REDUCING ENERGY REQUIREMENTS FOR SUPPLYING IRRIGATION WATER

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Introduction

It is well within current technological capability to achieve an overall reduction of 10 to 20% in the energy consumed annually for providing water for irrigation. The potential reduction is much greater. The barriers to attaining it are primarily human and not a lack of scientific information. The problem is twofold: (1) there is a need for a greatly expanded program of information dissemination to the principal water supply user, the irrigator; (2) farmers have a natural resistance to the change of status quo plus doubts about the economic advantages of the changes which must be made in irrigation practice if energy use is to be reduced. The current high price of fuel, the persisting local shortages and the alternatives of using less energy or not irrigating at all may, however, force change at a rapid pace.

Energy in relation to irrigation means energy for pumping water. Energy is needed for lifting water from wells, for providing pressure for sprinkler systems, for raising water to the high point of a field so that it can be used for surface irrigation. At the end of 1972 there were approximately 50 million acres of irrigated land in the United States. Ten million were sprinkled and 40 million surface irrigated (9). Essentially all sprinkled land requires the use of energy for pumping. As a very rough estimate, 50% of the surface irrigated land used pumped water, (reliable statistics are very difficulty to obtain). This means that probably over half of all irrigation agriculture in the United States requires a consumption of fossil fuels or hydro-power to provide a water supply.

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This past year irrigators only began to feel the pinch of the energy crisis. Fuel shortages occured in various areas. In the midwest, many growers turned to electricity as an alternative only to find a long waiting period before they could get connected. The short run energy supply picture for agricultural water supply is unclear. Even if the Federal Government is able to provide 100% of last year's requirements, local shortages could occur. This is especially true in states such as Nebraska where irrigation agriculture is rapidly expanding and the demand for fuel is increasing at a high annual rate.

Nebraska is currently the third state in the nation in terms of total irrigated acreage. By the year 2000 it could conceivably be first. Projections of the growth rate of irrigation suggest an increase in the state from the present 5 million acres up to 7.5 million acres by 1980 depending on the energy supply and a continued favorable economic climate for development. The most limiting factor could be the availability of energy for pumping water.

Using presently available technology there are several different procedures which can be used to reduce energy requirements for irrigation pumping. Some are common to all widely used irrigation methods while others are specific to a given method or general climatic zone. Perhaps none could be considered to have application throughout the entire irrigated region of the United States. However, the application of each one where appropriate would yield substantial improvement in the energy picture for agricultural water supply.

The suggested procedures include:

1. Increasing irrigation pumping plant efficiency.
2. Reducing water application.
3. Improved management of electric pumping plants.
4. Reuse of irrigation runoff water.
5. Improved irrigation system design.

Increasing Irrigation Pumping Plant Efficiency

There is one step which, if taken by all irrigation pump owners, could reduce energy requirements for pumping by 10 to 20% next year. That step would be the adjustment of all pumping plants to bring them up to field performance standards. This pertains to all nonelectric power plants and all deep well pumps, regardless of power plant type. Table 1 shows performance standards which have been established for deep well pumping plants. These are standards which have been generally accepted throughout the United States. They were developed and verified by several years of field and laboratory study (2, 12, 15). They are practical performance levels which can be obtained in the field when pump and power unit are in good condition and are properly adjusted.

Table 1. Performance standards for deep-well pumping plants

Energy source	Rated load hp-hr/gal for representative power units	Performance standard in whp-hr/gal[1]
Diesel	14.58[2]	10.94
Gasoline	11.54[2]	8.66
Tractor fuel	10.48[2]	7.86
Propane	9.2[2]	6.89
Natural gas	88.93[3] per 1000 cu. ft.	66.7 per 1000 cu. ft.
Electric	88 percent efficient	0.885 per kw-hr

[1] Based on 75 percent pump efficiency.
[2] Taken from Test D of Nebraska Tractor Tests Reports. Data corrected for 5 percent drive loss.
[3] Manufacturers' data corrected for 5 percent drive loss.
[4] Not corrected for drive loss. Assume a direct connection.

In a study conducted a few years ago 376 pumping plants were tested in Nebraska and compared with these standards (7). The results are summarized in Table 2. Less than 9% of the systems tested met the standard and less than 60% achieved 75% of the standard performance. The basic problem is that systems are frequently installed and receive minimum maintenance thereafter. Just like any other mechanical equipment, pumping plants need periodic adjustment by trained personnel to maintain operation at peak performance. Unfortunately, these units receive less maintenance than most any other comparable piece of equipment used in agriculture. No one would think of buying a new car and driving it for 10 years without maintenance. Many people will not hesitate to expect this type of performance from a pump. A thorough adjustment of pump and power plant requires about six hours by a trained technician and will cost less than $100. It is an excellent investment.

