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ENERGY MANAGEMENT STUDY OF IRRIGATION PUMPING PLANTS
FOR THE UTAH POWER AND LIGHT COMPANY

by

Jeffrey C. White

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Engineering

UTAH STATE UNIVERSITY
Logan, Utah

1979

ACKNOWLEDGMENTS

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It is entirely impossible for me to express in words the respect, love, and appreciation I have for my parents; and a mere acknowledgment in a thesis could never justly serve them retribution. I am eternally grateful to them for encouraging me to seek the rewards of a higher education. I would also like to express this same appreciation for Dr. John L. Seymour who has shown me "la renaissance du monde." There are all too many other people who deserve further credit for any veneration I might receive from this work, yet many of you I must thank in my prayers.

I would also like to thank my committee members and especially R. Kern Stutler, my major professor, for being so generous with his time and patience. The people of the Utah Power and Light Company have also gone to great extremes to provide financial and technical assistance. Thank you all!

Jeffrey C. White

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ABSTRACT

Energy Management Study of Irrigation Pumping Plants

For the Utah Power and Light Company

by

Jeffrey C. White, Master of Science

Utah State University, 1979

Major Professor: R. Kern Stutler

Department: Agricultural and Irrigation Engineering

All electric power utility companies are faced with yearly peak demands. They must supply sufficient generating capacity along with transmission and distribution facilities to carry these loads. In the past, peaking requirements of many utilities have been met by the use of gas turbines, which are not as efficient as base load plants, but require substantially lower capital investments. However, the fuel supplies used for gas turbines are becoming extremely difficult and expensive to procure and as a result, other means for meeting peak demands are being examined.

Energy management attempts to modify the power systems' load requirements to fit the systems' generating capacity, rather than supplying the generating capacity to meet the systems' load.

Irrigation loads comprise one of the largest single demands placed upon the Utah Power & Light (U.P. & L.) system. Because of their seasonal nature, they contribute extensively to the system load,

representing nearly 30% of the peak demand, but only 5% of the kilowatt-hour sales. In Idaho alone last year, irrigation consumed 47% of U.P. & L.'s capital investment while returning only 28% to the Company's revenue.

This study examines the potentials for implementing energy management programs in pump testing, irrigation water management, and irrigation load management within U.P. & L.'s service area which might be used to help alleviate these peak demand problems.

(81 pages)

INTRODUCTION

During the 1950's, the nominal price of electricity diminished to an all-time low while manual labor costs continued to increase. By the early 1960's, the electric industry was aggressively promoting the sale of electricity. Subsequently, irrigation system automation replaced expensive labor up until the late 1970's. Today, spiraling energy costs and deteriorating agricultural prices have made profitable farming difficult in many areas. This has caused electric power suppliers to take a completely different objective, i.e., conservation.

Energy management may be defined as the deliberate reshaping of an electric utility's load curve by conservation programs and/or load management schemes. Energy management has become increasingly necessary for several reasons. First, the cost of new generating capacity is rising faster than capital availability, along with the additional expense created by environmental and legal obstacles to power plant siting and construction. Second, the lead time required to put new generation facilities on line has doubled in the past few years. This means that base load coal-fired generation requires 8-10 years from the time that it is determined it will be needed until it is actually providing power. Other types of generation which use oil or gas can be planned and built in substantially less time, but these plants are usually used only to provide for peaking load requirements. Third, peaking plant installation must be approached cautiously since supplies of oil and gas are becoming scarce and costs are increasing.

Fourth, the transmission and distribution facilities required to carry energy to rural customers are becoming increasingly expensive and are difficult to build due to environmental and social pressures.

U.P.& L. serves more than five-thousand irrigation accounts, representing over 473,000 connected horsepower. They consume an estimated 5% of the company's total annual kilowatt-hour generation. It is also estimated that these accounts are used to irrigate nearly 860,000 acres of land throughout Utah, Eastern Idaho, and Southwestern Wyoming. The company's firm peak load occurs during the summer and reached 1824 megawatts on June 18, 1977, of which approximately 550 megawatts was attributed to irrigation.

Since irrigation pumping loads compose one of the largest single electrical blocks of this peak, this study attempts to determine if available energy management programs in pump testing, irrigation water management, and irrigation load management could appreciably alleviate irrigation load problems imposed on U.P.& L.

The goal is to help farmers obtain maximum agricultural output with minimum energy input, thereby promoting the best utilization of the utility's resources at the lowest price to the irrigation customer. This can be achieved if:

1. The generation, transmission and distribution facilities of the utility could be used in the most efficient manner,
2. The energy consumed could be used in the most efficient manner, and
3. The water that is pumped could be used in the most efficient manner.

REVIEW OF LITERATURE

According to Dvoskin, et al. (10), citing the 1969 U.S. Census of Agriculture, the number of irrigated acres in the United States has more than tripled since 1935, but it is not expected to change much after 1980. Sloggett (28) indicates that in the U.S., there were more than 35 million acres irrigated with pumped water during 1974 at approximately two acre-feet per acre. He estimates that this required about 260 trillion BTU's of energy, costing nearly \$594 million.

