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CONSERVATION

CONSERVING ENERGY THROUGH NEW IRRIGATION TECHNOLOGIES

Technical Briefing Report

July 1982

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Battelle
Pacific Northwest Laboratories
Richland, Washington

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Conserving Energy Through New Irrigation Technologies

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U.S. Department of Energy
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Pacific Northwest Laboratories
Richland, Washington 99352

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SUMMARY

The potential for energy conservation in irrigated agriculture is substantial. Farmers in the United States could reduce fuel consumption by an estimated 30% if they used more efficient irrigation wells, pumps, application systems, and watering practices.

Taking advantage of advances in irrigation technology is usually in the best interests of the farmer. Energy-conserving irrigation systems, such as those discussed in this report, reduce expenses for water and energy, decrease soil erosion and nutrient leaching, and increase the yields of some crops. Capital investments in energy-conserving irrigation equipment are usually recovered in less than 3 years by energy cost savings alone.

This report explores the benefits and applications of five irrigation technologies: mobile drop-tube irrigation, computerized scheduling, reduced-pressure center pivots, well design and development, and automated gated-pipe systems. These technologies have been developed by private companies and universities from around the nation, with financial and technical support from the U.S. Department of Energy.

Perhaps the most promising of the new irrigation technologies is the low-energy, precision-application (LEPA) system. This mobile system uses one-half the energy of conventional sprinkler systems and distributes water with greater efficiency through a series of low-pressure drop tubes suspended above the crop. Dropping the water down closer to the plants also reduces wind drift and evaporation.

Computerized methods of irrigation scheduling have been developed to help farmers conserve water and energy. Special computer programs determine when a crop needs water and how much to apply for optimal plant growth, thus preventing the unnecessary costs of pumping more water than the crop needs. Field test results show that replacing traditional scheduling methods of irrigation with computerized scheduling can reduce energy and water use by as much as 35%.

The irrigation industry is actively promoting reduced-pressure water application methods, particularly for center-pivot systems. Reduced-pressure systems expend less energy but produce the same crop yields as conventional high-pressure systems, as long as excessive water runoff does not occur. The initial purchase costs of a reduced-pressure center-pivot system are the same as for a high-pressure center pivot.

If well design and development techniques are applied when a well is drilled into an unconsolidated acquifer, the well's life expectancy, as well as its operating efficiency, can increase, the latter by as much as 40%. These techniques may cost a little extra, but they generally pay for themselves many times over in reduced energy costs.

In the future, automated gated-pipe irrigation systems may replace conventional gated-pipe systems, because automation reduces water, energy, and labor requirements by 25%.

The following chapters explore these five irrigation technologies in greater detail.

CONTENTS

MOBILE DROP-TUBE IRRIGATION

Mobile sprinkler systems are popular because they require less water and labor than do gravity-flow systems. Unfortunately, large amounts of electricity are needed to pressurize sprinkler systems and, as energy prices rise, the expense of operating the systems also increases.

The U.S. Department of Energy recently funded the development of an energy-conserving sprinkler system that uses one-half the energy of conventional sprinkler systems. Engineered at Texas A&M University and known as the low-energy precision application (LEPA) system, this irrigation method efficiently applies water at low pressure through a series of long drop tubes. Converting a conventional center-pivot system to a LEPA system requires an investment of about $4000 to $6000. The payback period for the system, based on energy cost savings, is generally less than 1 to 2 years for most pumping situations.

A Simple Technology for Efficient Irrigation

The LEPA system is structurally similar to conventional sprinkler systems, except that it uses drop tubes instead of sprinkler nozzles to distribute water (Figure 1). The drop tubes significantly reduce the water pressure needed for irrigation.

Another benefit of the LEPA system is that it applies water directly to crop furrows as the system moves down the field. Conventional sprinkler systems, in contrast, apply irrigation water from a considerable distance above the ground. Less water is wasted by LEPA's lower distribution pattern, because the water is less subject to winds that cause evaporation and uneven distribution.

The best features of a stationary drip irrigation system (like those used in orchards) and a center-pivot or lateral-move sprinkler system are combined in the LEPA concept. Like a stationary drip system, LEPA distributes water close to the crop's

Figure 1. The low-energy, precision application (LEPA) irrigation system distributes water with great precision and economy through drop tubes suspended above the crop.

root zone, thereby reducing evaporation. Because the force of gravity moves the water from the main pipe to the nozzle, little pressurization energy is required. Like center-pivot and lateral-move sprinkler systems, LEPA also offers mobility and labor-saving advantages.

A LEPA system can be constructed by modifying a center-pivot or lateral-move sprinkler. The main components necessary for the conversion are drop tubes, discharge water nozzles, and pressure regulators (see Figure 2). (The regulators are used to dissipate the energy or water pressure and control the flow rate.) Additional equipment includes manifold pipes, emitters, flow-control valves, and an optional intermediate pressure system.

The main line of the system houses the manifold pipes, from which the drop tubes and emitters are suspended (Figure 3). The emitters, which are designed to reduce plugging, operate at 1 to 5 pounds per square inch (psi) and irrigate a 40-inch-wide furrow. The size of the orifices on the emitters can be adjusted to compensate for friction losses within each manifold and to hold emitter pressures constant. Flow-control valves compensate for pressure losses in the main line and elevation changes in the field. An intermediate pressure regulator can be used to maintain the desired water pressure as water flows from the supply pipeline.

Field Tests

In field trials conducted on the Texas High Plains by researchers from a Texas A&M agricultural experiment station, the LEPA system was compared to conventional sprinkler and gravity-flow irrigation systems. The field test results confirmed that LEPA is significantly more efficient in its use of energy and water than are conventional systems. Compared to the sprinkler system, LEPA's water application and distribution efficiencies were, on the average, approximately 21% and 6% higher, respectively. Likewise, compared to the gravity-flow system, LEPA's water application and distribution efficiencies were 8% and 78% higher,