Table 2. Summary of performance tests on 376 deep well pumping plants

Percent of standard	Exceeding standard	90-100%	75-89%	50-74%	49% or less
Percent of pumping plants in each category	8.8%	14.9%	35.1%	32.2%	9.0%

A measure of possible energy savings from pumping plant adjustment may be obtained by applying the data of Table 2 to the present Nebraska situation. Table 3 shows the savings that could result if all irrigation pumping plants in the state were brought up to performance standards. These savings would result even with no other improvement in irrigation practices. Additional savings are possible with better water management.

Table 3*. Potential energy savings/year in Nebraska through pumping plant adjustment

Electricity	241,000,000 K.W. - hrs.
Diesel Fuel	17,600,000 gallons
L. P. Gas	27,900,000 gallons
Natural Gas	1.6×10^9 cubic feet
Gasoline	822,000 gallons

* Assumptions in computing tabulated values:

39,500 registered wells (1/1/73)
100 acres/well; 24.3% of area sprinkled & 75.7% surface irrigated.
135 feet lift to surface
70 psi at pump on sprinkler systems
18 inches gross water application for sprinklers
24 inches gross water application for surface irrigation
Type of power units: Gasoline - 1%; Diesel - 27%;
Electric - 30%; Natural gas - 15%;
L. P. gas - 27%

Reducing Water Application

Irrigation Scheduling

The most direct approach to reducing energy consumption by irrigation pumping plants is to pump less water. While this may seem obvious it is not so easy to implement in practice. Historically the farmer has substituted water for labor, finding it easier to put on "plenty" rather than doing a lot of hard physical labor to apply smaller quantities. With new developments in irrigation equipment good water control is easier to attain. The irrigator is more able to apply water when it is needed and only in the amounts needed. However, to determine "when" and "how much" requires, at the very least, weekly monitoring of soil moisture levels in the field.

A thorough job of irrigation scheduling requires additional calculations and data input beyond moisture monitoring. Most farmers either feel that they do not have the time or will not take the time to use a soil probe in the field for checking moisture or spend the time to install and read electrical resistance blocks. Furthermore many growers are not sure how to translate their findings in the field to specific quantities of water to be applied by their irrigation system.

Commercial irrigation scheduling services appear to have a strong potential for providing the grower with the day-to-day information he needs for properly operating his irrigation system. When an irrigation is correctly scheduled he irrigates at the time water is needed and, with proper equipment and guidance, applies the right amount. This usually reduces the quantity of water which is pumped during the growing season. These savings could amount to between 15 and 50% of the amount the grower normally pumps, depending upon his previous practices.

Commercial scheduling services have been successfully operating in Nebraska and Arizona for the last four years and are developing in the Pacific Northwest. A computer is used to make a daily water balance on each field that is scheduled. Meteorological data are used to estimate potential evapotranspiration which is then corrected for stage of growth of the crop. Information on rate and depth of rooting, soil water holding capacity on a given field, plus information on irrigation system capacity is used to determine when the grower should irrigate and how much should be applied.

The success of the "computer" approach depends upon the human element. The scheduling service sends a man to the field on a weekly basis to make a direct check of the actual soil water content. The field man uses the computer print-out as a guide but modifies it as field observations dictate and returns the revised data for reentry into the computer. Finally, he discusses the current situation with the grower while giving him the irrigation schedule for the coming week. Attempts to operate a scheduling service without field monitoring have not been very successful. If it rains, probing is required to see how much entered the soil. Furthermore, local variations in evaporative demand make it impossible to compute exact water use on every field. On the other hand, scheduling directly by field observation without the meteorological inputs and computer assistance works fairly well only in areas that have little or no growing season precipitation.

In Nebraska the commercial scheduling service has had good acceptance by both surface irrigators and those using sprinkler equipment. The company has received a repeat business of between 90 and 95% of its previous years' customers and is expanding rapidly. In 1974 almost 100,000 acres will be scheduled commercially within the state (3).

The potential of irrigation scheduling for reduction of pumping is illustrated by Figure 1 which shows a comparison of relative water application in 1973 between 32 nonscheduled irrigation systems and the average (rel. app. = 1.0) of 3 systems scheduled by a commercial service (16). All systems were in a two county area of southwest Nebraska.

