah	225	15
Washington	287	26
Wyoming	150	25

(a) Includes depth to static water level plus
drawdown in the well
Source: Sloggett 1979.

acre by state for gravity-flow and sprinkler systems. The volume of water applied per acre by sprinkler systems is systematically lower than that for gravity-flow systems because sprinkler systems have higher application and distribution efficiencies (i.e., a greater proportion of the water applied is available at the plant root zones and is distributed more uniformly over the entire crop). The average volume applied with sprinkler systems ranges from

TABLE 4. Average Water Volume Applied per Acre by State (Acre-ft/Acre)

<u>State</u>	<u>Weighted^(a) Average</u>	<u>Gravity-Flow^(b) Systems</u>	<u>Sprinkler^(b) Systems</u>
Arizona	5.40	5.46	4.37
Arkansas	1.83	1.85	1.48
California	3.17	3.30	2.64
Colorado	1.10	1.15	0.92
Florida	1.00	1.08	0.86
Idaho	3.20	3.51	2.81
Kansas	1.70	1.82	1.46
Montana	2.70	2.74	2.19
Nebraska	1.75	1.90	1.52
Nevada	5.00	5.05	4.04
New Mexico	2.75	2.83	2.26
Oklahoma	1.83	2.05	1.64
Oregon	3.00	3.35	2.68
Texas	1.50	1.58	1.26
Utah	3.00	3.13	2.50
Washington	4.20	4.89	3.91
Wyoming	1.83	1.86	1.49

(a) Slogget 1979

(b) Knutson et al. 1977, pp. 3-5.

0.86 acre feet/acre in Florida to 4.37 acre-feet/acre in Arizona, whereas the average volume of gravity-flow systems ranges from 1.08 acre-feet/acre in Florida to 5.46 acre-feet/acre in Arizona. All conventional sprinkler systems and gravity systems analyzed in this study are assumed to apply the average volume of water shown for each state in Table 4.

In addition to regional factors, a number of technical factors affect the quantity of energy used in irrigation. To calculate the amount of energy consumed in each state, it is necessary to consider the technical

characteristics of existing conventional irrigation equipment. The average efficiency for pumps already in use in the field is assumed to be 60%, a level which is consistent with empirical pump-testing results (Bonneville Power Administration 1981). In the economic analysis, the average efficiency for new pumps (based on data obtained from pump manufacturers) was estimated to be 70%, but wear and tear on the pumps through usage is likely to significantly reduce pump efficiencies.

Power unit efficiencies (Batty, Hamad and Keller 1974) used in the energy use calculations are:

- Diesel.....24%
- Electricity.....90%
- Gasoline.....19%
- LPG.....21%
- Natural gas.....19%

Application system operating heads (King et al. 1973) used in the energy use calculations are:

- Center Pivot.....200 ft
- Gravity Flow..... 12 ft
- Hand moved.....155 ft
- Lateral move.....180 ft
- Solid set.....160 ft
- Towline/sideroll.....160 ft
- Traveler/gun.....300 ft
- Trickle..... 50 ft

These system head figures reflect average values obtained from a review of current technical literature and contacts with irrigation vendors.

3.2 REGIONAL ENERGY CONSUMPTION

Tables 5, 6, and 7 summarize state-level irrigation energy consumption by water source, fuel and application system, which were computed using the

TABLE 5. Energy Use by State and Water Source (Billion Btu)

	<u>Ground Water</u>	<u>Surface Water</u>	<u>Total</u>
Arizona	15,134	685	15,819
Arkansas	4,761	417	5,179
California	15,039	7,189	22,228
Colorado	2,115	1,845	3,960
Florida	4,206	2,425	6,631
Idaho	7,016	5,821	12,837
Kansas	35,220	797	36,017
Montana	311	4,201	4,215
Nebraska	36,536	6,749	43,285
Nevada	1,782	2,015	3,796
New Mexico	15,508	903	16,411
Oklahoma	10,641	654	11,296
Oregon	1,637	3,221	4,858
Texas	51,231	5,439	56,671
Utah	1,101	1,177	2,278
Washington	3,261	6,142	9,403
Wyoming	<u>328</u>	<u>1,716</u>	<u>2,044</u>
Total	205,827	51,396	257,223

TABLE 6. Energy Use by Fuel (Billion Btu)

	<u>Electricity</u>	<u>Natural Gas</u>	<u>Diesel</u>	<u>Gasoline</u>	<u>LPG</u>	<u>Total^(a)</u>
Arizona	6,808	8,681	327	0	0	15,819
Arkansas	278	330	522	1,651	2,391	5,179
California	15,452	1,628	5,151	0	0	22,228
Colorado	1,565	900	396	99	998	3,960
Florida	238	435	4,141	872	947	6,631
Idaho	11,574	281	445	281	254	12,837
Kansas	2,001	26,161	4,999	0	2,856	36,017
Montana	3,815	0	149	376	170	4,512
Nebraska	4,195	14,097	16,234	640	8,117	43,285
Nevada	1,827	0	1,758	110	100	3,796
New Mexico	1,183	12,332	1,775	1,121	0	16,411
Oklahoma	454	7,540	957	268	2,072	11,296
Oregon	4,858	0	0	0	0	4,858
Texas	5,670	45,820	3,752	0	1,429	56,671
Utah	1,970	0	307	0	0	2,278
Washington	9,404	0	0	0	0	9,403
Wyoming	<u>995</u>	<u>473</u>	<u>467</u>	<u>59</u>	<u>52</u>	<u>2,044</u>
Total	72,290	118,679	41,383	5,483	19,388	257,223

(a) Totals may not add due to rounding (in total column).

TABLE 7. Energy Use by Application System
(Billion Btu)

	<u>Gravity Flow</u>	<u>Center Pivot</u>	<u>Towline/ Sideroll</u>	<u>Hand Moved</u>	<u>Solid Set</u>	<u>Traveler Gun</u>	<u>Trickle</u>	<u>Lateral Move</u>	<u>Total</u>
Arizona	14,537	609	225	324	36	0	38	19	15,819
Arkansas	4,633	7	4	512	4	19	1	0	5,179
California	13,512	413	786	5,191	1,619	39	668	0	22,228
Colorado	2,003	1,822	67	26	38	4	0	0	3,960
Florida	2,149	566	2	344	788	2,713	69	0	6,631
Idaho	4,279	2,239	2,381	3,579	358	0	0	0	12,837
Kansas	19,289	15,640	353	0	12	722	1	0	36,017
Montana	4,293	183	36	0	0	0	0	0	4,512
Nebraska	16,288	21,345	4,537	148	40	918	0	8	43,285
Nevada	3,264	403	0	20	109	0	0	0	3,796
New Mexico	13,394	2,837	101	67	0	0	11	0	16,411
Oklahoma	4,092	3,296	2,697	652	52	500	6	0	11,296
Oregon	1,066	669	1,469	1,282	116	255	2	0	4,858
Texas	34,424	9,286	7,862	3,450	27	1,505	118	0	56,671
Utah	1,291	139	524	312	4	8	1	0	2,278
Washington	1,364	2,623	2,484	2,390	517	12	13	0	9,403
Wyoming	<u>1,443</u>	<u>323</u>	<u>185</u>	<u>65</u>	<u>9</u>	<u>18</u>	<u>1</u>	<u>0</u>	<u>2,044</u>
Total	141,320	62,400	23,744	18,361	3,729	6,712	929	27	257,223

Note: Totals may not add due to rounding.

previously discussed parameters as input data. More detailed information is included in the computer tables in Appendix A, which contain a breakdown of energy use by state, water source, fuel type, and application system.

Table 5, energy used by state and water source, shows that 80% (206 trillion Btu) of the total energy used in pumping irrigation water is derived from groundwater supply systems which provide an estimated 40 to 50% of all water used in irrigation. The large lifts required to bring water to surface level accounts for the high energy usage associated with groundwater sources. Texas alone consumes 22% of the total energy consumed in the 17 states, with 90% used in groundwater irrigation. In Arizona, groundwater systems consume 96% of the energy used for irrigation, even though only 52% of Arizona's water is supplied from groundwater sources with an average lift of 375 ft. Texas, Nebraska, Kansas and California use 62% of the total energy consumed for irrigation, with 87% of this total being associated with groundwater supply systems. Of the 17 states shown, only six states use more energy in surface-water irrigation than in groundwater irrigation.

Table 6 is a breakdown by fuel type of energy consumed for irrigation in the 17 states. Forty-six percent of the total energy used for irrigation is supplied by natural gas, 28% by electricity, 16% by diesel, 8% by LPG, and 2% by gasoline. Type of fuel used depends on the price and availability of fuel in a particular state. In the West, cheap electricity is generally available, whereas in the Midwest and South, natural gas is the preferred fuel type.

A summary of energy used in irrigation by type of application system and by state is given in Table 7. Gravity irrigation application systems drawing water from ground or surface sources account for 55% of the energy consumed in irrigation, even though gravity irrigation is applied to approximately 70% of all irrigated acreage. Higher per-unit energy consumption for sprinkler irrigation is a result of higher operating pressures inherent in sprinkler application systems. Of the energy used for sprinkler irrigation, center pivots account for 54%, towline/sideroll, 20%; handmoves, 16%; traveler guns, 6%; solid sets, 3%; trickle, 1%; and lateral moves, less than 1%.

As discussed earlier, the numbers generated for Tables 5 through 7 were developed after reviewing current information on irrigation systems and by contacting experts within the government and the irrigation industry. The calculations in this report are based on reliable data believed to be representative of the current irrigation industry. The energy use values calculated in this report vary slightly from other published values, but overall, the magnitude of the variation is not large. Table 8 gives a comparison of the calculated values from these studies and two sets of data from USDA. Each document uses a different methodology to determine total energy used in irrigation.

In comparing the three sets of energy consumption data, the totals range from 243 to 265 trillion Btu. This range is believed to be relatively small, considering the variability in numbers associated with irrigated acreage, depth to ground water, application rates, etc. There are, however, considerable differences in values for some states. No rigorous effort has been made to determine the reason for these differences, which occur mainly in Texas, Arkansas, and Kansas. In these states, large amounts of energy are consumed in pumping from groundwater supplies. Differences in the percentage of water assumed to come from groundwater sources would result in significantly different values for the amounts of energy consumed.

TABLE 8. Comparison of Irrigation Energy Use Data by States (Billion Btu)

	<u>PNL</u>	<u>USDA^(a)</u>	<u>USDA-ESCS^(b)</u>
Arizona	15,819	22,010	29,105
Arkansas	5,179	4,700	4,755
California	22,228	16,720	17,407
Colorado	3,960	6,748	6,550
Florida	6,631	3,950	6,954
Idaho	12,837	7,073	7,793
Kansas	36,017	23,734	32,675
Montana	4,215	1,244	1,526
Nebraska	43,285	26,753	41,772
Nevada	3,796	2,095	1,367
New Mexico	16,411	20,675	15,178
Oklahoma	11,296	8,465	11,144
Oregon	4,858	5,694	3,111
Texas	56,671	76,628	77,412
Utah	2,278	2,596	1,697
Washington	9,403	12,820	5,111
Wyoming	<u>2,044</u>	<u>1,141</u>	<u>1,153</u>
Total	257,223	243,046	264,710

(a) USDA 1979

(b) Sloggett 1979.

NOTE: Numbers shown in (b) were calculated by converting the energy used by fuel type given in the report to billion Btu.

4.0 IRRIGATION TECHNOLOGY

This chapter briefly describes the conventional irrigation systems and the energy-conserving systems analyzed in this report. Descriptions of irrigation system equipment and practices surrounding its use are included for conventional systems because many of the energy-saving technologies offer improvements to specific components of conventional systems. To aid the reader in comparing the hardware of energy-conserving and conventional systems, the conventional irrigation systems section and the energy-conserving irrigation system sections describe wells, pumps, application systems, and scheduling systems.

4.1 CONVENTIONAL IRRIGATION SYSTEMS

High-technology, automatic irrigation systems were developed when energy was relatively cheap and readily available to farmers. At that time, labor costs were the primary factor in determining variable irrigation costs. Consequently, the high-technology systems that emerged in the market were designed primarily to reduce the labor required to irrigate, with little attention given to the amount of energy used by the system. Throughout this report, the term "conventional irrigation system" refers to irrigation systems developed and used without special energy-conserving features. Wells, pumps, conventional application systems and scheduling are described below.

Irrigation Wells

Conventional well-drilling techniques involve various types of drilling machines and different types of drilling fluids. The method used to drill a well depends on the depth to groundwater, the amount of water needed, and the material (soil type) being penetrated. Well drilling is commonly done with rotary, cable tool, and bucket auger techniques. Drilling fluid, referred to as "mud," is used to bring the loosened material to the surface. This mud also stabilizes the well walls. The same properties that contribute to wall stabilization can reduce the capacity of the well unless the mud is removed during the well development process.

After the drilling is complete, a screen and gravel pack may be added to the well. These devices permit the flow of water, but retard the movement of sand and rock into the well. The selection of the proper screen and gravel packs contribute significantly to the energy efficiency of the well.

During pumping periods, a well attains a new depth of water that is below the static, or nonpumping, water level. The difference between the static water level and the pumping water level is referred to as the well drawdown. A large drawdown increases the pumping depth, which means that more energy will be expended to lift water to the surface.

Irrigation Pumping Plants

An irrigation pump takes stationary water and imparts force to it that can then be used to lift water to a desired height, and, if need be, force water through sprinkler nozzles at high velocity. The impeller is the apparatus that transfers force to water; different impeller designs and sizes result in pumps with varying flow rates and lift capabilities. Gravity flow irrigation systems typically use pumps with high flow rates and low heads (lifts), whereas center pivot and other sprinkler systems use pumps with lower flow rates and higher heads. Other pump components include the diffuser, which is used with the impeller to pressurize irrigation water, and the pump housing.

The ability of the pumping plant to translate pumping energy to the water (via the impeller) is the pump efficiency. Every pump is designed to operate at a specific flow rate and lift, significant deviations from that flow rate or lift can reduce pump efficiency and result in excess energy consumption. For example, if the operating pressure of an irrigation system is reduced from 80 psi to 40 psi, and the pump used with the system was designed to deliver 80 psi, the system may lose efficiency because the pump is no longer operating at its intended level. Matching the pump to the system requirements is important in obtaining maximum pump efficiency. Pump efficiency tests for existing pumps indicate region-wide efficiencies of below 60% (Bonneville Power Administration 1981), whereas off-the-shelf pumps are designed to have efficiencies of as much as 75% -- which indicates considerable potential for improving pump efficiency.

Center-Pivot Irrigation

Center-pivot irrigation has been the fastest growing type of automated sprinkler system because it nearly eliminates labor. The basic center-pivot system, without a corner-catching device, irrigates a 130-acre circle (out of a 160-acre square field) and is composed of a series of towers (average length about 125 feet) coupled together. An alignment system is used to keep the system straight. Each tower includes a water supply pipe (four to eight inches in diameter) supported by A-frame trusses mounted on wheels that roll the pipe around the circle. The clearance ranges from five to twelve feet between the water supply pipe and the ground. The system is powered by motor driven gearboxes (electric, hydraulic, or water powered) which drive the wheels and cause the pipe system to pivot around a point in the center of the field. Rotational times range from 8 to 300 hours.

Water is supplied to the center-pivot system through a mainline pipe attached at the pivot point. Operating pressures of about 200 feet of head are required to deliver the water to the impact sprinklers that are mounted along the water supply pipe. Historically, these high pressures are typical for conventional center pivots; however, some reduced-pressure impact sprinklers are currently available.

Center pivots apply water efficiently, but require large amounts of energy to pressurize water and overcome friction losses resulting from distribution of water through the pipe. Center pivots presently account for about 42% of sprinkler-irrigated acreage and 11% of total irrigated acreage in the 17 top irrigation states.

Lateral-Move Irrigation

A newer form of sprinkler application is the linear, or lateral-move system. This system is basically a center-pivot machine without the pivot point. The system, which is best used on rectangular fields, moves linearly along the field at rates of up to 6.5 feet per minute. To facilitate automatic irrigations, the system has both tower-to-tower alignment and alignment up and down the field.

Water is supplied at the end or middle of the lateral-move system, either through a long flexible drag hose that must be moved periodically, or from a ditch that allows extraction by an on-board pump. Lateral systems allow for complete field irrigation and use somewhat less energy than a pivot because less water is carried to the far end of the system. The actual application of water is similar in lateral-move and center-pivot systems, as impact sprinklers are usually used, however, spray nozzles are also available. Lateral-move systems are relatively new, and are being sold by all the major center-pivot manufacturers.

Gated-Pipe Irrigation

Gated-pipe irrigation is a type of gravity flow irrigation that distributes water to the crop at low pressures of approximately five feet of head. A gated-pipe system is basically composed of 30-foot sections of aluminum or PVC pipe, available in several different diameter sizes, with six inches the diameter size most commonly used. Each section of pipe has regularly spaced openings with gates that open and close manually. When the gates are open, water is dispensed from the pipe into furrows between crop rows, from which it infiltrates into the soil, reaching adjacent plants.

Low-pressure gated-pipe application systems use a small amount of energy per unit of water applied. These systems, however, typically involve high labor costs and use larger amounts of water than sprinkler systems (because of uneven water application down the length of the furrow). A field may have enough sections of pipe to irrigate without moving the pipe. However, the pipe system is usually moved one or more times during an irrigation, resulting in the need for less pipe but more labor. Gated-pipe irrigation accounts for about 20% of the irrigated acres in the 17 states.

Irrigation Scheduling

Irrigation scheduling is the term used to describe the amount and timing of water applications to the crop. Water is applied according to factors such as crop needs, soil type, and climatic conditions. Conventional scheduling is generally the farmer's decision, based on past experience and knowledge of

current conditions concerning when and how much to irrigate. Some advanced scheduling methods are currently in use. However, for the purposes of this study, conventional irrigation scheduling is defined as scheduling without the aid of a computer.

4.2 ENERGY-CONSERVING IRRIGATION SYSTEMS

This section describes the energy-conserving irrigation projects under the Energy Conservation in Irrigated Agriculture Program. The projects are listed by technology and contractor in Table 9. Each project is described in terms of the technology used to reduce irrigation energy. Following this section is a technical comparison of conventional and energy-saving irrigation systems.