It is reported that 20% of all U.S. electrical consumption is related to the food industry (23). Estimates indicate that energy used for agriculture represents between 2 and 4% of the nation's total energy budget (18, 19). Longenbaugh (19) speculates that energy used for pumping irrigation water may exceed 25% of all energy used for agriculture. This would be approximately 1% of all the energy consumed in the U.S. In heavily irrigated regions, this figure may be very conservative since Jensen (18) indicates that energy used for irrigation comprises an estimated 13% of all energy consumed in California, 14% in Idaho, and over 50% in Nebraska. He also maintains that along with the power consumed by pumping, in some areas, substantial amounts in potential energy are lost each year to power plants which are downstream, because of diverted irrigation water.

During 1976, the Energy Research Development Agency (ERDA) sponsored a meeting of irrigation specialists from across the nation.

They proposed that there is a potential for irrigation energy savings of 25-30% through improvement of pumping plant efficiencies and also a savings of 25-30% through improvement of irrigation efficiencies by using better water management. They maintained that both improvements could be made by using existing technologies with no significant new research (19).

Energy management, as previously defined, can only alter a system's load curve through two methods, energy conservation and load management. Energy conservation not only reduces the peak power demand of a system, but also reduces the total energy requirement placed upon a system at any time. Essentially, conservation improves a systems load factor permanently without respect to time. (The load factor of a system may be defined as the ratio of the average demand to the peak demand. Thus, the ideal load factor for a system is 1.0.) The electric power industry is now developing many different conservation programs at all levels of consumption.

Load management attempts to redistribute peak electric loads to off-peak periods. (Load management should be differentiated from conservation.) Since load management will not improve the efficiency at which energy is consumed, no energy will be saved. Yet, load management will save capital expenditures of a utility since it improves the efficiency at which generation, transmission and distribution facilities are used, thereby deferring new construction. This in turn will defer rate increases to users. Essentially though, the same amount of total energy is still consumed (except for insignificant ramifications that do not affect the main principle)

(5). Unlike conservation, load management is very time dependent because redistribution of electrical demand must occur during the period of peak consumption. There are various ways to redistribute system loads, but all may be categorized as either direct, such as ripple and radio control systems, or indirect, such as rate structure incentives and volunteer customer regulation.

Pump Testing Programs

Pump testing is a term commonly used to describe the determination of the efficiency of irrigation pumping plants. By improving pumping plant efficiencies, energy can be used in the most efficient manner. Programs to improve pumping efficiencies have existed for some time, although in the past, these programs evolved out of concern over declining water levels rather than diminishing energy resources. In 1923, the Pacific Gas and Electric Company (then the San Joaquin Power and Light Company) began providing free pump test services to its irrigation customers in California (29). They estimate that since that time, 270,000 tests have been made resulting in savings of over \$11 million in power costs. Approximately 15% of the pumps they test each year are in need of repair or adjustment (26).

More recently, pump testing programs have been established in Colorado, Texas, Nevada, New Mexico, Nebraska and Kansas. During 1964 and 1965, Colorado State University conducted extensive pump efficiency tests in Eastern Colorado which indicated that some pumping plants were operating at very low efficiencies. Tests conducted during 1976 and 1977 (under the auspices of several

individual Colorado power companies) indicated that over 62% of the open discharge pumping plants had efficiencies less than 50%, whereas only 9% of the sprinkler irrigation systems pumping plants had efficiencies less than 50% (19). These results included tests on 410 pumps, 288 of which were open discharge while 122 were sprinkler systems. The median efficiency for the open discharge systems was slightly less than 45% and between 56-60% for the sprinklers. Pumping plant efficiencies of about 65% and above are considered to be acceptable (24).

The University of Arizona studied 50 pumping plant units in Central Arizona and determined that approximately half of these pumps were using almost 46% more electricity than properly selected and adjusted pumps (13).

Until this study, there have been no detailed investigations about the status of irrigation pumping plant efficiencies in Utah or Eastern Idaho, although it is reported that tests made by the U.S. Geological Survey have shown efficiencies as low as 25% in Southern Utah (12).

Longenbaugh (19) noted in his studies that the average kilowatt-hour (Kwh) consumption per well each year generally increases. He indicated that the major single reason for pump inefficiency was that the total pumping head had changed since the pump was originally selected due to either declining water levels or modifications in the irrigation system by the farmer. He further noted other reasons for inefficiencies including:

- * Inadequate well testing
- * Improper pump selection
- * Poor selection of power plants
- * Improper well construction
- * Inadequate pump maintenance
- * Improper operating procedures

As noted, declining water tables may suggest lower pump efficiencies. The Detroit Diesel Allison Division of General Motors recently conducted a survey and asked irrigators throughout the country if the water table had dropped sufficiently to cause an increase in pumping horsepower or caused them to redrill their wells. Fifteen percent of the Utah irrigators and five percent of the Idaho irrigators replied to the affirmative (7). Thus, it appears that there may be lower pumping efficiencies in Utah than in Idaho.