Allowing an error of +10% and -20% (the latter to allow for a greater end of season moisture depletion than was obtained on the scheduled systems), it appears that, four systems may have been under-irrigated and eleven applied excessive amounts of water. This points out that scheduling does not automatically decrease water application. In this case some fields would have had additional water applied if they had been scheduled. Nevertheless, an overall average reduction in pumping of 12-15% would have been achieved on the 32 systems if irrigation scheduling had been used. On some systems the savings would have been dramatic.

Programmed Depletion of Soil Moisture

In areas where several inches of precipitation normally fall during the growing season a planned or "programmed" depletion of soil moisture can be used on deep rooted crops to avoid the application of several inches of irrigation water. It is especially useful on sprinkler irrigated fields where maximum water control can be exercised. Programmed depletion to reduce energy consumption can be used in areas where enough winter or spring precipitation occurs to refill the soil moisture reservoir after depletion the previous year. In general the soils should have an available moisture holding capacity of 1.5 inches/ft. or better and have a profile depth about equal to the principal rooting depth of the crop.

Current design practices for irrigation systems call for a capacity to apply water at a rate approximately equal to the peak evapotranspiration rate of the growing crop (1). Several years of field research at various locations in Nebraska having a wide range of growing season rainfall, indicate that under the conditions previously specified an irrigation system capacity equal to about one-half to two-thirds of the evapotranspiration rate is sufficient. During peak ET periods when water use exceeds application, the plants withdraw from stored soil moisture a quan-

