**An Analysis of the Research and
Development Effort in the Private Sector
to Reduce Energy Consumption in
Irrigated Agriculture**

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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AN ANALYSIS OF THE RESEARCH AND DEVELOPMENT
EFFORT IN THE PRIVATE SECTOR TO REDUCE
ENERGY CONSUMPTION IN IRRIGATED AGRICULTURE

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PREFACE

The Pacific Northwest Laboratory, operated by the Battelle Memorial Institute, has been supporting the Agriculture and Food Processing Branch of the Office of Industrial Programs, Department of Energy, since 1977 in its efforts to issue a program opportunity notice for the design, development, and demonstration of new technologies for reducing crude oil and natural gas consumption in the irrigation of agricultural crops, while not reducing agricultural productivity. Toward that end PNL has technically and administratively monitored the ten successful contractors under that program opportunity notice.

In an effort to integrate the work of each of the ten contractors, PNL has undertaken the analysis of research and development in the private sector to identify participants and activities that would be of benefit to the ongoing Department of Energy contracts. This research report is intended to form a catalyst to further interaction between the public and private sectors.

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SUMMARY

Manufacturers of irrigation equipment perform research and development in an effort to improve or maintain their position in a very competitive market. This report describes the market forces and conditions that create the intense competition and provide incentive for invention. Particular emphasis is placed on the market force of increased energy costs, but the analysis is developed from the perspective that energy is but one of many inputs to agricultural production.

This analysis is based upon published literature, patent activity profiles, microeconomic theory, and conversations with many representatives of the irrigation industry. The published literature provides an understanding of the historical development of irrigation technology, a description of the industry's structure, and various data, which were important for the quantitative analyses. The patent activity profiles, obtained from the U.S. Patent Office, provided details of patent activity within the irrigation industry over the past decade. Microeconomic theory was used to estimate industry-wide research and development expenditures on energy-conserving products. The results of these analyses were then compared with the insights gained from conversations with the industry representatives.

CONCLUSIONS

- The irrigation equipment industry is characterized by intense competition for a limited, but expanding market. Although a few of the larger manufacturers control a high percentage of the market, no single firm is in a monopoly position. The extent of the irrigation equipment market varies from year to year and depends on weather, crop prices, and other factors beyond the control of the industry. The past few years have been characterized as particularly bad for the industry, and many small firms have been forced to close or sell-out to larger firms.
- Energy is one of many inputs to irrigated agriculture. While the absolute cost of energy has risen dramatically the past few years, the prices of all other major inputs have also risen. Relative energy cost increases were not considered to be significant by the irrigation equipment industry until the late 1970s.
- The irrigation equipment industry is involved with a variety of research and development activities. The availability of venture capital is the greatest constraint on these activities and therefore projects are often short-term, low-budget efforts dealing with modification of existing products. The industry did respond well to the market force of increased labor costs, but a lag time of approximately seven years was identified between the onset of the trend toward higher labor costs and the introduction of new labor-saving products. The development of labor-saving products continues to be the most important research and development goal of the industry.
- The total annual research and development expenditure of the irrigation equipment industry is estimated to be \$33 million. Of this, only about \$5 million is spent on projects that lead to patentable products and only about \$2 million is spent on products that would conserve energy.

- The irrigation equipment industry is generally not interested in any direct federal incentives to promote development of energy-efficient products. Instead, many representatives of the industry suggest that incentives be aimed at their customers, the agriculturalists, to create a market demand for energy-efficient products. Such incentives could include educational programs and tax advantages.

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I. INTRODUCTION

Innovation has been a hallmark in the free enterprise elements of the American experience. It has given the nation flexibility and hope when faced with shifts in the availability of resources. Flexibility and hope appear to be in need now with respect to the "energy crisis." In the wake of reduced supplies of fossil fuels, innovation could result in the necessary alternatives for continued progress. The purpose of the research presented in this report is to examine the innovative process in the irrigation equipment industry and to estimate the energy-conserving effects of this innovation.

America has been most successful when it combined the remarkable achievements of an innovative private sector with farsighted investment of public resources. Abundant production of high quality food is one result of this cooperative effort. However, it is also argued that the normal market distribution process is so intricate and sensitive that no government mechanism can stimulate it (Simon 1978). An important goal of this study is to identify government activities that stimulate and those that dull the creativity of innovation.

SPECIFICATION OF THE PROBLEM

An objective of the Department of Energy's Office of Industrial Programs is to serve as a focal point for facilitating necessary interaction between the private (manufacturing) and public (government) sectors to induce energy conservation through technological transfer at competitive market prices (Walden 1978). A national program to increase energy efficiency in irrigated agriculture, managed by Pacific Northwest Laboratory, represents a public sector effort to seek technical alternatives in the maintenance of abundant food supplies with less energy (Cone et al. 1978; Cone 1979).

An understanding of current innovations can form the basis for interaction to induce energy conservation through technological transfer. The immediate problem is to identify the participants, the activities, and the resultant products of energy-conserving innovations in the private sector in order to induce maximum synergism with the national program.

APPROACH TO THE ANALYSIS

The analysis presented in this report has been developed in two phases. The purpose of the first phase was to establish an understanding of the innovative process within the irrigation equipment industry by reviewing published accounts of the industry, and interpreting patent data. The industry setting as defined in Chapter II, which contains a brief chronology of irrigation technology, a description of the market forces that guide the irrigation equipment industry, and a sketch of the industry structure. A profile of patent activity was obtained from the U.S. Patent Office and is examined in Chapter III. Based on the analysis of these secondary data sources, a micro-economic analysis was performed to estimate the expenditures made by the industry for research and development. This analysis is based on the premise that invention is largely an economic activity pursued for gain. Expected gain varies with expected sales of goods embodied in the invention. Expected sales of improved capital goods are largely determined by present capital goods sales (Schmookler 1966). Higher levels of sales are expected to result in higher dollar expenditures, and scientific and engineering manpower levels devoted to research and development.

The second phase of the research tested the conclusions drawn by the first phase with the collection of primary data from the industry itself. Representatives of irrigation equipment and components were contacted by telephone to gain insight into the private sector's perception of energy conservation. The results of conversations with over thirty management and technical representatives of the irrigation equipment industry are detailed in Chapter IV. Among the topics addressed are the industry's extent of concern for energy conservation, the particular products that are being developed to conserve energy, and suggestions of incentives that the federal government could provide to facilitate innovation in the private sector. Other insights gained from these telephone conversations are incorporated throughout the report where appropriate.

Techniques and methods of irrigation differ among geographic areas of the country because of differing climatic, topographic, and soil conditions. Surface irrigation techniques are not applicable to hilly and sandy fields.

Low-pressure sprinkler techniques can cause problems on heavy soils. The application of the technology described in the previous chapters to geographic regions is discussed in the fifth chapter.

All of the results of Chapters II through V are drawn together in Chapter VI to provide an estimate of the potential energy savings due to the research and development effort of the private sector.

II. THE RELATIONSHIP BETWEEN THE IRRIGATION EQUIPMENT INDUSTRY AND IRRIGATED AGRICULTURE

The irrigation equipment industry supplies a diverse market with an equally diverse line of products. The wide range of soil types, water sources, crops, and climates in America requires specialization of irrigation equipment. Development of this specialized equipment requires research efforts from several manufacturing sectors. Because the customers of this industry are agriculturalists (the sector of the American economy that most closely obeys the laws of a perfectly competitive free market system), the irrigation equipment industry is inherently competitive. In order to survive, a company must continually improve its product line.

The purpose of this chapter is to describe the irrigation equipment industry and its relationship with the agricultural sector, which supports it. A historical summary of irrigation development in the United States is presented to describe the development of relationships between the irrigation equipment industry and the irrigated agricultural sector, and the effects technological advances have had on the development of irrigation. The second section describes how the optimal combination of inputs is determined by the relative prices of the various inputs. Irrigation is one of many inputs to agricultural production. The third section discusses the estimated annual sales volume of the entire irrigation equipment industry and its projected growth based on recent trends. This analysis is based largely on a study by Pavelis (1978). The final section in this chapter describes the diverse structure of the irrigation equipment industry. A total of 536 firms involved with this industry has been identified, including 213 manufacturers and 323 service companies. Of the manufacturers, product lines and estimates of sales volume are known for 120 of the manufacturers, which are listed in the Appendix.

TECHNOLOGICAL DEVELOPMENT OF IRRIGATION IN THE UNITED STATES

The emergence of an irrigation equipment industry is a relatively recent phenomenon, although the practice of irrigation dates back millenia. Any record of the first irrigation in America has been lost to prehistory, but some

ditches the Hohokam Indians constructed in the Salt River Valley of Arizona prior to A.D. 1400 are still in use (Linsley and Franzini 1972). The technology used to construct these ditches consisted of wooden and stone tools operated by manual labor. The only energy consumed by irrigation was that expended by the workers and that of the gravity-flowing water.

The Mormons began the reclamation of the western United States in 1847 when they built a diversion dam across City Creek that provided water for five acres of land at Salt Lake City . Construction of low dams to divert water to small parcels of land continued throughout the century. The technology had improved considerably from that of the prehistoric Hohokam as metal tools were available and beasts of burden provided much of the energy.

The exploitation of groundwater also began in the mid-nineteenth century when wind energy began to be harnessed. A typical farm yard windmill could deliver 35 gallons per minute from a depth of 25 feet in a 15 mile per hour wind (Eldridge 1975). Wind continued to be the major energy source for pumping until the rural electrification program of the mid-twentieth century.