Irrigation Water Management Programs

Irrigation water management is the term most frequently used to denote methods employed in obtaining optimum irrigation efficiencies. By improving irrigation efficiencies, the water that is pumped can be used in the most efficient manner. Although the expression is often modified, irrigation efficiency usually depends upon the efficiency at which water is conveyed, applied to the field and stored (15).

An effective irrigation water management program can identify inefficient irrigation systems and practices. Irrigation water management entails the use of water as an input by manipulating plant growth to obtain a desirable growth pattern. In this regard, water

must not be considered as a separate part of a management program, but as it relates to both pump testing and load management. The primary goal of irrigation water management should be to achieve the optimum yield rather than the maximum yield (50).

Systems having higher efficiencies are generally those using sprinkle and trickle automation, while surface irrigation systems generally have lower irrigation efficiencies. It should be noted that surface runoff reuse systems can greatly improve the efficiencies of most surface irrigation systems.

Improvement of irrigation efficiencies can reduce the amount of water required, thus decreasing pumping time and conserving energy. At the University of Nebraska, Gilly (30) has calculated energy savings of from 60 to 70% for surface systems and 50 to 62% for sprinkler systems by merely adjusting and improving present designs. His calculations involve pump adjustments or replacements, installation of runoff recovery systems, irrigation scheduling, and conversion to low-pressure sprinkling systems.

The amount of seasonal application or hours of yearly operation, has also been shown to be a major criterion for selecting low energy irrigation systems. For example, an Oregon State University study (35) indicates that a center pivot system can use less total energy than a permanent set system when less than 23 inches of irrigation is applied per year and can use more energy than a permanent set system when applying more than 23 inches per year. Selection of the proper irrigation system may require careful consideration of these and many other factors for successful farming in the future.

Irrigation scheduling has proven to be an integral part of water management. Irrigation scheduling involves the determination of crop water requirements for the purpose of planning the proper amount of irrigation applications at optimum frequencies. In Idaho last year some irrigators participating in irrigation scheduling programs reported power costs \$12 to \$15 per acre lower than growers who were not scheduling, with no apparent difference in yields (14).

Irrigation Load Management Programs

Load management may involve control of many kinds of loads such as water heating and air conditioning but load management of irrigation pumps appears to offer the most effective way to reduce peak demand for U.P.& L. Load management improves the efficiency at which generation, transmission and distribution facilities are used. Most of the literature on irrigation load management has been reported by Stetson, et al. in Nebraska. His experiments on this subject began as early as 1973.

In Nebraska, the need for these programs has become critical. Shortages of oil and gas have caused many irrigators to convert to electrical pumping units. These new loads have greatly reduced the system load factors of the utilities because of their seasonal nature. Irrigation loads produce high summertime power demands for three or four months and remain dormant the rest of the year. There are two major reasons why rural power districts, who must buy their power from wholesale suppliers, cannot meet these demand increases. First, they cannot justify the construction cost of new transmission and distribution facilities required to carry these loads for such a small

fraction of time each year. Second, most of these smaller power districts must pay penalty or "ratchet charges" to the wholesale suppliers when the winter load falls below some specified percentage of the summer peak. The greater the difference between summer and winter loads, the greater the penalty. For example, in 1971 the Custer Public Power District (CPPD) paid over \$40,000 in ratchet charges while the Southwestern Public Power District (SPPD) paid more than \$260,000 in 1975 (25, 27).

As a result, many of these power districts are only willing to add new irrigation customers each year in proportion to their winter load increase. Now the time lag between application for power and connection varies from months to several years (34).

Any load management program involves three interdependent elements: rate design incentives, control methods, and loads to control (21). These off-peak irrigation programs have been developed to operate irrigation systems during hours when industrial, residential, and air-conditioning power demands are below their daily peak. Theoretically, by scheduling the operating times of different irrigation systems, an almost uniform power demand could be created each day (34): It is this uniform power demand which all utilities desire since the best use of their generating, transmission, and distribution facilities is achieved.

CPPD first began irrigation load management experiments in 1973. In this program, 20 center-pivots and 6 surface irrigation systems were scheduled, representing 2,120 horsepower (hp). CPPD paid irrigation scheduling costs plus \$1.50 per acre to voluntary cooperating irrigators. All systems were turned off from 2 p.m. until 10 p.m. on

days when demand was high. Twenty-eight days of shutdowns between July 1 and September 2 reduced peak power demand by 1022 kilowatts (kw) over the 1972 peak with no reported adverse effects on yields (33).

In 1974, the voluntary program was reduced and an additional mandatory control program employed. Ten center-pivot and three surface systems were involved in the 1974 project, representing 1,130 hp. During this year, radio-controlled units were installed to automatically remove power from a central control point. Another 289 hp was placed under control through an interruptive contract in which new irrigation loads would only be guaranteed 16 hours of uninterrupted power service per day. During this season, systems were shut down 17 different days and peak demand increased 2604 KW over that of 1973, but it was noted that 1974 was an unusually hot dry year (33).

In 1975, 1055 hp was continued under voluntary control with free irrigation scheduling still supplied. From 5 p.m. to 10 p.m. 2780 hp was scheduled to be turned off and 730 hp from 11 a.m. to 5 p.m. During the season, irrigation interruptions occurred only on 12 different days. It was noted that experience in monitoring sub-station loads reduced the number of days power was turned off (31).