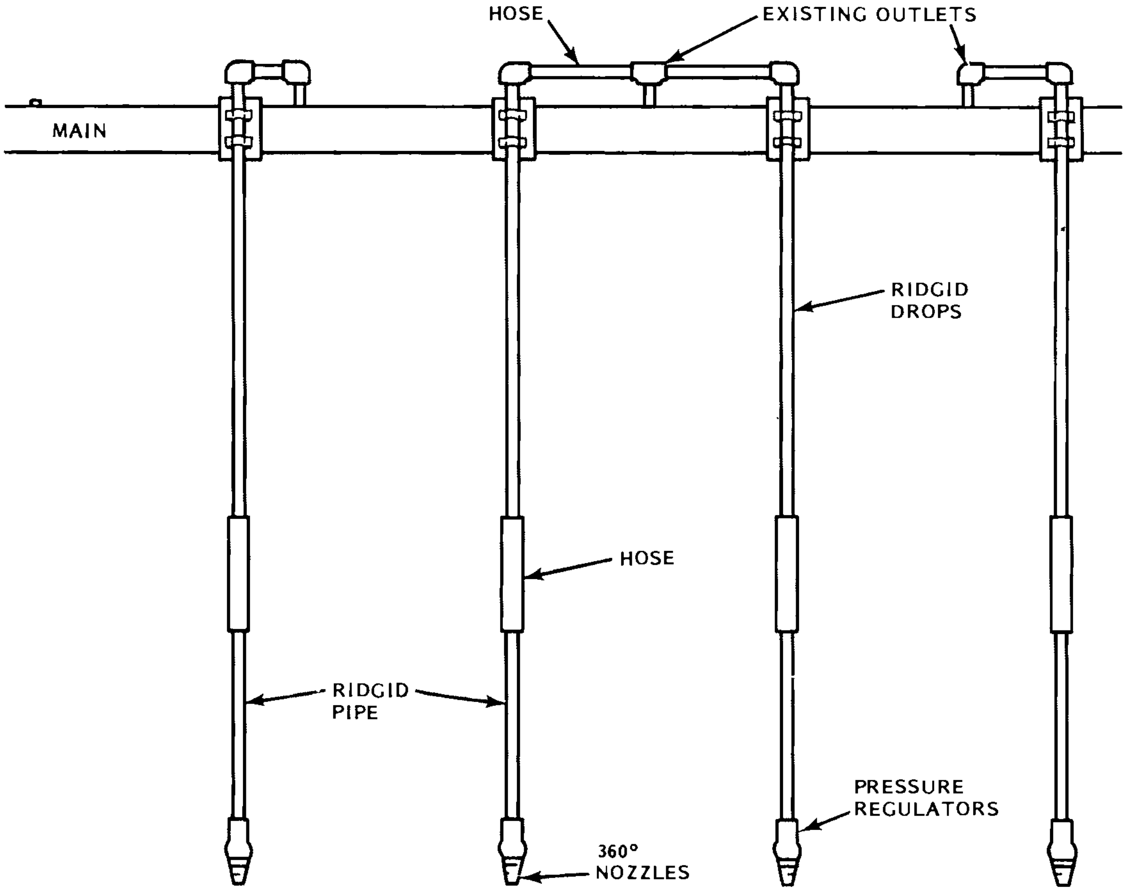

Figure 2. The LEPA pipe and nozzle assemblies shown here are easily installed on center-pivot and lateral-move sprinkler systems.

Figure 3. Nozzles attached to the end of the drop tubes typically operate at 1 to 5 psi and are designed to resist plugging.

respectively. The combination of higher water application and distribution efficiencies results in higher crop yields per unit of water applied (Figure 4).

Water pressure requirements for the LEPA system are lower than for other mobile irrigation systems, making LEPA even more energy efficient than the reduced-pressure systems currently on the market. In operation, a LEPA system requires almost 90% less water pressure than a conventional high-pressure center pivot or a lateral-move irrigation system, and almost 65% less pressure than a reduced-pressure center-pivot system (Figure 5).

No changes in cultivation practices are required with a linear LEPA system. However, the Texas field test demonstrated that the LEPA system performs better when used in conjunction with microbasin tillage (Figure 6). With this tillage technique, a series of earthen dikes is made within the furrows to trap irrigation water as it is applied. Microbasin tillage is especially effective for uniformly distributing water in tight soils and on sloping fields. This technique also eliminates runoff and erosion. Tillage equipment, which can be pulled behind a tractor, was developed in the test project (Figure 7).

For center-pivot LEPA systems, circular furrows are necessary. Several farmers have demonstrated that circular furrows can be

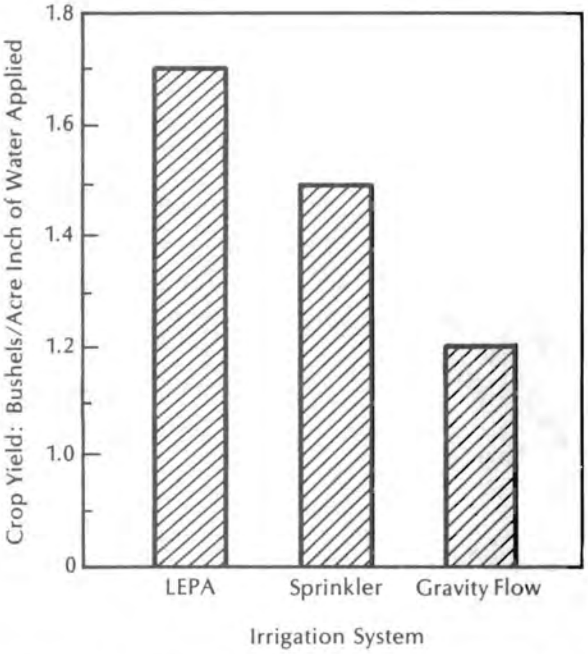

Figure 4. Soybean crop yields are higher with a LEPA irrigation system than with conventional sprinkler and gravity-flow systems, because LEPA systems apply and distribute water more efficiently.

plowed successfully by following the tracks of the LEPA system.

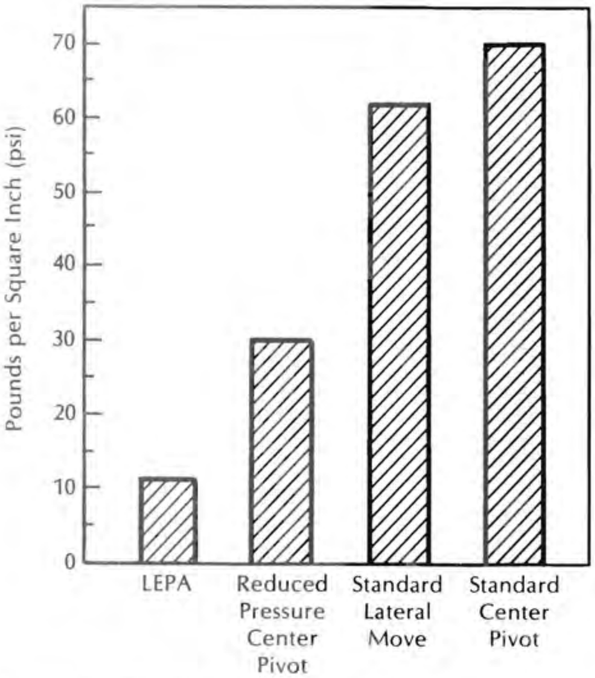

Figure 5. The LEPA system uses 90% less water pressure than conventional, high-pressure center pivots.

The LEPA system is most appropriate for row crops and has been used successfully to irrigate cotton, soybeans, grain sorghum, and corn. The system has not yet been demonstrated for irrigation of small grains. Local farmers who observed the tests in Texas were impressed with the LEPA system's performance and energy efficiency. In fact, some farmers have adopted LEPA and are now using it to irrigate their crops.

Reducing Irrigation Costs

Farmers who depend on irrigation to water their crops could reduce energy expenses considerably by installing a low-pressure, water-conserving LEPA irrigation system. The energy savings will vary with each farming operation, depending on the water needs of the crop, the growing conditions, the amount of lift required to deliver water to the crop, and the local price of energy.

The energy-savings potential of a LEPA system can be substantial. For example, in a 1980 Texas field test under well conditions featuring a groundwater lift of 280 feet, the LEPA system used 28.7 kilowatt hours/bushel as compared to 37.3 kilowatt hours/bushel for a lateral-move sprinkler system. Conventional tillage practices were used for both tests.

Figure 6. Runoff and erosion are reduced through the use of small earthen basins, which hold the irrigation water in the crop furrows until it can seep into the ground.