TABLE 9. Ten Energy-Conserving Irrigation Technologies Studied in the Energy Conservation in Irrigated Agriculture Program

<u>Technology</u>	<u>Contractor</u>
Well Design and Development	University of Minnesota, Staples Irrigation Research Center
Column and Pump Redesign	Aerospace Research Corporation
Variable Speed Pumping	Foster-Miller Associates
Reduced-Pressure Center-Pivot Systems	University of Nebraska
Low-Energy Precision Application Systems	Texas A&M Research Foundation
Automated Gated-Pipe Systems	Kansas State University
Computerized Irrigation Scheduling	J. M. Lord, Inc.
Instrumented Irrigation Scheduling	Prossen Industries
Groundwater Supply Optimization	University of California, Davis
Pipe Network Design Optimization	Keller Engineering

Well Design and Development

The research conducted by the University of Minnesota's Irrigation Research Center at Staples addressed the effects of well design and development

practices on pumping energy. Surging and jetting were two well development technologies investigated. Both methods facilitate the movement of water from the aquifer into the well, thus increasing well efficiency. Surging involves rapid raising and lowering of a piston-like device in the well, which creates a back-and-forth surging action through the well screen. Drilling mud and fine particles move into the well and are then removed. In jetting, a tool with several nozzles is lowered into the well and inside the screen. Water is forced through the nozzles as the tool is rotated slowly and moved up and down. At the same time, compressed air is pumped into the well at a rate approximately 1.5 times greater than the flow through the nozzles. The jetting and pumping actions combine to produce a flushing action that loosens and removes fine particles from the well. Increases in well efficiency translate into energy savings through a reduction in pumping energy needed to lift water to field level. Although this technology is not easily applied to existing wells, it is applicable to new wells.

Column and Pump Redesign

The average energy efficiency of commercially available turbine pumps is between 65 and 75%. An important contributor to efficiency reductions is impeller losses. Column pipe design can also reduce overall pumping efficiency. Aerospace Research Corporation modified the design of a conventional pump in an effort to reduce pumping energy. The redesigned pump and column differed from conventional pumps and columns in four respects: 1) the impeller and diffuser design was modified; 2) the impeller blades were mechanically polished to reduce friction losses; 3) a smaller, high-strength line shaft was installed; and 4) a packer was used to seal the well casing so it could be used as a supplementary water conduit. This technology saves energy, as water is more efficiently lifted and pressurized for use in an irrigation system.

Variable-Speed Pumping

Irrigation pumping systems in use today are designed and installed to deliver water at constant rates and pressures that meet or exceed peak demand requirements. Because operating delivery rates usually fall below peak

requirements, energy is wasted in the form of excess capacity. Foster-Miller Associates analyzed the applicability of variable-speed pumping to irrigated agriculture. A computer simulation model was developed to compare the costs of variable-speed pumping to the costs of constant-speed pumping. Because the model uses parameters of any designated irrigation system as inputs, it can be used to model any farm operation. Given the large share of total irrigation energy expended to pump water, elimination of excessive pumping could result in substantial energy savings.

Reduced-Pressure Center-Pivot Systems

The energy-conserving irrigation technology research conducted at the University of Nebraska addressed reduced-pressure center-pivot irrigation. The standard impact sprinkler heads, requiring high operating pressures, were replaced with heads that operate effectively at lower pressures. However, as system pressures fall, water application rates generally increase because the effective area over which water is being applied decreases. It is also believed that lower operating pressures increase water runoff and soil erosion. To prevent the additional runoff and erosion associated with lower operating pressures and increase water application efficiency, water-conserving tillage techniques were implemented with the reduced-pressure system. The primary focus of this project was to determine the total efficiency of reduced-pressure versus high-pressure systems, with specific reference to water application efficiencies, crop yields, water use, and energy conservation.

Low-Energy Precision Application (LEPA)

The LEPA system developed by the Texas Agricultural Experiment Station at Lubbock concerns energy use and water application efficiency. The purpose of this project was to develop and evaluate an application system that would be both energy conserving and efficient in the application of irrigation water. Conventional center-pivot and lateral-move irrigation machines were modified to accept drop-tube and discharge-emitter (nozzles) irrigation equipment of the LEPA system. Long drop tubes were attached to the supply line of the machine, and low-pressure discharge emitters, operating at five to ten feet of head,

were attached to the drop tubes. The emitters, about one foot from the soil surface, apply water directly to the surface, resulting in increased water application efficiency. The LEPA system has the ability to handle a wide range of flow rates, so that it can be used with either low- or high-capacity wells. Energy savings are realized from lower operating pressures and water use savings that result from precise water application. LEPA's use has been successfully demonstrated on row crop fields.

Automated Gated-Pipe Systems

The reduction of high labor costs and water application inefficiencies associated with gated-pipe irrigation systems was the focus of research conducted by Kansas State University. Because considerable amounts of labor are needed to open and close the gates of conventional systems, farmers usually change water application from one part of the field to another according to labor availability rather than strictly according to crop needs. The technical approach taken by Kansas State University was to use a radio transmitter and receivers to automatically direct water flow through flow-control valves to individual sections of gated pipe. Labor requirements are reduced because water application is controlled from a central transmitting station. Crop needs are met by programming timers that control the length of water settings. Through automated operations, cutback-head and surge-flow water management techniques can be applied to increase water distribution efficiency. This automated system increased water application efficiency, thus reducing irrigation energy requirements.

Computerized Irrigation Scheduling

Conventional scheduling practices are subjective in nature, lacking precision in the timing and quantity of irrigation water applied to the field. Considerable irrigation water is lost because of the tendency of farmers to overirrigate crops. J. M. Lord, Inc., developed a computer-predictive model that schedules irrigation according to measured input parameters such as soil moisture content, crop water requirements, and weather patterns. Reducing the amount of water expended in overirrigation translates into a reduction in energy used to pump and apply irrigation water.

Groundwater Supply System Optimization

The University of California at Davis identified factors influencing groundwater supply energy use. A pumping and well performance optimization model was identified for diagnosing the causes of energy use inefficiencies in a groundwater system and to evaluate the effects of the inefficiency on the amount of energy used. An algorithm was assembled to address the question of when to replace or repair pumping equipment. The model's contribution to energy conservation lies in its ability to isolate the causes of groundwater system inefficiencies, helping decision-makers to evaluate capital and energy cost tradeoffs when making investments in irrigation equipment.

Pipe Network Optimization

The tradeoff between the capital costs of large diameter irrigation pipe and the increased operating energy costs of small diameter pipe suggests an optimal pipe size, depending on lifting and application system requirements. Currently, pipes for most irrigation systems are sized by hand methods which are both time consuming and likely to ignore the relationship between energy costs and capital costs. Keller Engineering upgraded a life-cycle cost computer program capable of optimizing irrigation pipe network design and developed a user's manual aimed at irrigation system designers. The potential for energy savings comes through reductions in friction losses in the pipe system.

4.3 TECHNICAL COMPARISON

Each of the energy-conserving systems analyzed yields an improvement in at least one of the factors that influence the energy use of conventional irrigation systems. Table 10 lists the system types and improvement over the conventional counterparts. As shown in the table, the technologies have been divided into similar categories for uses in comparing irrigation system technologies. Two projects, the groundwater supply optimization program and the optimal pipe network design, are not discussed in the comparison because of the nature of the projects. Both were measurement and design techniques, which complicates any comparison with conventional counterparts.

TABLE 10. Energy-Saving Parameters of Energy-Saving Technologies Compared to Conventional Systems

<u>TECHNOLOGY</u>		<u>ENERGY-SAVING PARAMETERS</u>	
<u>APPLICATION SYSTEMS</u>		<u>(Operating Pressure (ft))</u>	
Conventional Systems			
Gated Pipe			5
Center Pivot			200
Lateral Move			180
Energy-Conserving Systems			
Automated Gated Pipe			5
Center-Pivot LEPA			25
Lateral-Move LEPA			25
Reduced-Pressure Center Pivot			70
<u>WELLS</u>	<u>Reduction in Drawdown (%)</u>	<u>Well Drawdown Efficiency (%)</u>	
Conventional	0		24
Surged	20		37
Jetted	35		43
<u>PUMPS</u>	<u>Pump Efficiency (%)</u>		
Conventional	60 ^(a)		
Redesigned	From 70 initial to 75 redesigned ^(a)		
Variable Speed Pump	From 70 initial to 74.2		
<u>SCHEDULING SYSTEMS</u>	<u>Reduction in Water Use (%)</u>		
Computerized Sprinkler	24 ^(b)		
Instrumented Sprinkler	20 ^(b)		

(a) Conventional pump efficiencies of 60% were used for existing field units. The redesigned pump was tested to have an operating efficiency of 70% off-the-shelf and was then improved to 75%.

(b) The percent reductions in water usage were obtained from controllable irrigation systems such as sprinklers and are not necessarily true for all system types.

Two irrigation application systems reduce energy use by lowering operating pressures. The reduced-pressure impact sprinkler irrigation system lowers operating pressure from 200 to 70 feet of head. Similarly, the LEPA system reduces operating head from 180 and 200 feet to 25 feet. The automated gated-pipe system relies on an improvement in irrigation water application efficiency to achieve energy savings.

Well development reduces energy use by reducing the overall lift required to bring water to the surface. Surging techniques reduce the drawdown in conventional wells by 20%, while jetting reduces drawdown by 35%.

The two pump projects improved the operating efficiency (shaft power input to water power output) of pumping. The redesigned column and pump increased operating efficiency by 5 percentage points and the variable-speed pumping increased operating efficiency to 4.2 percentage points. Increased operating efficiencies reduce the amount of energy used to pump a volume of water.

Irrigation scheduling technologies make it possible to save energy by reducing the amount of water applied to the crop. Using the computerized irrigation scheduling resulted in a 24% reduction in water applied, with little impact on yield. Water savings with the instrumented system are placed at 20%. These water savings are applicable only to irrigation systems where water application amounts can be fully controlled (such as sprinkler systems) and may not be achieved where application amounts cannot be fully controlled.

Calculating Energy Savings

The amount of energy savings technically achievable by substituting an energy-conserving system for a conventional one is calculated by substituting the technical parameters of conserving systems for those of conventional systems. The energy use for conserving systems are then compared with those of conventional systems to determine potential energy savings from energy-saving irrigation systems. Percentage change in energy use technically achievable through substitution of energy-savings systems for conventional systems is calculated as the change in energy use, divided by base energy use, times 100.

$$\% E_{ijswf} = \left(\frac{E_{jswf} - E_{iswf}}{E_{jswf}} \right) \times 100 \quad (7)$$

where:

$\% E_{ijswf}$ = percentage change in energy use obtained by substituting energy-savings system i, for conventional system j, in state s, using water source w, and fuel f

E_{iswf} = energy use for energy-saving system i, in state s, using water source w, and fuel f (Btu/acre)

E_{jswf} = energy use for conventional system j, in state s, using water source w, and fuel f (Btu/acre).

Change in Energy Use

The amount of energy that can technically be saved by using an energy-conserving system varies widely among different energy-saving systems and different regions of the country. Table 11 shows the range in percentage changes in energy use possible for both gravity flow and sprinkler application systems. More detailed information on energy savings by state, water source, and application system are presented in the tables of Appendix B. Table 11 gives the overall range of numbers from the Appendix B tables.

The percentage change in energy use for the surged well in Table 11 combined with a gravity system ranges from 6% in Florida to 16% in Colorado. Combined with a sprinkler system, a surged well saves between 2% in Florida to 12% in Oklahoma. Similarly, a jetted well with a gravity application system saves from 3% in Idaho to 20% in Colorado. Variable speed pumping (assumed to be used only in Arizona) and the column and pump redesign reduce energy use by 19% and 6%, respectively.

For a reduced-pressure center-pivot irrigation system, the percentage reduction in energy used ranges from 20% for groundwater in Arizona to 65% for surface water in Arizona. The percentage reduction in energy use when LEPA

TABLE 11. Range of Percent Change in Pumping and Application Energy Use for Energy Conserving Systems

<u>Technology</u>	<u>Gravity</u>		<u>Sprinkler</u>	
	<u>Maximum</u>	<u>Minimum</u>	<u>Maximum</u>	<u>Minimum</u>
Surged Well	16%	6%	12%	2%
Jetted Well	20%	3%	16%	2%
Pump Redesign	6%	6%	6%	6%
Variable-Speed Pump	19%	19%	19%	19%
Reduced-Pressure Center Pivot	NA	NA	65%	20%
LEPA-Center Pivot & Lateral Move	NA	NA	90%	41%
Automated Gated Pipe	21%	21%	NA	NA
Computerized Scheduling	NA	NA	24%	24%
Instrumented Scheduling	NA	NA	20%	20%

NA-Not applicable.

center-pivot and lateral-move systems are compared with conventional center-pivot and lateral-move systems ranges from 41% for groundwater applications in Arizona to 90% for surface-water applications in Arizona. The percentage reduction in energy use for LEPA center pivots is greater than that for the reduced-pressure center pivots because LEPA systems reduce water volume, as well as operating pressure, and because the operating pressure of the LEPA system is even lower than that of the reduced-pressure system.

Automating gated-pipe operations can reduce the amount of water required by conventional gated-pipe irrigation systems by 21%, through greater control over the water applied. This translates directly into a 21% energy use reduction for automated gated pipe.

Computerized and instrumented scheduling systems tend to be ineffective when combined with gravity flow systems which, in general, are not highly controlled. Results are therefore reported for sprinkler applications only. Since scheduling systems save energy by reducing the quantity of water applied, the percentage reduction in energy use is exactly equal to the percentage reduction in water use, which is 24% for computerized scheduling and 20% for instrumented scheduling.

5.0 ECONOMIC ANALYSIS

This chapter discusses the costs of energy used in irrigation and the method used to compare the economic performance of energy-saving irrigation systems with those of conventional systems currently in widespread use. In many cases, the decision to purchase an energy-conserving system, rather than a conventional system, involves a tradeoff of increased expense for equipment and operation/maintenance cost versus lower energy costs. Since these costs occur over time, they must be discounted to reflect the time value of money. In this analysis, all costs for both conventional and energy-saving systems are converted into levelized annual costs. These costs are then compared, using irrigation systems that perform similar functions, to determine the conditions under which energy-saving systems offer cost savings relative to conventional systems.

Information generated in a comparative economic analysis allows us to anticipate where energy-saving systems are likely to penetrate the irrigation market. Provided that both conventional and energy-saving systems offer the same benefit stream (i.e., similar crop yields), energy-saving systems should be able to penetrate the market when and where they provide lower total irrigation costs than conventional alternatives.

5.1 ENERGY COSTS BY STATE

Energy costs form a large portion of the total irrigation costs in many states and are determined by the price of energy and the quantity consumed. Table 12 shows the average prices paid for diesel, electricity, gasoline, LPG, and natural gas in the 17 largest irrigation states. The range of prices, particularly for electricity and natural gas, varies widely among states. For example, using 1980 data, the price of electricity ranged from a low of \$4.19/MMBtu in Washington to a high of \$16.12/MMBtu in Arizona. Similarly, the price of natural gas for the same period varied from a low of \$1.34/MMBtu in Arkansas to a high of \$3.66/MMBtu in Oregon. The extent to which relative fuel prices influence the mix of fuels used for irrigation is evidenced by the fact that states, such as Washington, Oregon, Idaho, and Montana, that have

inexpensive hydroelectric sources for electricity tend to use a greater proportion of electricity to power irrigation systems than states with more expensive sources of electricity. Similarly, other states that have low relative prices for natural gas tend to use a greater proportion of natural gas. Gasoline, which is relatively more expensive than other energy sources in every state, is not widely used anywhere as an energy source for irrigation.

TABLE 12. 1979 Fuel Costs by State (\$/MMBtu)

	<u>Diesel^(b)</u>	<u>Electricity^(a)</u>	<u>Gasoline^(b)</u>	<u>LPG^(c)</u>	<u>Natural Gas^(c)</u>
Arizona	5.14	16.12	6.56	5.59	2.64
Arkansas	5.00	13.19	6.48	4.27	1.34
California	5.07	12.90	6.56	5.19	2.69
Colorado	5.00	11.72	6.48	4.27	2.26
Florida	6.01	14.65	6.88	6.31	2.78
Idaho	5.00	7.62	6.72	4.68	3.46 ^(a)
Kansas	5.21	14.07	6.72	3.86	1.65
Montana	5.07	8.79	6.64	4.17	1.97
Nebraska	5.21	11.72	6.80	3.76	2.02
Nevada	5.14	11.72	6.56	5.39	2.68
New Mexico	5.07	14.65	6.32	4.27	2.35
Oklahoma	5.58	12.60	6.56	4.17	3.44
Oregon	4.85	7.03	6.56	5.69	3.66
Texas	5.07	13.48	6.16	4.27	2.86
Utah	5.14	12.31	6.64	5.29	2.29
Washington	4.71	4.69	7.36	4.78	3.42
Wyoming	5.21	9.96	7.52	4.47	2.30

(a) Edison Electric Institute 1980.

(b) United States Department of Agriculture 1980.

(c) Energy Information Administration 1980.

The total amount spent annually for energy in irrigated agriculture in the 17 largest irrigation states is approximately \$1.4 billion. This figure represents more than 90% of the energy costs of irrigation in the entire

United States. Table 13 shows the annual cost of energy (in 1979 dollars) used in irrigation in each of the 17 states included in the analysis. These figures are calculated by multiplying average state-level energy prices from Table 12 with 1980 state-level energy use from Table 6. It is realized that in some areas, irrigators have obtained special arrangements for power at costs below the statewide average. The statewide average is, however, a reasonable surrogate for the market value of fuel consumed. Texas, California and Nebraska have the highest annual energy costs for irrigation, amounting to more than \$190 million in each of these states. Arizona and Kansas also consumed over \$100 million annually for irrigation energy.

TABLE 13. Calculated Energy Cost of Irrigation by State and Fuel (\$1000)

	<u>Diesel</u>	<u>Electricity</u>	<u>Gasoline</u>	<u>LPG</u>	<u>Natural Gas</u>	<u>Total</u>
Arizona	1,681	109,745	0	0	22,917	134,343
Arkansas	2,610	3,667	10,698	10,210	442	27,627
California	26,116	199,344	0	0	4,379	229,839
Colorado	1,980	18,342	642	4,261	2,048	27,273
Florida	26,510	3,501	5,999	5,976	1,209	43,195
Idaho	2,225	88,194	1,707	1,189	972	94,287
Kansas	26,045	28,154	0	11,024	43,171	108,394
Montana	755	33,490	2,497	709	0	37,451
Nebraska	84,579	49,165	4,352	30,520	26,294	194,910
Nevada	9,036	21,412	722	539	0	31,709
New Mexico	8,999	17,331	7,085	0	28,980	62,395
Oklahoma	5,340	5,720	1,758	8,640	25,938	47,396
Oregon	0	34,152	0	0	0	34,152
Texas	19,023	76,432	0	6,102	159,648	261,205
Utah	1,578	24,251	0	0	0	25,829
Washington	0	44,105	0	0	0	44,105
Wyoming	<u>2,433</u>	<u>9,910</u>	<u>444</u>	<u>232</u>	<u>1,083</u>	<u>14,102</u>
17 State Total	218,910	766,915	35,904	79,402	317,081	1,418,212

5.2 LEVELIZED COST ANALYSIS

Net-present-value analysis is a standard method used to compare the value of investments over time. With this method, the value of a business over time is reflected by the net present value (NPV), or discounted value, of future cost and income streams. Organizing production and investment activities so that future income streams are maximized will maximize the value of the business. When deciding whether to invest in a conventional irrigation system or in an energy-conserving system, a wealth-maximizing farmer would compare the expected NPV associated with both systems, choosing (all other factors being equal) the system offering the highest expected NPV.