The McCook Public Power District (MPPD) first initiated an irrigation load management program in 1974. Cooperating irrigators were paid half the fee for the commercial scheduling service. Seventeen irrigators participated, representing 2245 hp. Irrigation systems in this program were scheduled to be turned off on a staggered basis since the high-demand period lasted longer than individual systems should be turned off. One group was scheduled to be off from 11 a.m.

to 3 p.m., another group from 2:30 p.m. to 7 p.m., and a third group from 4 p.m. to 9 p.m. The peak demand of MPPD increased 24.2% over the 1973 peak and the average demand increase in 1974 for all rural power districts in Nebraska was also around 24%. However, maximum demands were shifted from 7 p.m. to 10 p.m. (33).

In 1975, off-peak schedule of surface irrigation systems had one-sixth of the cooperating systems off each day from Monday through Saturday since over-irrigation and low application efficiency would occur if the systems were started again to complete the irrigation at the lower end of the field. During this season, maximum demand increased only 320 kW even though 1300 kW of new load was added to the system (31).

The Elkhorn Public Power District (EPPD) began an irrigation load management project in 1975. A telemetering system was designed to monitor three substation loads and transmit the information to the district office. Radio controls were installed on 2000 hp of irrigation load. During peak demand hours, 1900 hp was turned off. It was estimated that nearly \$8,000 per month was saved during months when demands fell below the ratchet penalty level (31).

In 1975, the Wheatbelt Public Power District (WPPD) began an intensive public awareness program to inform irrigators of the need to control peak demands and reduce energy costs. Irrigators were grouped into threes and asked to develop a schedule among themselves so that one-third of the systems were off all season. This program also proved to be effective since the 1975 peak demand increased only 2500 kW over the 1974 peak even though 10,000 kW of new irrigation load was added (31).

In 1976, SPPD began an experimental load management program. They installed a ripple control system and placed 271 individual pumps under direct control. Participating irrigators were given choices between daily control or weekly control. Daily control meant that pumps could be shut off during the peak use period of any day. Irrigators on this schedule were offered rates which roughly equalled those of the previous year. Weekly control meant pumps could be shut down on the same day of each week if it looked as though the system might peak on that day (27). The rates were designed so that an irrigator with a 100 hp motor who operated 1000 hours in a season could save \$500 with weekly control or \$1,000 with daily control. These rates are shown in Table 1. No pumps were shut off from 10 p.m. to 8 a.m. or on Sundays. Daily control was generally selected by sprinkler irrigators while surface irrigators preferred weekly control (32).

Farmers who had equipment failure were allowed to override the ripple system until they could catch up on crop water needs. Most farmers reported that they had improved their water management skills and many learned to fill soil reservoirs by preirrigating before the peak water-use season (32).

Expenditures for the program by the company were estimated at \$5.66 per controlled hp (32). Plessey LTD of New Zealand who installed the ripple control system estimates typical total costs for control equipment and installation at \$30 per controlled kW for irrigation (6). Even though 4900 kW of new irrigation load was connected in 1976, the peak demand was reduced 423 kW below the 1975 peak (32).

However, not all rural power circuits may be able to use scheduling to control demands with the same effectiveness. Substation analyses have revealed two types of demand patterns that generally occur. These patterns are shown in Fig. 1. At substation A, the daily

TABLE 1.--1976 Electrical Rates for Irrigation With and Without Load Management for Customers of Southwest Public Power District, Palisade, Nebraska (32).

No Control

First	200 kWh per hp at 8.0¢ per kWh
Next	300 kWh per hp at 2.8¢ per kWh
All excess	kWh at 2.0¢ per kWh

Weekly Control (Controlled only on a selected day of the week)

First	200 kWh per hp at 5.0¢ per kWh
Next	300 kWh per hp at 2.8¢ per kWh
All excess	kWh at 2.0¢ per kWh

Daily Control (Controlled on any day and probably more than 1 day per week)

First	200 kWh per hp at 5.0¢ per kWh
Next	300 kWh per hp at 2.0¢ per kWh
All excess	kWh at 1.5¢ per kWh