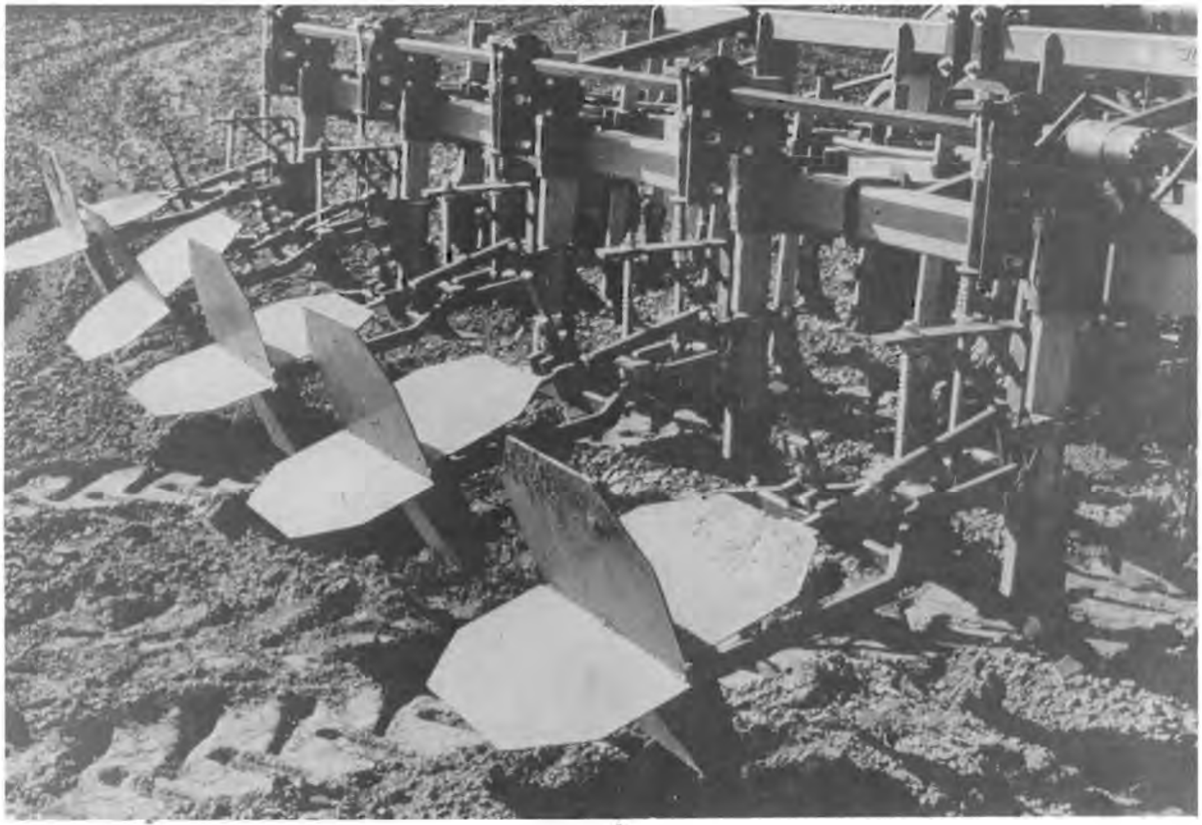

Figure 7. This plow, developed for the Texas field tests, created the earthen dikes or microbasins shown in Figure 6.

Similarly, in the same field test, the LEPA system used 20.1 kilowatt hours/bushel with microbasin tillage practices; the conventional sprinklers without microbasins, on the other hand, used 30.1 killowatt hours/bushel. Thus, in comparison to conventional systems, the LEPA system can result in energy savings of from 43% to 86%, depending on the tillage practice used.

To estimate your potential energy savings from using LEPA instead of a conventional center-pivot sprinkler system, first multiply your current annual energy costs for a 130-acre field by 0.25. [This reflects the improved efficiency of water use for the LEPA system--see (A) in the box to the right.] Add the resulting figure to the energy cost savings that result from the lower operating pressure of the LEPA system [see (B) in box]. The energy cost savings ultimately depend on the unit cost of fuel and the average acre-feet of irrigation water applied.

Annual energy cost savings for the LEPA system have been calculated for several types of irrigation situations. These savings are identified in Table 1.

How to Calculate Annual Energy Cost Savings From LEPA Irrigation on Your Farm*

Annual Energy cost savings = (A) [Current annual energy costs per 130-acre field] x 0.25 +

(B) [fuel savings per acre-foot of water applied† x unit cost of fuel x average acre-feet of water applied annually]

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*Assuming conversion from 70-psi to 11-psi system at the pivot pad.

†Annual fuel savings per acre-foot of water applied annually would be approximately 29,500 kWh of electricity, 458,000 cubic feet of natural gas, or 2,642 gallons of diesel fuel.

TABLE 1. Average Annual Energy Cost Savings of LEPA Center-Pivot and Lateral-Move Systems Compared to Conventional Sprinkler Systems

System Comparison	Irrigation Water	Cost Savings, $	
		Range	Average
LEPA Lateral Move vs. Conventional Lateral Move (for 160 acres)	Groundwater	2,208-16,123	5,050
	Surface	1,866-11,238	4,190
LEPA Center Pivot vs. Conventional Center Pivot (for 130 acres)	Groundwater	1,901-10,358	4,100
	Surface	1,703-7,502	3,820

The LEPA system can be installed as a new system or retrofitted to an existing center-pivot or lateral-move system. The estimated costs for a LEPA system are determined by the nature of the installation. Converting a conventional center-pivot system to a LEPA center-pivot system involves purchase of the drop-tube package and pressure regulators, which cost about $4000 to $6000.

The energy cost savings that result from irrigating with a LEPA system will return the capital costs for a retrofit installation on an existing center-pivot or lateral-move system in a relatively short time. The estimated payback period is 1/2 to 4-1/2 years, depending on the extent of the conversion, investment requirements, the cost of energy, and operating conditions. When labor and water savings are included in the analysis, the LEPA system will also return the costs of conversion from gravity-flow systems in generally less than 5 years.

COMPUTER ASSISTED IRRIGATION SCHEDULING

Excessive amounts of energy and water are consumed in agriculture because of the tendency to over-irrigate crops. Over-irrigation occurs largely because farmers perceive it to be safer for maintaining crop yields than under-irrigation, and because historically both water and energy have been inexpensive and readily available. Typically, irrigation needs are exceeded by as much as 20% through conventional methods, which rely on the personal judgment and time schedule of the irrigator.

Energy price increases make over-irrigation quite costly. A relatively new method of determining when and how much to irrigate--computerized irrigation scheduling--provides a scientific basis for determining optimal times to irrigate and the precise quantity of water to apply. Commercially available in certain areas since 1969, computerized scheduling programs account for such agricultural variables as rainfall, water intake by plants, crop cover, and soil type, to determine the optimal timing and irrigation volumes (Figure 8). Scheduling is effective for all types of irrigation systems where water volumes can be carefully controlled. The benefits of investing in some type of advanced scheduling program almost always outweigh the costs.

Currently, 1% of all irrigated land in the United States (approximately 500,000 acres) is served by some form of computer-assisted irrigation scheduling. Ultimately, scheduling could be applied to nearly 15 million acres of farm land.

Figure 8. Using field data collected by this farmer, a computer will calculate an irrigation schedule and water application rate that produces ideal watering conditions for crop growth.

Applying Computer Technology on Farms

Conventional scheduling practices vary from irrigation on a calendar basis to irrigation by stages of crop growth. Since the 1950s, more sophisticated methods based on periodic collection of climatic, crop, and soil data have been used to determine irrigation schedules and volumes.

In the early years, however, the determination of schedules based on climatic, crop, and soil data was time-consuming and tedious because of the frequent calculations necessary to maintain up-to-date schedules. With the advent of small computers, calculations are performed quickly and irrigation analysis is often more accurate.

Today, a number of private consultants and governmental agencies are set up to provide irrigation scheduling services that allow irrigators to conserve water and energy. Scheduling programs require input data on the moisture-holding capacity of the soil, the amount of water applied through irrigation or rainfall, daily weather conditions (including temperature, relative humidity, solar radiation, and wind patterns), and the type and stage of plant growth (Figure 9). Given information about these factors, a specially programmed computer calculates the crop's consumption of water from one day to the next. The computer subtracts moisture used by the plant and adds water supplied by irrigation and rainfall in a simulated analysis of the moisture content of the soil. Irrigations are then scheduled to maintain appropriate moisture levels in the soil.