During the nineteenth century, the size of irrigation projects was limited due to a lack of resources in the private sector. One attempt at a large-scale project that ended in failure was the irrigation of the Imperial Valley through the Mexican Alamo Canal. Violent floods of the Colorado River destroyed the brush dam diversion and changed the natural course of the river. The uncontrollable rampage created the Salton Sea and wreaked havoc upon would-be irrigators. Those involved with the effort recognized that controlling the Colorado floods would require a high dam. The Reclamation Act of 1902 provided the authority for the Federal government to expend its resources in such a venture and placed the technological burden of irrigation design on the Reclamation Service, which later became the Bureau of Reclamation and is now the Water and Power Resources Service. Advances in the design of dams, canals, and hydroelectric plants allowed utilization of water resources that were previously wasted. Large storage dams ensured a reliable source of water, which allowed development of large parcels of land. Concrete-lined canals could convey water farther and more efficiently than unlined

canals. Hydroelectric generation provided a cheap source of power for pumping water over mountains and extracting groundwater that was too deep for windmills.

While the scale of irrigation was rapidly expanding during the first few decades of this century, the method of applying the water to the crops had not changed in centuries. The only practical means of distributing water was to flood the field by manually controlling the flow in ditches. Some labor was saved by the utilization of siphon tubes beginning in the 1940s. The spring-actuated impulse sprinkler head had been invented in 1933 by Rain Bird Sprinkler Manufacturing Company, but its widespread use had been delayed until the development of mobile sprinkler systems. In 1952, a patent was granted for the center-pivot irrigation machine and Valmont Industries began to supply the growing market for irrigation equipment (Splinter 1976). Sprinklers allowed irrigation of soils too permeable for flooding and land too steep or rolling for flood irrigation. Agriculturalists liked the new technology because it decreased labor requirements and increased productivity. Sprinkler systems began to be widely accepted in the mid-1960s when the cost of farm labor started to increase dramatically. Although energy requirements of operating sprinklers are considerably greater than those of surface application systems, this was not of great concern during the days of relatively inexpensive energy.

Drip irrigation is an application technique developed more recently, but has had limited acceptance for use on certain row crops, vineyards and orchards, especially in water-scarce areas. The industry expects rapid expansion of drip irrigation for the foreseeable future (McNeill 1978) because they are water-, energy- and labor-efficient. Water is conserved because it is delivered right to the point where it is needed and evaporation is negligible. Energy is conserved because operating pressures are very low and labor requirements are small because the systems are typically solid-set. The major drawback to drip systems is high installation costs.

Other recent technological developments of significance include soil moisture monitors, such as the neutron probe, and computerized scheduling techniques. Moisture instruments were brisk but have dropped off sharply since the drought. To avoid the "Tragedy of the Commons" problem (Hardin 1968), computerized

scheduling is best done on a district-wide scale. Some experiments with computerized scheduling techniques (Gear et al. 1977) have been performed by some irrigation districts in water-scarce areas, and this practice is expected to play a major role in future irrigation.

The technology of irrigation has been continually advancing. From its primitive beginnings when only the growers were involved, interest in irrigation has grown to include the government and the non-agricultural private sector. Today, the three sectors interact to respond to the needs of a changing world. Most people realize that one of the most significant changes occurring in the world today is the trend toward higher energy prices. One may expect that this dramatic change would force a response by manufacturers in the form of energy-conserving technology. The next section describes why price increases may not always provide such incentives because the optimum combination of inputs is determined by the relative prices of all inputs.

FACTORS INFLUENCING THE DEMAND FOR IRRIGATION EQUIPMENT

The derived demand for irrigation equipment (as for any agricultural production input) is directly related to the demand for agricultural products and the relative prices of the various inputs to agricultural production, such as land, labor, and energy. The relative prices of these three agricultural, in constant terms, inputs are compared with agricultural output (an indicator of the demand for agricultural products) and consumer prices in Figure 1. Physical agricultural output (as opposed to the dollar value of the output) has risen slowly but steadily since 1950. Average farm land value (an indicator of rent or mortgage payments or opportunity costs of landowners) rose slowly until the early 1970s when it increased sharply. Fossil fuel prices actually decreased (in real terms) during the 1960s but rose sharply in 1973 and 1974 due to the oil embargo. The rate of increase dropped off during 1975 through 1977, but available data does not reflect the price increases of recent months. Labor costs increased sharply beginning in the mid-1960s and have continued to increase steadily.

FIGURE 1. Indices of Agricultural Input Prices, Consumer Prices, and Agricultural Output

A specific demand for agricultural output may be satisfied with an infinite number of input combinations. The optimal combination of inputs is that which satisfies the output demand with the lowest total production cost. As the relative prices of the various inputs change, the optimal combination of inputs change; agriculturalists will substitute inputs with lower relative costs for inputs with higher relative costs. Examples of input substitution include the widespread acceptance of self-propelled sprinkler systems in response to increasing labor costs in the 1960s, or the adoption of drip irrigation systems in response to water shortages in certain parts of California.

A rational approach to determine the optimal combination of inputs requires a life-cycle cost analysis to define the tradeoff between capital and operational costs. However, there are inherent problems with this approach. Often, the agriculturalists who have the ultimate responsibility for choosing a system are not knowledgeable in the subtleties of life-cycle cost analysis and may not even be aware of some of the costs involved. This situation tends to favor systems with low capital costs because initial costs seem, at the time, to be more important than operational costs to be incurred over the life of the system. Uncertainties of future costs is another problem inherent to life-cycle cost analysis. Irrigation equipment may have a design life of ten to twenty years but the only cost component that remains fixed over this span is the capital repayment. Labor and fuel prices are determined by market forces and are constantly changing. Irrigators deciding in the mid 1960s to install capitaland energy-intensive sprinkler systems in response to high labor costs had no knowledge of the dramatic fuel price increases experienced in the 1970s. Fuel cost was not an important factor in the decision process of the 1960s, but many systems installed then are still operating today. If the irrigators had had clairvoyance with respect to fuel costs, perhaps they would have selected systems that were less energy-intensive but more laborer capital-intensive.

Irrigation Equipment as a Substitute for Land

Land is one of the most basic inputs to agricultural production. Agriculture may be considered as a conversion process between solar energy and food energy. The only way to increase the solar energy input is to increase the

land area under cultivation. However, agricultural production may also be increased by improving the efficiency of the energy conversion process. Application of fertilizer is one common efficiency improvement technique; irrigation is another. Without irrigation much of the land in the West could not support any agricultural production.

An agriculturist operating in a free market economy must decide which inputs should be increased to respond to an increase in the demand for agricultural products. He may increase his dryland production by purchasing or leasing additional farm land, or he may increase the yield from his existing land by installing an irrigation system. The agriculturalist would choose the option that provides the lowest marginal cost of production. The marginal cost of production for the expanded crop land option is calculated by dividing the annualized cost of land (either rent or mortgage payments) by the dryland yield, whereas that for the irrigation option is calculated by dividing the annualized capital and operational costs of the irrigation system by the increased yield of irrigated land over dryland.

Land values are increasing rapidly because there is a limited amount of land from which the demand for agricultural products must be satisfied. Competition for this fixed quantity of land is fierce due to increasing demands for urban and recreational land. This competition is reflected in Figure 1, by the steep slope of the land value curve, starting in the early 1970s. Because of the high land values, the most cost-effective method for increasing crop production in many cases is to increase yields by irrigating rather than by increasing acreage.

Irrigation Equipment as a Substitute for Labor

Labor is a major agricultural operating cost that has been rising sharply since the mid-1960s, as indicated in Figure 1. Another problem facing irrigators is the availability and reliability of farm labor. At one time farmers could trust their hired hands to remain through the growing season, but now the competition for and mobility of farm workers allows them to move frequently. If an irrigator is to harvest a successful crop, he must provide

constant attention to his fields and irrigation systems. Some systems, such as siphon-tube flooding or hand-line sprinklers, have relatively low capital costs but are quite labor-intensive. Other systems, such as center pivot sprinklers, have minimal operational labor requirements but are rather capital-intensive. The consensus among irrigation equipment representatives contacted by telephone was that the development of labor-saving devices has been the most important objective in their industry for at least the past two decades because of the market demand by irrigators for such systems.

The Response to Fuel Price Increases of the 1970s

Although fuel costs increased dramatically in the 1970s, energy-use levels in irrigated agriculture have not been profoundly affected (Johnson 1979). One reason for this lack of response is the fact that the relative fuel price increases have not been as dramatic as the actual price increases. General inflation, as reflected in the Consumer Price Index in Figure 1, has also experienced sharp increases during the 1970s. Another reason is the fact that operating energy-intensive systems installed prior to fuel cost increases are still profitable, so there is little incentive for irrigators to replace their existing systems until they are worn out. Very recently, however, irrigation equipment manufacturers have begun to perceive a market demand for energy-efficient products. Over half of the industry's representatives contacted said that energy efficiency is now an important objective of their R&D effort, but all of these admitted that this is a recent phenomenon. No one claimed to have been very concerned about energy efficiency until about two years ago and many said their concern had arisen within the past year (along with the skyrocketing oil prices of 1979).

IRRIGATED ACREAGE AND THE VALUE OF INSTALLED EQUIPMENT AND FACILITIES

Irrigated acreage in the United States has increased steadily during the last 40 years. Pavelis (1978) identified four major triggers for this expansion: 1) World War II created a demand for increased agricultural commodities and caused an expansion into the arid west, 2) general advances in agricultural production methods have made agriculture more profitable, 3) widespread droughts in humid regions from 1955 to 1965 helped advertise and permanently

establish irrigation in those regions, and 4) improvements in the technology of irrigation equipment have reduced labor requirements and simplified adoption of irrigation systems.