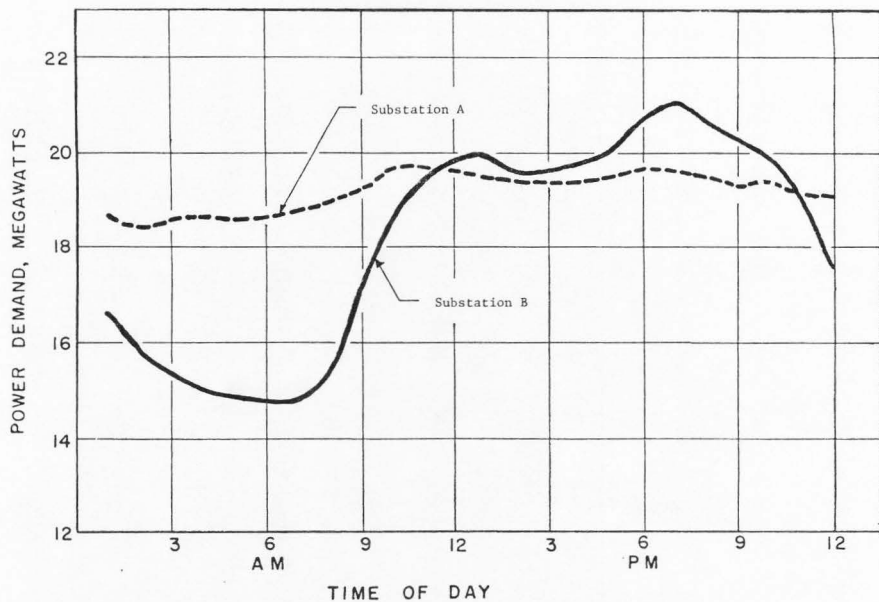


FIG. 1.--Typical daily demand patterns for two rural substations (2).

load fluctuation is relatively small, and the peak demand could probably not be controlled unless some pumps were turned off for 24-hour periods. At substation B, the peak demand could be reduced by turning some pumps off between 11 a.m. to 4 p.m. and a greater number off between 4 p.m. to 9 p.m. (2).

Load management systems can be classified as either "direct" or "indirect." From the work previously done in this area, it appears that a combination of both these two methods might be the most effective in reducing peak electrical demands.

Direct Control.--These systems involve the direct regulation by the utility to decide when to turn loads off and on.

Ripple Control Systems.--This system turns electricity on and off by superimposing an audio frequency on existing power lines. These signals are transmitted throughout the entire power system instantaneously from a control center. The signals are coded so that different switches can receive signals to turn them on and off independently or collectively (32). There are at least three companies who market these systems. Ripple control systems promise to be the most efficient method for direct control (27).

Radio Control Systems.--In this system, radio signals are sent from a transmitter in the control center to a receiver which operates a switching mechanism in the pump panel. This system is extraneous to the power circuitry system.

Time Clock Systems.--These systems are independent of a control center but switch power on and off according to a predetermined time interval manually set on the control in the pump panel, but these systems are not as popular since they do not allow the margin of safety and flexibility offered by radio, ripple, and manual operation (2).

Temperature Controls.--In 1976, Anschutz (3) conducted experiments in Kansas to determine if temperature-controlled pumping could meet the objectives of irrigation load management. Two center-pivot systems were scheduled by a thermostat control to turn off the systems when the temperature reached 95°F and to turn them on at 90°F. A third center-pivot system was used as a reference and was controlled manually under optimum conditions. Results indicated that thermostat control was not an effective approach to electric load management of irrigation pumps. Stetson, et al. (34) found very low correlation between electrical demand and evapotranspiration or electrical demand and temperature.

However, the Minnkota Power Cooperative in Minnesota and North Dakota experiences a winter peak due to heating demands and have found that system demand correlates very closely to temperature under these circumstances. A note of interest is that since Minnkota is a winter peaking company and the Nebraska Power District is a summer peaking company, Minnkota and the Nebraska Public Power District have contracted an exchange of summer and winter capacity (20).

Indirect Control.--With programs utilizing these methods, the individual irrigation customers are given the responsibility and incentive to operate pumps only during off-peak periods or to organize individually alternating irrigation schedules.

Volunteer Regulation.--This program is more educational in nature than others. Although essentially all of the programs require some public educational efforts, this program promotes off-peak power usage through intensive public awareness campaigns. These programs have proven to be quite effective in many cases (31).

Dual Metering.--In this program, incentives for off-peak power usage is given through rate structure benefits. Dual metering is usually used to record both peak period power consumption (which is billed at a higher rate) and off-peak power consumption (which is billed at a lower rate). At this time, there is no literature available on the expense or the effectiveness of this type of program.

In summary, energy management is a relatively new area of interest since it was born from the repressions of the "energy crises." Today, energy shortages have compelled the electric power industry and electric consumers to use both energy and utility equipment resources in the most efficient manner. It appears that various combinations of conservation and load management programs can be implemented to achieve these goals, but each power company must design programs to meet its own unique and individual needs.

METHODOLOGY

In order to keep the cost of energy as low as possible for the irrigation customer, the utilities' expenses must be minimized. Thus, if a utility could defer its capital expenditures for more generation, transmission, and distribution facilities, rate increases to customers could also be deferred. Energy management of irrigation pumping plants can achieve this through three different methods. One is by using transmission and distribution facilities in the most efficient manners. This involves the implementation of a load management program to redistribute irrigation loads to off-peak periods. Another is by using energy in the most efficient manner. This involves the implementation of a pump testing program to identify inefficient pumping plants. The third is by using water in the most efficient manner. This involves the implementation of an irrigation water management program to identify inefficient irrigation systems and also inefficient irrigation practices.

Pump Testing

Pumping plants have energy losses associated with friction created by mechanical parts touching each other and the resistance

moving water encounters while in contact with various surfaces in the pump column (Fig. 2). If any of the components of the pumping plant wear out or perform ineffectively, excessive energy is wasted. A pump test can determine if there is excessive energy lost during operation of the plant.