Field Tests

In 1979 and 1980, at test sites in the San Joaquin Valley of California, agricultural scientists compared the performance of computer-assisted and conventional irrigation scheduling methods on tomato, grain, and cotton crops. Test plots were treated the same except for the scheduling method used. Performance factors analyzed were energy consumption, water use, and crop yield.

The test results indicated that irrigations scheduled by computer either used less water--and thus less energy--to produce comparable crop yields, or that they used the same amount of water to produce higher yields than conventionally scheduled irrigation. The higher the degree of control over water-application timing and amounts, the greater the savings of water and energy. Because sprinkler systems offer more control over irrigation water volumes than do gravity-flow systems, the overall energy and water savings tended to be greater for sprinkler-irrigated fields.

The water savings resulting from the use of computerized scheduling varied for the types of crop grown. For grain and tomatoes, the water savings were 31% and 35%, respectively.

Water Savings from Computerized Scheduling

Grain	31%
Tomatoes	35%
Cotton	0%

Although the amount of water did not change for cotton, cotton yields increased by 6%. At 1980 cotton prices, this increase represented an additional profit for farmers of $60 per acre.

The cotton yield increased because, for crops such as cotton and corn, the timing of water applications is more important than

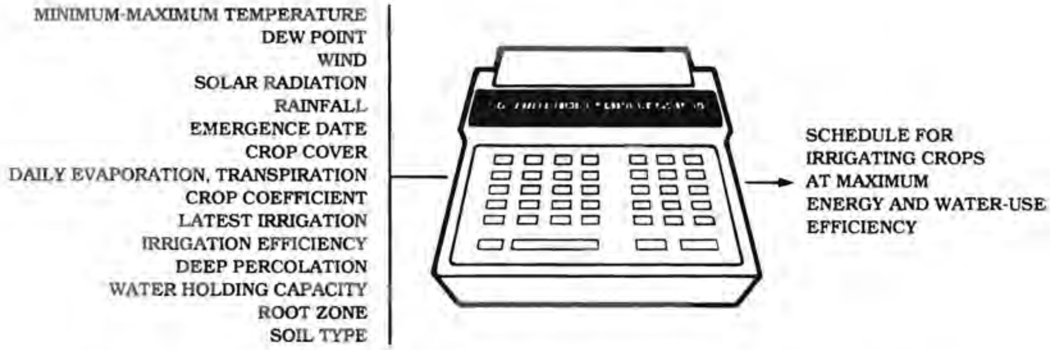
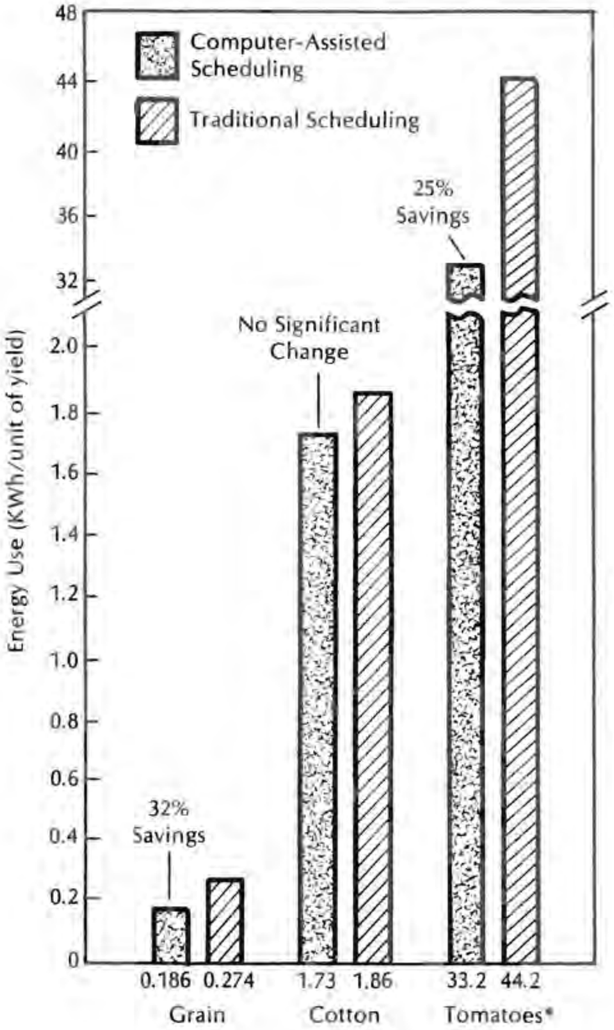


Figure 9. Computers merge a variety of information quickly and accurately.

the volume. No significant differences in the yields of grain and tomatoes were noted. The net result of computerized scheduling was a higher crop yield per unit of energy used for all three crops (Figure 10).

Cost Savings From Computerized Scheduling

Computerized scheduling reduces energy costs because less water is pumped. Additional money can be saved if the billing for irrigation water in your area is based on the volume of water used. An estimate of the total cost savings can be obtained by multiplying the percent of water that you will save by using computerized scheduling by your current energy and water costs. For example, in the San Joaquin tests, the water savings for sprinkler-irrigated grain were 31%. If the energy cost of irrigating 130 acres of grain by sprinklers is $13,000 annually, the annual energy cost savings from using computerized scheduling (assuming a 31% reduction in water use) would be approximately $13,000 x 0.31, or $4000.



*Surface irrigated

Figure 10. Computer-based irrigation scheduling makes possible higher crop yields per unit of energy use.

If water costs $4 an acre-foot and two acre-feet are applied annually, water costs would be approximately $1,040 on 130 acres. Thus, an additional $1,040 x 0.31, or $325, could be saved through computerized scheduling. Energy cost savings from computerized scheduling tend to be higher for groundwater-supplied systems than for surface-water supplied systems (see Table 2).

TABLE 2. Annual Energy Cost Savings from Using Computerized Scheduling on a 130-Acre Center Pivot

	Cost Savings, $	
Water Source	Average	Range
Groundwater	2000	676-7973
Surface	1083	444-2773

The net economic benefits of computerized scheduling depend on the cost of obtaining such services, as well as on the level of energy and water cost savings. Scheduling services vary in sophistication from the publication of printed data about crop water requirements to services where the irrigator is given specific recommendations on how much water to apply. Consequently, the cost of obtaining scheduling services depends on the level of service provided.

In 1980, the cost of hiring a private consultant to provide complete computer-based scheduling services for one year was approximately $5 an acre (or $650 for 130-acre plots) on farms 1000 acres or larger. Given the energy cost savings presented in the table above, the costs of obtaining complete scheduling services are returned by energy savings in almost every case. The only exception is where surface water, which has a very small pumping head, is used.

Because the total cost of providing scheduling services for small farms is nearly the same as for farms of 1000 to 5000 acres, small farms could reduce per-acre scheduling costs by purchasing scheduling information as a cooperative. Clearly, some type of advanced irrigation scheduling is beneficial in every farming situation where water application amounts can be carefully controlled.

CENTER-PIVOT IRRIGATION AT REDUCED PRESSURES

The growing demand for energy-conserving irrigation equipment has led to the development of reduced-pressure center pivots that have the labor-saving characteristics of standard center pivots but use less energy. Thus, they cost less to operate (Figure 11). Most performance problems previously encountered with the use of reduced-pressure systems have been corrected, and the systems are now considered reliable.