The NPV associated with a particular irrigation system is the discounted sum of revenues minus expenditures for a farm operation using that system. The revenue of a farm in a given year is equal to the prices received times the quantities sold for all crops grown on the farm that year. Farm expenditures include the costs of all resources used in the production process and any tax liabilities incurred. An irrigation system can affect the NPV of a farm operation in two ways: (1) it can affect revenues by increasing the quantity of crops produced, or (2) it can change the cost of maintaining a given level of crop production. The NPV of an irrigation system is represented mathematically as follows:

$$\begin{aligned} NPV_i = & \sum_{t=1}^n \frac{B_{it}(1-T)}{(1+d)^t} - \sum_{t=1}^n \frac{[EC_{it} + OM_{it}](1-T)}{(1+d)^t} \\ & + \sum_{t=1}^n \frac{D_{it} \times T}{(1+d)^t} - I_i + \frac{SV_{in}}{(1+d)^n} \end{aligned} \quad (8)$$

where

NPV_i = net present value associated with irrigation system i

B_{it} = change in revenues minus nonirrigation expenditures
associated with irrigation system i , in year t

EC_{it} = energy cost for irrigation using irrigation system i in year t

OM_{it} = nonenergy operating and maintenance cost of irrigation system i , in year t

D_{it} = depreciation expense for irrigation system i , in year t

T = tax rate

d = discount rate (minimal acceptable rate of return)

I_i = initial cost of irrigation system i

SV_{in} = salvage value of irrigation system i , in terminal year

t = time index

n = lifespan of irrigation system

i = subscript value for irrigation system i

The first term on the right hand side of Equation (8) represents the discounted after-tax value of annual benefits associated with using the irrigation system. These benefits are equal to the prices of crops grown, times the change in production attributable to irrigation, minus any changes in expenditures for nonirrigation activities. When multiplied by 1 minus the tax rate, these benefits reflect after-tax benefits. Because the benefits accrue over a period of years, they must be divided by a discounting factor, $(1 + d)^t$, to reflect the present value of future benefits.

The second term in Equation (8) represents the discounted after-tax costs of operating and maintaining the irrigation system. Energy costs are separated from other operation and maintenance costs to highlight their important role in the economic analysis of energy-conserving systems. These costs are multiplied by 1 minus the tax rate to adjust for after tax costs, and then divided by the discounting factor to reflect the present value of future costs. The third term in Equation (8) is the discounted value of tax credits for depreciation on the irrigation system. The last two terms represent the initial costs and the discounted salvage value of the irrigation system.

Energy costs in a specific year for the irrigation systems (EC_{it}) are calculated by simply multiplying the quantity of energy used times the price of energy. Quantity of energy used is computed by substituting technical characteristics and regional information for each system into the energy-use equations and multiplying by the number of acres irrigated to obtain total energy used per system.

$$EC_{it} = (E_{it} \times P_{ft}) \times \theta_i \quad (9)$$

$$P_{ft} = P_{fo} \times \sum_{k=1}^t (1+r)^k \quad (10)$$

EC_{it} = energy cost for irrigation system i , in year t (\$)

E_{it} = energy use per acre for irrigation system i , in year t
(MMBtu/acre)

P_{ft} = price of fuel f , in year t (\$/MMBtu)

P_{fo} = price of fuel f , in initial year (\$/MMBtu)

θ_i = number of acres irrigated

(160 acres for noncenter-pivot system)

(130 acres for center-pivot system)

r = real fuel price escalation rate

A positive NPV for an irrigation system indicates that the present value of benefits exceeds the present value of costs, and that the system yields a rate of return on investment of at least d . The larger the NPV for an irrigation system, the greater the increase in a farmer's wealth from an investment in the system. When choosing between systems, a wealth-maximizing farmer invests in the irrigation system offering the highest NPV when costs and benefits are discounted at his minimum acceptable rate of return. When comparing two systems, Equation (8) can be rewritten in the following form:

$$\begin{aligned} \Delta NPV = & \sum_{t=1}^n \frac{\Delta B_t (1-T)}{(1+d)^t} - \sum_{t=1}^n \frac{(\Delta EC_t + \Delta OM_t) (1-T)}{(1+d)^t} \\ & + \sum_{t=1}^n \frac{\Delta D_t T}{(1+d)^t} - \Delta I + \frac{\Delta SV_n}{(1+d)^n} \end{aligned} \quad (11)$$

where:

$$\begin{aligned} \Delta NPV &= NPV_j - NPV_k \\ \Delta B_t &= B_{jt} - B_{kt} \\ \Delta EC_t &= EC_{jt} - EC_{kt} \\ \Delta OM_t &= OM_{jt} - OM_{kt} \\ \Delta D_t &= D_{jt} - D_{kt} \\ \Delta I &= I_j - I_k \\ \Delta SV_n &= SV_{jn} - SV_{kn} \\ j &= \text{subscript value for irrigation system } j \\ k &= \text{subscript value for irrigation system } k \\ n &= \text{terminal year for irrigation system.} \end{aligned}$$

In Equation (11), ΔNPV represents the difference between the net present values for irrigation systems j and k . If the value of ΔNPV is positive, a wealth-maximizing farmer would invest in system j , if ΔNPV is negative, he would invest in system k , and if it is zero, he would be indifferent between investing in either system.

Expression of the farmer's investment decision criteria in terms of changes in costs and benefits between two systems allows us to ignore benefit or cost components that are equal between two systems. This is convenient in the case of irrigated agriculture since it can be argued that, as long as crop yields and nonirrigation costs of production do not differ between two irrigation systems, the first term in Equation (11) can be ignored. If this term can be ignored for two irrigation systems, the NPV between the two systems can be expressed simply as the difference between the life-cycle costs for each system.

The life-cycle cost (LCC_i) for any irrigation system i is the discounted cost of owning, operating, and maintaining the system. Thus, the change in NPV between irrigation systems j and k can be represented mathematically as follows:

$$\Delta NPV = \Delta LCC = LCC_k - LCC_j, \quad (12)$$

where:

$$LCC_i = \sum_{t=1}^n \frac{(EC_{it} + OM_{it})(1-T)}{(1+d)^t} - \sum_{t=1}^n \frac{D_{it} T}{(1+d)^t} + I_i - \frac{SV_{in}}{(1+d)^t} \quad (13)$$

Equation (11) indicates that when benefit streams for two irrigation systems are equal, comparison of the life-cycle costs can determine which system offers the higher NPV. From Equations (12) and (13) it is apparent that ΔNPV will be positive if LCC_k exceeds LCC_j , negative if LCC_j exceeds LCC_k , and zero if LCC_j equals LCC_k . On the basis of life-cycle costs, a farmer would choose system j over system k only if its life-cycle cost was less than that for system k .

It should be emphasized that comparing irrigation systems on the basis of life-cycle costs, as in Equation (12), is only valid if the systems have functionally comparable technologies. For example, the life-cycle costs of a gravity flow irrigation system could not be meaningfully compared to those of a center-pivot sprinkler system, since the latter employs a different level of technology. Comparisons can be made, however, between high-pressure and low-pressure center pivots because the level of technology is comparable.

In general, the present value analysis discussed above is an appropriate way to compare the economic value of irrigation systems because it shows the effect of system choice on the investor's wealth. Life-cycle cost analysis does, however, have one drawback that makes it cumbersome for use in the

economic analysis of this study; it does not easily accommodate the comparison of systems having different lifespans. Life-cycle cost analysis assumes that reinvestment in each system occurs at regular intervals. If the irrigation systems being compared have different lifespans, life-cycle costs must be calculated on the basis of a lifespan equal to the least common multiple of the different systems' lifespans. This analysis can get somewhat complicated.

Levelized, or annualized, cost analysis is an alternative to life-cycle cost analysis that does not require that irrigation systems have equal lifespans to be comparable. Levelized cost analysis converts the present value of each system's cost to a uniform annual cost stream. The annual, or levelized, costs for systems can be compared directly to determine which system is least expensive for a given level of benefits.

The levelized cost for an irrigation system i can be calculated using the formula:

$$LEV_i = \left[I_i - \frac{SV_i}{(1+d)^n} \right] \times \left[\frac{d(1+d)^n}{(1+d)^n - 1} \right] + \left[(EC_i + OM_i) \times (1-T) \right] - (D_i T) \quad (14)$$

The comparative analysis of two irrigation systems with different lifespans is performed by calculating the difference between the levelized costs of each system:

$$\Delta LEV = LEV_k - LEV_j \quad (15)$$

$$= \left[I_k - \frac{SV_k}{(1+d)^n} \right] \left[\frac{d(1+d)^n}{(1+d)^n - 1} \right] - \left[I_j - \frac{SV_j}{(1+d)^m} \right] \left[\frac{d(1+d)^m}{(1+d)^m - 1} \right] + \left[(\Delta EC + \Delta OM) \times (1-T) \right] - (\Delta D \times T) \quad (16)$$

The results obtained by comparing levelized costs between two systems are the same as those obtained by comparing life-cycle costs of systems with similar life spans. If ΔLEV is positive then ΔLCC is positive, if ΔLEV is

negative then ΔLCC is negative, and if ΔLEV is zero then ΔLCC is zero. The magnitudes of ΔLEV and ΔLCC , however, will be different; ΔLEV measures the difference between annual cost streams, and ΔLCC measures the difference between discounted costs of the systems over their entire lives.

The formula for levelized costs, Equation (14), must be modified slightly to account for the effects of inflation and real energy price escalation. For the purposes of this analysis, it is assumed that salvage value is stated in real terms, operating and maintenance costs increase at the same rate as general price inflation, energy prices increase at a rate faster than general price inflation, and annual depreciation is constant in nominal terms. With these assumptions, no adjustments are necessary in Equation (14) for initial investment, salvage value or operating and maintenance costs. However, energy costs and depreciation must be adjusted to account for the effects of real energy price escalation and general price inflation.

To adjust energy costs for real energy price escalation it is necessary to: 1) escalate annual energy costs by the real energy price escalation rate, n ; 2) convert those escalated costs to present value; and 3) levelize the present value costs. Levelized energy costs (EC_i) can be adjusted by multiplying energy costs in the initial year times adjustment factors as follows:

$$EC_i = EC_i^0 \times \left[\sum_{t=1}^n \frac{(1+r)^t}{(1+d)^t} \times \frac{d(1+d)^n}{(1+d)^n - 1} \right] \quad (17)$$

To adjust depreciation for inflation it is necessary to: 1) deflate annual depreciation by the rate of inflation, p ; 2) convert real depreciation into present value terms; and 3) levelize depreciation cost. Levelized depreciation (D_i) is found by multiplying depreciation in the initial year (D_i^0) by an adjustment factor:

$$D_i = D_i^0 \times \left[\sum_{t=1}^n \frac{1}{(1+d)^n (1+p)^n} \right] \left[\frac{d(1+d)^n}{(1+d)^n - 1} \right] \quad (18)$$

The formula for levelized cost is adjusted for real energy price escalation and inflation by substituting EC_i and D_i from Equations (17) and (18) for EC_i and D_i in Equation (14). Equation (15) is then used, as before, to perform the comparative analysis calculations.

5.3 DATA AND ASSUMPTIONS

Equations (1) through (5) and (12) through (16) above are the basis for the computer model used to do the comparative analysis. To actually perform the comparisons, data are needed for the variables contained in these eight equations. Specifically, the following data are required:

- Volume of water pumped
- Efficiencies of pumps, wells, and power units
- Theoretical and actual drawdowns
- Water lift
- System operating pressures
- Initial capital costs for all systems components
- Salvage value
- Fuel costs
- Operating and maintenance costs for all system components
- Depreciation expense
- Lifespans of system components
- Tax rate, rate of inflation, and fuel price escalation rate
- Discount rate (minimal acceptable rate of return)

The data inputs and assumptions used to generate the results of this report are described in this section.

Irrigation Parameters

To standardize the costs analysis, the concept of generic irrigation systems is used. Except for center-pivot systems, all the systems compared in the analysis are assumed to irrigate 160 acres, center pivots are assumed to irrigate 130 acres. All system costs are based on the equipment needed by each type of system to cover the 160 (130) acres. Additionally, the cost, lifespan, and efficiency of each system component is assumed to be constant for all states, and the yields and nonirrigation production costs are assumed

to be the same for each system and state. When an energy-conserving technology is aimed at a specific system component, like an improved pump, only the cost changes associated with that particular system component are analyzed; the parameters of the other components are assumed to remain constant.

Wells

The efficiencies, costs, and lifespans of conventional, surged, and jetted wells are shown in Table 14. The capital costs of both the surged and jetted wells include an additional \$4 charge per foot for exploration and pre-drilling operations. The total costs for wells in each state are calculated by multiplying the capital costs per foot in Table 14 times the state average pumping lift in Table 3. Development costs, given as \$400 for a surged well and \$1600 for a jetted well, represent one-time development costs. Salvage values of wells are assumed to be zero, and operating and maintenance costs were assumed to be the same for all wells.

TABLE 14. Well Drawdown Efficiency, Cost, and Lifespan

<u>Well Type</u>	<u>Well Drawdown Efficiency</u>	<u>Capital Costs (per foot)</u>	<u>Development Cost</u>	<u>Life (Years)</u>
Conventional	24.2%	\$40	0	20
Surged	36.9%	\$44 ^(a)	\$ 400	20
Jetted	42.6%	\$44 ^(a)	\$1600	20

(a) Includes \$4/ft charge for exploration and test drilling.

The theoretical and actual drawdowns are given in feet for the 17 largest irrigation states in Table 15. The actual drawdowns shown for conventional wells were obtained from unpublished data from the Irrigation Research Center at Staples, Minnesota. Theoretical drawdowns were computed by multiplying actual drawdowns by an assumed efficiency of 0.242. Actual drawdowns for surged and jetted wells were then calculated by dividing theoretical well drawdown by assumed efficiencies of 0.369 and 0.426, respectively.

TABLE 15. Theoretical and Actual Well Drawdowns by State (ft)

State	Theoretical Drawdown	Actual Drawdown		
		Conventional	Surged	Jetted
Arizona	29.04	120	79	68
Arkansas	6.05	25	16	14
California	12.10	50	33	28
Colorado	14.52	60	39	34
Florida	4.84	20	13	11
Idaho	4.84	20	13	11
Kansas	12.10	50	33	28
Montana	8.47	35	23	20
Nebraska	7.26	30	20	17
Nevada	12.10	50	33	28
New Mexico	16.94	70	46	40
Oklahoma	21.87	90	59	51
Oregon	19.36	80	53	45
Texas	19.36	80	52	45
Utah	19.36	80	53	45
Washington	19.36	80	53	45
Wyoming	12.10	50	33	28

Source: Unpublished data obtained from the Irrigation Research Center, Staples, Minnesota.

Pumps

For the purposes of the economic analysis, conventional new pump efficiencies were assumed to be 70% for all states. For the redesigned pump and variable-speed pump, efficiency estimates were calculated by adding the 70% base efficiency to the incremental improvement in pump efficiency that was obtained in the field testing of these technologies by the project contractors (Hamrick 1980 and Foster-Miller 1981). For the redesigned impeller, these calculations resulted in an efficiency of 75%, and for the variable-speed pump, 74.2%.

The cost of impeller redesign was assumed to be all R&D, with no extra cost to the farmer. Contractor research (Hamrick 1980) indicated that the pump packer cost would be compensated in large measure by a reduction in line and pipe costs. Thus, the change in capital costs for the redesigned pump column, impeller and housing was assumed to be only \$200. For the variable-speed pump, capital costs were estimated to be \$8000, and the technical complexity of the variable-speed pump was assumed to require \$400 a year for additional operating and maintenance costs.

The power unit (prime mover) efficiencies used in the economic analysis were: diesel, 24%; electricity, 90%; and natural gas, 19%. State-level economic analyses were performed for all three fuels and are reported in detail in Appendix A of a companion volume, Potential Cost Savings from Investments in Energy-Conserving Irrigation Systems. Fuel costs are reported in Table 12.

Application Systems

Table 16 shows application system operating pressures, capital costs, operating and maintenance costs, and lifespans used to generate the comparative analysis results. The real salvage value of the application systems is assumed to be 10% for all systems. Costs given are manufacturers' estimates.

Irrigation Scheduling Systems

The capital investment costs, operating costs, and reductions in water usage associated with computerized and instrumented irrigation scheduling systems are shown in Table 17. These estimates were obtained from the field test results of J. M. Lord and Prossen, except for the water use reductions for gravity flow systems. Water use reductions for advanced scheduling on gravity flow systems were shown to be very small in field testing; thus, a small number was arbitrarily assigned to represent these reductions. Note that the computerized system has no initial investment costs because farmers are assessed an annual per-acre charge for the service. The instrumented irrigation scheduling, on the other hand, involves hardware that is purchased and installed.

TABLE 16. Application Systems: Operating Pressure, Cost, and Lifespan

	<u>Operating Pressure (ft)</u>	<u>Capital Costs (\$)</u>	<u>Annual O&M Costs (\$)</u>	<u>Useful Life (Years)</u>
<u>Conventional System</u>				
Center Pivot ^(b)	200	38,000	1,140	15
Lateral Move ^(a)	180	51,000	1,530	15
Gated Pipe ^(a)	5	14,850	1,481	15
<u>Energy Conserving Systems</u>				
Reduced-Pressure Center Pivot ^(b)	70	38,000	1,140	15
Center-Pivot LEPA ^(b)	25	45,000	1,350	15
Lateral-Move LEPA ^(a)	25	58,600	1,758	15
Automated Gated Pipe ^(a)	5	36,760	2,369	15

(a) 160-acre generic system.

(b) 130-acre generic system.