The Utah State University Agricultural Experiment Station and U.P. & L. sponsored research to study efficiencies of electrically powered pumping plants. A pump test team traveled to California in order to observe pump testing methods employed by the Pacific Gas & Electric (P.G. & E.) Company (who have been actively involved in a gratis pump test service since 1923). From this experience, the team developed a similar procedure for testing electrically powered pumping plants.

Areas Tested.--Seven different agricultural areas were used to sample the efficiencies of irrigation pumps throughout the U.P. & L. service region. With the assistance of the USU Extension Service, farmers were familiarized with the study and their consent was solicited to sample test irrigation pumps. Four areas were tested throughout Utah along with two areas in Eastern Idaho. These regions are referenced according to the U.P. & L. division within which the tests were made (Fig. 3). The areas tested in these divisions include:

Rexburg Division--Rexburg and St. Anthony

Preston Division--Preston, Malad, Bancroft, Benson, Smithfield,
and Amalga.

Ogden Division-- Tremonton, Bear River City, Bothwell,
Snowville, and Garland.

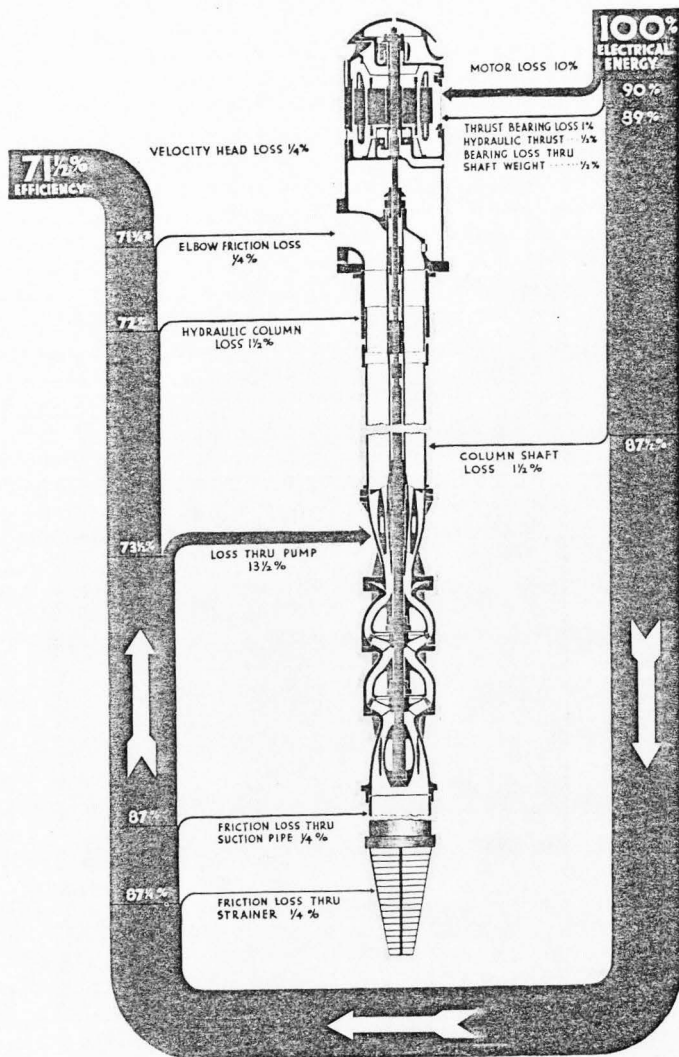


FIG. 2.-- Typical Energy Losses Associated with a Deepwell Turbine Pumping Plant (22).