Bringing new land under irrigation entails some capital expenditure by the landowner. As indicated in Figure 2, the net value of irrigation equipment and facilities has closely paralleled the irrigated acreage. The slope of the net value line is somewhat steeper than that of the acreage line because the marginal cost of irrigation (the cost to irrigate one more acre) is greater than the average cost and is continually increasing. This is due to advancements in irrigation technology that allow irrigation of land previously thought to be unirrigatable, although at a high unit cost.

Acreage data for Figure 2 was obtained from three different sources, which accounts for the slope discontinuity between the 1978 reported value and the 1985 projection. Based on actual reported data for the years 1975 through 1978, the projection seems somewhat low. The U.S. Water Resources Council (1978), which provided the 1985 and 2000 projections, reported an actual 1975 acreage of about two million acres less than that reported by the Irrigation Journal. Data prior to 1966 is from Ruttan (1965) and data for the net value line is from Pavelis (1978).

Table 1 illustrates the growth of irrigated acreage and the irrigation equipment industry during the 1970s. Acreage data is from Irrigation Journal Survey issues, while the value of irrigation equipment is adopted from Pavelis (1978). The total net value column is analogous to the net value curve in Figure 2 except it has been adjusted to 1975 dollars from 1972 dollars, using an escalation factor of 1.379 as suggested by Pavelis (1978). Depreciation is assumed to occur as a straight line over 18 years.

Pavelis (1978) estimated that 52% of the total value of irrigation equipment and facilities, including capital costs of storage dams, diversion structures, and conveyance canals, was paid for by the federal government. These structures are more appropriately categorized into the heavy construction industry as opposed to the irrigation equipment industry. Theoretically, these costs are reimbursed through irrigation districts with user fees,

FIGURE 2. Irrigated Farmland and Net Value of Irrigation Facilities in the United States (U.S. Department of Commerce 1978; Ruttan, 1965; Irrigation Journal; U.S. Water Resources Council, 1978)

although federal taxpayers ultimately pay for a significant portion. The remaining 48% of the value, the capital cost that agriculturalists paid for irrigation equipment on their land, is the money that supports the irrigation equipment industry, and is shown in the right hand column of Table 1. When inflation is accounted for, Table 1 indicates that the irrigation equipment industry has had annual sales of over one billion dollars since 1976.

TABLE 1. Irrigation Equipment Investment (1975 Dollars)

Year	Number of New Acres Under Irrigation(a) (millions)	Number of New Acres Under Sprinkler Irrigation(a) (millions)	Total Net Value of Facilities(b) (billions)	Depreciation During Year(c) (millions)	Net Investment During Year (millions)	Gross Investment During Year (millions)	Gross Irrigator Investment During Year (millions)
1970			14.67				
1971	0.60	0.51	14.92	829	250	1079	513
1972	-0.50	0.24	14.96	831	40	871	418
1973	1.53	1.08	15.68	871	720	1591	764
1974	1.55	1.00	16.47	915	790	1705	818
1975	1.01	0.97	16.92	940	450	1390	667
1976	2.87	2.65	18.50	1030	1580	2610	1253
1977	1.55	1.89	19.50	1150	1000	2150	1032
1978	2.19	1.24	20.25	1190	750	1940	931

(a) From Irrigation Journal

(b) From Pavelis, 1978

(c) Assumes Straightline depreciation over 18 years - actual experiences indicate that 18 years is somewhat long

THE IRRIGATION EQUIPMENT INDUSTRY

The irrigation equipment industry is a competitive industry. Although a few large manufacturers of complete irrigation systems supply a high percentage of the market, no single firm is in a monopoly position. The largest firm in the irrigation equipment industry, Valmont Industries, had irrigation equipment sales of \$60 million in 1975 (Weitz 1976), while industry-wide sales in 1975 were estimated to be \$705 million.

The irrigation equipment industry consists of manufacturers, distributors, and consultants. The manufacturing sector is mainly responsible for technology development. Some of the larger manufacturers own their own distributors that deal exclusively with their company's products. Distributors are more typically independently owned and usually carry several manufacturer's product lines; often they will design systems for their customers or recommend certain brand names. Sometimes an irrigator will want independent advice and will hire a consultant to design the system most appropriate to his application. Consultants may also be hired for irrigation scheduling, although this segment of the industry is in its infancy. The Irrigation Association's 1977 Directory of Irrigation Manufacturers lists 536 firms involved with irrigation, including 213 manufacturers and 323 distributors or consultants.

The Irrigation Association publishes more detailed information on its corporate members. The 1979 Membership Directory lists 122 manufacturers by product line and annual sales volume range. This self-reported data is summarized in Table 2 and detailed in the Appendix. Assuming that the average sales volumes of the firms in each range below \$20 million was the midpoint of each range and assuming that the average sales volume of firms above \$20 million was \$35 million, the total sales volume of these 122 manufacturers in 1978 would have been about \$573 million. Considering the fact that only 57% of the identified manufacturers are members of the Irrigation Association, this estimate of industry sales volume is not inconsistent with that based on the data from Pavelis (1978).

The expiration of the original center pivot patent in the late 1960s allowed many companies to enter the sprinkler system market at a time when

TABLE 2. Manufacturers of Irrigation Equipment by Component and Sales Volume

Manufactured Components	Manufacturer's Sales Volume(a)						Total Number of Companies
	\$0 to \$500,000	\$500,000 to \$1 million	\$1 million to \$5 million	\$5 million to \$10 million	\$10 million to \$20 million	\$20 million and over	
Sprinkler Heads	6	5	7	1	2	4	25
Center Pivots	3	0	7	5	3	2	20
All Other Sprinkler Systems	2	5	11	3	1	1	23
Controls	9	9	10	4	5	5	42
Drip Systems	2	1	1	1	1	1	7
Pumps and prime movers	5	5	8	1	3	2	24
Pipe and fittings	0	4	8	6	7	7	32
Valves	6	4	8	5	4	5	34
Filters, Strainers & Sand Separators	4	3	1	1	1	2	12
Moisture Measuring Devices	1	0	0	0	1	0	2
Total Number of Manufacturers	37	23	38	9	8	7	122

(a) The Irrigation Association, 1979

demand for such systems was expanding rapidly. This growth in the sprinkler market since 1960 is shown in Figure 3. Entrance to the sprinkler system market is relatively easy for an established farm implement distributor or metal fabrication company because most of the components, such as pipe, sprinkler heads, gear mechanisms, and prime movers, are readily available from suppliers. The initial capital investment required for market entrance must only be large enough to provide a fabrication shop, an inventory of parts, and miscellaneous fixed costs, such as employee training and wages, insurance, etc. Because many of the larger manufacturers prefer to make large irrigation systems (for parcels 160 acres or greater), the smaller local firms fill a market void by providing systems to small and irregularly-shaped fields.

While the irrigation equipment industry is quite competitive in the long term, large manufacturers can exert some market pressure for short periods. To cover high fixed costs, large manufacturers must maintain cash flow. During industry-wide sales slumps they may cut prices to reduce inventory and cover fixed costs, while cutting back on production to reduce variable costs. Smaller firms must adjust their prices to stay competitive but may not be able to cut production if inventories are low. Many small firms find it difficult

FIGURE 3. Sprinkler-Irrigated Acreage in the United States
(Source: Irrigation Journal)

to remain solvent during these sales slumps and are susceptible to acquisition by larger (often non-agricultural) companies.

Almost all the irrigation equipment representatives contacted by telephone stated that the past few years have been very poor for the industry in general. One representative estimated that the industry lost between \$50 and \$100 million in 1978 and 1979. This fact has caused some small firms to fold and others to merge or be bought-out. Several reasons were given for the depressed market condition, but most cited low crop prices as being the main cause. When irrigators are barely able to cover last year's production costs, few are willing to invest in new capital equipment. Other reasons cited for the business slowdown included high interest rates, a bad atmosphere created by the farmers' strike, which relates to low crop prices, and above-average rainfall for the past two years. A few representatives commented that because larger manufacturers cut prices when business slowed and exerted price control over the entire industry, other companies were forced to follow suit. The effect of this was to eliminate some smaller firms and to increase the market strength of larger firms.

In spite of the bleak recent past, most irrigation representatives are cautiously optimistic about the future. Although no one predicts a dramatic surge in market demand, most expect steady growth for their company and the industry. Several cited the growing international market (especially the Middle East) as offering the greatest potential for future sales.

CONCLUSION

Based on the analysis presented in this chapter, the irrigation equipment industry can be described as a competitive industry that has grown rapidly during the past two decades. This rapid growth has been in response to increased demands for the industry's products, which have developed due to increases in the relative prices of land and labor. To estimate the industry response to the market force of high energy prices one must understand the process of technological innovation and invention. The next chapter addresses this subject.

III. AN ESTIMATE OF THE RESEARCH AND DEVELOPMENT EXPENDITURES IN THE IRRIGATION EQUIPMENT INDUSTRY

Manufacturers perform research and development to maintain or improve their share of the market for their particular products. The amount of money a given manufacturer would be willing to expend on research depends on the return they expect when the product is commercialized. Therefore, the return on research investment is dependent upon the demand for the particular product. Predicting demand trends is often difficult because a new product usually requires several years to develop (prior to 1974 no one could have predicted with certainty that there soon would be a demand for energy-saving products), but it is important for optimizing long term operations of a given industry. The purpose of this chapter is to identify trends in industrial research expenditure and to estimate the response of the irrigation equipment industry to increased demands for energy-conserving products.