TABLE 17. Cost and Reduction in Water Usage of Irrigation Scheduling Systems

<u>System</u>	<u>Reduction In Water Use</u>	<u>Annual Operating Cost/Acre</u>	<u>Capital Investment</u>
Computerized Gravity Flow Sprinkler	5%	\$5	\$ 0
	24%	\$5	\$ 0
Instrumented Gravity Flow Sprinkler	4%	\$6.25	\$10,000
	20%	\$6.25	\$10,000

Economic Parameters

The economic parameters used in the economic analysis are as follows:

- Discount Rate - 10%
- Real fuel price escalation rate - 2%
- General inflation rate - 6%
- Tax rate - 25%

The impact of the assumptions regarding the real fuel price escalation rate and the discount rate (minimum acceptable rate of return) are examined in a sensitivity analysis in the companion report Potential Cost Savings from Investments in Energy-Conserving Irrigation Systems. Depreciation expense is calculated using straight-line methods, and is equal to capital costs less the discounted real salvage value, divided by the lifespan of the component.

COMPARATIVE ANALYSIS RESULTS

This section summarizes the comparative analysis of the energy- and cost-saving performance of selected irrigation systems. The comparative analysis results are discussed here because they will determine which markets the energy-saving technologies are likely to penetrate. An analysis of the sensitivity of the results to changes in two of the important input parameters--the discount rate and the real fuel price escalation rate--revealed that changes in these parameters does not affect comparative analysis results significantly. For more detailed information on the comparative analysis, the reader is referred to the companion cost savings report.

Results from the comparative analysis are presented in several tables. In the tables, energy-use and cost-comparison numbers will be negative whenever the energy-conserving systems outperform the conventional systems (reduces energy use or overall cost), because the performance measures of the conventional systems are subtracted from the corresponding measures of energy-saving systems. The important relationship between energy cost savings and any additional capital or operating and maintenance costs associated with a conserving technology is summarized in the after-tax cost columns in the comparison tables. If the value of the energy savings generated by an

energy-conserving irrigation system offset additional equipment and operating costs, the after-tax total cost difference will be negative, reflecting net economic benefits. A positive after-tax cost difference indicates that an economic loss is associated with an energy-saving system.

Well Development

The energy use, energy cost, and total after-tax cost differences for the two well development techniques are shown in Table 18. In general, the surged wells offered slightly lower savings in energy costs and energy use than did jetted wells, but the lower savings were obtained for lower capital and operating costs in comparison to the costs of savings for jetted wells.

Surging costs are small enough, relative to jetting costs, to result in greater after-tax cost savings for surged wells in most states. The cost effectiveness of jetting depends on the resultant reduction in drawdown and the volume of water pumped. The data in Table 18 show that for states with high drawdown or large volumes of applied irrigation water (like Arizona, Oklahoma, and Utah) the jetted wells offer higher benefits than surged wells. Surged wells offer cost savings in all states but Idaho, and jetted wells offer cost savings in all but four states.

The economic benefits of the well development techniques are subject to qualifications according to the type of well and the drilling methods used. The results in Table 18 would not be representative of cases where bentonite drilling fluid is not used or where wells are drilled into aquifers where few fine particles are present.

Column and Pump Redesign

The evaluation of the column and pump design modifications was based on comparisons of both gravity flow and sprinkler irrigation systems; operation of the improved pump was evaluated with a gated-pipe application system and with a center-pivot system. The energy use, energy cost, and after-tax costs of the systems with improved columns and pumps were compared to similar systems with conventional pumps. The results of the comparisons for the gated-pipe and center-pivot systems are shown by state and primary fuel in Table 19.

TABLE 18. Change in Energy Use, Energy Cost, and After-Tax Cost for Conventional Well Versus Surged and Jetted Wells^(a)

State	Fuel ^(b)	Surged (160 acres)			Jetted (160 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)	Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-198	-3722	-2522	-248	-4672	-3103
Arkansas	E	-14	-215	-78	-18	-270	11
California	E	-48	-729	-429	-61	-914	-437
Colorado	E	-20	-276	-79	-25	-346	-1
Florida	D	-23	-161	-25	-29	-202	75
Idaho	E	-20	-174	40	-25	-218	137
Kansas	NG	-123	-237	-29	-154	-297	56
Montana	E	-29	-296	-116	-36	-371	-42
Nebraska	D	-60	-366	-171	-75	-459	-110
Nevada	E	-76	-1044	-670	-96	-1310	-739
New Mexico	NG	-278	-764	-383	-349	-958	-399
Oklahoma	NG	-239	-960	-542	-300	-1205	-595
Oregon	E	-73	-601	-249	-92	-755	-234
Texas	NG	-174	-579	-262	-218	-727	-242
Utah	E	-73	-1053	-606	-92	-1321	-677
Washington	E	-103	-562	-211	-129	-705	-187
Wyoming	E	-28	-325	-108	-35	-408	-40

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with an unimproved well from those associated with surged or jetted wells.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 19. Change in Energy Use, Energy Cost, and After-Tax Cost for Redesigned Pump Column, Impeller and Housing^(a) Using Groundwater

State	Fuel ^(b)	Conventional Gated Pipe (160 acres)			Conventional Center Pivot (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)	Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-123	-2248	-1663	-121	-2212	-1636
Arkansas	E	-7	-107	-56	-18	-277	-184
California	E	-22	-329	-223	-39	-577	-409
Colorado	E	-9	-113	-61	-14	-188	-118
Florida	D	-24	-164	-99	-46	-312	-211
Idaho	E	-56	-487	-342	-63	-545	-385
Kansas	NG	-94	-177	-109	-126	-237	-154
Montana	E	-17	-170	-104	-32	-315	-213
Nebraska	D	-44	-262	-173	-82	-487	-341
Nevada	E	-31	-418	-290	-58	-776	-558
New Mexico	NG	-202	-540	-381	-232	-618	-440
Oklahoma	NG	-118	-460	-322	-149	-584	-414
Oregon	E	-54	-429	-298	-60	-479	-336
Texas	NG	-91	-295	-198	-115	-373	-256
Utah	E	-43	-596	-423	-51	-714	-512
Washington	E	-84	-450	-314	-92	-488	-342
Wyoming	E	-17	-193	-121	-25	-284	-189

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with systems using conventional pumps from those associated with systems using the redesigned column and pump.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

According to Table 19, the pump design modification offers economic benefits over new, off-the-shelf pumps in all of the states listed, since the total annualized after-tax cost differences between conventional and improved systems are negative for all states. Benefits range from \$56 to \$1663 per year for a modified-design pump operating in conjunction with a gated-pipe system and between \$118 and \$1636 per year when the modified design is used on a center-pivot system.

The after-tax benefits of a redesigned pump are primarily related to the small capital cost increases calculated by the system's developers (Hamrick 1980) for the redesign of the impeller and diffuser and the installation of the casing packer and new line shaft. This cost is easily offset by the value of the realized energy savings. Although the comparative analysis suggests that the redesigned pump is an economically sound technology, there are some doubts as to the technical feasibility of the redesigned column and pump in the long run. The potential viability of this pump design in the market and its contribution to energy conservation in irrigation will depend upon technical, instead of economic, considerations.

Variable-Speed Pumping

Energy savings and after-tax costs associated with electrically powered variable-speed pumping were calculated for both gated-pipe and center-pivot application systems. Results from the groundwater analysis are shown in Table 20. The higher energy savings realized for center-pivot systems are related to the higher energy requirements of pressurized sprinklers.

The positive after-tax total cost figures of Table 20 imply that the 4.2 percentage point increase in system efficiency effected by electrically powered variable-speed pumping does not result in sufficient energy cost savings to offset the \$8000 in additional capital costs required to purchase the pump. When annualized, total costs of a variable-speed pump are equal to \$1027 of capital costs plus \$400 of additional operating and maintenance costs. As seen by the positive after-tax cost numbers in Table 20, the capital and operating costs of variable-speed pumping generally outweigh the benefits of reduced energy costs. These results suggest that variable-speed pumping is not cost effective except in regions, like Arizona, where the pumping depth and the volume of water applied are uncommonly high.

TABLE 20. Change in Energy Use, Energy Cost, and After-Tax Cost for Variable-Speed Pumping^(a)

State	Fuel ^(b)	Conventional Gated Pipe (160 acres)			Conventional Center Pivot (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)	Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-104	-1909	-190	-103	-1878	-168
Arkansas	E	-6	-91	1173	-16	-235	1065
California	E	-19	-279	1032	-33	-490	874
Colorado	E	-7	-96	1169	-12	-160	1121
Florida	D	-20	-139	1137	-39	-265	1042
Idaho	E	-48	-414	931	-53	-463	894
Kansas	NG	-80	-150	1128	-107	-201	1090
Montana	E	-14	-144	1133	-27	-268	1040
Nebraska	D	-38	-222	1074	-70	-413	931
Nevada	E	-27	-355	975	-49	-659	747
New Mexico	NG	-172	-458	897	-197	-525	847
Oklahoma	NG	-100	-391	948	-127	-496	869
Oregon	E	-46	-364	968	-51	-407	936
Texas	NG	-77	-250	1053	-97	-317	1004
Utah	E	-36	-506	862	-43	-606	786
Washington	E	-72	-382	954	-78	-414	930
Wyoming	E	-14	-164	1118	-21	-241	1060

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with systems using conventional electric pumps from those associated with systems using electrically powered variable-speed pumps.

(b) NG = Natural Gas
D = Diesel
E = Electricity.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

Reduced-Pressure Center-Pivot Systems

Table 21 contains the comparative evaluation of a conventional center-pivot versus a reduced-pressure center-pivot system. The results for surface-water and groundwater sources were identical since the only variable operating element in the comparison was the system operating pressure. Significant energy use and energy cost savings were realized with the reduced-pressure system for all states.

Because the capital and operating and maintenance costs were assumed to be the same for both the high- and the reduced-pressure systems, the after-tax cost numbers in Table 21 are simply tax-adjusted energy cost savings. The greatest economic savings were realized in those states where energy use and costs are highest.

Low-Energy Precision Application Systems

The Low-Energy Precision Application (LEPA) irrigation method was evaluated for use on both lateral-move and center-pivot systems. In the comparisons, performance was analyzed for both groundwater and surface-water sources. The comparative analysis calculations for the lateral-move LEPA technology are shown in Table 22 and imply that significant benefits are associated with use of the LEPA system.

The after-tax cost advantage of the LEPA system over a conventional lateral-move irrigation system is more than \$1000 per year on 130 or 160 acres in almost every state for both groundwater and surface-water sources. Energy cost savings realized by the LEPA system result from two factors: 1) a reduction in system operating pressure, and 2) a reduction in the water volume applied. The \$975 annual increase in capital costs and the \$228 annual increase in operating and maintenance costs are more than offset by energy cost savings.

The energy-saving performance comparisons for LEPA and conventional center-pivot irrigation systems are presented in Table 23. The comparative after-tax cost results shown in Table 23 imply that the center-pivot LEPA system is economically feasible for all states and both water sources. The

TABLE 21. Change in Energy Use, Energy Cost, and After-Tax Cost for Center Pivot Versus Reduced-Pressure Center Pivot^(a)

State	Fuel ^(b)	Surface/Groundwater (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-410	-7502	-5626
Arkansas	E	-139	-2079	-1559
California	E	-247	-3627	-2720
Colorado	E	-86	-1148	-861
Florida	D	-302	-2064	-1548
Idaho	E	-263	-2280	-1710
Kansas	NG	-648	-1215	-911
Montana	E	-205	-2050	-1538
Nebraska	D	-534	-3163	-2372
Nevada	E	-379	-5042	-3782
New Mexico	NG	-1003	-2679	-2009
Oklahoma	NG	-728	-2846	-2134
Oregon	E	-251	-2006	-1505
Texas	NG	-559	-1818	-1363
Utah	E	-234	-3277	-2458
Washington	E	-366	-1953	-1465
Wyoming	E	-140	-1580	-1185

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with conventional high-pressure center-pivot systems from those associated with reduced-pressure center-pivot systems.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 22. Change in Energy Use, Energy Cost, and After-Tax Cost for Lateral Move Versus LEPA-LM(a)

State	Fuel(b)	Groundwater (160 acres)			Surface Water (160 acres)		
		Energy Use(c)	Energy Cost(d)	After Tax Cost(d)	Energy Use(c)	Energy Cost(d)	After Tax Cost(d)
Arizona	E	-880	-16123	-11027	-619	-11328	-7431
Arkansas	E	-224	-3352	-1449	-213	-3192	-1329
California	E	-420	-6157	-3552	-378	-5538	-3089
Colorado	E	-148	-1969	-412	-132	-1754	-250
Florida	D	-505	-3451	-1523	-460	-3138	-1289
Idaho	E	-517	-4477	-2293	-403	-3486	-1550
Kansas	NG	-1178	-2208	-591	-995	-1866	-335
Montana	E	-345	-3445	-1519	-331	-3305	-1414
Nebraska	D	-898	-5315	-2921	-825	-4883	-2598
Nevada	E	-636	-8474	-5290	-585	-7786	-4775
New Mexico	NG	-1943	-5187	-2825	-1524	-4068	-1986
Oklahoma	NG	-1348	-5267	-2886	-1119	-4375	-2216
Oregon	E	-493	-3939	-1889	-384	-3067	-1236
Texas	NG	-1035	-3365	-1458	-883	-2869	-1087
Utah	E	-444	-6206	-3589	-360	-5033	-2710
Washington	E	-733	-3904	-1863	-570	-3036	-1212
Wyoming	E	-247	-2791	-1028	-217	-2454	-775

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with conventional high-pressure lateral-move systems from those associated with LEPA lateral-move systems.

(b) D = Diesel

E = Electricity

NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 23. Change in Energy Use, Energy Cost and After-Tax Cost for Center-Pivot Versus LEPA Center-Pivot System^(a)

State	Fuel ^(b)	Groundwater (130 acres)			Surface Water (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)	Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-778	-14254	-9709	-566	-10358	-6788
Arkansas	E	-203	-3039	-1301	-194	-2914	-1204
California	E	-379	-5560	-3189	-345	-5058	-2813
Colorado	E	-133	-1776	-351	-120	-1601	-220
Florida	D	-457	-3122	-1360	-420	-2867	-1169
Idaho	E	-461	-3988	-2010	-368	-3183	-1407
Kansas	NG	-1057	-1981	-505	-908	-1703	-296
Montana	E	-312	-3114	-1355	-300	-3001	-1270
Nebraska	D	-812	-4805	-2623	-752	-4445	-2360
Nevada	E	-575	-7661	-4765	-533	-7102	-4346
New Mexico	NG	-1733	-4627	-2489	-1392	-3718	-1807
Oklahoma	NG	-1207	-4718	-2557	-1022	-3993	-2014
Oregon	E	-439	-3509	-1651	-351	-2801	-1120
Texas	NG	-927	-3013	-1279	-803	-2611	-977
Utah	E	-397	-5546	-3179	-328	-4593	-2464
Washington	E	-652	-3473	-1623	-519	-2767	-1094
Wyoming	E	-222	-2510	-902	-198	-2237	-697

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with conventional high-pressure center-pivot systems from those associated with LEPA center-pivot systems.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

net after-tax benefits of the LEPA center pivot range from \$351 to \$9709 per year for groundwater systems and from \$220 to \$6788 per year for surface-water systems.

Automated Gated-Pipe Systems

The results of the comparison of the energy use, energy costs, and after-tax costs of a conventional gated-pipe irrigation system and the radio-controlled automated gated-pipe system are given in Table 24 for both groundwater and surface-water sources. Energy savings result from a 20% reduction in the volume of water applied to the field, realized through improved water application and distribution efficiencies. However, the annualized cost differences between radio-controlled automated and conventional gated-pipe systems are positive in all of the cases analyzed, except for groundwater systems in Arizona, indicating economic losses ranging from \$1903 to \$3003 per year for groundwater systems and from \$3007 to \$3213 per year for surface-water systems.

Computerized Irrigation Scheduling

The results of the comparisons of computerized and conventional scheduling on a center-pivot system are presented for groundwater in Table 25, and for surface water in Table 26. The change in water use is added to the list of system performance measures for surface water (Table 26) because water-user charges may be levied against farmers irrigating with surface water. If water-user charges are assessed at a fixed rate, water savings have no impact on farm costs. If, however, charges are levied at a variable rate according to the amount of water used, every unit of water saved reduces irrigation costs. The water savings are shown for comparison only, and the economic benefits have not been added into the resultant savings.

The comparative calculations for computerized scheduling imply that, for groundwater, at a cost of \$5 per acre for the service, computerized scheduling would be economically feasible in every state for center-pivot systems. Other comparisons, which are not presented here, demonstrate that computerized scheduling would not generally be economically feasible on gravity flow irrigation systems.

TABLE 24. Change in Energy Use, Energy Cost, and After-Tax Cost
for Gated Pipe Versus Automated Gated Pipe^(a)

State	Fuel ^(b)	Groundwater (160 acres)			Surface Water (160 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)	Energy Use ^(c)	Energy Cost ^(d)	After Tax Cost ^(d)
Arizona	E	-368	-6744	-1815	-5	-89	3177
Arkansas	E	-21	-320	3003	-7	-98	3170
California	E	-67	-987	2503	-9	-129	3147
Colorado	E	-26	-340	2989	-3	-41	3213
Florida	D	-72	-491	2875	-8	-54	3203
Idaho	E	-169	-1462	2147	-10	-86	3179
Kansas	NG	-283	-531	2845	-31	-57	3200
Montana	E	-51	-510	2861	-32	-316	3007
Nebraska	D	-133	-786	2654	-32	-187	3103
Nevada	E	-94	-1253	2303	-22	-298	3020
New Mexico	NG	-607	-1620	2028	-24	-64	3196
Oklahoma	NG	-353	-1381	2208	-36	-141	3137
Oregon	E	-161	-1287	2278	-10	-76	3186
Texas	NG	-272	-885	2583	-60	-194	3098
Utah	E	-128	-1787	1903	-11	-155	3127
Washington	E	-253	-1350	2231	-27	-143	3136
Wyoming	E	-51	-579	2809	-10	-112	3159

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with conventional gated-pipe systems from those associated with a radio controlled automated gated-pipe system.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 25. Change in Energy Use, Energy Cost, and After-Tax Cost for Computerized Water Scheduling^(a) Using Groundwater

State	Predominant Fuel ^(b)	Conventional Center Pivot (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After-Tax Cost
Arizona	E	-435	-7973	-5492
Arkansas	E	- 67	-1011	-271
California	E	-141	-2064	-1060
Colorado	E	-51	-676	-19
Florida	D	-167	-1144	-370
Idaho	E	-225	-1949	-974
Kansas	NG	-454	-852	-151
Montana	E	-115	-1145	-371
Nebraska	D	-292	-1729	-809
Nevada	E	-210	-2794	-1608
New Mexico	NG	-830	-2216	-1174
Oklahoma	NG	-533	-2082	-1074
Oregon	E	-215	-1718	-801
Texas	NG	-410	-1332	-511
Utah	E	-184	-2571	-1441
Washington	E	-330	-1759	-832
Wyoming	E	-91	-1028	-284

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with irrigation systems using conventional irrigation scheduling practices from those associated with the same systems using computerized scheduling.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 26. Change in Energy Use, Energy Cost, After-Tax Cost, and Water Use for Computerized Water Scheduling^(a) Using Surface Water

State	Fuel ^(b)	Energy Use ^(c)	Conventional Center Pivot (130 acres)		
			Water Use ^(d)	Energy Cost ^(e)	After-Tax Cost ^(e)
Arizona	E	-151	-136.5	-2773	-1591
Arkansas	E	-56	-46.8	-836	-140
California	E	-95	-81.9	-1398	-561
Colorado	E	-33	-28.6	-444	155
Florida	D	-117	-27.3	-799	-112
Idaho	E	-102	-87.1	-882	-174
Kansas	NG	-257	-45.5	-482	126
Montana	E	-99	-68.9	-992	-257
Nebraska	D	-214	-46.8	-1268	-463
Nevada	E	-154	-126.1	-2049	-1049
New Mexico	NG	-378	-70.2	-1009	-270
Oklahoma	NG	-288	-50.7	-1124	-356
Oregon	E	-97	-83.2	-778	-96
Texas	NG	-246	-39.0	-799	-112
Utah	E	-93	-78.0	-1301	-483
Washington	E	-153	-122.2	-816	-125
Wyoming	E	-58	-46.8	-661	18

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with systems using conventional scheduling from those associated with the same system using computerized scheduling.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) Million Btu/yr (negative numbers indicate decrease in use).