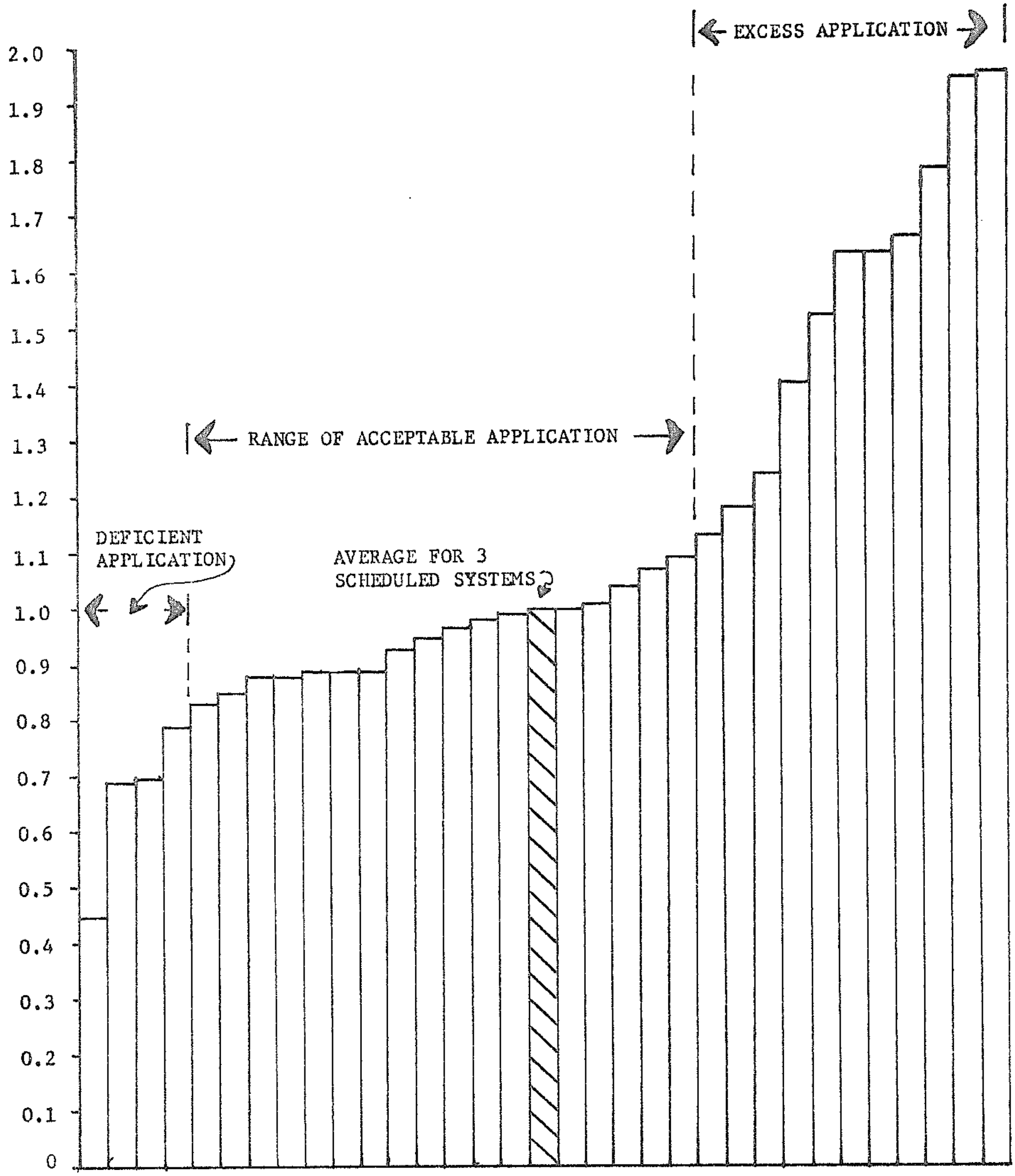

Figure 1. Comparison of relative water application on scheduled and non-scheduled irrigation systems.

tity equal to the difference between what is needed and what is applied as irrigation. The soil moisture reservoir is refilled by precipitation during the non-growing season.

To achieve "programmed" depletion of soil moisture irrigations systems must be designed to fit crop, soil, and climatic conditions in order to hold the maximum depletion of soil moisture within safe limits. Its application to the conditions of the northern and central Great Plains has been amply documented and demonstrated (8, 6, 11, 14). The concept is simple but growers have been reluctant to accept it because it is contrary to the traditional approach of maintaining a full or nearly full soil moisture reservoir.

Programmed soil moisture depletion is illustrated by Table 4 which shows 1971 research data for irrigated corn grown at North Platte, Nebraska (13). No statistical difference was found between yields on the three treatments, although treatment C received only a little over half of the irrigation of treatment A.

Table 4. Total water use and grain yields of corn on solid set sprinkler irrigated plots at the University of Nebraska North Platte Station for three quantities of irrigation in 1971

Irrigation Treatment[1/]	Rain	Irrigation Inches	Stored Moisture Change in Root Zone	Total Water Use Inches	Corn Yield Bu/A
A	12.5	16.1	-2.3	30.9	159
B	12.5	13.3	-3.7	29.5	160
C	12.5	8.5	-6.7	27.7	155

1/ A = .95 inch per irrigation, 2 applications per week, equivalent to a water application of .27 inch per day.

B = 1.48 inch per irrigation per week, equivalent to .21 inch per day.

C = .95 inch per irrigation per week, equivalent to .14 inch per day.

The water application of .95 inches per week on treatment C was sufficient to meet in full evapotranspirational demand for the first half of the growing season. During the latter half of the season the plants withdrew 6.7 inches of water from the soil profile to supply the difference between demand (which can exceed .3 inches per day) and irrigation application. The total water use figure is the sum of irrigation, plus the change in the stored soil moisture from beginning to end of the growing season, plus a rainfall amount of 12.5 inches. The total use probably included some deep percolation on treatments A and B.

By maintaining a moisture deficit in the root zone, more precipitation that falls during the growing season is retained and used. In contrast when high moisture levels are maintained by heavy irrigation as was the case for treatment A, more of the rainfall either runs off or percolates through the soil profile.

Depending on crop, soil and climate a programmed depletion of soil moisture can reduce the water application and associated energy requirements for pumping from 20 to 50%. Using this method in conjunction with irrigation scheduling a maximum saving of energy can be obtained. Scheduling procedures can assure proper water application during the first half of the growing season when root zones are shallow and only small water deficits can be tolerated. In areas of substantial summer precipitation, scheduling tells the grower when to resume irrigation if he receives enough rainfall to "erase" the moisture deficit during the peak water use period.

Improved Management of Electric Pumping Plants

Electricity is the energy source for over half of all irrigation pumping plants in the United States. It is preferred because it is convenient, in many areas inexpensive, and during a fuel shortage, a certain source of power.

Because irrigation is a very seasonal user of electricity it creates problems for the power suppliers. Power demand for irrigation normally occurs over a three to four month period each year which coincides with the time that air conditioning load is high. The wholesale power supplier must invest in generating equipment with a capacity sufficient to meet the peak demand, yet part of that capacity may go unused nine to ten months of the year. In some areas the retail power distributor must pay a penalty for having a high summer demand in relation to the winter load. For some this problem has become so serious that they can connect only a few additional irrigation customers per year.