PATENT DATA

One indicator of the amount and the direction of ongoing research is an analysis of recent patent trends in the specific industry (Schmookler 1966). A profile of patent activity that included patent classes and subclasses most relevant to the irrigation equipment industry was obtained from the U.S. Patent Office. The selected categories are listed in Table 3. The profile included 320 patents granted since 1963, 279 of which were of U.S. origin. Of the U.S.-owned patents, 135 were granted to corporations, 140 to individuals, and only one to the U.S. Government. Individuals with patents often sell or license them to corporations, but this activity is not reflected in the profile because the ownership reported by the Patent Office is as of the date the patent was granted.

Patents granted from 1969 were listed by their owners. The companies that dominated the market for complete irrigation systems also dominated the patent activity. Lindsay Manufacturing Company and Gifford Hill Company each had six patents granted since 1969, while Lockwood Corporation and R. M. Wade Company each had four, and Valmont Industries had three. Eight companies had two

TABLE 3. Patent Classes and Subclasses Included in Analysis

<u>Class</u>	<u>Class Title</u>	<u>Subclass</u>	<u>Subclass Title</u>
166	Wells	227	Screens
239	Fluid Sprinkling, Spraying and Diffusing	177	Circumferentially Moving Distributor or Supply Pipe with Outrigger Type Support
239		178	Guided or Propelled Translating Distributor Means
239		200	With Fixed Support for or Ground Installed Supply Means
251	Valves and Valve Actuation	12	Fluid-Actuated or Retarded
251		76	Impact Type Actuator
251		213	Mechanical Movement Actuator
405	Hydraulic and Earth Engineering	36	Drainage or Irrigation
417	Pumps	321	Motor Driven

patents. A total of 85 companies had patents granted in the selected classes and subclasses since 1969, although this figure includes a few foreign companies.

The total number of patents granted since 1969 to selected companies principally selling irrigation equipment was also obtained from the Patent Office, although no breakdown of patent classification was available. In Table 4 this information is compared with data from the selective patent profile. Of the 95 patents granted to the seven selected companies, 27 were included in the profile of selected patent classes. Certainly many, although not all of the 95 patents, are applicable to irrigation equipment. If it is assumed that the 184 private sector patents in the profile granted between 1969 and 1978 represent half of all patents applicable to irrigation equipment, the total number of patents relating to irrigation in that time period

TABLE 4. Patents Granted to Selected Irrigation Equipment Manufacturers (1969 to 1978)

<u>Company</u>	<u>Total Patents Granted</u>	<u>Patents Granted in Selected Classes (Table 3.1)</u>
Rain Bird Sprinkler Mfg. Co.	21	1
R. M. Wade Co.	18	4
Lockwood Corporation	14	4
Lindsay Manufacturing Company	13	6
Gifford-Hill Company	10	6
Nelson Irrigation Company	10	3
Valmont Industries	<u>9</u>	<u>3</u>
Total	95	27

would be 368. Based on research and development expenditures of all manufacturing industries and total patents granted, each patent requires an average research and development expenditure of about \$135,000 when adjusted to 1978 dollars (National Science Board 1975). Therefore, the estimated 368 irrigation equipment patents granted from 1969 to 1978 would have required a research and development expenditure of \$50 million, or an average annual expenditure of \$5 million. However, a conclusion that may be drawn from the many conversations with irrigation equipment representatives is that a very small portion of their research expenditures ever results in a patentable product because much of their effort is devoted to objectives such as cost control and minor modifications to their existing product lines. Furthermore, many patents that are applied for are never granted. Therefore, basing estimates of research expenditures solely on patent data would tend to underestimate the actual annual expenditure.

To test the effect of market forces on research output, the patents granted since 1969 in the patent profile were categorized based on their titles. Because of the patents brief titles a subjective categorization was made, but it was felt that such a categorization could reveal general trends. Two researchers performed independent categorizations and obtained nearly

identical results, shown in Table 5. Because many of the patent titles were not listed with their owners, it was not possible to get an accurate accounting of corporate versus individually-owned patents in each category.

Many of the titles were quite non-descriptive of the invention, but did indicate that it was applicable to irrigation, as patent Number 3687372 - "Apparatus for Irrigating Land" demonstrates. The largest number of patent titles indicated that the invention would save operational labor requirements. Any title that made reference to self-propelled irrigation systems, such as patent Number 3606161 - "Self-Propelled Sprinkling Apparatus and Safety Means Therefore," was considered a labor-saving invention. Patent Number 3556467 - "Valve Actuators" was an example of a patent dealing with valves. A few of the patents, such as patent Number 3887021 - "Method and Apparatus for Boring Drain Holes in Ground," related to drainage systems. The Patent Office warned that due to the complexities of their classification system, non-relevant patents inevitably find their way into patent activity profiles. An example of a patent not applicable to irrigation systems is Number 3561466 - "Anaesthetist's Ventilator."

None of the patent titles relating to irrigation systems indicated that the invention would conserve energy, but as indicated by the conversations with the industry's representatives, the concern for energy conservation is a relatively recent phenomenon; it can take several years for an idea to proceed from inception to its patent application and several more years for a patent to be granted. The analysis shows that the industry did respond well to the market force of higher farm labor costs. Figure 4 shows the relative cost of farm labor and the number of labor-saving patents granted. The cost of labor started its dramatic rise around 1965 as the index of farm wage rates began increasing at a rate of over 10 points a year. It was not until the early 1970s, however, that the number of labor-saving patents started to increase. A linear regression of the labor-saving patent granted in each year, starting in 1969, has been increasing at an average annual rate of 0.76 patents per year. If the selected categories represent half of the total irrigation patents, the actual rate of increase of labor-saving patents starting in 1969 would be 1.5 patents per year.

TABLE 5. Subjective Categorization of Patents Granted Since 1969
(Based on Patent Title)

<u>Subjective Category</u>	<u>Patent Owners</u>	<u>1969</u>	<u>1970</u>	<u>1971</u>	<u>1972</u>	<u>1973</u>	<u>1974</u>	<u>1975</u>	<u>1976</u>	<u>1977</u>	<u>1978</u>	<u>Total</u>
General Irrigation Devices	Corporate	3	3	2	3	2	1	4	4	2	5	29
	Individuals	0	0	1	0	0	0	0	0	0	2	3
	Unknown	2	1	2	4	0	1	4	6	5	4	29
Labor Saving Devices	Corporate	2	1	6	4	6	5	3	4	2	4	37
	Unknown	1	0	3	3	4	3	3	9	7	5	38
Valves	Corporate	0	1	1	0	2	3	1	1	0	0	9
	Unknown	1	0	2	0	3	0	0	1	1	0	8
Drainage Devices	Corporate	1	1	1	0	1	1	0	0	0	0	5
	Unknown	1	0	0	2	0	0	1	1	1	1	7
Wells	Corporate	0	0	3	0	0	1	0	1	1	1	7
	Unknown	1	0	0	1	0	0	0	0	0	0	2
Not Applic- able to Irrigation	--	2	5	7	3	3	2	2	8	0	2	34
Total in Selected Categories		14	12	28	20	21	17	18	35	19	24	208

FIGURE 4. Cost of Farm Labor and Labor-Saving Patents 1) (U.S. Census Bureau, 1978) 2) Classes and Subclasses are listed in Table 3.

If the seven year lag time between market motivation and patent activity that was observed in the labor situation applies to the energy situation, the energy cost increases starting in 1974 could be expected to spur energy-conserving patents in the 1980s. The research that would spawn these patents is presently being conducted and several industry representatives have predicted that major technological developments would occur in the near future (Ross 1979).

Based on the analysis presented in this section, the irrigation equipment industry has yet to respond to the recent increases in the relative price of energy. However, a lag time of approximately seven years has been identified between the onset of increases in the relative price of labor and patent responses to that market force. It is speculated that there will be a similar lag in the response to increases in the relative price of energy.

VOLUME OF SALES AND EXPECTED PROFITABILITY

Another approach to estimating research expenditures is based on volume of sales. According to the National Science Foundation (1976) manufacturers spent an average of 2.0% of their sales volume on research and development over the period from 1961 to 1974. Telephone conversations with representatives of irrigation equipment indicated that their industry's research and development expenditures are close to the sector-wide average. Seventeen representatives were willing to provide a rough estimate of their company's R&D expenditures and only a few of those contacted (mostly non-management engineers) said that they did not know what their company's R&D expenditures were. Only one refused to answer on proprietary grounds. The most common R&D estimate was three percent of sales, with the low being less than one percent and the high ten percent. The representative who mentioned ten percent explained that both his company's research budget and sales varied from year to year, and that the ten percent expenditure was reached only in recent years because sales had been down. A representative whose company spends about eight percent of sales on research commented that his company's expenditures were much higher than most of its competitors; however, most of those who responded believed that their company's R&D expenditures were below the industry average. Of those 17 representatives contacted the average estimated R&D expenditure was 3.3% of sales. Based on the estimated billion dollars of annual sales developed in Chapter II, the industry-wide expenditure on research and development is estimated to be \$33 million.