(e) In dollars/yr (negative numbers indicate decrease in cost).

Instrumented Irrigation Scheduling

Results for the instrumented irrigation scheduling system are presented in Tables 27 and 28, which follow the format of Tables 25 and 26. The changes in the estimated water volume applied between center-pivot systems scheduled with the instrumented system and the corresponding conventional systems are only slightly different from comparable estimates made for the computerized scheduling system. The increased costs generated by the instrumented system, in comparison to conventional scheduling, for almost all states are the result of large capital and operating-and-maintenance costs. The fully-instrumented system has annualized additional capital costs of \$1283 and additional operating and maintenance costs of \$1000. When used with conventional center-pivot systems, these costs are offset by reductions in energy costs in only a few cases.

TABLE 27. Change in Energy Use, Energy Cost, and After-Tax Cost for Instrumented Scheduling System^(a) Using Groundwater

State	Fuel ^(b)	Surface/Groundwater (130 acres)		
		Energy Use ^(c)	Energy Cost ^(d)	After- Tax Cost ^(e)
Arizona	E	-361	-6606	-3169
Arkansas	E	-56	-843	1154
California	E	-118	-1736	484
Colorado	E	-42	-553	1371
Florida	D	-136	-926	1091
Idaho	E	-188	-1629	564
Kansas	NG	-376	-706	1257
Montana	E	-95	-950	1073
Nebraska	D	-243	-1440	705
Nevada	E	-175	-2333	36
New Mexico	NG	-692	-1847	401
Oklahoma	NG	-451	-1762	464
Oregon	E	-181	-1449	699
Texas	NG	-342	-1110	953
Utah	E	-153	-2143	-179
Washington	E	-274	-1459	691
Wyoming	E	-76	-857	1143

(a) Changes are is calculated by subtracting the energy use, energy cost, and after-tax cost associated with irrigation systems using conventional scheduling practices from those associated with the same systems using instrumented scheduling.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) In dollars/yr (negative numbers indicate decrease in cost).

TABLE 28. Change in Energy Use, Energy Cost, After-Tax Cost, and Water Use for Instrumented Scheduling System^(a) Using Surface Water

State	Fuel ^(b)	Conventional Center Pivot (130 acres)		After-Tax	
		Energy Use ^(c)	Water Use ^(d)	Energy Cost ^(e)	Tax Cost ^(e)
Arizona	E	-125	-113.1	-2298	62
Arkansas	E	-47	-39.0	-697	1263
California	E	-80	-68.9	-1176	904
Colorado	E	-27	-23.4	-363	1514
Florida	D	-95	-22.1	-647	1301
Kansas	NG	-213	-37.7	-399	1486
Montana	E	-82	-57.2	-824	1168
Nebraska	D	-178	-39.0	-1056	993
Nevada	E	-128	-105.3	-1711	503
New Mexico	NG	-315	-58.5	-841	1155
Oklahoma	NG	-243	-42.9	-951	1072
Oregon	E	-80	-70.2	-656	1294
Texas	NG	-205	-32.5	-666	1286
Utah	E	-78	-65.0	-1084	973
Washington	E	-127	-101.4	-677	1278
Wyoming	E	-49	-39.0	-551	1373

(a) Changes are calculated by subtracting the energy use, energy cost, and after-tax cost associated with conventional scheduling systems from those associated with an instrumented scheduling system.

(b) D = Diesel
E = Electricity
NG = Natural Gas.

(c) Million Btu/yr (negative numbers indicate decrease in use).

(d) Million Btu/yr (negative numbers indicate decrease in use).

(e) In dollars/yr (negative numbers indicate decrease in cost).

6.0 POTENTIAL ENERGY AND WATER SAVINGS FROM ENERGY- CONSERVING IRRIGATION SYSTEMS

This section discusses the amount of energy savings made possible by substituting energy-conserving irrigation systems for conventional systems where it is cost effective to do so. The factors that influence the rate of market penetration of a new technology are discussed first. Then the method used to calculate the upper limit of energy savings for each energy-conserving system is described. Finally, the results obtained by this procedure and adjustments made for double counting are reported. It is assumed in calculating baseline estimates of energy savings from the use of energy-conserving technologies that irrigated acreage levels will remain at current levels. The possible effects of rising energy costs on energy consumption of conventional irrigation systems is not considered, nor is the potential effect of changing cropping patterns.

6.1 MARKET PENETRATION

In this study, energy savings will be calculated based upon an assumed level of 100% market penetration in those markets where the use of energy-conserving systems is cost effective. However, many factors influence the rate at which the new energy-conserving technologies penetrate the market and how closely they approach their maximum potential of 100% penetration. Possible limitations to the market penetration of the energy-conserving technologies analyzed in this study are the following:

- Changes in cultivation techniques necessary to use LEPA or reduced-pressure center pivots. These changes could include the plowing of circular furrows (in the case of a LEPA system) or using reduced-tillage techniques (in the case of reduced-pressure center pivots) to limit soil erosion.
- Operating performance problems associated with the redesigned column and pump, variable-speed pumping, automated gate-pipe and instrumented scheduling systems. None of these systems have been extensively proven for use in commercial farming applications.

- Site specific limitations on system use. For example, reduced-pressure center-pivot systems may not be appropriate for use on fields with steep slopes and heavy soils, and LEPA may not be appropriate for use on non-row-crop fields.

Various economists and rural sociologists have undertaken theoretical and empirical studies of the factors that influence the rate of expected market penetration. E.M. Rogers, a rural sociologist, hypothesized that the rate of adoption of an innovation is influenced by five characteristics: 1) relative advantage, 2) compatibility, 3) divisibility, 4) communicability, and 5) complexity (Rogers 1962). Rogers' definition of relative advantage was the degree to which an innovation is superior to ideas it supersedes, but for purposes of this study, relative advantage will be measured by the profitability of the new technology relative to conventional technologies of a similar type. This variable should be positively related to the rate of market penetration. Compatibility is the degree to which an innovation is compatible with existing production methods and should also be positively related to the rate of market penetration. Divisibility, the degree to which an innovation can be used on part of a farmer's operation rather than all of it, and communicability, the ease with which the results of the innovation can be communicated, are also believed to be positive influences on the rate of adoption. Complexity, the degree to which an innovation is difficult to understand and use, is thought to be a negative influence.

Economists, including Mansfield (1961) and Griliches (1958), have identified several variables likely to influence the rate of market penetration of an innovation. These factors include: 1) profitability, 2) costs relative to other alternatives, 3) risk (both economic and technical), and 4) size of initial investment relative to the average value of assets of firms in an industry. Costs relative to other alternatives reflect the gross costs of the innovation rather than the net costs, which are reflected in profitability and should be negatively related to the rate of market penetration. Risk measures both the technical and economic risks of investing in the innovation; it, too, is a negative influence. The size of the investment relative to the average

value of assets of firms in an industry is a measure of the significance of the investment relative to those assets, and also should be negatively related to the market penetration rate.

In an empirical study (Fliegal and Kivlin 1966), it was determined that innovations perceived to be less risky, in addition to those perceived as being more profitable, were accepted most rapidly. Direct contribution of the innovation to a major occupational interest also enhanced acceptance. Mansfield (1961) empirically identified the size of an investment as being a significant negative influence on the rate of acceptance of an innovation.

6.2 EVALUATION OF MARKET PENETRATION RATES FOR ENERGY-CONSERVING SYSTEMS

For purposes of this study, seven variables identified by both rural sociologists and economists will be used to evaluate the rate of market penetration for each technology. These variables are: 1) profitability, 2) risk, 3) size or costs of the investment, 4) compatibility, 5) communicability, 6) complexity, and 7) divisibility. Of the seven, profitability, compatibility, divisibility and communicability should be positively related to the rate of market penetration; and complexity, risk, and size of investment should be negatively related.

Profitability

Based on the results of the levelized cost analysis, reduced-pressure center pivot, computerized irrigation scheduling, LEPA, and column and pump redesign were profitable in all situations analyzed. Well development was profitable in some situations, but in others it was not. The other systems were unprofitable.

Risk

Reduced-pressure center pivot, LEPA, and well development were determined to involve less risk because they have already been used, to some degree, in commercial farming situations. The variable-speed pumping has also been used commercially in the chemical industry. The pump and column redesign was determined to involve a higher degree of risk, based on evidence (conversations with several engineers in the pumping industry) which emphasized that

the design has not been used commercially. The radio controlled automated gated-pipe irrigation system and the instrumented irrigation scheduling systems were determined to involve substantial amounts of risk, based on the technical problems that were incurred in the testing of these systems. It is believed that while the computerized irrigation scheduling system has been used in commercial farming applications, many farmers still perceive the risk of underwatering to be greater than the risk of overwatering and will enroll slowly in the scheduling program until the program is extensively proven.

Size of Investment

The size of investment is greater for those technologies with greater initial capital costs, and relative capital costs were discussed earlier.

Compatibility

In most instances, few changes in existing operations would be needed before using the reduced-pressure center-pivot irrigation system or computerized irrigation scheduling services; thus, these systems are highly compatible. Well development and variable-speed pumping require slightly more changes, but their impacts on existing operations would also be relatively slight. A number of changes in these operations may be necessary to install the LEPA system, the redesigned column and pump, the radio-controlled automated gated-pipe system or the instrumented scheduling system.

Communicability and Complexity

Communicability and complexity are closely related. In general, information about complex systems will be more difficult to communicate. It is believed that information about the reduced-pressure center pivot, the LEPA system, computerized scheduling, and well development will be generally easy to communicate because these systems are relatively simple in design. Information about the other four systems will be more difficult to communicate because of their technical complexity. Evaluations of the complexity of the technologies are similar to those for communicability except for the variable-speed pump. This technology is quite complex to design, but because the system is automatic, little of the complexity should carry over to the operation.

Divisibility

Most of the systems are very divisible and could be used on small parts of an entire farming operation if limited use was desired.

Comparative Rates of Market Penetration

Taken together, the evaluation of the technologies with respect to the rate of market penetration indicate that the reduced-pressure center-pivot irrigation system and computerized irrigation scheduling will most quickly penetrate their respective markets. The LEPA irrigation system and well development will also penetrate rapidly. The other systems are expected to penetrate at much slower rates. These results tend to be consistent with current trends in the irrigation industry. Reduced-pressure center-pivot irrigation systems and computerized irrigation scheduling systems are already making inroads into irrigation operations. LEPA systems and well development are also being used, although on a more limited basis.

6.3 ENERGY SAVINGS

The potential of an energy-saving irrigation system to save energy depends on the system's technical capability to save energy and its ability to penetrate the irrigation market. Regardless of how much energy a system is technically capable of saving, that system will not save energy unless it is accepted in the market. Market acceptance of energy-conserving systems depends primarily on their ability to decrease irrigation costs when substituted for conventional irrigation systems.

Method of Calculating Energy Savings

Forecasting the actual market penetration of a particular technology is a difficult, if not impossible, task. However, it is unlikely, in the absence of market distortions, that a technology will ever show widespread penetration in markets where it is not cost effective. The economic comparative analysis discussed in Chapter IV identifies the markets where energy-conserving systems decrease irrigation costs relative to conventional systems. This information, along with information on current irrigated acreage, energy use, and technical

ability to reduce energy use, is used to estimate the upper limit of energy savings that could be expected from each of the conserving systems analyzed in this study.

The upper limit for energy savings is calculated for each conserving system in 17 leading irrigation states using the following formula:

$$E_{is} = (\Delta E_{ijswf} \times MS_{ijswf} \times E_{jswf})/100 \quad (19)$$

where:

E_{is} = Maximum potential change in energy use from energy-conserving system i, in state s

ΔE_{ijswf} = Percentage change in energy use comparing conserving system i to conventional system j, in state s, for water source w and fuel f

MS_{ijswf} = Market share of conserving system i, relative to conventional system j, in state s, for water source w, and fuel f (to determine maximum possible savings, $MS = 0$ where system i does not produce cost savings, and $MS = 1$ where system i generates cost savings)

E_{jswf} = Total amount of energy used by conventional system j, in state s, for water source w and fuel f.

Upper Limit to Energy Savings

In order to estimate an upper limit for savings from each individual energy-conserving system, it is assumed that if the system is cost effective, relative to a conventional system in a particular state and application, it will be able to totally displace the conventional system. The assumption of 100% market penetration where a system is economical allows us to gauge an upper limit for the maximum possible energy saved by each system. This analysis is not meant to suggest that these levels of savings will actually be achieved, for it is doubtful that any particular system will achieve 100% market share. Furthermore, if one conserving system, such as a reduced-pressure center-pivot irrigation system, displaces a conventional high-pressure

center-pivot system, that same conventional center pivot could not simultaneously be replaced by an LEPA center-pivot irrigation system. Therefore, energy-savings figures for individual energy-conserving systems can include double counting of energy savings and, therefore, must be adjusted to measure the expected aggregate energy saving for all conserving systems considered together.

Tables 29 through 38 identify an upper limit of expected energy savings for individual energy-conserving irrigation systems based on current irrigation acreages. These figures cannot be added across systems to compute aggregate energy savings for conserving systems because they include double counting of savings. The numbers in these tables represent the annual energy savings (in billion Btu) that would be achievable if a particular energy-conserving system is substituted for a conventional system in every situation in which it is cost effective to do so.

Table 39 summarizes the maximum potential energy savings (from Tables 29 through 38) expected for each individual technology, excluding the possibility of competition from other energy-saving technologies. Zeros indicate that the technology would not penetrate the market on the basis of energy savings.

Expected Energy Savings

The fact that several alternatives are available to save energy at a particular technology level (i.e., two well techniques, two center-pivot techniques, two scheduling systems, etc.) and that one system may be economic in certain situations over another will result in use of a particular energy-conserving system in a specific situation. Therefore, the total potential energy savings from application of these systems must eliminate any double counting of numbers such as would occur if the numbers in Table 39 were simply added and totaled. Table 40 has grouped systems by similar technological type and eliminated any potential functional use double counting.

In addition, the interaction of energy savings alternatives causes the sum of the energy savings of the individual measure to be greater than the energy savings from implementing all of the alternatives together. This source of "double counting" can best be illustrated by an example. Suppose

TABLE 29. Upper Limit of Energy Savings from Surged Wells (Billion Btu)

State	Ground Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	1,584	0	1,584
Arkansas	531	0	531
California	1,793	0	1,793
Colorado	265	0	265
Florida	166	0	166
Idaho	0	0	0
Kansas	2,437	0	2,437
Montana	32	0	32
Nebraska	2,130	0	2,130
Nevada	259	0	259
New Mexico	1,331	0	1,331
Oklahoma	1,124	0	1,124
Oregon	127	0	127
Texas	5,554	0	5,554
Utah	114	0	114
Washington	222	0	222
Wyoming	32	0	32
TOTAL	17,709	0	17,709

(a) Totals may not add due to rounding.

TABLE 30. Upper Limit of Energy Savings from Jetted Wells (Billion Btu)

State	Ground Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	1,987	0	1,987
Arkansas	0	0	0
California	2,251	0	2,251
Colorado	332	0	332
Florida	0	0	0
Idaho	177	0	177
Kansas	0	0	0
Montana	0	0	0
Nebraska	2,673	0	2,673
Nevada	0	0	0
New Mexico	1,670	0	1,670
Oklahoma	1,411	0	1,411
Oregon	159	0	159
Texas	6,970	0	6,970
Utah	0	0	0
Washington	279	0	279
Wyoming	40	0	40
TOTAL	17,955	0	17,955

(a) Totals may not add due to rounding.

TABLE 31. Upper Limit of Energy Savings from Pump and Column Redesign (Billion Btu)

State	Ground Water(a)	Surface Water(a)	Total(a)
Arizona	864	0	864
Arkansas	272	0	272
California	859	0	859
Colorado	120	0	120
Florida	240	0	240
Idaho	400	0	400
Kansas	2,012	0	2,012
Montana	17	0	17
Nebraska	2,087	0	2,087
Nevada	101	0	101
New Mexico	886	0	886
Oklahoma	608	0	608
Oregon	93	0	93
Texas	2,927	0	2,927
Utah	62	0	62
Washington	186	0	186
Wyoming	18	0	18
TOTAL	11,762	0	11,762

(a) Totals may not add due to rounding.

TABLE 32. Upper Limit of Energy Savings from Variable-Speed Pumping (Billion Btu)

State	Ground Water(a)	Surface Water(a)	Total(a)
Arizona	2,890	0	2,890
Arkansas	0	0	0
California	0	0	0
Colorado	0	0	0
Florida	0	0	0
Idaho	0	0	0
Kansas	0	0	0
Montana	0	0	0
Nebraska	0	0	0
Nevada	0	0	0
New Mexico	0	0	0
Oklahoma	0	0	0
Oregon	0	0	0
Texas	0	0	0
Utah	0	0	0
Washington	0	0	0
Wyoming	0	0	0
TOTAL	2,890	0	2,890

(a) Totals may not add due to rounding.