Figure 2 shows the annual power demand over a five-year period for a retail public power district in Nebraska facing the irrigation load problem (10). There is a rapidly growing summer demand, a large differential between summer and winter loads and a very sharp summer peak as irrigation and air conditioner power demands coincide. The darkened area in Figure 2 indicates when the district has to pay a penalty to the wholesale power

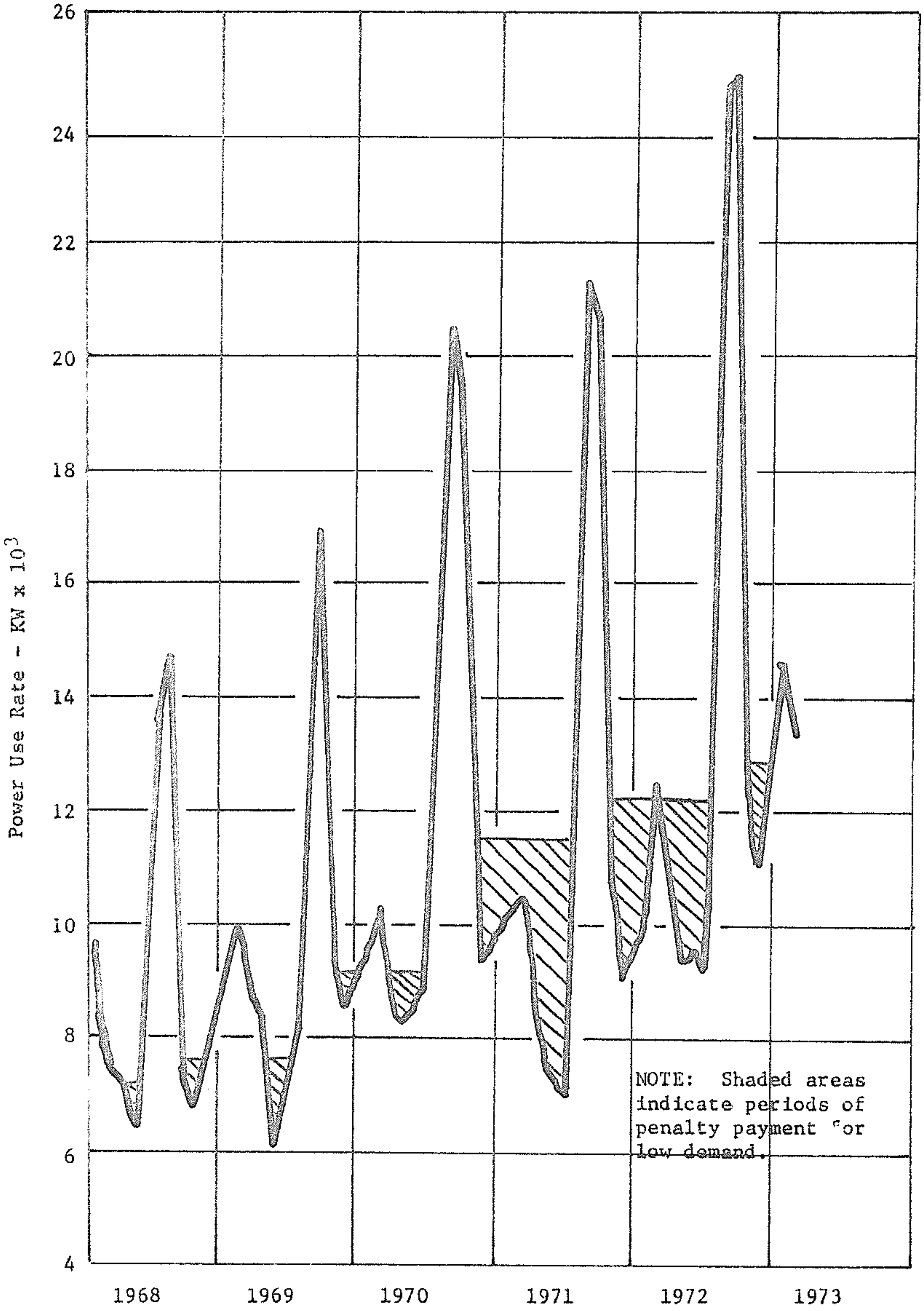

Figure 2. Five year power demand; Custer Public Power District, Nebraska.