Estimating research expenditures based on sales in a specific year inherently lacks precision because of the lag time between research and commercialization. The actual research expenditure made by a firm in a given year is

determined by the expected profitability of the potential inventions (Schmookler 1966). When industry representatives were asked about the role of expected profitability in their R&D planning procedures, the 22 representatives who felt qualified to respond all agreed that new development projects are never undertaken unless the market demand for the resultant product is such that profits will pay off research investment within one to three years. The opportunity cost of research and development expenditures is quite high because other types of investments have immediate returns. Therefore, most R&D projects are short term, low budget efforts typically dealing with modification of existing equipment because the availability of venture capital is the biggest constraint on research activities. New product development generally requires longer R&D efforts with correspondingly longer payback periods. Those more sophisticated development projects require longer development periods, and therefore, venture capital is more difficult to obtain. One representative commented that because of these constraints, technological changes in the irrigation equipment may be characterized as "evolutionary" as opposed to "revolutionary."

The profitability of an invention may be estimated by estimating the demand for the new or improved technology. As described in Chapter II, the demand for a given agricultural input is determined by the demand for agricultural outputs and the relative prices of all agricultural inputs. The demand for energy-conserving irrigation equipment will be directly proportional to the price of energy, assuming there is direct substitutability between energy and equipment that conserves energy, and assuming irrigators react in an economically rational manner. The extra capital expenditure an irrigator would be willing to make for an energy-conserving irrigation system would be exactly equal to the present value of the energy that would be saved (i.e., the difference between the energy required to obtain the same performance with either system) over the life of the new system. Because irrigators would be willing to pay more for an energy-conserving system than they would be willing to pay for an energy-wasting system that provides the same performance, equipment manufacturers have an opportunity to increase their sales volumes without increasing their production capabilities. The consensus among manufacturers

is that the incremental market demand for their products due to an energy efficiency improvement would warrant an energy-conserving development effort only if the resultant product achieved an energy efficiency improvement of at least 20% over existing technology.

Based on these insights obtained from irrigation equipment industry representatives and on other assumptions summarized in Table 6, a present-value analysis of the expected profitability of energy-conserving technology can provide an estimate of the industry-wide expenditure on energy conservation research. The assumptions used in this analysis are representative of those values that would be used by manufacturers when making production decisions. Irrigation manufacturers perceive a market demand for energy-efficient products and undertake research projects to achieve an efficiency improvement of 20% ready for the market in 1983. The research investment must be paid-off in three years. Irrigation energy use in 1983 is 0.34 quads unchanged from 1978 (Cone et. al. 1978) . Irrigation systems have an average life of 15 years, so in any given year 6.7% of all existing systems are replaced. The cost of energy is \$5 per million Btu. The interest rate on venture capital is 20%. Profits on sales after taxes is 7.8% (U.S. DOC, 1979). Irrigators have perfect knowledge of the market place and therefore behave in an economically rational manner. The additional money they are willing to pay for an efficient system is equal to the present value of the energy saved during the first three years of operation.

TABLE 6. Assumptions for Present Value of
Expected Profitability Analysis

- 3 year development period
- 20% energy savings
- 3 year payback period
- \$5 per million Btu 1980 energy cost
- 0.34 Quads per year present energy use
- 6.7% of all irrigation systems replaced each year
- 20% interest rate on venture capital
- 7.8% profit on sales after taxes

The energy used by the systems replaced in a given year is $0.34Q/15$ or 0.023 quads. The potential savings of the new technology is therefore $20\% \times 0.023Q$, or 0.0045 quads. The value of this energy is \$5 per million Btu $\times 0.0045Q$ or \$23 million per year. The three year present value of this energy is \$57 million so this is the extra capital the irrigators would be willing to pay for the energy-efficient systems. The extra profit that the irrigation manufacturers could make on their new products would be $7.8\% \times 57$ million or \$4.5 million, per year. The 1980 value of this extra profit over the years 1983 to 1985 is \$6.5 million. Therefore, the irrigation equipment industry would be willing to spend a total of \$6.5 million during 1980-1982, if it would result in products that achieved 20% energy efficiency improvements and were ready for the market in 1983. The annual research expenditure for this effort would then be \$2.2 million in 1980 terms.

CONCLUSION

Based on the analysis presented in this chapter, the total annual research and development expenditure by the irrigation equipment industry is estimated to be \$33 million. This figure is based on the total annual sales estimated in Chapter II and on the estimates of R&D expenditure as a percent of sales that were provided by 22 representatives of the industry. An analysis of patent trends indicates that of the total R&D expenditure only about \$5 million per year is spent on the development of patentable products. A present value analysis of the expected profitability of energy-conserving technology suggests that the industry should be spending about \$2.2 million per year on the development of energy-efficient products.

Research expenditures alone do not result in new technology. The next chapter will describe the energy-saving efforts of the irrigation equipment industry and the products that will result from the R&D.

IV. ENERGY EFFICIENT PRODUCTS

Chapters II and III have analyzed technology development in the irrigation equipment industry on the basis of patent data and other data from published sources. Energy conservation has been addressed in a generic sense. The purpose of this chapter is to detail the efforts of energy conservation research in the irrigation equipment industry and to describe the resultant products. This analysis is based on conversations with representatives of the industry.

Irrigation equipment representatives contacted by telephone were identified through the Irrigation Association 1979 Directory and other miscellaneous sources. The researchers asked to speak with whoever was responsible for research and development. The titles of the 39 people representing 32 of the larger manufacturers contacted were almost evenly split between technical and marketing managers.

Most of those contacted were quite receptive and willing to generally discuss the problems of energy conservation and their efforts to achieve it. The insights gained from these conversations will be described in three sections. The first section of this chapter describes qualitatively the industry's extent of concern for energy. Energy conservation is only one of several objectives of the private sector's research effort. The second section will describe the products that are being developed to achieve energy efficiency and the many problems that must be overcome. The final section of this chapter discusses the industry representatives' suggested incentives that the federal government could provide to facilitate energy conservation in irrigated agriculture. Most of these suggested incentives would be aimed at the irrigators themselves rather than at the irrigation equipment industry.

THE EXTENT OF CONCERN FOR ENERGY CONSERVATION

Until recently, energy conservation was not considered to be a very important goal of irrigation technology development. Only 9 of the 39 industry representatives contacted claimed that developing energy-efficient products was the most important goal of their R&D effort, while ten said that energy

efficiency had low priority. The rest expressed a concern for energy conservation but said that other goals, particularly development of labor-saving products, were more important. Cost control, development of structural systems, and general product development were other goals that were given priority over energy-saving products by various manufacturers. Of those representatives who expressed a concern for energy conservation, almost all admitted that their concern developed quite recently. Some said their efforts began as long as two years ago, but most said that their concern was raised only in the last six months or year. The dramatic energy cost increases of the 1974 "energy crisis" were not great enough to create long term concern in the industry because a market demand for energy efficient products was not perceived, but the increases of 1979 have convinced many that the crisis is real. Now that the price of diesel fuel is over one dollar per gallon, the representatives expect to see a demand for energy-efficient products.

ENERGY-CONSERVING PRODUCTS

Energy-conserving products that are currently being developed or planned may be categorized into seven groups: low-pressure systems, efficient pumps, efficient pipes, efficient gear boxes, micro-processor controls, low weight systems, and solar or wind applications.

Low-Pressure Systems

The means for energy conservation that was mentioned most often by irrigation equipment manufacturers was the reduction of operating pressure of sprinkler systems. Fourteen of the eighteen sprinkler systems or sprinkler head representatives said that their companies were working on the development of low- or medium-pressure systems, and eight of those fourteen mentioned pressure reduction as an important goal and said that their companies are modifying their products for low-pressure systems.

Most representatives said that their goal was to reduce the pressure of center pivot systems from 70 or 80 psi to 35 or 40 psi. Some said that it may

be feasible to attain further pressure reductions down to 20 psi, but this would be more applicable to lateral move systems than to center pivots. With center pivots, maintaining a high coefficient of uniformity of the application rate at low pressures is a problem because the speed of movement increases with the distance from the center. Another problem with sprinkler pressure reduction is soil compaction due to the large droplet size inherent to low-pressure systems. These inherent problems are being addressed by manufacturers of sprinkler heads. Another energy-saving development related to low-pressure systems involves booster pumps at the end of center pivots to irrigate corners. A booster pump allows the sprinklers along the length of the center pivot to operate at relatively low pressure so only the water directed to corners must be pumped to high pressure.

Representatives of traveling gun systems said that it is feasible to reduce the pressure of their systems from about 130 psi to perhaps 80 psi, but as the pressure is reduced so is the range of the system.

Pump Efficiency

Representatives of all four pump manufacturers contacted said that they were constantly attempting to improve the efficiency of their products, but technology has reached a point where further efficiency improvements can be attained only at great expense. Improving pump efficiency requires careful machining to minimize friction and the gaps between impellers and casing. Friction may also be reduced by an epoxy coating or by careful polishing. One representative commented that it may not be cost-effective to polish irrigation pump components because the potential benefits could be eliminated quickly by sand scratching and other abuses in the field. While the nameplate efficiency of pumps coming off the assembly line is typically quite high (75% to 80%), it is rarely attained in the field because of poor maintenance and improper pump sizing. Another problem facing pump manufacturers is the difficulty of producing high quality castings, a lost art according to one representative.

Pipe Efficiency

Two methods of reducing pipe head losses were mentioned by irrigation equipment representatives. The first method is to optimize the design of the

pipe network. Research along this line is being conducted by irrigation consultants and equipment distributors and is not generally a concern of irrigation equipment manufacturers. Manufacturers are concerned with developing smoother pipe materials to reduce friction. Specific materials being considered include soft, flexible, synthetic rubber for traveling gun hoses, smooth plastic pipe rather than steel, and epoxy-coated steel pipe. One pipe manufacturer stated that a 6-inch steel pipe coated with their epoxy has the same head loss as a 6-5/8 inch uncoated steel pipe.