TABLE 33. Upper Limit of Energy Savings from Reduced-Pressure Center-Pivot Sprinkler Irrigation Systems (Billion Btu)

State	Ground Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	107	98	205
Arkansas	3	0	3
California	84	131	215
Colorado	271	713	985
Florida	136	161	297
Idaho	251	832	1,075
Kansas	5,154	346	5,501
Montana	4	86	90
Nebraska	7,419	2,499	9,919
Nevada	48	171	220
New Mexico	678	310	988
Oklahoma	984	161	1,145
Oregon	44	313	358
Texas	2,574	738	3,313
Utah	11	60	72
Washington	201	1,074	1,276
Wyoming	9	171	181
TOTAL	17,986	7,864	25,850

(a) Totals may not add due to rounding.

TABLE 34. Upper Limit of Energy Savings from Low-Energy Precision Application Center-Pivot Irrigation Systems (Billion Btu)

State	Ground-Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	204	135	340
Arkansas	4	0	5
California	129	183	312
Colorado	421	994	1,415
Florida	206	224	430
Idaho	440	1,150	1,590
Kansas	8,401	485	8,887
Montana	6	126	133
Nebraska	11,272	3,520	14,792
Nevada	74	241	315
New Mexico	1,171	430	1,602
Oklahoma	1,631	226	1,857
Oregon	77	438	516
Texas	4,267	1,061	5,328
Utah	19	51	104
Washington	358	15,522	1,880
Wyoming	14	243	258
TOTAL	28,986	11,071	39,772

(a) Totals may not add due to rounding.

TABLE 35. Upper Limit of Energy Savings from Low-Energy Precision Application Lateral-Move Irrigation Systems (Billion Btu)

State	Ground-Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	205	131	336
Arkansas	4	0	5
California	130	183	313
Colorado	421	994	1,415
Florida	206	225	431
Idaho	440	1,149	1,589
Kansas	8,401	486	8,887
Montana	6	127	133
Nebraska	11,272	3,520	14,791
Nevada	74	241	315
New Mexico	1,171	430	1,601
Oklahoma	1,631	226	1,857
Oregon	77	439	516
Texas	4,269	1,060	5,329
Utah	20	86	106
Washington	358	1,522	1,880
Wyoming	15	245	260
TOTAL	28,700	11,064	39,764

(a) Totals may not add due to rounding.

TABLE 36. Upper Limit of Energy Savings from Automated Gated-Pipe Irrigation Systems

State	Ground-Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	3,032	0	3,032
Arkansas	0	0	0
California	0	0	0
Colorado	0	0	0
Florida	0	0	0
Idaho	0	0	0
Kansas	0	0	0
Montana	0	0	0
Nebraska	0	0	0
Nevada	0	0	0
New Mexico	0	0	0
Oklahoma	0	0	0
Oregon	0	0	0
Texas	0	0	0
Utah	0	0	0
Washington	0	0	0
Wyoming	0	0	0
TOTAL	3,032	0	3,032

(a) Totals may not add due to rounding.

TABLE 37. Upper Limit of Energy Savings from Computerized Irrigation Scheduling (Billion Btu)

State	Ground Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	231	67	298
Arkansas	113	19	132
California	970	949	1,920
Colorado	172	0	172
Florida	577	499	1,077
Idaho	369	1,170	2,040
Kansas	3,862	0	3,862
Montana	2	50	53
Nebraska	5,134	1,259	6,393
Nevada	36	91	127
New Mexico	594	123	718
Oklahoma	1,576	134	1,711
Oregon	230	675	905
Texas	4,515	753	5,268
Utah	69	166	236
Washington	587	1,342	1,929
Wyoming	11	133	145
TOTAL	19,556	7,438	26,994

(a) Totals may not add due to rounding.

TABLE 38. Upper Limit of Energy Savings from Instrumented Irrigation Scheduling (Billion Btu)

State	Ground Water ^(a)	Surface Water ^(a)	Total ^(a)
Arizona	191	0	191
Arkansas	0	0	0
California	0	0	0
Colorado	0	0	0
Florida	0	0	0
Idaho	0	0	0
Kansas	0	0	0
Montana	0	0	0
Nebraska	0	0	0
Nevada	0	0	0
New Mexico	0	0	0
Oklahoma	0	0	0
Oregon	0	0	0
Texas	0	0	0
Utah	0	0	0
Washington	0	0	0
Wyoming	0	0	0
TOTAL	191	0	191

(a) Totals may not add due to rounding.

TABLE 39. Upper Limit of Energy Savings by Technical Area (Billion Btu)

	<u>Ground</u>	<u>Surface</u>	<u>Total</u>
Surged Wells	17,709	NA	17,709
Jetted Wells	17,955	NA	17,955
Pump Column, Impeller and Housing Redesign	11,762	NA	11,762
Variable-Speed Pumping	2,890	NA	2,890
Reduced-Pressure Center Pivot	17,986	7,865	25,851
LEPA Center-Pivot and Lateral-Move	28,700	11,064	39,764
Automated Gated Pipe	3,032	0	3,032
Computerized Irrigation Scheduling	19,556	7,434	26,994
Instrumented Irrigation Scheduling	191	0	191

NA-Not applicable.

TABLE 40. Potential Energy Savings in Irrigated Agriculture (Trillion Btu)

<u>Technology</u>	<u>Energy</u>
Wells	13 ^(a)
Pumping Losses	11
Sprinkler Application	32
Gravity Application	3
Scheduling	<u>28</u>
TOTAL	87

(a) This technology is only effective on wells in unconsolidated aquifers. Approximately 77% of all wells in the U.S. are in unconsolidated aquifers (14 = 18 x 0.77).

that current energy use of a conventional center pivot could be reduced by 10% through conversion to reduced pressure and by 20% through computerized scheduling. The current energy use of the center pivot is 250,000 kWh per year. The sum of the individual energy savings would be computed as the following:

$$\begin{aligned}(250,000) - (250,000)(.9) &= 25,000 \\(250,000) - (250,000)(.8) &= 50,000 \\ \text{Total energy savings} &= \underline{75,000}\end{aligned}$$

However, the total savings of introducing both measures simultaneously would be equal to the following:

$$(250,000) - (250,000)(.9)(.8) = 70,000$$

It was not possible, within the scope of this project, to consider all of the impacts of the interaction of the various conservation alternatives on total potential energy savings. However, a "first order adjustment" for interaction impacts was made by assuming that computerized scheduling of sprinkler irrigation would be implemented before all other conservation alternatives were implemented. Computing the interactive impacts of scheduling is straightforward, since a reduction in water use as a result of using computerized scheduling translates into a directly proportional reduction in energy use.

It was assumed in this study that using scheduling on sprinkler irrigated fields would reduce energy use by approximately 24% in all applications where the use of scheduling is cost effective. Thus, to account for the first order interaction of scheduling with wells, pumps, and application systems, the energy savings of using these other conservation alternatives on sprinkler irrigated land were reduced by 24%.

A final consideration in estimating the aggregate potential for energy savings from using energy conservation technologies is that the 17 states which are analyzed in detail use approximately 95% of the total energy used in irrigation. Thus, the total potential energy savings from these 17 states were increased by 5% to reflect this consideration.

The overall annual expected energy savings by applying the conserving systems to existing 1980 irrigated averages, where economically feasible, is expected to be over 87 trillion Btu annually by the year 2000. Thirty-seven percent of the total expected savings is from use of sprinkler application technologies, and 32% of the savings is from using scheduling systems. The annual savings of 87 trillion Btu out of the current 270 trillion Btu used for irrigation amounts to a savings of 32% for irrigation usage.

6.4 WATER SAVINGS

In terms of promoting national welfare, water savings could be equally as important as energy savings. Water is a scarce resource, and its scarcity is expected to continue increasing as greater demands for water in electric power plants, synthetic fuel plants, irrigation and other uses deplete available supplies. Arid areas in the West and Southwest will be particularly prone to water shortages.

Several of the technologies under study will save water as well as energy. These water-conserving technologies are the LEPA system, computerized irrigation scheduling, instrumented irrigation scheduling, and the automated gated-pipe system. In this section, the potential water savings as a result of using these systems will be discussed.

Method of Calculating Water Savings

The LEPA system will save water primarily by decreasing the amount of water retained in the root zone and from reduced evaporation. Water savings for the LEPA system compared to a conventional center pivot system are estimated to be 18% (Lyle and Bordorsky 1981).

Scheduling will save water by two methods. First, irrigation applications will be more timely, which will increase water use efficiency by the crop plants (reductions in deep percolation and runoff losses). Second, the amount of water applied will more accurately reflect crop needs. Estimated water savings as a result of computerized scheduling are 24% for sprinkler irrigation systems, while water savings from instrumented scheduling will be 20% (Lord & Gartung 1981, Prossen 1981).

Automated gated-pipe systems will also save water by enabling more timely application of water through reduction of labor necessary for such applications and greater control of application amounts. Use of an automated gated-pipe system will result in estimated water savings of 20% (Mangese and Bloom 1981).

The methodology for estimating the total potential water savings for the technologies which conserve water is similar to the one used in estimating energy savings.

Water savings estimates are based on the assumption that water-saving technologies will only penetrate the markets where their use is cost effective, but in these markets, penetration will be 100%. Information on gated-pipe-irrigated acreage, sprinkler-irrigated acreage, center-pivot-irrigated acreage, average annual amount of water applied by surface methods, and average annual amount of water applied by sprinklers is presented in Table 41 for each of the 17 major irrigation states.

The total water applied by each irrigation method was calculated by multiplying the irrigated acreage for each method by the average amounts of water applied. From these figures, total water savings resulting from the use of water-conserving technologies was calculated by multiplying the total water applied for each irrigation method by the estimated percentage reduction in water use available for each water-conserving technology. It was assumed that LEPA would replace conventional center-pivot systems, automated gated-pipe systems would replace conventional gated-pipe systems, and scheduling systems would be used on all sprinkler-irrigated acreage.

Expected Water Savings

The estimated water savings from using LEPA rather than conventional center-pivot systems is presented in Table 42 for each of the 17 states except Arkansas, where current information on the amount of land under center-pivot irrigation was unavailable. These estimates were calculated based on an 18% reduction in water use for the LEPA system and on the assumption that LEPA would penetrate center-pivot markets in all states regardless of whether surface water or groundwater was being used for irrigation.

TABLE 41. 1980 Irrigated Acreage and Water Application Amounts

State	Gated-Pipe Irrigated Acreage	Center-Pivot Irrigated Acreage ^(a)	Other Sprinkler Irrigated Acreage	Surface Water Applied ^(b) (acre/feet)	Sprinkler Water Applied ^(b) (acre/feet)
Arizona	8,000	68,000	30,000	4.46	4.37
Arkansas	825,000	73,000	NA	1.85	1.48
California	3,500,000	2,025,000	75,000	3.30	2.64
Colorado	100,000	700,000	680,000	1.15	0.92
Florida	0	815,550	114,250	1.08	0.86
Idaho	70,000	1,832,100	420,800	3.51	2.81
Kansas	2,052,600	1,273,400	1,184,300	1.82	1.46
Montana	0	241,390	43,430	2.74	2.19
Nebraska	2,508,860	3,128,300	2,424,000	1.90	1.52
Nevada	50,300	65,700	40,000	5.05	4.04
New Mexico	NA	160,000	150,000	2.83	2.26
Oklahoma	170,000	480,240	209,000	2.05	1.64
Oregon	0	1,028,000	159,000	3.35	2.68
Texas	270,000	2,197,000	920,000	1.58	1.26
Utah	NA	258,886	31,050	3.13	2.50
Washington	13,000	1,339,000	388,000	4.89	3.91
Wyoming	250,000	179,000	88,000	1.86	1.49

(a) Brantwood Publications. 1980. Irrigation Journal Annual Survey.

(b) Energy Use Tables developed by Pacific Northwest Laboratory.

The estimated water savings from using computerized scheduling on sprinkler-irrigated acreages is presented in Table 43. These estimates were calculated based on a 24% reduction in water use for computerized scheduling and on the assumption that computerized scheduling would penetrate the market for sprinkler irrigation using either surface or groundwater, except in the states of Kansas and Colorado. The levelized cost analysis indicates that use

TABLE 42. Estimated Water Savings for Using LEPA Rather Than Conventional Center Pivot

State	Total Water Applied by Center Pivot(a) (acre/ft)	Total Water Savings(b) (acre/ft)
Arizona	131,100	23,598
Arkansas	NA	NA
California	198,000	35,640
Colorado	625,600	112,608
Florida	98,255	17,686
Idaho	1,182,448	212,841
Kansas	1,729,078	311,234
Montana	95,112	17,120
Nebraska	3,684,480	663,206
Nevada	161,600	29,088
New Mexico	339,000	61,020
Oklahoma	342,760	61,697
Oregon	426,120	76,702
Texas	1,159,200	208,656
Utah	77,625	13,973
Washington	1,517,080	273,074
Wyoming	<u>131,120</u>	<u>23,602</u>
TOTAL	11,989,578	2,141,745

(a) Calculated by multiplying total 1980 center-pivot acreage by average acre-feet of water applied under sprinkler irrigation.

(b) Calculated by multiplying by 0.18, which represents the reduction in water use that could be obtained by using the LEPA system.

TABLE 43. Estimated Water Savings for Computerized Irrigation Scheduling with Sprinkler Irrigation Systems

State	Total Water Applied by Sprinkler ^(a) (acre/ft)	Total Water Savings ^(b) (acre/ft)
Arizona	297,160	71,318
Arkansas	108,040	25,930
California	5,346,000	1,283,040
Colorado	644,000	42,659 ^(c)
Florida	701,373	168,330
Idaho	5,148,201	1,235,568
Kansas	1,859,164	418,088 ^(d)
Montana	528,644	126,875
Nebraska	4,755,016	1,141,204
Nevada	265,428	63,703
New Mexico	361,600	86,784
Oklahoma	787,594	189,022
Oregon	2,755,040	661,210
Texas	2,768,220	664,373
Utah	647,215	155,332
Washington	5,235,490	1,256,518
Wyoming	266,710	64,010
TOTAL	32,474,835	7,653,964

- (a) Calculated by multiplying total 1980 sprinkler acreage by average acre-feet of water applied under sprinkler irrigation.
- (b) Calculated by multiplying by 0.24, which represents the reduction in water use that could be obtained through scheduling.
- (c) Scheduling would be economic only for groundwater irrigation, which includes 27.6% of irrigated acreage in Colorado according to numbers developed by Dvoskin, Nichol and Heady 1975.
- (d) Scheduling would be economic only for groundwater irrigation, which includes 93.7% of irrigated acreage in Kansas, according to numbers presented in Dvoskin and Heady 1976.

of computerized scheduling for sprinkler irrigation would only be cost effective for groundwater irrigation in Kansas and Colorado, and water-savings estimates for these states are for groundwater only.

No water savings were calculated for instrumented scheduling. Based on the levelized cost analysis, instrumental scheduling would only penetrate sprinkler irrigation markets in Arizona. However, the economic benefits of using computerized scheduling in Arizona would be substantially greater than the economic benefits of instrumented scheduling. It is believed that farmers would utilize computerized rather than instrumented scheduling, and water savings estimates are based on this assumption.

The results of the levelized cost analysis demonstrated that the after-tax costs of automated gated-pipe systems were higher than the costs of conventional gated-pipe systems in every case studied for groundwater irrigation in Arizona. Thus, the automated system is assumed to only penetrate the market for conventional gated-pipe systems using groundwater in Arizona. Potential water savings from the use of the automated system in Arizona are calculated as follows:

$$\begin{array}{rclclcl}
 (8000) & \times & (.523) & \times & (5.46) & \times & (.20) & = & 4569 \text{ acre/ft} \\
 \text{Acres irrigated} & & \% \text{ of} & & \text{Average} & & \% \text{ reduction} & & \text{Total water} \\
 \text{by gated pipe} & & \text{groundwater} & & \text{water} & & \text{for automation} & & \text{savings} \\
 & & & & \text{applied} & & & & \\
 & & & & \text{(acre-feet)} & & & &
 \end{array}$$

When the total water savings from LEPA, computerized scheduling, and automated gated pipe systems are summed, approximately 9.8 million acre-feet of water could potentially be saved. This is equal to the capacity of several large water storage reservoirs and could be a significant factor in improving the future water supply situation.

These calculations are based on results obtained from the contractors performing the research projects. It is assumed that the amount of water can be saved without affecting crop yields in any way. If, however, crop yields do suffer, then the resultant savings will be reduced.

7.0 PROSPECTS FOR INCREASING THE ACREAGE UNDER IRRIGATION

The amount of land brought under irrigation in the future will have a significant impact on the energy savings which will result from the use of energy-conserving irrigation technologies. While a detailed projection of irrigated acreages is beyond the scope of this study, information on the current trends in irrigated acreage and the possible factors which are likely to modify these trends can be used to develop some rough forecasts of future irrigated acreages.

The annual percentage changes in irrigated acreage which have occurred during the last 20 years are shown in Table 44. Note that all percentage changes from 1959 to 1980 were positive, except for 1980. The average rate of growth in irrigated acreage in the 21-year period from 1959 to 1980 was 2.06%.

TABLE 44. Total Irrigated Acreage and Percentage Change
in Irrigated Acreage, 1959-1980

<u>Year</u>	<u>Total Irrigated Acreage (1000)</u>	<u>Annual Percentage Change in Irrigated Acreage</u>
1959 ^(a)	33,164	2.3
1964	37,057	2.2
1969	39,122	1.1
1972 ^(b)	49,951	---
1973	51,480	3.1
1974	53,029	3.0
1975	54,044	1.9
1976	56,911	5.3
1977	58,459	2.7
1978	58,893	0.7
1979	61,148	3.8
1980	61,039	-0.2

(a) Source: U.S. Census of Agriculture, 1959, 1964, and 1969.

(b) Source: Brantwood Publications, 1972-1980.
Irrigation Journal Annual Survey.

Technological advances have played a large role in causing the steady increase in irrigated acreage. These advances, such as center-pivot systems, have traditionally been aimed at saving labor rather than water and energy.

The annual change in irrigated acreage is quite variable; many factors can influence the relative amount of irrigated acreage in a given year. These factors include drought, net farm income, financing costs, and availability of water rights.

Because energy costs are a significant factor in determining operating costs for irrigation systems, these costs should influence the amount of acreage brought under irrigation. Economic theory tells us that a farmer will irrigate if the marginal value product of irrigation is greater than or equal to the marginal cost of irrigation. An increase in energy costs increases the marginal costs of irrigation, other factors remaining constant. If a farmer was previously irrigating at the point where marginal value product was equal to marginal cost, an increase in marginal value product would be necessary for irrigation to continue. If the marginal value product of irrigation, which is primarily determined by crop prices and crop yields as a result of irrigation, does not rise as fast as the marginal cost of irrigation, irrigated-acreage growth should be slowed.