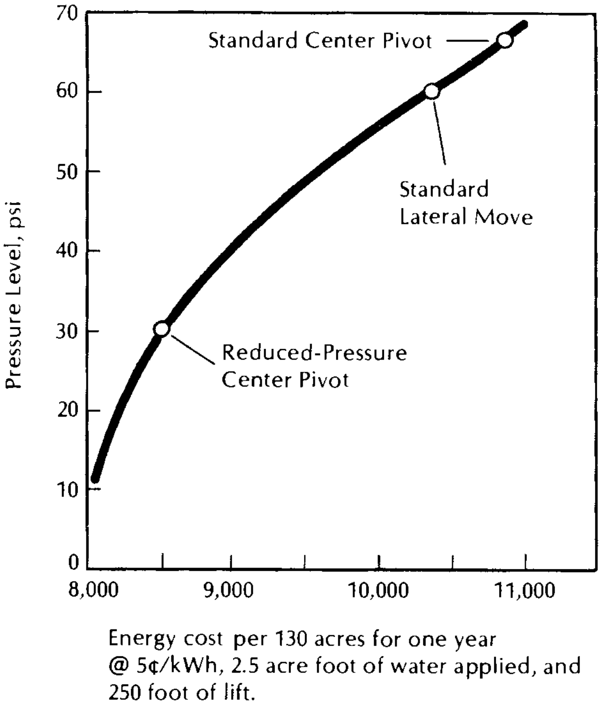


Figure 11. Reduced-pressure irrigation systems cost less to operate than high-pressure systems.

Reduced-Pressure Irrigation Technology

Several types of reduced-pressure center pivots are available; the appropriate system for your farm depends on such factors as soil, topography, cultivation practices, and crops. Most of the new systems available through irrigation companies operate at 30 psi. This is approximately 40 psi below the operating pressure of high-pressure center pivots. Reduced-pressure pivot and lateral-move systems are similar to their high-pressure counterparts, except that they are equipped with either impact sprinklers or spray nozzles specifically designed for use at low pressures.

Because these impact sprinklers and nozzles have lower operating pressures, they distribute water over a narrower area than do high-pressure sprinklers. Consequently, to provide full irrigation coverage, more nozzles or sprinklers are needed. In addition, reduced-pressure systems require slightly more flow-regulating equipment than conventional high-pressure systems to maintain uniform application rates throughout the irrigation system.

Lowering the pumping pressure of an irrigation system enlarges water droplets and increases the water application rate. These two factors can contribute to water runoff unless appropriate soil and field conditions exist. However, correct cultivation practices can reduce or eliminate the possibility of water runoff.

When to Use Reduced-Pressure Center Pivots

Generally, reduced-pressure center-pivot irrigation systems perform best on light soils and on fields with slopes of less than 5 percent. Light soils have a high water-absorption capacity, compensating in part for the higher water application rates of reduced-pressure irrigation. Moreover, the lighter soils can accommodate large water droplets without soil compaction problems.

Field Tests

The Department of Energy recently funded a study to compare the performance of reduced-pressure and high-pressure center-pivot systems. The variables evaluated included water runoff, crop yields, and energy use. At a test site near the University of Nebraska, researchers mounted high-pressure and low-pressure sprinklers and low-pressure spray nozzles on an experimental center pivot (see Figure 12). Each system was then used at a different point in the pivot's rotation.

For the field trials, three alternative tillage methods were used and compared: (1) a reduced till method involving chopping corn stalks in the spring, tilling the field, planting corn, and cultivating the crop; (2) a disk method involving disking

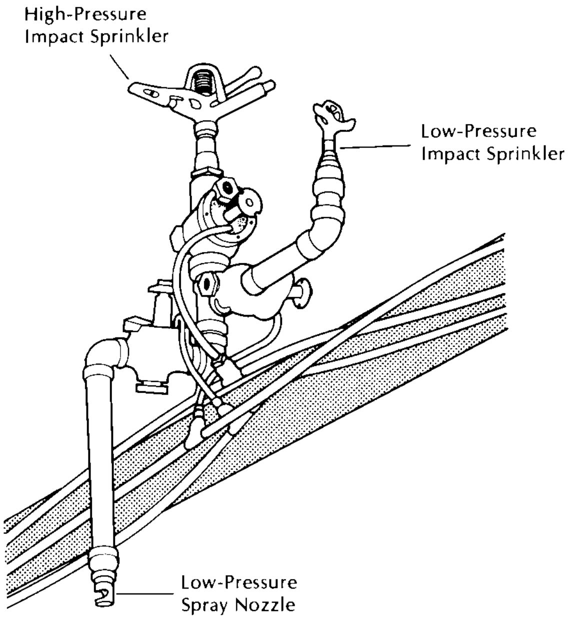


Figure 12. The Nebraska field test compared the efficiency of high- and low-pressure impact sprinklers and a low-pressure spray nozzle.

twice in the spring, planting corn, and cultivating the crop; and (3) a chisel method involving chopping stalks in the spring, tilling, planting, cultivating, and subsoiling.

The most significant finding of the Nebraska field tests was that crop yields did not change as a result of using reduced-pressure irrigation methods. The researchers concluded that reduced-pressure systems decrease crop yields only when excessive water runoff occurs.

The field test results also suggest that reduced-pressure impact sprinklers perform better than spray nozzles, especially on heavy soils and steep slopes. Runoff from the reduced-pressure sprinklers never exceeded 1% of the total volume of water applied. This is comparable to conventional high-pressure-irrigation runoff levels. For the nozzle systems without side booms (extension pipes that spread water over a wider coverage band for a lower instantaneous application rate), however, runoffs as high as 10% to 13% of the water applied were recorded. The average runoff volume from the nozzle system was about 2%.

The severity of runoff problems depended on the slope of the field, soil type, and the cultivation method used. Both of the reduced-pressure systems used in the study created few runoff problems on light, high-intake soils, and on slopes of less than 5%. Generally, spray nozzle systems without side booms should not be used on heavy soils or on fields with slopes greater than 5%. The Nebraska tests also indicated that the larger water droplets associated with reduced pressures did not harm the soil, even though the larger droplets caused a light crust to form on the soil surface.

The chisel cultivation treatment limited runoff far better than did reduced-till or disk methods. Even for the spray nozzle system, runoff was generally less than 1% on plots where the chisel treatment was used. Disking promoted the most water runoff.

Typically, variations in water pressure caused by changes in field elevation are more pronounced for low-pressure systems than for high-pressure systems. Discharge variations can be prevented by installing pressure regulators or flow control nozzles. Such devices were not used in the Nebraska study.

Cost Savings Through Reduced Pressure

The main benefit of reduced-pressure center-pivot irrigation is energy cost savings, which average about $2,725 per year for a 130-acre field on which excessive runoff does not occur. The energy savings could range from $1,150 to $7,500, depending on the amount of water used to irrigate and the cost of energy.

Annual energy cost savings resulting from a conversion to reduced-pressure irrigation on your farm can be estimated by multiplying the fuel savings per acre-foot of water applied (see the box below) by your unit cost of fuel and total acre-feet of irrigation water applied.

How to Calculate Annual Energy Cost Savings From Reduced-Pressure Irrigation for Your Farm*

Energy cost savings = fuel savings per acre-feet of water applied† x unit cost of fuel x average acre-feet of water applied

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*Per 130-acre field; assuming conversion from 70-psi system to 30-psi system.

†The annual fuel savings per acre-foot of water applied would be approximately 20,000 kWh of electricity, 310,000 cubic feet of natural gas, or 1,785 gallons of diesel fuel

The reduced-pressure system will result in energy cost savings unless extreme conditions exist. Studies show that as long as water use does not increase by more than 30% to compensate for higher runoff, a reduced-pressure system will reduce total energy costs.