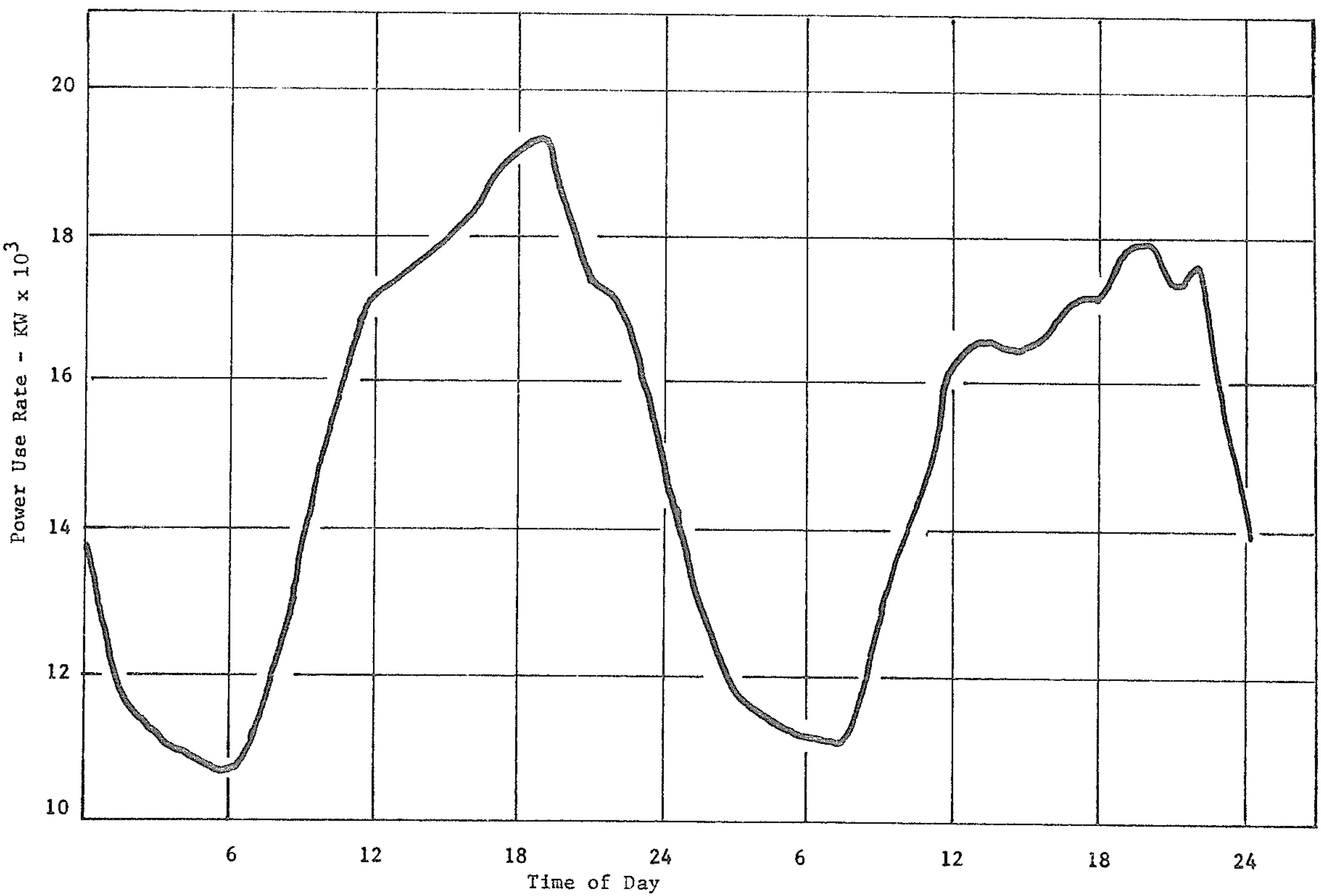

Figure 3. Hourly energy demand during "normal" irrigation operation.

supplier because the power use rate dropped below 65% of the summer peak. (The latter is determined as the peak one hour use rate on the peak day of the year, less a small irrigation load allowance by USBR). In order to hold the penalty within acceptable bounds, the utility district has severely restricted the number of new irrigation pumps it will connect each year. Other districts not on the penalty system have taken similar steps to limit new connections because of the danger of overloading their facilities during peak demand periods.

Part of the "peaking" problem is caused by the large difference between afternoon maximum power demand and the early morning minimum. This is shown by Figure 3, a typical hourly energy demand curve over a two-day period in the summer. Peaking occurs around 7:00 P.M. when domestic air conditioning and irrigation loads are all high.