Energy prices began to increase rapidly in 1973 with the advent of OPEC and the world oil embargo. Before 1973, energy prices were relatively stable and declining in "real" terms (i.e., the rate of increase in energy prices was less than the rate of increase in the general inflation rate). Most forecasts for the next 20 years (to the year 2000) call for instability and real increases in energy prices. Thus, it is believed that the period since 1973 is more indicative than the period previous to 1973 of the changes in irrigated acreage that are likely to occur in the next 20 years.

The total amount of irrigated acreage in the United States from 1973 to 1980 is illustrated in Figure 1. This figure provides little evidence that energy price increases since 1973 have influenced the amount of irrigated acreage. The average annual rate of increase in total U.S. irrigated acreage,

FIGURE 1. Total Irrigated Acreage in the United States (1000 Acres)

represented in Figure 1, was 2.54% from 1973 to 1980, which is actually higher than the average annual rate of increase from 1959 to 1980.

Sprinkler irrigation is much more energy intensive than gravity flow irrigation. Thus, energy price increases should have a greater impact on sprinkler-irrigated acreage than on total irrigated acreage. The total amount of sprinkler-irrigated acreage in the U.S. is illustrated in Figure 2. This figure indicates that energy price increases have not affected sprinkler-irrigated acreage substantially. The average annual increase in sprinkler-irrigated acreage from 1973 to 1980 was 10.4%. This indicates that from 1973 to 1980, the market share of total irrigated acreage gained by sprinkler systems was increasing.

Annual changes in total and sprinkler-irrigated acreage are illustrated in Figure 3. These annual changes appear to represent a "random walk," with no clearly discernible pattern. Changes in sprinkler-irrigated acreage are less variable than changes in total irrigated acreage. This lesser variability may be attributed to the relatively high costs of installing sprinkler irrigation systems, which necessitate that the systems be used continuously, not merely when a dry year occurs.

The relationship between the numbers used to develop Figures 1 through 3 and time was examined by estimating the simple correlation between time and total irrigated acreage, sprinkler-irrigated acreage, and change in total and sprinkler-irrigated acreage. Two equation specifications were used: a linear specification, and a nonlinear logarithmic specification.

Little correlation between the annual change in irrigated acreage and time was found. This result would be expected from the random patterns of Figure 3. A high degree of correlation was found between time and total irrigated acreage and time and sprinkler-irrigated acreage. The linear specification of the correlation equation fit the data better than the nonlinear specification in all cases.

The results of the correlation analysis on data from 1973 to 1980 indicate that the most accurate method for forecasting future irrigated acreage on the basis of current trends would be simple linear extrapolation. However, although the effects of higher energy prices should be captured in

FIGURE 2. Total Sprinkler Irrigated Acreage in the United States (1000 Acres)

FIGURE 3. Annual Change in Total and Sprinkler Irrigated Acreage (1000 Acres)

the 1973-1980 data, there may be some lag time between the occurrence of higher energy prices and their effect on irrigated acreage. In addition, it is believed that several factors, which are not accounted for in the 1973-1980 data, will cause future increases in irrigated acreage to be reduced.

Reduced water tables will have a significant impact on future irrigated acreages. Groundwater tables in many areas, especially in the arid Southwest region, are being rapidly depleted. Thus, without the rapid introduction of energy-conserving pumps and wells, irrigation from groundwater sources will require higher prices and more energy. Total irrigation energy costs will escalate faster than energy prices, and the rate of increase in irrigated acreage will be reduced.

Publicly funded irrigation activities will impact the amount of land brought under irrigation in the future. A summary of the 1978 status of projects being developed by the federally funded Bureau of Reclamation is presented in Table 45. Of the projects listed in Table 45, a total of 1,623,410 acres is actually under construction or has been authorized for construction. The rest of the projects remain in the study or study-completed stage.

It is believed that future expansion in irrigated acreage will be limited by the general tightness of future public funding. It appears that the government will be more apprehensive, in the future, about subsidizing the development of irrigated acreage.

Higher costs for publicly provided irrigation services are another important factor which will inhibit future irrigation development. Many authorities argue that the cost which irrigation users have traditionally paid for publicly provided irrigation water is substantially below the true costs of providing this water. A movement is currently underway to cause water-user fees to more accurately reflect the true costs of water delivery. Success in this movement could raise water-user fees substantially and possibly lead to a reduction in future irrigated acreage.

TABLE 45. Summary of Projected Development(a)

<u>State</u>	<u>Project</u>	<u>Size (acres)</u>	<u>Status (as of 1978)</u>
Arizona	Central Arizona Project	240,000	Under construction
California	Auburn-Folsom South Unit		Constructing cur- tailed due to safety concerns
	Tehama-Colusa Canal	244,000	Under construction
	Westlands	550,000	Under construction
	San Felipe Division	38,700	Under construction
	Butte Valley Division		Study
	Calaveras County Division		Study
	Appraisal		
	Central Valley Total Water Management		Study
	Consumnes River Division Re- formulation		Study
	Delta Support		
	East Side Division, Mid-Valley Canal, 650,000 acre-feet		Study
	Folsom South-American River Alternatives		Study
Colorado	Upper Colorado Resource Western Energy Expansion		Study Study
Idaho			
Kansas	Scandia Unit	18,000	Study
Montana	Moorhead Unit	40,000	Study
	Three Forks Division	185,000	Study
	Yellowstone Division		Study
	Sun-Teton Division		Study
	Northeast Montana Division	38,850	Study
	Flathead River Project	15,000	Study deferred
	Hardin Unit	43,600	Proposed, but not authorized for construction
	Marias-Milk Unit	72,000	Study
	West Bench Unit	6,450	Fund authorized
	Cracker Box and Stipek	5,580	Study completed
Nebraska	Cedar Rapids Division		Study
	Elkhorn Division		Study
	Crofton Unit		Study
	Little Blue Unit	20,000	Study
	Sunbeam Unit	30,000	Study

TABLE 45. (Continued)

<u>State</u>	<u>Project</u>	<u>Size (acres)</u>	<u>Status (as of 1978)</u>
Nevada			
New Mexico	Jicarilla Apache Indian Reservation	9,450	Study
North Dakota			
Oklahoma	Crimer Hills Project		
Oregon	Catherine Creek Reservoir Grants Pass Division Medford Division Tualatin Project Umatilla Basin	18,000	Study Study Study Study Study
South Dakota	Pollock-Herreid Unit Forth Thompson Unit Grass Rope Unit Sioux Falls Unit	15,000 5,900 3,800	Project authorized Study completed Study completed Report under review
Texas	American Canal Extension Cibolo Project Texas Basins Project	750,000	Project authorized Project authorized Study
Utah	Ute Indian Unit		Study
Washington	Second Bacon Siphon and Tunnel Oroville-Tonasket Unit Touchet Division Kennewick Division	500,000 10,000 6,300	Under construction Authorized Study Study
Wyoming	Polecat Bench Area Muddy Ridge Area Green River Basin	19,260 9,000	Authorized Study Study

(a) Bureau of Reclamation 1978.

An example is provided by recent events related to the 500,000-acre Second Bacon Siphon and Tunnel project in Washington state. This project comprises nearly a third of the total acreage that is under construction or has been authorized for construction by the Bureau of Reclamation. Irrigation service authorities have proposed a price for the water from this project, when it is completed, that is substantially higher than what water users are paying on other public projects, but which, they say, more accurately reflects the true cost of providing the water. Farmers have responded that they cannot afford to pay the proposed price and, therefore, will not use the water.

A final factor likely to inhibit future irrigation expansion is that most areas that require irrigation and have easily accessible water supplies have already been developed. Future development will have to take place in land areas more marginal either in terms of the need for irrigation or the availability of water.

For the reasons cited above, it is believed that irrigated acreage will probably grow at a rate of from 1.0 to 2% per year to the year 2000, even though this acreage grew at a rate of 2.54% in a period of rapidly escalating energy prices from 1973 to 1980. The total energy savings resulting from the use of energy-conserving technologies will increase if irrigated acreage is increased. The amount of increased energy savings, however, will depend on the type of system used to irrigate the new land. If it is assumed that the mix among the various types of irrigation systems will remain constant, then estimated energy savings from the use of the energy-saving technologies over conventional technologies for a 1.0 to 2.0% annual increase in irrigated acreage could range between 70 and 140 trillion Btu.

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APPENDIX A

ENERGY USE IN IRRIGATION TABLES

APPENDIX A

ENERGY USE IN IRRIGATION TABLES

The tables contained in Appendix A were generated from the energy-use equations and irrigation data discussed in Chapter 2 of this report. Each of the top 17 irrigation states (according to irrigated acreage) is shown in a separate table which contains irrigation energy-use information. Energy usage in each table is shown by application system type, water source and fuel type. As an example, Arizona uses 15,819 billion Btu for irrigation, with 15,134 billion Btu being used by systems supplied with ground water. Out of the 15,134 billion Btu, natural gas amounts for 8,307 billion Btu. Gravity flow irrigation systems amount for 14,537 billion Btu in Arizona with 7,760 billion Btu from LPG sources being supplied from groundwater sources.

TABLE A.1. Energy Used by Irrigated Agriculture in Arizona (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	6085	7760	293	0	0	172	219	8	0	0	14537
Cnt Pivot	199	254	10	0	0	63	80	3	0	0	609
Tlineside	86	110	4	0	0	24	30	1	0	0	255
Hand Moved	110	140	5	0	0	29	37	1	0	0	324
Solid Set	12	16	1	0	0	3	4	0	0	0	36
Trav/Gun	0	0	0	0	0	0	0	0	0	0	0
Trickle	15	19	1	0	0	2	2	0	0	0	38
Lateral	6	8	0	0	0	2	2	0	0	0	19
Total By Source			15134					685			15819

TABLE A.2. Energy Used by Irrigated Agriculture in Arkansas (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	231	274	434	1370	1984	18	22	34	108	157	4633
Cnt Pivot	0	0	1	2	3	0	0	0	0	0	7
Tlineside	0	0	0	1	1	0	0	0	0	0	4
Hand Moved	24	28	44	140	203	4	5	7	23	34	512
Solid Set	0	0	0	1	1	0	0	0	0	0	4
Trav/Gun	1	1	2	5	7	0	0	0	1	1	19
Trickle	0	0	0	0	0	0	0	0	0	0	1
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			4761					417			5179

TABLE A.3. Energy Used by Irrigated Agriculture in California (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	7333	772	2444	0	0	2060	217	687	0	0	13512
Cnt Pivot	140	15	47	0	0	147	16	49	0	0	413
Tlineside	276	29	92	0	0	271	28	90	0	0	786
Hand Moved	1832	193	611	0	0	1777	187	592	0	0	5191
Solid Set	568	60	189	0	0	557	59	186	0	0	1619
Trav/Gun	12	1	4	0	0	15	2	5	0	0	39
Trickle	293	31	98	0	0	171	18	57	0	0	668
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			15039					7189			22228

TABLE A.4. Energy Used by Irrigated Agriculture in Colorado (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	551	317	140	35	351	241	139	61	15	153	2003
Cnt Pivot	265	152	67	17	169	455	262	115	29	290	1822
Tlineside	10	6	3	1	7	16	9	4	1	10	67
Hand Moved	4	2	1	0	3	6	4	2	0	4	26
Solid Set	6	3	1	0	4	9	5	2	1	6	38
Trav/Gun	1	0	0	0	0	1	1	0	0	1	4
Trickle	0	0	0	0	0	0	0	0	0	0	0
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			2115					1845			3960

TABLE A.5. Energy Used by Irrigated Agriculture in Florida (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	65	118	1119	236	256	13	23	223	47	51	2149
Cnt Pivot	11	20	193	41	44	9	17	160	34	37	566
Tlineside	0	0	1	0	0	0	0	1	0	0	2
Hand Moved	7	13	122	26	28	5	10	93	20	21	344
Solid Set	16	29	278	58	64	12	23	214	45	49	788
Trav/Gun	51	93	883	186	202	47	85	810	170	185	2713
Trickle	2	3	30	6	7	1	1	14	3	3	69
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			4206					2425			6631

TABLE A.6. Energy Used by Irrigated Agriculture in Idaho (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	3036	74	117	74	67	822	20	32	20	18	4279
Cnt Pivot	813	20	31	20	18	1206	29	46	29	26	2239
Tlineside	928	23	36	23	20	1219	30	47	30	27	2381
Hand Moved	1409	34	54	34	31	1818	44	70	44	40	3579
Solid Set	140	3	5	3	3	183	4	7	4	4	358
Trav/Gun	0	0	0	0	0	0	0	0	0	0	0
Trickle	0	0	0	0	0	0	0	0	0	0	0
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			7016					5821			12837

TABLE A.7. Energy Used by Irrigated Agriculture in Kansas (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	1061	13880	2652	0	1516	10	131	25	0	14	19289
Cnt Pivot	837	10944	2091	0	1195	32	416	80	0	45	15640
Tlineside	19	248	47	0	27	1	9	2	0	1	353
Hand Moved	0	0	0	0	0	0	0	0	0	0	0
Solid Set	1	8	2	0	1	0	0	0	0	0	12
Trav/Gun	38	502	96	0	55	2	22	4	0	2	722
Trickle	0	1	0	0	0	0	0	0	0	0	1
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			35220					797			36017

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TABLE A.8. Energy Used by Irrigated Agriculture in Montana (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	253	0	10	25	11	3377	0	132	333	151	4293
Cnt Pivot	8	0	0	1	0	146	0	6	14	7	183
Tlineside	2	0	0	0	0	29	0	1	3	1	36
Hand Moved	0	0	0	0	0	0	0	0	0	0	0
Solid Set	0	0	0	0	0	0	0	0	0	0	0
Trav/Gun	0	0	0	0	0	0	0	0	0	0	0
Trickle	0	0	0	0	0	0	0	0	0	0	0
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			311					4201			4512

TABLE A.9. Energy Used by Irrigated Agriculture in Nebraska (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	1440	4839	5573	220	2786	139	466	536	21	268	16288
Cnt Pivot	1658	5575	6420	253	3210	410	1377	1586	63	793	21345
Tlineside	356	1198	1380	54	690	83	280	322	13	161	4537
Hand Moved	12	39	45	2	23	3	9	10	0	5	148
Solid Set	3	11	12	0	6	1	2	3	0	1	40
Trav/Gun	70	236	271	11	136	19	63	73	3	37	918
Trickle	0	0	0	0	0	0	0	0	0	0	0
Lateral	1	2	2	0	1	0	0	1	0	0	8
Total By Source			36536					6749			43285

TABLE A.10. Energy Used by Irrigated Agriculture in Nevada (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	785	0	755	48	43	786	0	756	48	43	3264
Cnt Pivot	54	0	52	3	3	140	0	134	8	8	403
Tlineside	0	0	0	0	0	0	0	0	0	0	0
Hand Moved	3	0	3	0	0	7	0	7	0	0	20
Solid Set	15	0	15	1	1	37	0	36	2	2	109
Trav/Gun	0	0	0	0	0	0	0	0	0	0	0
Trickle	0	0	0	0	0	0	0	0	0	0	0
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			1782					2015			3796

TABLE A.11. Energy Used by Irrigated Agriculture in New Mexico (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	938	9775	1407	889	0	28	290	42	26	0	13394
Cnt Pivot	169	1764	254	160	0	35	368	53	33	0	2837
Tlineside	6	64	9	6	0	1	12	2	1	0	101
Hand Moved	4	42	6	4	0	1	8	1	1	0	67
Solid Set	0	0	0	0	0	0	0	0	0	0	0
Trav/Gun	0	0	0	0	0	0	0	0	0	0	0
Trickle	1	8	1	1	0	0	1	0	0	0	11
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			15508					903			16411

TABLE A.12. Energy Used by Irrigated Agriculture in Oklahoma (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	161	2674	340	95	734	3	58	7	2	16	4092
Cnt Pivot	122	2021	257	72	555	11	179	23	6	49	3296
Tlineside	101	1667	212	60	458	8	134	17	5	37	2697
Hand Moved	24	403	51	14	111	2	32	4	1	9	652
Solid Set	2	32	4	1	9	0	3	0	0	1	52
Trav/Gun	18	302	38	11	83	2	31	4	1	9	500
Trickle	0	4	0	0	1	0	0	0	0	0	6
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			10641					654			11296

TABLE A.13. Energy Used by Irrigated Agriculture in Oregon (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	672	0	0	0	0	393	0	0	0	0	1066
Cnt Pivot	159	0	0	0	0	510	0	0	0	0	669
Tlineside	383	0	0	0	0	1086	0	0	0	0	1469
Hand Moved	339	0	0	0	0	943	0	0	0	0	1282
Solid Set	30	0	0	0	0	86	0	0	0	0	116
Trav/Gun	52	0	0	0	0	203	0	0	0	0	255
Trickle	1	0	0	0	0	1	0	0	0	0	2
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			1637					3221			4858

TABLE A.14. Energy Used by Irrigated Agriculture in Texas (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	3218	26002	2129	0	811	227	1830	150	0	57	34424
Cnt Pivot	793	6405	525	0	200	136	1103	90	0	34	9286
Tlineside	678	5482	449	0	171	108	874	72	0	27	7862
Hand Moved	298	2410	197	0	75	47	380	31	0	12	3450
Solid Set	2	19	2	0	1	0	3	0	0	0	27
Trav/Gun	126	1018	83	0	32	25	199	16	0	6	1505
Trickle	11	86	7	0	3	1	9	1	0	0	118
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			51231					5439			56671

TABLE A.15. Energy Used by Irrigated Agriculture in Utah (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	701	0	109	0	0	416	0	65	0	0	1291
Cnt Pivot	33	0	5	0	0	87	0	14	0	0	139
Tlineside	134	0	21	0	0	318	0	50	0	0	524
Hand Moved	81	0	13	0	0	189	0	29	0	0	312
Solid Set	1	0	0	0	0	2	0	0	0	0	4
Trav/Gun	2	0	0	0	0	5	0	1	0	0	8
Trickle	0	0	0	0	0	1	0	0	0	0	1
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			1102					1177			2278

TABLE A.16. Energy Used by Irrigated Agriculture in Washington (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	813	0	0	0	0	551	0	0	0	0	1364
Cnt Pivot	755	0	0	0	0	1868	0	0	0	0	2623
Tlineside	772	0	0	0	0	1712	0	0	0	0	2484
Hand Moved	751	0	0	0	0	1639	0	0	0	0	2390
Solid Set	161	0	0	0	0	357	0	0	0	0	517
Trav/Gun	3	0	0	0	0	9	0	0	0	0	12
Trickle	6	0	0	0	0	7	0	0	0	0	13
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			3261					6142			9403

TABLE A.17. Energy Used by Irrigated Agriculture in Wyoming (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	136	64	64	8	7	566	268	265	34	30	1443
Cnt Pivot	12	6	6	1	1	145	69	68	9	8	323
Tlineside	8	4	4	0	0	83	39	39	5	4	185
Hand Moved	3	1	1	0	0	29	14	14	2	2	65
Solid Set	0	0	0	0	0	4	2	2	0	0	9
Trav/Gun	1	0	0	0	0	8	4	4	0	0	18
Trickle	0	0	0	0	0	0	0	0	0	0	1
Lateral	0	0	0	0	0	0	0	0	0	0	0
Total By Source			328					1716			2044

TABLE A.18. Energy Used by Irrigated Agriculture in the United States (Billion Btu)

System	Groundwater					Surface Water					Total by System
	Elect	Nat Gas	Diesel	Gas	LPG	Elect	Nat Gas	Diesel	Gas	LPG	
Grav Flow	27479	66548	17585	3000	8566	9822	3684	3023	655	959	141320
Cnt Pivot	6029	27176	9958	570	5397	5400	3917	2427	226	1298	62400
Tlineside	3760	8831	2258	145	1375	4958	1444	646	57	269	23744
Hand Moved	4900	3306	1154	220	473	6499	729	862	92	127	18361
Solid Set	958	182	509	66	89	1253	106	451	53	64	3729
Trav/Gun	375	2154	1379	213	515	335	407	918	176	241	6712
Trickle	329	151	137	7	11	184	31	72	3	3	929
Lateral	7	10	3	0	1	2	3	1	0	0	27
Total By Source			205827					51396			257223

APPENDIX B

PROPORTIONAL ENERGY USE CHANGE TABLES

APPENDIX B

PROPORTIONAL ENERGY USE CHANGE TABLES

The tables contained in Appendix B were generated by substituting the technical parameters of conserving systems for those of conventional systems in the energy-use formulas. The change shown in the tables has been calculated by dividing the change in energy usage (conventional minus conserving) divided by the base energy usage (conventional).