Equipment and Installation Costs

The price of a reduced-pressure irrigation system is nearly identical to that of a conventional high-pressure system.

Converting an existing high-pressure center-pivot system to a reduced-pressure system costs approximately $4400 for alterations to the center pivot alone. Modifications to the pumping plant are also necessary, the cost of which will depend on the existing pump's lift, operating efficiency, and other factors.

The expense of retrofitting an existing high-pressure center pivot with reduced-pressure components usually can be recovered in less than 3 years. On farms where pumping heads are extremely large (~300 feet), the payback period may be longer.

TECHNIQUES TO IMPROVE WELL EFFICIENCY

Several techniques are available to increase the efficiency of irrigation wells that draw from unconsolidated aquifers. Most irrigation wells operate at a meager efficiency of 25% to 40%. Through proper design and development of a well when it is drilled, improved efficiencies of 60% to 80% are attainable.

Making wells more efficient will conserve a great deal of energy, as 70% of all of the energy used in irrigated agriculture is used to lift water from beneath the ground to field level. Producing the desired water flow for the least investment cost has long been an important goal in well construction. Generally, however, little thought has been given to constructing wells with reduced drawdowns, even though drawdown is directly related to a well's energy use. Now that the high price of energy is reducing farm profits, more interest is being shown in applying well-development and well-design techniques that lessen drawdown and conserve energy.

Wells waste energy if they are installed with poorly designed well screens and gravel packs, or if they are given little or no well development. These design factors should be considered before a well is drilled, and well development should begin immediately afterwards. Overpumping, surging, and jetting are three well-development techniques for removing the fine particles that can inhibit water flow and increase well drawdown.

Well design and development are relatively inexpensive, if completed when the well is new. Usually, the investment costs for improving well efficiency in unconsolidated (loose-formation) aquifers are returned many times over during the life of the well.

Design Factors for Irrigation Wells

Most of the wells constructed for crop irrigation in the United States operate in unconsolidated aquifers. In these kinds of aquifers, the very process of drilling a well can restrict natural water-flow characteristics and can reduce efficiency. When a well is drilled with rotary drilling equipment, for example, the borehole made by the drilling bit is held open by the hydraulic pressure of a drilling fluid until the screen and casing are installed. The invasion of this drilling fluid causes the formation of a mud cake, which clogs the pore spaces through which water would otherwise permeate into the well. This results in a larger well drawdown and higher energy demands by the well (see Figure 13).

Traditionally, bentonite has been used as the primary component of well drilling fluid. Recently, however, new types of organic drilling fluid have been introduced which have the potential for reducing energy losses caused by mud blockage in the well.

When designing a well, care should be taken to select an appropriate gravel pack and well screen. Gravel packs are placed inside a well primarily to keep sand and silt from entering the well's interior. Ideally, gravel packs should limit sand pumping but should not significantly decrease the permeability of the well to water flow, which could increase well drawdown.

Well screens are also used to reduce the number of fine particles entering the well. Screen slots should be sized so that they are small enough to limit sand pumping but large enough to prevent plugging of the well screen.

Techniques for Making Wells More Efficient

Well development techniques are used to dislodge drilling fluid, remove fine particles that clog water pathways, break up sand formations, and reduce the effects of soil compaction caused by the construction process. Overpumping is a commonly used technique that involves pumping water from

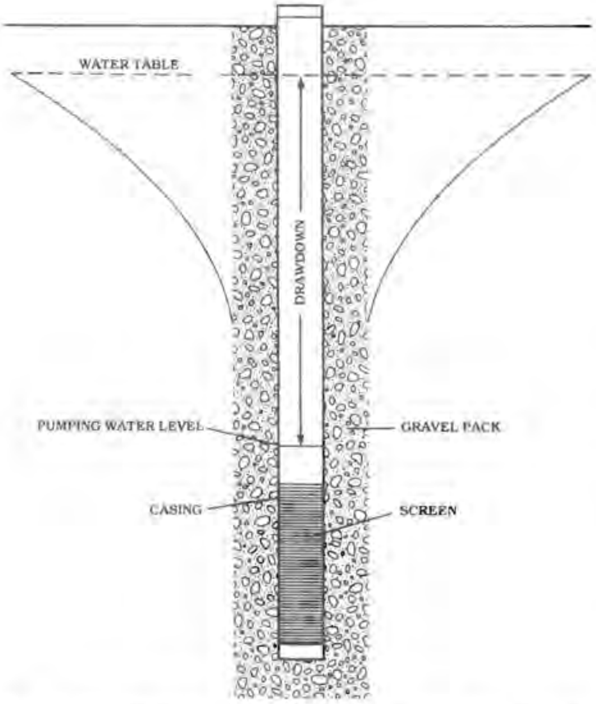

Figure 13. Well drawdown occurs when mud and sand collect in a well and impede the aquifer's natural permeability.

a newly constructed well at a higher capacity than the well is designed for. Overpumping creates large, rapidly moving water flows that flush out mud and fine particles that have built up on the screen. A variation of this method, known as rawhiding, is commonly used to develop wells. Overpumping is generally not as effective in removing particles from a well as are surging or jetting.

In surging, a rubber plunger is lowered into the well approximately to the top of the well screen and then is moved up and down rapidly (Figure 14). This movement creates a back-and-forth surging action through the screen and washes the mud and fines into the well where they can be removed. Surge blocks take many forms, and every well driller has a favorite design.

High-velocity water jets are used in jetting to remove mud from the well screen and walls. A special hose with two or four nozzles is lowered into the well opposite the screen, and water is forced through each nozzle (see Figure 15). The jetting tool is then rotated slowly and moved up and down. At the same time, compressed air is pumped through the well at a rate approximately 1.5 times greater than the flow through the nozzles. The combined actions of the jetting tool and the compressed-air pumping produce a flushing action that cleans the well.

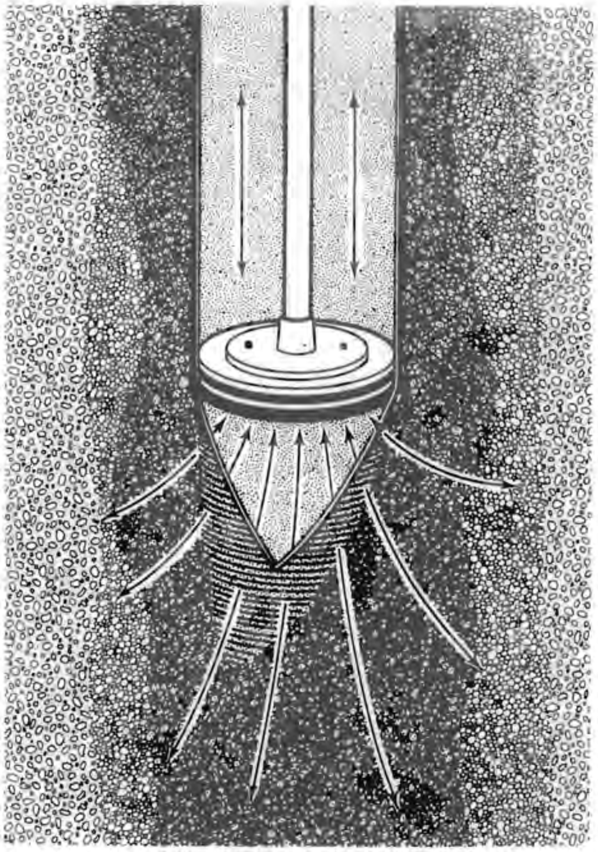

Figure 14. This surge block acts like a rubber plunger in removing debris from the well screen.