Through application of irrigation scheduling a procedure has been developed for reducing the effect of the irrigation load on the peak power demand. The objective is to reduce the differential between daytime and nighttime demand during the summer. This can be done by turning off irrigation systems during daily peak use periods. This serves to reduce maximum daily peaks and thus reduces the overall summer peak, for a given total connected load. For a given transmission capability it becomes possible for electric utilities to connect additional irrigation customers.

The new procedure now being used in Nebraska makes use of the "excess" capacity of many irrigation systems. When proper use is made of stored soil moisture, thenormal system capacity of .3 to .4 inch per day is greater than necessary for medium textured soils in the Northern Great Plains. The average irrigation system need operate only 60 to 70% of the time. The systems can therefore be turned off during the early evening hours when domestic and air conditioning power uses are higher. Timeclocks or radio controls can be used to facilitate switching.

Application of the new management procedure was made this past summer on an experimental basis (17). Twenty-six irrigation systems with electric pumping plants all served by the same transformer substation were operated only between 11:00 P.M. and 3:00 A.M. the following day. Power was off to the systems during "peak use" hours for three separate periods totaling 28 days during the growing season. All systems were computer scheduled and field checked to assure that a high level of soil moisture was maintained prior to the period of off-peak operation. This assured adequate moisture in storage when systems were able to run only part time.

When the irrigation systems were under controlled operation, the daily peak was shifted from 7:00 P.M. to the early morning hours. The daily minimum occurred between 5:00 and 8:00 P.M., the normal peak demand period. By having a large number of systems under remote control and by varying the hours of operation, an almost uniform 24-hour power demand could be created.

Using this method of operation, a utility district with summer peaking loads may be able to serve a larger number of irrigators without expanding generating and/or transmission facilities. It is quite important, however, that growers participating in such a program use some form of soil water monitoring or irrigation scheduling.

Reuse of Irrigation Runoff Water

A well designed surface irrigation systems may have runoff losses which average 25 to 30% of all water applied (4). A poorly designed or managed system will have more. For normal furrow irrigation of row crops runoff is necessary to achieve a uniform water penetration in the soil profile. Where the water source is a well, the cost of collecting the runoff water and pumping it to the head of the field for reuse is often only a fraction of the cost of pumping the same amount of water directly from the well. The exact relationship is dependent upon the pumping lift from the well and the design of the return system.

Eighty percent of all irrigated land in the United States is served by surface or gravity irrigation. The portion of this land that requires a pumped water supply is not exactly known, but probably is at least one half of the total acreage or a minimum of 20 million acres. Installation of a reuse system on all of these lands having a substantial pumping lift could reduce total power consumption from 10 to 25% or more for the systems involved.

Increasing numbers of irrigation farmers are installing reuse systems because they make economic sense and are required in some cases for environmental protection purposes. This a conservation practice which should be vigorously encouraged and which can bring immediate returns in terms of energy savings.

Improved Irrigation System Design

Automatic Surface Irrigation Systems

Significant energy savings can be realized through modernization of present irrigation systems and application of recently developed equipment and design procedures on new ones. Because sprinkler irrigation has more readily lent itself to mechanization, the main thrust in new developments in water control has been in this area. The mechanization of surface irrigation has been much slower. Most irrigators still make 12 or 24 hour "sets" or water applications because it fits their labor schedule, regardless of whether the crop and/or soil conditions dictate this length of time. The result is excess water application, a part of which goes to deep percolation and the remainder to runoff.

Various procedures have been developed to solve this problem. They include reducing row length on light textured soils, shorter application times, and the use of the "cutback" furrow stream (using a high volume initial stream to give rapid water advance down the row with subsequent reduction in flow rate). They all work but so does the farmer in order to use them. It has been cheaper and easier to substitute water for labor, the latter being expensive and in many cases unavailable. The energy shortage increases the attractiveness of newly developed alternatives to present methods.

An automatic surface irrigation system has been developed which can provide greater than 90% water application efficiency (5). Figure 4 shows a schematic of the system. Gated pipe delivers water to the furrows. A reuse system is used to return runoff water to the head of the field and automatic valves are used to shift from set to set at whatever time interval is dictated by the soil conditions and system design. This may be as short a period as three or four hours! Rapid water advance assures a uniform application. The newly developed pneumatic valves are the key to the system. Energy savings of 50% or more may be realized in comparison to traditional approaches. The cost per acre, including land leveling, is comparable to that for the center-pivot irrigation machines, yet power consumption is much lower since only a low hydraulic head is required on a gated pipe as compared to the 60 to 90 PSI needed for standard sprinkler equipment.