The 10 technologies discussed in "Potential Energy and Water Savings from Energy-Conserving Irrigation Systems" are included, one technology for each table. The tables have been broken down by state, water source and conventional system type. As an example, the surged well will save 13 (-.1299 in Table B.1) of the energy currently used in groundwater-supplied gravity flow systems in the state of Texas and 7 (-.0688 in Table B.1) of the energy in surface-supplied systems in Texas. Zeros in the tables indicate that a given state does not use a particular system, a particular system is not comparable with an energy conserving system, a system is not able to be used with a particular water source, or an energy-conserving system is more expensive than a particular conventional system and is assumed not to penetrate. Zeros do not imply that technical energy savings are not possible from replacing a particular conventional system with an energy-conserving system.

TABLE B.1. Proportional Change in Energy Use for Surged Well

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	-.1299	-.0688	-.0765	-.0776	-.0765	-.0551	-.1101	-.0725
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	-.0922	-.0344	-.0397	-.0405	-.0397	-.0258	-.0688	-.0369
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	-.0896	-.0453	-.0506	-.0514	-.0506	-.0359	-.0748	-.0478
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	-.1067	-.0718	-.0772	-.0779	-.0772	-.0612	-.0972	-.0744
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	-.0920	-.0535	-.0588	-.0595	-.0588	-.0438	-.0803	-.0560
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	-.1411	-.0555	-.0637	-.0649	-.0637	-.0420	-.1076	-.0593
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	-.0921	-.0565	-.0616	-.0623	-.0616	-.0469	-.0817	-.0590
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	-.1467	-.0778	-.0864	-.0876	-.0864	-.0622	-.1244	-.0819
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	-.1564	-.0645	-.0738	-.0751	-.0738	-.0492	-.1215	-.0688
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	-.0990	-.0591	-.0646	-.0654	-.0646	-.0486	-.0871	-.0617
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	-.1195	-.0331	-.0391	-.0400	-.0391	-.0239	-.0782	-.0359
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	-.0643	-.0233	-.0270	-.0275	-.0270	-.0174	-.0475	-.0250
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	-.1076	-.0402	-.0463	-.0472	-.0463	-.0301	-.0803	-.0430
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	-.1536	-.0574	-.0662	-.0675	-.0662	-.0430	-.1147	-.0615
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	-.1162	-.0648	-.0715	-.0725	-.0715	-.0524	-.1001	-.0680
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	-.1062	-.0492	-.0555	0.0564	0.0555	0.0382	-.0860	-.0521
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE B.2. Proportional Change in Energy Use for Jetted Well

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	-.1630	-.0864	-.0960	-.0973	-.0960	-.0691	-.1382	-.0909
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	-.1157	-.0432	-.0498	-.0508	-.0498	-.0324	-.0864	-.0463
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	-.1339	-.0901	-.0969	-.0978	-.0969	-.0768	-.1220	-.0934
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	-.1154	-.0672	-.0737	-.0747	-.0737	-.0550	-.1008	-.0703
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	-.1770	-.0697	-.0800	-.0815	-.0800	-.0527	-.1350	-.0745
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	-.1156	-.0710	-.0773	-.0782	-.0773	-.0589	-.1025	-.0740
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	-.1841	-.0976	-.1084	-.1100	-.1084	-.0781	-.1561	-.1027
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	-.0311	-.0185	-.0203	-.0205	-.0203	-.0153	-.0273	-.0194
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	-.1963	-.0810	-.0926	-.0942	-.0926	-.0617	-.1524	-.0864
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	-.1243	-.0742	-.0811	-.0821	-.0811	-.0610	-.1093	-.0775
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	-.1333	-.0617	-.0697	-.0708	-.0697	-.0480	-.1080	-.0654
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE B.3. Proportional Change in Energy Use for Variable-Speed Pumping

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	-.1914	-.1914	-.1914	-.1914	-.1914	-.1914	0.0000	-.1914
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE B.4. Proportional Change in Energy Use for Redesigned Pump

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	0.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571	-.0571
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE B.5. Proportional Change in Energy Use for LEPA-Lateral Move

State	Source	Grav Flow	Cent Piv	Tow/Side	Hand Move	Sol Set	Trav/Gun	Trickle	Lat Move
Texas	G	0.0000	-.5388	0.0000	0.0000	0.0000	0.0000	0.0000	-.5145
	S	0.0000	-.7779	0.0000	0.0000	0.0000	0.0000	0.0000	-.7577
Nebraska	G	0.0000	-.6583	0.0000	0.0000	0.0000	0.0000	0.0000	-.6339
	S	0.0000	-.8323	0.0000	0.0000	0.0000	0.0000	0.0000	-.8155
Kansas	G	0.0000	-.5576	0.0000	0.0000	0.0000	0.0000	0.0000	-.5331
	S	0.0000	-.8474	0.0000	0.0000	0.0000	0.0000	0.0000	-.8318
Arizona	G	0.0000	-.4296	0.0000	0.0000	0.0000	0.0000	0.0000	-.4090
	S	0.0000	-.8975	0.0000	0.0000	0.0000	0.0000	0.0000	-.8861
New Mexico	G	0.0000	-.4989	0.0000	0.0000	0.0000	0.0000	0.0000	-.4756
	S	0.0000	-.8800	0.0000	0.0000	0.0000	0.0000	0.0000	-.8670
California	G	0.0000	-.6429	0.0000	0.0000	0.0000	0.0000	0.0000	-.6183
	S	0.0000	-.8633	0.0000	0.0000	0.0000	0.0000	0.0000	-.8489
Washington	G	0.0000	-.4747	0.0000	0.0000	0.0000	0.0000	0.0000	-.4522
	S	0.0000	-.8150	0.0000	0.0000	0.0000	0.0000	0.0000	-.7970
Oklahoma	G	0.0000	-.5388	0.0000	0.0000	0.0000	0.0000	0.0000	-.5145
	S	0.0000	-.8444	0.0000	0.0000	0.0000	0.0000	0.0000	-.8285
Idaho	G	0.0000	-.4879	0.0000	0.0000	0.0000	0.0000	0.0000	-.4650
	S	0.0000	-.8601	0.0000	0.0000	0.0000	0.0000	0.0000	-.8454
Colorado	G	0.0000	-.6284	0.0000	0.0000	0.0000	0.0000	0.0000	-.6037
	S	0.0000	-.8633	0.0000	0.0000	0.0000	0.0000	0.0000	-.8489
Oregon	G	0.0000	-.4879	0.0000	0.0000	0.0000	0.0000	0.0000	-.4650
	S	0.0000	-.8601	0.0000	0.0000	0.0000	0.0000	0.0000	-.8454
Arkansas	G	0.0000	-.7319	0.0000	0.0000	0.0000	0.0000	0.0000	-.7096
	S	0.0000	-.8474	0.0000	0.0000	0.0000	0.0000	0.0000	-.8318
Florida	G	0.0000	-.6664	0.0000	0.0000	0.0000	0.0000	0.0000	-.6422
	S	0.0000	-.8766	0.0000	0.0000	0.0000	0.0000	0.0000	-.8633
Montana	G	0.0000	-.6583	0.0000	0.0000	0.0000	0.0000	0.0000	-.6339
	S	0.0000	-.7319	0.0000	0.0000	0.0000	0.0000	0.0000	-.7096
Nevada	G	0.0000	-.6583	0.0000	0.0000	0.0000	0.0000	0.0000	-.6339
	S	0.0000	-.8323	0.0000	0.0000	0.0000	0.0000	0.0000	-.8155
Utah	G	0.0000	-.5176	0.0000	0.0000	0.0000	0.0000	0.0000	-.4938
	S	0.0000	-.8474	0.0000	0.0000	0.0000	0.0000	0.0000	-.8318
Wyoming	G	0.0000	-.5900	0.0000	0.0000	0.0000	0.0000	0.0000	-.5652
	S	0.0000	-.8178	0.0000	0.0000	0.0000	0.0000	0.0000	-.8000

TABLE B.6. Proportional Change in Energy Use for Reduced-Pressure Center Pivot

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	0.0000	-.3250	0.0000	0.0000	0.0000	0.0000	0.0000	-.2895
	S	0.0000	-.5417	0.0000	0.0000	0.0000	0.0000	0.0000	-.5000
Nebraska	G	0.0000	-.4333	0.0000	0.0000	0.0000	0.0000	0.0000	-.3929
	S	0.0000	-.5909	0.0000	0.0000	0.0000	0.0000	0.0000	-.5500
Kansas	G	0.0000	-.3421	0.0000	0.0000	0.0000	0.0000	0.0000	-.3056
	S	0.0000	-.6047	0.0000	0.0000	0.0000	0.0000	0.0000	-.5641
Arizona	G	0.0000	-.2261	0.0000	0.0000	0.0000	0.0000	0.0000	-.1982
	S	0.0000	-.6500	0.0000	0.0000	0.0000	0.0000	0.0000	-.6111
New Mexico	G	0.0000	-.2889	0.0000	0.0000	0.0000	0.0000	0.0000	-.2558
	S	0.0000	-.6341	0.0000	0.0000	0.0000	0.0000	0.0000	-.5946
California	G	0.0000	-.4194	0.0000	0.0000	0.0000	0.0000	0.0000	-.3793
	S	0.0000	-.6190	0.0000	0.0000	0.0000	0.0000	0.0000	-.5789
Washington	G	0.0000	-.2669	0.0000	0.0000	0.0000	0.0000	0.0000	-.2355
	S	0.0000	-.5752	0.0000	0.0000	0.0000	0.0000	0.0000	-.5340
Oklahoma	G	0.0000	-.3250	0.0000	0.0000	0.0000	0.0000	0.0000	-.2895
	S	0.0000	-.6019	0.0000	0.0000	0.0000	0.0000	0.0000	-.5612
Idaho	G	0.0000	-.2790	0.0000	0.0000	0.0000	0.0000	0.0000	-.2466
	S	0.0000	-.6161	0.0000	0.0000	0.0000	0.0000	0.0000	-.5759
Colorado	G	0.0000	-.4063	0.0000	0.0000	0.0000	0.0000	0.0000	-.3667
	S	0.0000	-.6190	0.0000	0.0000	0.0000	0.0000	0.0000	-.5789
Oregon	G	0.0000	-.2790	0.0000	0.0000	0.0000	0.0000	0.0000	-.2466
	S	0.0000	-.6161	0.0000	0.0000	0.0000	0.0000	0.0000	-.5759
Arkansas	G	0.0000	-.5000	0.0000	0.0000	0.0000	0.0000	0.0000	-.4583
	S	0.0000	-.6047	0.0000	0.0000	0.0000	0.0000	0.0000	-.5641
Florida	G	0.0000	-.4407	0.0000	0.0000	0.0000	0.0000	0.0000	-.4000
	S	0.0000	-.6311	0.0000	0.0000	0.0000	0.0000	0.0000	-.5914
Montana	G	0.0000	-.4333	0.0000	0.0000	0.0000	0.0000	0.0000	-.3929
	S	0.0000	-.5000	0.0000	0.0000	0.0000	0.0000	0.0000	-.4583
Nevada	G	0.0000	-.4333	0.0000	0.0000	0.0000	0.0000	0.0000	-.3929
	S	0.0000	-.5909	0.0000	0.0000	0.0000	0.0000	0.0000	-.5500
Utah	G	0.0000	-.3059	0.0000	0.0000	0.0000	0.0000	0.0000	-.2716
	S	0.0000	-.6047	0.0000	0.0000	0.0000	0.0000	0.0000	-.5641
Wyoming	G	0.0000	-.3714	0.0000	0.0000	0.0000	0.0000	0.0000	-.3333
	S	0.0000	-.5778	0.0000	0.0000	0.0000	0.0000	0.0000	-.5366

TABLE B.7. Proportional Change in Energy Use for Automated Gated Pipe

State	Source	Grav Flow	Cent Piv	Tow/Side	Hand Move	Sol Set	Trav/Gun	Trickle	Lat Move
Texas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	-0.2145	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE B.8. Proportional Change in Energy Use for Computerized Scheduling

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	0.0000	-.2381	-.2381	-.2381	-.2381	-.2381	0.0000	-.2381
	S	0.0000	-.2381	-.2381	-.2381	-.2381	-.2381	0.0000	-.2381
Nebraska	G	0.0000	-.2368	-.2368	-.2368	-.2368	-.2368	0.0000	-.2368
	S	0.0000	-.2368	-.2368	-.2368	-.2368	-.2368	0.0000	-.2368
Kansas	G	0.0000	-.2397	-.2397	-.2397	-.2397	-.2397	0.0000	-.2397
	S	0.0000	-.2397	-.2397	-.2397	-.2397	-.2397	0.0000	-.2397
Arizona	G	0.0000	-.2403	-.2403	-.2403	-.2403	-.2403	0.0000	-.2403
	S	0.0000	-.2403	-.2403	-.2403	-.2403	-.2403	0.0000	-.2403
New Mexico	G	0.0000	-.2389	-.2389	-.2389	-.2389	-.2389	0.0000	-.2389
	S	0.0000	-.2389	-.2389	-.2389	-.2389	-.2389	0.0000	-.2389
California	G	0.0000	-.2386	-.2386	-.2386	-.2386	-.2386	0.0000	-.2386
	S	0.0000	-.2386	-.2386	-.2386	-.2386	-.2386	0.0000	-.2386
Washington	G	0.0000	-.2404	-.2404	-.2404	-.2404	-.2404	0.0000	-.2404
	S	0.0000	-.2404	-.2404	-.2404	-.2404	-.2404	0.0000	-.2404
Oklahoma	G	0.0000	-.2378	-.2378	-.2378	-.2378	-.2378	0.0000	-.2378
	S	0.0000	-.2378	-.2378	-.2378	-.2378	-.2378	0.0000	-.2378
Idaho	G	0.0000	-.2384	-.2384	-.2384	-.2384	-.2384	0.0000	-.2384
	S	0.0000	-.2384	-.2384	-.2384	-.2384	-.2384	0.0000	-.2384
Colorado	G	0.0000	-.2391	-.2391	-.2391	-.2391	-.2391	0.0000	-.2391
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	0.0000	-.2388	-.2388	-.2388	-.2388	-.2388	0.0000	-.2388
	S	0.0000	-.2388	-.2388	-.2388	-.2388	-.2388	0.0000	-.2388
Arkansas	G	0.0000	-.2432	-.2432	-.2432	-.2432	-.2432	0.0000	-.2432
	S	0.0000	-.2432	-.2432	-.2432	-.2432	-.2432	0.0000	-.2432
Florida	G	0.0000	-.2442	-.2442	-.2442	-.2442	-.2442	0.0000	-.2442
	S	0.0000	-.2442	-.2442	-.2442	-.2442	-.2442	0.0000	-.2442
Montana	G	0.0000	-.2420	-.2420	-.2420	-.2420	-.2420	0.0000	-.2420
	S	0.0000	-.2420	-.2420	-.2420	-.2420	-.2420	0.0000	-.2420
Nevada	G	0.0000	-.2401	-.2401	-.2401	-.2401	-.2401	0.0000	-.2401
	S	0.0000	-.2401	-.2401	-.2401	-.2401	-.2401	0.0000	-.2401
Utah	G	0.0000	-.2400	-.2400	-.2400	-.2400	-.2400	0.0000	-.2400
	S	0.0000	-.2400	-.2400	-.2400	-.2400	-.2400	0.0000	-.2400
Wyoming	G	0.0000	-.2416	-.2416	-.2416	-.2416	-.2416	0.0000	-.2416
	S	0.0000	-.2416	-.2416	-.2416	-.2416	-.2416	0.0000	-.2416

TABLE B.9. Proportional Change in Energy Use for Instrumented Scheduling

<u>State</u>	<u>Source</u>	<u>Grav Flow</u>	<u>Cent Piv</u>	<u>Tow/Side</u>	<u>Hand Move</u>	<u>Sol Set</u>	<u>Trav/Gun</u>	<u>Trickle</u>	<u>Lat Move</u>
Texas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nebraska	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Kansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arizona	G	0.0000	-0.1991	-0.1991	-0.1991	-0.1991	-0.1991	0.0000	-0.1991
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
New Mexico	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
California	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Washington	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oklahoma	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Idaho	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Colorado	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Oregon	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Arkansas	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Florida	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Montana	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Nevada	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Utah	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wyoming	G	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	S	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

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Forrestal Building
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Dr. G. Pratt
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Administration
Beltsville, MD 20705

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Research
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Caparra Heights Station
San Juan, Puerto Rico 00935

Mr. John Archbold
Foxlease Farms of Archbold
Investment Co.
Upperville, VA 22176

Dr. Larry P. Walker
Agricultural Engineering Department
Cornell University
Ithaca, NY 14853

Mr. Tom Snider
CENTEC
11800 Sunrise Valley Drive
Reston, VA 22091

Dr. David Pinkerton
Energy Management Corp.
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