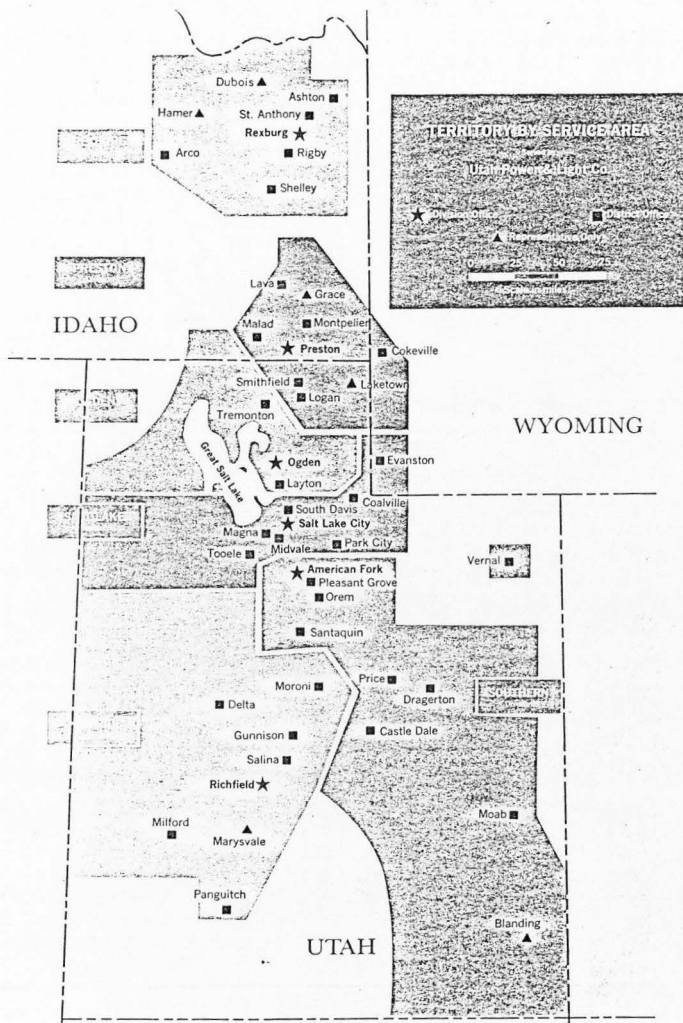


FIG. 3.-- Service Area of the Utah Power and Light Company.

Southern Division--Santaquin, Elberta, and Cedar Valley.

Telluride Division--Milford, Minersville, and Beaver.

There were no pump tests made within the Salt Lake division, but results from the Southern division are presumably similar.

Measurements.--The overall efficiency of a pumping plant can be defined as the ratio of the water horsepower output to the electrical horsepower input. To determine this ratio, three measurements were made, i. e., the flowrate, the total dynamic head, and the electrical horsepower input (Fig. 4). All calculations of the pump test report were based upon these three measurements, and the accuracy of these measurements predicated the accuracy of the results obtained in the test.

Apparatus.--Although some of the instruments used in pump testing were commercially obtainable, several devices had to be designed and fabricated in order to meet the specific requirements of the pump test team.

Flowrate Measurements.--There are many ways to measure flow-rates. Some of the most common instruments used are nozzles, orifices, flumes, venturi meters, weirs, and propellor meters. A. L. Collins of Berkeley designed and manufactured an instrument which operates on the pitot principle. The P.G. & E. has successfully used this instrument in its pump testing program, and it was also employed for this study.

The Collins Flow Gauge measures the velocity of the water traveling within a pipe. The gauge consists of two main parts: the

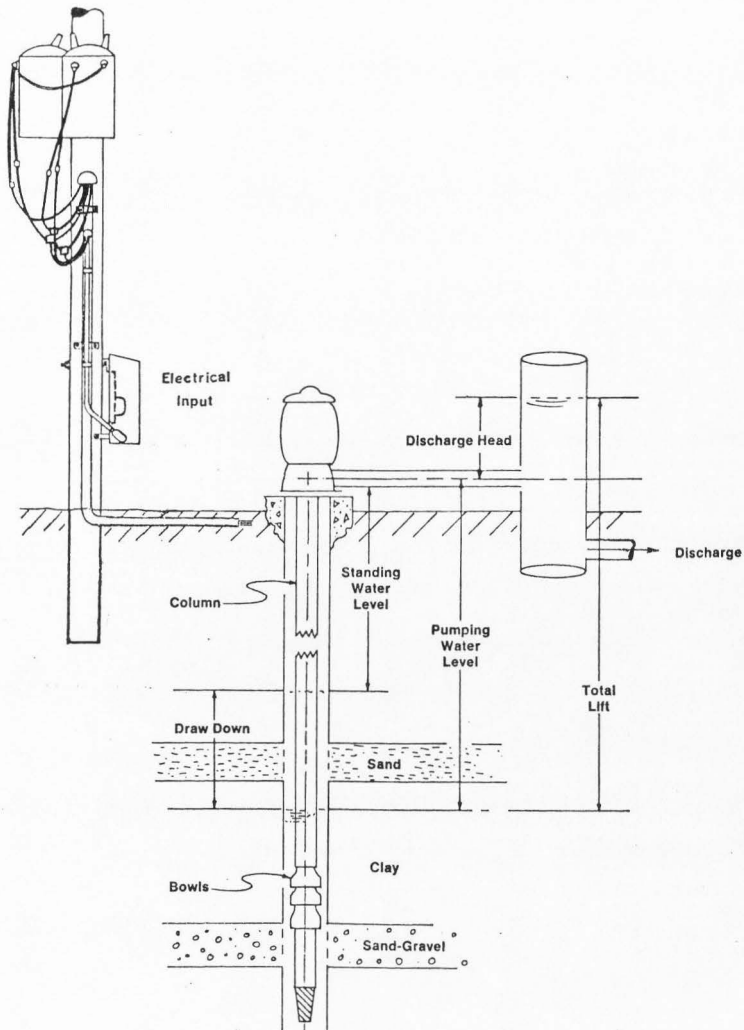


FIG. 4.-- Pump Test Measurements of a Deepwell Turbine Pumping Plant.

impact tube which passes through and attaches to the pipe, and the manometer which is connected to the ends of the impact tube with hoses. When connected to the manometer, the impact tube is designed to show the variation between the stagnation pressure and the piezometric pressure in the pipe. The scale on the manometer reads directly in feet per second of flow.