Gear Box Efficiency

Several sprinkler system representatives cited gear boxes as the source of significant efficiency losses within moving sprinkler-irrigation systems, which use worm gear transmissions that have inherent inefficiencies. However, few sprinkler system manufacturers actually manufacture the gears they use so they must rely on gear manufacturers to develop more efficient gear boxes. A representative of a gear manufacturer said that other, more efficient gear systems are available and have wide spread use in other applications, but inefficient worm gears are used on sprinkler systems because they act as a brake when the system is rolling downhill. If other types of gears were used, some other type of brake would be required and this would add significantly to the cost of the system.

Micro-Processor Controls

One manufacturer has recently developed a side-roll sprinkler system that is controlled by micro-processors. When each irrigation set is completed, the system automatically shuts down, moves to its next preprogrammed location, and begins the next irrigation set. While this system was developed primarily to save labor, it could have the effect of saving energy by saving water. With manually-controlled systems, irrigators typically over-water each set because it is not convenient for them to move the system at the optimal time. An automatic system can move whenever the irrigator wants it to--even when he is sleeping.

Several industry representatives mentioned that micro-processors could be applied in more intricate ways, such as soil moisture monitoring and automatic scheduling. One manufacturer was reported to be actively involved with this development, but others commented that the market demand for such technology is still years away because few irrigators would be willing to accept it. The feeling was expressed that when the market demand develops, the industry could quickly respond by providing the products.

Weight Reduction

One industry representative mentioned that energy could be saved by reducing the weight of moving sprinkler systems. Aluminum pipe has been used in place of steel; however, the capital cost of an aluminum sprinkler system constrains its use. None of the representatives mentioned using plastic pipe because of its problems with low strength and stiffness when it is suspended.

Wind and Solar Applications

A few irrigation equipment representatives referred to solar energy as having possible applications to irrigation. Windmills were once the most common prime mover of irrigation pumps, and with recent advances in windmill design they could once again provide a significant portion of an irrigator's pumping requirements.

Another potential solar energy source for moving sprinklers is photovoltaic cells. One representative calculated that a photovoltaic cell 15 inches wide, placed along the length of a center pivot, could provide enough power to keep the system rotating, although the representatives stressed that such a system is still many years away from commercialization. Another manufacturer constructed a solar-powered pump and pivot system using photovoltaics but has since dismantled it because of prohibitive costs. However, this research on the use of solar energy to move the sprinklers will continue.

SUGGESTED FEDERAL INCENTIVES

Each representative was asked for suggestions of incentives that the federal government could provide to facilitate the development of energy-conserving products by the private sector. The majority felt that the

best way to facilitate the development of new technology was to stimulate the demand for that technology, because their research and development activities were guided by market forces, specifically the demand for their products.

The incentive system that was mentioned most often was an educational effort aimed at irrigators. Nine of the representatives suggested that if the irrigators understood that operating costs could be substantially reduced by using efficient products, they would be willing to pay more capital for them. This demand would then provide incentive to the irrigation equipment industry to develop new efficient products.

Tax incentives were mentioned by several representatives. There are two types of tax incentives that would have the effect of stimulating market demand for energy-efficient irrigation products. Five manufacturers suggested a fuel tax increase to raise prices so irrigators would be more conscious of energy use. This approach could be coupled with a complex power rate structure that would reward irrigators who conserved energy and penalize those who wasted energy. Four representatives suggested accelerated depreciation allowances to allow irrigators to invest in new, more efficient systems sooner because their old system would pay for itself faster.

Three representatives suggested an expansion of the U.S. Soil Conservation Services cost sharing programs, which currently provide funds for use in soil or water conservation projects. If this program were expanded to include energy conservation, more irrigators would be able to invest in new irrigation equipment.

There were fewer suggestions of incentives that would be aimed at the irrigation equipment manufacturers. Eight representatives expressed the opinion that market forces alone were sufficient incentive to develop more efficient products. Five specifically said that federal policies do not now inhibit technology development, but that any change in policy could have a deleterious effect. Incentives that were mentioned by at least one manufacturer included tax credits for R&D investments, streamlining the process of patent application, and direct federal grants or low interest loans to manufacturers.

CONCLUSION

Based on the analysis presented in this chapter, the irrigation equipment industry is actively involved with the development of more efficient products. The concern for energy conservation, however, competes with other concerns of irrigation equipment manufacturers.

This chapter has described the specific products that are being developed by the irrigation equipment industry to conserve energy. The next chapter describes how these products will be applied geographically.

V. GEOGRAPHICAL DISTRIBUTION OF ENERGY CONSERVATION POTENTIAL

As described in Chapter II, specialized irrigation equipment is required to meet the needs of a wide range of soil types, water sources, crops, and climates. Energy requirements and applications vary greatly among irrigation systems. The purpose of this chapter is to identify regional variations in irrigation energy use and to project how technological developments will affect energy use in each region.

Of the many factors that affect the energy requirements of a given irrigation system, two factors applicable as geographical discriminators are the proportion of groundwater use within a region and the proportion of sprinkler irrigation within a region. Areas that have abundant surface water sources distribute much of that water by gravity, and therefore distribution energy requirements are quite low. Groundwater, on the other hand, must be pumped to the surface, and the amount of energy required to do this is dependent on the depth to that groundwater. Regions dependent on deep aquifers, water-bearing rocks, as their water source offer the greatest potential for energy savings. The first section of this chapter will compare groundwater use among regions and the average depth to groundwater within regions. High-pressure sprinklers are major users of energy for water application. Some regions are dependent upon sprinklers for water application because of soil type, terrain, or crop type and offer the potential for large energy savings through pressure reduction. The second section of this chapter will compare sprinkler application among regions. Two important factors that will be considered are total acreage under sprinklers and the rate of growth of sprinkler irrigation.

The U.S. Department of Agriculture (USDA) has divided the nation into agricultural production regions. A modification of the USDA regions is used in this analysis. As shown in Figure 5, the Northeast and Appalachian Regions have been combined to form the East Region (Region 1) and the Delta Region has been added to the Southeast Region (Region 2). The Pacific Region has been divided into a Southwest (Region 8) and a Northwest Region (Region 9). Arizona

FIGURE 5. Agricultural Production Regions

and Idaho have been moved from the Mountain Region (Region 7) to the Southwest and Northwest Regions, respectively, because irrigation practices in those states are quite similar to those of their western neighbors. Hawaii and Alaska have also been added to the Southwest and Northwest Regions, respectively.

GROUNDWATER USE AMONG REGIONS

Lifting groundwater is the largest single end use of energy for irrigation. Table 7 shows groundwater use by region.

All regions except the East and the Northwest obtain over half of their irrigation water from the ground. The Northern Great Plains region, with 91.2% of irrigation water obtained from the ground, is most dependent on groundwater. The Southwest, Southern Great Plains, and the Lake States Regions also are dependent on groundwater for over 80% of their irrigation supply.

All regions east of the Mississippi River have relatively shallow aquifers compared to the Western regions. The Northwest and Southern Great Plains Regions have particularly high average groundwater lifts of 230 feet and 200 feet, respectively.

Another factor that affects pumping energy use and varies significantly among regions is the amount of water applied. The East requires an average of only 0.50 acre-feet of water per acre, while the Southwest requires 4.00 acre-feet per acre. In general, western regions require significantly higher application rates than eastern regions.

The energy required to lift groundwater may be calculated by multiplying the depth to groundwater by the weight of the water applied and dividing by an assumed pump efficiency. The average pumping energy for each region has been calculated and is listed in the sixth column of Table 7 in million Btus per acre, with the assumption of 70% pump efficiency and conversion of foot-pounds to Btus. The Northwest has the highest average pumping energy requirement for groundwater-irrigated land (3.96 million Btus per acre). This requirement is due to the combined effects of deep aquifers (average depth of 230 feet) and

TABLE 7. Irrigation Groundwater Use by Region (1977 Data)

Region	Irrigated Acreage(a) (millions)	Percent of Ground Water Use ^(b)	Average Depth to Ground Water(b) (feet)	Average Water Applied(b) (acre-ft/acre)	Average Pumping Energy(c) (million Btus per acre)	Energy Saved Due to Efficiency Improvement(d) (billion Btus per year)
1 - East	0.60	33.4	90	0.50	0.22	3
2 - Southeast	6.37	62.0	115	1.35	0.77	204
3 - Corn Belt	0.60	77.5	85	0.60	0.25	8
4 - Lake States	0.79	80.6	80	0.80	0.32	14
5 - Northern Great Plains	10.83	91.2	110	1.45	0.80	524
6 - Southern Great Plains	9.85	82.0	200	1.65	1.65	887
7 - Mountains	12.41	54.9	160	2.75	2.20	997
8 - Southwest	9.49	86.2	115	4.00	2.30	1250
9 - Northwest	7.45	45.8	230	3.45	3.96	901

(a) Irrigation Journal, November/December 1978.

(b) Sloggett, 1979.

(c) Assumes 70% pump efficiency.

(d) Assumes efficiency improves from 70% to 75%.

high application requirements (3.45 acre-feet per acre). Other regions with rather high average pumping energy requirements include the Southwest (2.30 million Btus per acre) and the Mountains region (2.20 million Btus per acre). Eastern regions all have rather low average pumping energy requirements due to the combined effects of high aquifers and low application requirements.