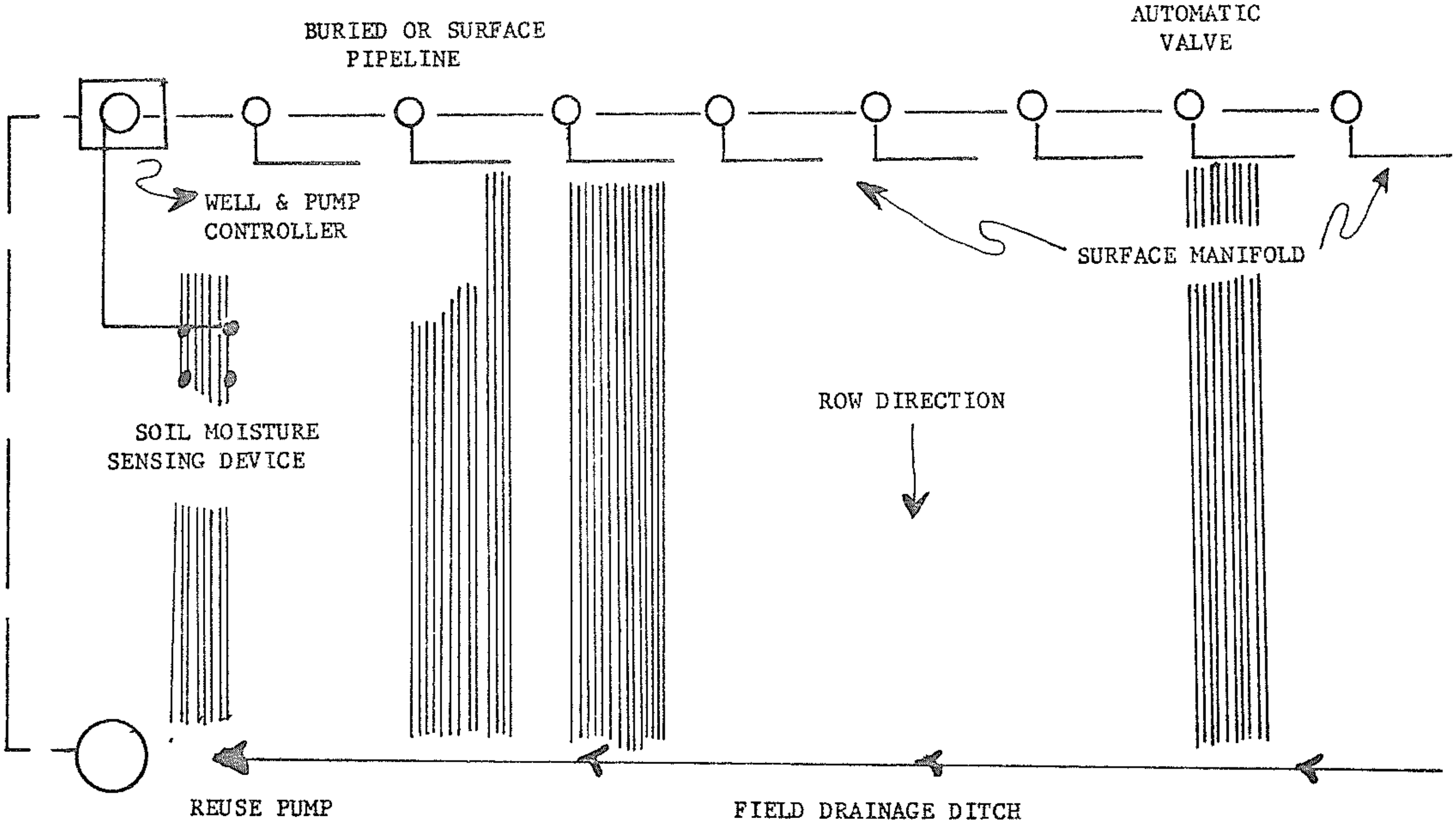

Figure 4. Schematic of automatic surface irrigation system.

Conclusions

Technology is available for obtaining a considerable reduction in the present rate of energy consumption for providing irrigation water. There is no single solution with universal application. The approach must be to fit various solutions to the soil, climatic and economic conditions of each region. The present problem is one of convincing the irrigator that the new methods will work in his situation. A serious roadblock to lowering energy use is a shortage of financial and manpower input to extension and demonstration programs in irrigation management. The high cost of available fuel and/or a shortage of it is going to force many water users to search for viable alternatives to present irrigation practices. The challenge is to clearly and convincingly present alternatives that will allow a reduction in energy consumption while maintaining a high level of production.

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