Ideally, all well drilling operations should include an aquifer survey, initial exploration and test drilling, careful well design based on the geographic and geologic features of the formation, use of an appropriate drilling method, well development, and performance testing of the pump. If exploration and test drilling are not undertaken, the risk of well failure is high for wells drilled in unconsolidated formations. Data from the test drills should be used to determine the optimal gravel-pack filter for the well, the best screen-slot sizes, and the length of the screen. The success of a well--its longevity, energy efficiency, and production--depend on these measures.

Field Tests

At the University of Minnesota's irrigation testing grounds near Staples, Minnesota, several well designs and development techniques were tested in 10 experimental

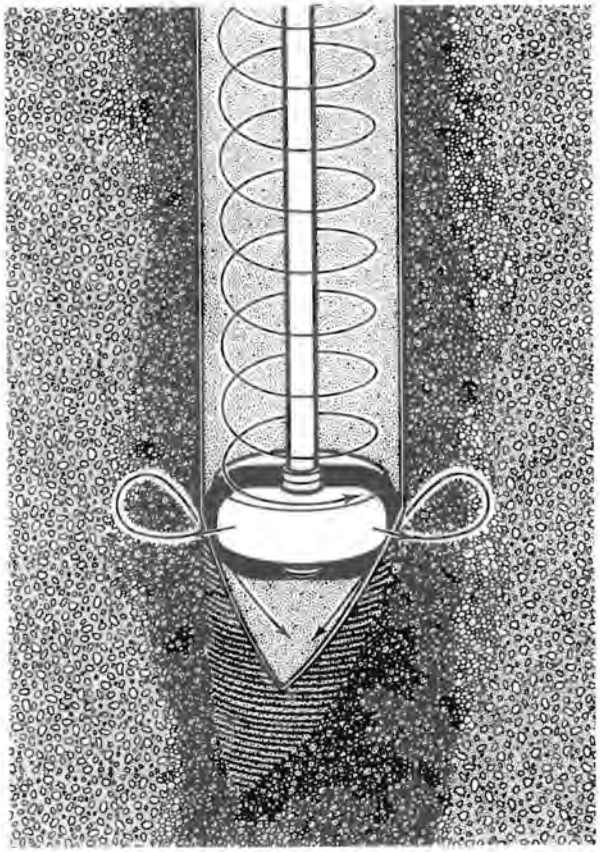

Figure 15. Jetting tools bombard the interior of a well with high-velocity water flows, which dislodge mud and sand.

wells drilled in an unconsolidated aquifer. Some of the wells were drilled using bentonite drilling fluid, and others were drilled using an organic fluid. Also, screen slot sizes and the amount of open screen area were varied among the wells. Different gravel packs were installed, and surging or jetting treatments were applied to each well.

The test results indicate that matching well screen slot sizes and gravel packs to the size of the particle fines in the aquifer enhances well performance. Complete well failure occurred when the gravel packing was purposely oversized.

Wells drilled with organic drilling fluid were generally more efficient than wells drilled with bentonite fluid. The former, however, did not respond to well development. In wells drilled with bentonite fluid, surging and jetting increased well efficiency by nearly 13% and 18%, respectively. Well drawdown was reduced by 35% through surging and by 45% through jetting.

Specific capacities (the ratio of flow rate to actual well drawdown) are often used to evaluate well performance. The specific capacity of wells drilled using bentonite fluid increased 53% after surging treatments and 74% after jetting (Figure 16).

The Economic Benefits of Well Development

Reduced operating costs more than compensate for the initial costs of correct well design and development. The estimated energy cost savings from surging and jetting on a 160-acre field range from $160 to $4670 per year (see Table 3). Although the energy cost savings of jetting are higher than those of surging, the initial investment costs for jetting are also higher (Table 4).

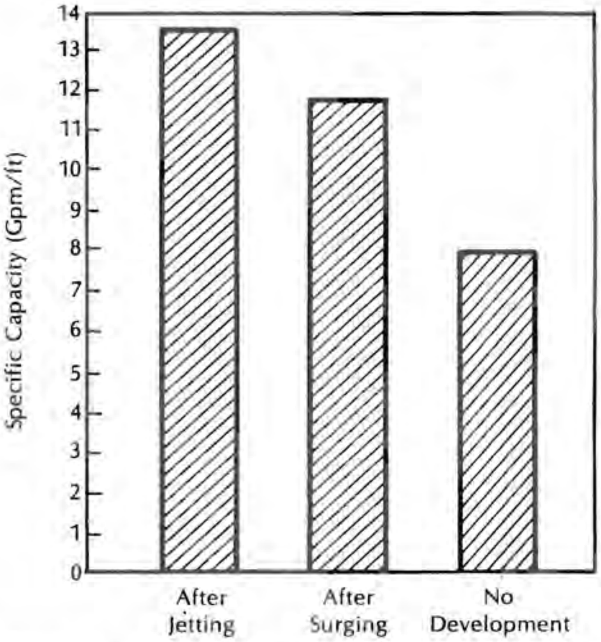

Figure 16. Jetting and surging appreciably improve well performance.

TABLE 3. Estimated Annual Energy Cost Savings for Well Development in Unconsolidated Aquifers Supplying Water for 160 Acres

	Cost Savings, $	
	Average	Range
Surging	710	160-3700
Jetting	890	200-4670

TABLE 4. Capital and Development Costs for Wells

Well Type	Drilling (Per Foot), $	Development Cost, $
Conventional	40	0
Surge	44*	400
Jetted	44*	1600

*Includes $4 per foot charge for exploration and test drilling.

In general, surging offers higher net economic benefits than does jetting because the lower capital costs of surging are more easily returned by energy cost savings. In areas of high energy costs and deep pumping depths, however, jetting may be more beneficial than surging.

The information presented in Tables 3 and 4 demonstrates that both surging and jetting in unconsolidated aquifers will return their initial investment costs in a relatively short time. The payback period for surging is generally less than 2 years, and the payback period for jetting is generally less than 3 years. The costs of investing in high quality, open-area well screens, correct gravel packing, and well development are also returned in less than 2 years, based on a cost analysis performed as part of the Staples project.

GATED-PIPE IRRIGATION BY REMOTE CONTROL

A promising new concept in crop irrigation--gated-pipe watering by remote control--combines the labor- and water-saving characteristics of mobile sprinkler systems with the energy-conserving features of gated-pipe systems. A prototype of the system has been built by engineers at Kansas State University (see Figure 17) and has been used successfully to irrigate 150 acres of corn for two growing seasons. Field tests show that the radio-controlled system applies water more efficiently, uses 22% less energy, and requires 25% less labor than conventional gated-pipe or sprinkler irrigation systems.

Gated-Pipe Irrigation Technology

Automated gated-pipe systems use the standard equipment of conventional gated-pipe systems, such as gated pipe and distribution pipelines. Batteries, radio transmitters and receivers, servos, and flow-control valves supply the automation. Servos are radio-activated control mechanisms (like those used to operate model airplanes) that convert radio signals into mechanical action. The timing and duration of the watering are controlled either by a microcomputer or by an irrigation controller similar to the ones used on many sprinkler systems.

To start the flow of water, the controller or microcomputer in the control panel commands the transmitter to send a programmed radio signal to the receivers. The radio signal is then forwarded to the servos, which respond by opening the pilot valves on the flow-control valves. Water-filled rubber diaphragms in the appropriate control valves are then deflated, and irrigation water is allowed to pass through the valves into the open gated pipes, which release the water into crop furrows (Figure 18).