Any irrigator with a groundwater source would benefit from pumping efficiency improvements, but those regions with deep aquifers, high application requirements, and many acres irrigated with groundwater would benefit the most. In order to compare the benefits among regions of pumping energy efficiency improvements, the total energy saved within each region because of an assumed efficiency improvement from 70% to 75% has been calculated and is shown in the seventh column of Table 7 in billion Btus saved per year. The Southwest would save the most energy (1.254 billion Btus per year), followed by the Mountain Region (0.999 billion Btus per year). Although the Northwest has the greatest pumping energy requirements per groundwater-irrigated acre, its potential savings rank only third (0.901 billion Btus per year) because most of the irrigated land in that region is supplied with surface water. The Southern and Northern Great Plains also offer significant pumping energy savings potential, 0.888 and 0.527 billion Btus per year, respectively. The Southeast would save 0.203 billion Btus per acre if average pumping efficiency was improved from 70% to 75%. The eastern regions offer only minor energy savings potential due to the relatively few acres under irrigation.

SPRINKLER USE AMONG REGIONS

As described in Chapter IV, the means of saving energy in irrigation that was mentioned most often by irrigation equipment representatives was the reduction of the operating pressure of sprinkler systems. Regions that have many acres under sprinklers will soon be in a position to achieve considerable energy savings as new low-pressure technology becomes available. This section will identify those regions.

Table 8 shows the growth of irrigated acreage and percentage of sprinkler-irrigated acreage among regions from 1974 to 1979. The percentage of irrigated

**TABLE 8. Irrigated Acreage and Percentage of Sprinkler-Irrigated Acreage
(Irrigation Journal Surveys)**

Region	1974		1975		1976		1977		1978		1979	
	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage	Total Irrigated Acreage (millions)	Percent Sprinkler Acreage
1 - East	0.54	99	0.49	99	0.57	99	0.60	99	0.65	99	0.63	99
2 - Southeast	3.94	5	4.02	8	5.07	26	5.42	28	5.91	28	6.15	32
3 - Corn Belt	0.40	49	0.45	52	0.52	60	0.60	64	0.67	68	0.83	71
4 - Lake States	0.39	90	0.42	93	0.48	96	0.79	98	1.02	96	1.04	99
5 - Northern	7.94	28	8.45	30	9.73	35	10.83	38	11.23	40	11.62	41
Great Plains												
6 - Southern	9.26	24	9.38	24	9.64	25	9.85	26	9.85	27	9.94	27
Great Plains												
7 - Mountains	12.40	12	12.32	12	12.45	13	12.41	15	12.54	15	11.82	13
8 - Southwest	10.03	16	9.91	17	10.39	16	9.49	16	10.29	17	11.22	19
9 - Northwest	7.33	34	7.57	38	7.59	41	7.45	46	7.54	46	7.81	53

land served by sprinklers has shown a steady increase in all regions except the East, where over 99% of the small amount of irrigated land is sprinkler-irrigated, and the Mountain and Southwest Regions, where conditions are particularly well suited to flood irrigation. The Southeast has had a particularly rapid rise, notably in Florida and Georgia, in both total irrigated acreage and percentage of sprinklers. Total acreage in the Southeast has increased 56% in six years and the proportion of sprinkler-irrigated acreage has increased from only 5% in 1974 to 32% in 1979. Much of this increase came in the drought years of 1976 and 1977. The Northern Great Plains and the Northwest Regions have also shown rapid growth in sprinkler-irrigated acreage and have a good potential for energy conservation because of the large number of acres irrigated with sprinklers. Irrigated acreage in the Northern Great Plains Region increased from 7.94 million acres in 1974 to 11.62 million acres in 1979, while the proportion of sprinkler-irrigated acreage increased from 28% to 41%. In the Northwest, the total irrigated acreage has risen only 7% since 1974, but the proportion of sprinkler-irrigated acres has risen from 34% to 53%. This indicates that land is either being converted from flood to sprinkler irrigation or flood-irrigated land is being reverted to dryland as other areas are installing sprinklers.

It is interesting to note that manufacturers of sprinkler systems tend to be located close to their markets, but when contacted, most irrigation equipment representatives claimed that their companies marketed all over the country and many were involved with international markets. However, based on this analysis of sprinkler growth trends, the largest markets for sprinkler systems seem to be the Northwest, Northern Great Plains, and Southeast Regions. Figure 6 shows a map of the agricultural production regions with the locations of all sprinkler manufacturers with annual sales of \$5 million or more (as reported in the Irrigation Association's 1979 Directory). These manufacturers are congregated in Nebraska, Oregon and Washington where the biggest markets are found.

FIGURE 6. Locations of Major Sprinkler System Manufacturers

CONCLUSION

Irrigators in all regions will benefit from technology improvements that conserve energy. The most significant and immediate energy savings due to technology improvements will likely be in the areas of pumping efficiency and sprinkler pressure reductions. Therefore, those regions that are dependent on pumped groundwater and high-pressure sprinklers offer the greatest potential for energy conservation. Based on the analysis presented in this chapter, the regions that will benefit the most from the technology improvements in irrigation equipment are the Southwest, Northwest, and Northern Great Plains Regions. The West, in general, offers great potential for energy conservation simply because most of the nation's irrigated land is in the West. While individual irrigators in the East could also benefit, the cumulative effect of those benefits would still be small. The Southeast is the only eastern region where energy conservation could be significant, as it is currently in a period of rapid sprinkler irrigation expansion.

VI. AN ESTIMATE OF THE POTENTIAL ENERGY SAVINGS FROM RESEARCH AND DEVELOPMENT IN THE PRIVATE SECTOR

The purpose of the analysis presented in this report has been to determine the research and development effort in the private sector to reduce energy consumption in irrigated agriculture. It was necessary to identify the participants, the activities and the resultant products of energy-conserving innovations in the private sector to achieve the greatest impact of the National Program to Increase Energy Efficiency in Irrigated Agriculture. Discussions with representatives of 32 irrigation equipment manufacturers revealed that the industry is genuinely concerned about energy conservation but their research and development activities have been constrained by market forces. Within the past year, manufacturers have perceived an increased market demand for energy-efficient products and have responded in many ways.

SUMMARY

Based on an analysis of historic information, it was found that forces in the marketplace have guided technological change in the irrigation industry. Chapter II described how irrigators attempt to minimize production costs by substituting inputs with low relative prices for inputs with high relative prices. Irrigation technology was initially developed by agriculturists in response to increasing demands for food and increasing land values. Beginning in the 1940s and spiraling in the 1960s, increases in the cost of farm labor created incentives to develop labor-saving products such as the center pivot sprinkler system. The demand for labor-saving technology and the continually increasing demand for agricultural products spurred the development and expansion of the irrigation equipment industry. This industry includes over 200 manufacturers producing equipment for wells, pumps, prime movers, pipe, application systems, instrumentation, and scheduling techniques. The annual sales volume of this industry is estimated to be approximately one billion dollars for on-farm activities.

An extensive body of literature that relates sales volume to expenditures for research and development is available. In Chapter III estimates of research expenditures provided by irrigation representatives were compared with published estimates of research expenditures of the entire manufacturing sector. Based on this analysis, it is estimated that the irrigation equipment industry spends a higher percentage of its sales volume on research and development than the average manufacturing industry. Irrigation manufacturers reported an average R&D expenditure of 3.3% of total sales, while the entire manufacturing sector spends only 2% of sales on R&D. Based on this and the irrigation industry's estimated sales volume, annual research and development expenditures of the irrigation equipment industry are estimated to be \$33 million. Based on an analysis of patent trends, about \$5 million per year of this total research budget is spent on the development of patentable products. The rest is spent on modifications of existing designs, cost control, and other non-patentable items. The industry representatives explained that their biggest constraint on research and development activities is the availability of venture capital. The high opportunity cost of venture capital limits development projects to short-term efforts, which have short payback periods. The resultant products of such projects are typically modifications of existing products rather than revolutionary designs. A present value analysis of the expected profitability of a short-term energy conservation development effort indicated that the industry would not be willing to invest more than \$2.2 million per year on energy efficiency improvements.

Chapter IV detailed the effort of the irrigation equipment industry to develop energy-efficient products. Many manufacturers are involved with the development of low- and medium-pressure systems. A major problem in this effort is controlling the application rate to prevent excessive runoff and soil compaction. Other energy efficiency improvements are feasible by improving the quality of pumps, reducing friction in pipes, applying alternative types of gear drives, and reducing the weight of mobile sprinkler systems. Other efforts to save energy involve the application of micro-processor instrumentation for scheduling optimization and the application of solar and wind technology.

Most irrigation representatives feel that market forces provide sufficient incentive for their industry to be actively involved with new product development; therefore, few suggested any incentives that would be aimed at the industry. Most of the federal incentives that they suggested would be aimed at the irrigator and would have the effect of stimulating the market demand for energy-efficient technology.

Chapter V described how energy-efficient irrigation products may be distributed geographically. Two geographical discriminators that were identified are the use of groundwater and the use of sprinklers. Regions that would benefit the most from groundwater pumping efficiency improvements include the Southwest, Mountains, Northwest, and Southern Great Plains, and the Southeast.

CONCLUSION

The effects of new technology on energy conservation in irrigated agriculture are dependent on future market forces and are therefore difficult to predict. However, based on estimates provided by many industry representatives and assuming 100% market penetration of new technology, estimates of potential energy savings in the year 2000 are provided in Table 9 under three scenarios. The first scenario assumes that no additional incentives are provided by the federal government. The annual effect of this is estimated to be a savings of about 0.05 quads. The second scenario, which assumes that some incentives are aimed at the irrigation equipment industry, would have very small effect on energy conservation because most manufacturers agree that sufficient incentive is provided by market forces. The only segment of the industry that would have a noticeable effect is the fledging instrumentation and scheduling segment. The third scenario assumes incentives are aimed at both the irrigation equipment industry and at irrigators themselves. This could have a significant effect because it would stimulate market forces that provide the incentive for the private sector to develop new technology. The overall effect of a proper incentives program could be an annual energy saving as high as 0.16 quads.

TABLE 9. Estimates of Energy Savings in Irrigated Agriculture in the Year 2000

Product Category	Potential Energy Savings Without Additional Incentives		Feasible Energy Savings With Proper Incentives to Industry		Feasible Energy Savings With Proper Incentives to Industry and Irrigators	
	Efficiency Improvements (%)	Energy Saved (quads)	Efficiency Improvements (%)	Energy Saved (quads)	Efficiency Improvements (%)	Energy Saved (quads)
Wells	10	0.01	10	0.01	20	0.02
Pumps and Prime Movers	5	0.01	5	0.01	30	0.06
Distribution and Application Equipment	20	0.02	20	0.02	40	0.04
Instrumentation and Scheduling	5	<u>0.01</u>	10	<u>0.02</u>	20	<u>0.04</u>
Total Savings		0.05		0.06		0.16

The estimates of potential savings provided in Table 9 are based largely on a consensus of opinion, which developed from conversations with industry representatives. Under the first scenario, the status quo of market forces would cause the irrigation equipment industry to develop energy efficient technology at their evolutionary rate. The industry would have no incentive to increase their R&D effort beyond its historic proportions. Most industry representatives agree that there are no reasonable incentives that the federal government could provide directly to the industry that would significantly stimulate technology development. Indeed, some representatives believe that any attempt to do so could stifle their efforts. However, many representatives believe that the potential for significant efficiency improvements exists and would be attained if the industry perceived the effort as profitable. If the federal government could aim incentives at the irrigators to convince them that it would be economically sound to conserve energy, two energy-conserving effects could be created. The first effect would be to use existing irrigation equipment more efficiently, and the second would be to convince them to consider improved energy-efficient equipment when making capital investments. The combined effects of improved technology and improved use of existing technology would lead to significant energy savings, particularly in the energy-intensive end uses of groundwater pumping and sprinkler application. These energy savings, however, can only be accomplished if market forces dictate that they are prudent.

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APPENDIX

MANUFACTURERS OF IRRIGATION EQUIPMENT

TABLE A.1. (contd)

[illegible]

**TABLE A.2. Manufacturers of Irrigation Equipment with Annual Sales
Volume From \$500,000 to \$1 Million**

Manufacturers	Prime Movers	Sprinkler Heads	Center Pivots	Other Sprinkler Systems	Controls	Drip Systems	Pumps	Pipe	Valves	Filters, Strainers, Sand Separators	Moisture Measuring Devices
AL'S MACHINE SHOP		X						X			
AQUANOMICS IRR. SYSTEMS			X								
BRAND - REX COMPANY			X		X						
CLA-VAL COMPANY		X			X				X		
CLOW CORP.						X		X	X		
FELTON ALUMINUM CO.				X				X			
GENERAL ELECTRIC CO.	X				X						
GLOBAL WATER SYSTEMS		X				X					
THE GORMAN-RUPP CO.	X				X		X				
GREEN LAWN SPRINKLER CO.				X				X	X		
IRRIGATION ACCESSORIES CO.					X			X			
ITT MARLOW					X		X				
KURIYAMA OF AMERICA, INC.								X			
LAVAL SEPARATOR CORP.									X	X	
MIDWEST IRRIGATION CO.				X				X	X		
PERFECTION SPRINKLER CO.								X	X	X	
RANDOLPH MFG. CO.	X										
SENNINGER IRRIGATION, INC.		X			X						
SKINNER IRRIGATION		X			X				X		
STA-RITE INDUSTRIES, INC.	X						X				
TAMAQUA CABLE PRODUCTS CORP.					X						
TRAVIS PATTERN & FOUNDRY INC.				X				X	X		
VERMEER MFG., CO.				X				X			

**TABLE A.3. Manufacturers of Irrigation Equipment with Annual Sales
Volume From \$1 Million to \$5 Million**

<u>Manufacturers</u>	<u>Prime Movers</u>	<u>Sprinkler Heads</u>	<u>Center Pivots</u>	<u>Other Sprinkler Systems</u>	<u>Controls</u>	<u>Drip Systems</u>	<u>Pumps</u>	<u>Pipe</u>	<u>Valves</u>	<u>Filters, Strainers, Sand Separators</u>	<u>Moisture Measuring Devices</u>
A & P STEEL, INC.			X								
AG-RAIN, INC.				X				X			
ALCAN SHEET AND PLATE								X			
ANGUS IRRIGATION DIVISION								X			
BEALL PIPE & TANK CORP.								X			
BENNETT & BENNETT, INC.								X			
BERKELEY PUMP CO.	X				X		X		X		
CORNELL PUMP CO.							X				
CUSTOM STAMPING & MFG. CO.					X						
DEUTZ CORP.	X										
DURST	X		X	X							
GOODYEAR TIRE & RUBBER CO.								X			
GOULDS PUMPS INC.	X						X				
HALE FIRE PUMP CO.							X				
HYDRO ENGINEERING, INC.				X	X						
JACUZZI BROS. INC.							X				
KROY METAL PRODUCTS CO.				X				X			
LASCO INDUSTRIES								X	X		

TABLE A.3. (contd)

Manufacturers	Prime Movers	Sprinkler Heads	Center Pivots	Other Sprinkler Systems	Controls	Drip Systems	Pumps	Pipe	Valves	Filters, Strainers, Sand Separators	Moisture Measuring Devices
LIMA ELECTRIC CO., INC.	X										
MCDOWELL MFG. CO.			X	X				X	X		
MID-WEST FABRICATING CO.				X				X	X		
MOODY SPRINKLER CO., INC.		X			X				X		
MOULTON IRRIGATION CO.			X	X				X	X		
L. R. NELSON CORP.		X			X				X		
PACIFIC PUMPING CO.	X				X		X				
PERKINS ENGINES, INC.	X										
PRINGLE MFG. CO.			X								
RAIN FOR RENT, INC.				X				X	X	X	
SAFE-T-LAWN, INC.		X			X				X		
SARGENTS MFG. CO., INC.		X									
TRW-REDA PUMP CO.	X						X				
THUNDERBIRD IRR., INC.				X							
WATERMAN INDUSTRIES, INC.									X		
WEATHER-MATIC SPRINKLER DIV.		X			X				X		
WESTERN RAIN-TROL CORP.		X							X		
WHITE'S INC.	X										

**TABLE A.4. Manufacturers of Irrigation Equipment with Annual Sales
Volume From \$5 Million to \$10 Million**

<u>Manufacturers</u>	<u>Prime Movers</u>	<u>Sprinkler Heads</u>	<u>Center Pivots</u>	<u>Other Sprinkler Systems</u>	<u>Controls</u>	<u>Drip Systems</u>	<u>Pumps</u>	<u>Pipe</u>	<u>Valves</u>	<u>Filters, Strainers, Sand Separators</u>	<u>Moisture Measuring Devices</u>
ALUMINUM CO. OF AMERICA								X			
BUSH-HOG/REDI-RAIN		X		X		X	X	X	X		
BUTLER MFG. CO.			X								
CONSOLIDATED PIPE & TUBE CO.				X				X			
HASTINGS IRRIGATION PIPE CO.	X			X			X	X	X		
HEINZMAN ENGINEERING, INC.			X	X			X	X	X		
HASTINGS IRRIGATION PIPE CO.	X			X			X	X	X		
MARTIN MARIETTA ALUMINUM								X			
NELSON IRRIGATION CORP.		X		X							
SIMPSON EXTRUDED PLASTICS CO.								X			

TABLE A.5. Manufacturers of Irrigation Equipment with Annual Sales
Volume From \$10 Million to \$20 Million

Manufacturers	Prime Movers	Sprinkler Heads	Center Pivots	Other Sprinkler Systems	Controls	Drip Systems	Pumps	Pipe	Valves	Filters, Strainers, Sand Separators	Moisture Measuring Devices
ALUMAX IRRIGATION PRODUCTS				X	X			X	X	X	
JOHNS-MANVILLE SALES CORP.		X		X	X			X	X		
PIERCE CORP.			X	X				X	X		
REED IRRIGATION SYSTEMS		X			X	X		X	X	X	X
REINKE MFG. CO., INC.			X								
REYNOLDS METALS CO.								X			
R. M. WADE & CO.			X	X			X	X	X		

TABLE A.6. Manufacturers of Irrigation Equipment with Annual Sales
Volume of \$20 Million and Over

Manufacturers	Prime Movers	Sprinkler Heads	Center Pivots	Other Sprinkler Systems	Controls	Drip Systems	Pumps	Pipe	Valves	Filters, Strainers, Sand Separators	Moisture Measuring Devices
THE CARBORUNDUM CO.	X			X	X			X			
GIFFORD-HILL & CO., INC.		X	X	X				X	X	X	
LINDSAY MFG. CO.		X	X	X			X	X	X		
LOCKWOOD CORP.			X	X				X	X		
RAIN BIRD SPRINKLER MFG. CORP.		X		X	X	X		X	X	X	
THE TORO COMPANY		X		X	X			X	X		
VALMONT INDUSTRIES, INC.			X					X			

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