To stop the flow of water, the radio transmitter signals the pilot valves to inflate the diaphragms with water from a tiny reservoir in the flow-control valves, and water flow through the gated pipes is halted.

Currently, a radio-control system specifically designed for use in irrigation is not commercially available. However, many

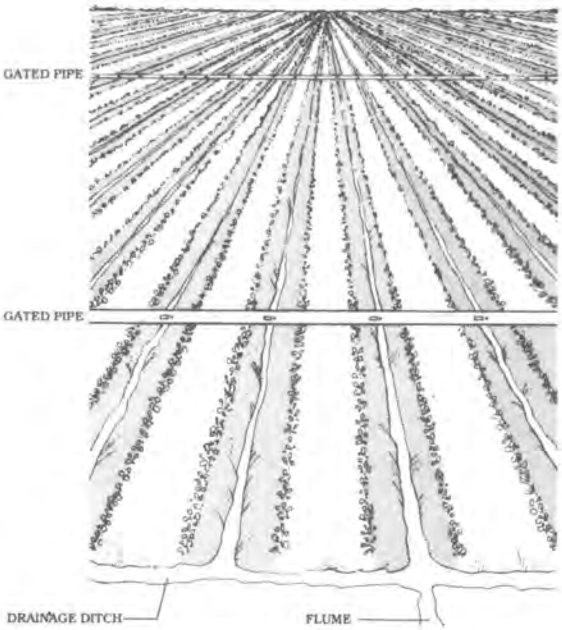

Figure 17. Gated pipes set at intervals across a field supply irrigation water to crop furrows. The automated system requires minimal labor and conserves energy.

Figure 18. The water flow to this crop was activated by remote control, based on a preprogrammed irrigation schedule.

of the concepts behind the development of the prototype have proved to be sound. If farmers generate sufficient demand for automated gated-pipe systems, irrigation manufacturers probably will make them available in a relatively short time. A promising modification to the automated system will be the use of electrical wiring rather than radio controls to transmit commands.

Field Tests

In field tests conducted near Kansas State University, an automated gated-pipe system was installed and successfully used to irrigate 150 acres of corn during two growing seasons on land belonging to a commercial farmer. The test results confirmed that automation allows for better control of irrigation timing and water distribution, leading to a significant increase in water application efficiency.

Water application efficiencies averaged 75% for the automated gated-pipe system compared to 60% for conventional methods of gravity flow irrigation. Water distribution efficiencies were also improved.

Application Efficiencies

Conventional Gated Pipe	60%
Automated Gated Pipe	75%

Improved water-application efficiencies translate into fuel savings for the farmer. Less fuel is consumed simply because less water is pumped to irrigate crops. Calculations based on data from the field tests indicate that the automated system uses approximately 22% less electricity, diesel fuel, natural gas, or propane than a conventional system (Table 5).

Labor and Energy Savings Through Automation

Conventional gated-pipe systems have been in use for many years, but their labor requirements are relatively high. An irrigator must manually open and close the gates of the pipeline, usually once every 12 or 24 hours. Frequently, the changing of irrigation sets is more suited to the farmer's work schedule than to the moisture needs of the crop. Prolonged and inflexible water applications result in inefficient, wasteful irrigation. Labor is usually too costly or is not available to change irrigation sets often enough to obtain high levels of efficiency in water and energy use.

TABLE 5. Estimated Annual Equivalent Fuel Requirements

	Electricity, kWh	Diesel, gal	Natural Gas, 1000 ft^3	Propane, gal
Conventional Gated Pipe	216,121	17,483	3,277	31,726
Automated Gated Pipe	168,154	13,603	2,550	24,684
Savings	47,967	3,880	727	7,042

Through automation, changes in irrigation sets can be made according to the moisture needs of the crop and without the constant attention of the irrigator. Automation reduces manpower requirements by an estimated 25% (Table 6).

The lower labor and fuel requirements of the gated-pipe irrigation system substantially reduce its operating costs compared to a conventional system, even though repair costs for the automated system are slightly higher (Table 7).

An automated gated-pipe irrigation system capable of irrigating 150 acres costs approximately $37,000 when purchased new. This is less than for a center pivot. Regular gated-pipe systems, in contrast, cost about $15,000. If land leveling is necessary, the costs for both automated and conventional gated-pipe systems will increase. The payback period for the automated system depends on fuel and labor expenses on the farm where it is installed.

TABLE 6. Annual Labor Requirements for Four Complete Irrigations of a 150-Acre Site

	Man hours			
System	Preparation	Operation	Total	Labor/ Acre
Conventional Gated Pipe (2600-ft run)	64	114	178	1.2
Automated Gated Pipe (1600-ft run)	80	57	137	0.9

TABLE 7. Annual System Operating Costs for 150 Acres*

	Fuel Used			
	Electricity (6¢/kWh)	Diesel ($1.20/ gal)	Natural Gas ($2.50/ 1000 ft^2)	Propane (70¢ gal)
Automated Gated Pipe	$12,501	$18,736	$ 8,787	$19,691
Conventional Gated-Pipe	14,438	22,451	9,664	23,679
Center-Pivot	15,647	23,461	10,991	24,658

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* Annual operating costs are the sum of annual labor, fuel, and repair costs. Labor is prices at $6/hr, fuel at the prices indicated, and repairs at 1.5% of original component prices for the conventional gated-pipe system and 5.5% of original component prices for the automated gated-pipe and center-pivot systems.

DEFINITIONS

Actual well drawdown	the vertical difference (in feet) between the water level in a well when the pump is off and the water level when the pump is on.
Application head	the amount of force necessary to pressurize an irrigation system.
Aquifer	a water storage and supply medium.
Pumping head	the vertical distance (in feet) between field level and the water level in a well when the pump is off.
Specific capacity	a performance measurement for a well which is calculated as the ratio of well flow rate to actual well drawdown.
Theoretical well	the drawdown that would occur in a well if well efficiency drawdown were 100% and drawdown were determined totally by aquifer characteristics.
Total operating head	the force exerted by a column of water of a given depth. For irrigation, it is the sum of well head, pumping head, and application head.
Unconsolidated aquifer	an aquifer in which the material surrounding the aquifer is not cemented together. An aquifer surrounded by sandy soil is an example of an unconsolidated aquifer, whereas one surrounded by sandstone is not.
Water application efficiency	the ratio of the amount of water stored in the crop root zone to the amount of water applied. It is a measurement of the amount of water that is actually made available to the crop and is not lost in runoff, evaporation, or deep percolation.
Water distribution efficiency	a measurement of the variance in the average depth of applied irrigation water. It is calculated by subtracting from 1 the ratio of the average deviation in stored water depth to the average stored water depth and then by multiplying by 100.
Well efficiency	a measurement of the efficiency of a well in providing water for pumping. Well efficiency is calculated by dividing the ratio of flow rate to actual drawdown by the ratio of flow rate to theoretical drawdown and multiplying by 100.
Well head	the amount of force required to overcome well drawdown.

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TECHNICAL INFORMATION RESOURCES

The following firms and universities helped develop the energy-conserving irrigation equipment and systems discussed in this brochure. Funding and technical guidance were provided by the Department of Energy.

Low-Energy Precision Application (LEPA)
Texas Agricultural Experiment Station
The Texas A&M University System
Route 3
Lubbock, TX 79401
William M. Lyle
(806) 889-3315

Computerized Scheduling
J. M. Lord, Inc.
1685 E Street, Suite 109
Fresno, CA 93706
Joe Lord
(209) 268-9755

Reduced-Pressure Irrigation
The University of Nebraska--Lincoln
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