The impact tube was hollow except for a thin partition in the middle. There was one small orifice on each side of this partition at a 180° spacing. Thus, when one orifice was pointed directly upstream into the flowing force of the water in the pipe, it experienced the combined pressure created by the impact of the moving water plus the static water pressure within the pipe. This is known as the stagnation pressure. At the same instant, the other orifice pointed directly downstream and only experienced the static pressure within the pipe. This is known as the piezometric pressure. The difference between these two pressures registered on the U tube manometer where the velocity was read directly on a calibrated scale. Since the velocity of the water nearer the pipe wall was slower than at the center of the pipe, the average water velocity was estimated by placing the orifices on the impact tube at a predetermined distance from the pipe center. This distance produced a pressure differential indicating the mean velocity of a normal parabolic flow profile on the manometer. Since the inside diameter of the pipe and, hence, the area had been previously measured, the pipe flowrate was easily calculated as the product of the mean velocity and the pipe area.

The Collins Flow Gauge was tested in the hydraulic laboratory with weighing tanks and found to give favorably accurate results.

Total Dynamic Head Measurements.--The total dynamic head of a vertical turbine pumping plant is the total vertical lift from the water level in the well to the pump plus the pressure head created on the discharge side of the pump.

To determine the distance from the pumping water level in the well to the discharge level, an electric sounder was employed. This instrument was a simple electrical circuit consisting of a battery, ground wire, sounding probe, and a milliammeter.

Many river or reservoir pumping plants used centrifugal pumps. At these installations, the vertical lift was determined with a surveying level and a Philadelphia rod.

The pressure head created on the discharge side of the pump was obtained by attaching a pressure gauge. In situ pressure gauges already placed on the pump by the farmer were often inaccurate and were replaced by calibrated gauges during the test. The pressure gauge reading was converted from psi to feet of water in order to be added to the water level measurement. The sum of these two measurements represents the total dynamic head of the pumping plant.

Measurement of Electric Horsepower Input.--The electric horsepower input to the motor was measured by timing the disc on the watt-hour meter for a given number of revolutions.

Procedure.--Upon arrival at the pump installation, several primary questions were considered such as the following:

1. Could the well be sounded and was there a place to insert the probe, or could a hole be cut through an exposed section of well casing?

2. Where could the pipe be tapped to obtain the best flow characteristics?

3. If the pump was running, could it be shut down safely or could it be tested while running?

4. If the discharge pipe did not run full, could it be filled?

5. Where was the electric meter and was it accessible?

6. Was all electrical circuitry protected from the spray of pressurized water?

7. Could all measurements be made safely with no risk to personnel or machinery and how could potential dangers be mitigated?

After these details had been fully assessed, the pump test began. If the pump was not running, the standing water level was measured with the sounder. This measurement was not required to determine the efficiency of the pumping plant, but it enabled the drawdown to be calculated which gave some ideas of the aquifer characteristics.

The discharge pipe was then drilled, tapped, and the inside diameter measured. The Collins Flow Gauge was then installed along with a pressure gauge, if required. The orifices of the impact tube were placed in a neutral position before starting the pump in order to decrease the possibility of sand entering and plugging off the manometer.

The pump was then started and while the well was drawing down, the information on the pump data sheet was recorded such as: name,

where TDH is the total dynamic head in feet, P is the discharge pressure head in pounds per square inch as noted from the pressure gauge, and L is the pumping lift in feet as measured with the sounder.

From the flowrate and the total dynamic head, the water horsepower output of the pumping plant was determined from the equation:

$$\text{WHP} = \frac{Q \cdot \text{TDH}}{3960} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where WHP is the water horsepower, Q is the flowrate in gallons per minute, and TDH is the total dynamic head in feet.

The next step was to determine the electrical horsepower input by timing the disc in the watthour meter for a certain number of revolutions. Accurate enough results were obtained by timing the disc for 10 to 20 revolutions during a period of about 60 seconds. (It should be noted that if the well had not reached normal operating conditions, the electrical horsepower input measured would not reveal the true horsepower input requirements of the pumping plant under normal operating conditions.) The electrical horsepower input was obtained from the following equation:

$$\text{HPI} = \frac{4.8257 \cdot \text{PK}_h \cdot n}{t} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where HPI is the horsepower input, PK_h is the primary watthour constant, n is the number of revolutions for which the watthour meter disc was timed, and t is the time required in seconds for the watthour meter disc to turn n revolutions.

horsepower input. Table 2 shows the overall maximum plant efficiencies which might be expected for different motor sizes. Larger motors tend to be more efficient because their greater capital investment justifies design to meet better tolerances.

If the efficiency of the pump was desired, the brake horsepower (BHP) was first calculated. The BHP was found by multiplying the electrical horsepower input (HPI) by the mechanical efficiency of the motor. Table 3 provided an index of typical motor efficiencies that could be expected for average field installations no longer new.

Before the pump was shut down, all calculations were completed in order that any measurement could be verified without having to restart the pump and wait for the pumping level to stabilize again.

Irrigation Water Management

Evaluation of irrigation efficiencies throughout the U.P. & L. service area were estimated from the data collected during the pump testing programs. Batty, et al. (4) suggest that pumping energy can be calculated or estimated by knowing the irrigation requirements, irrigation efficiency, pumping efficiency, and pumping head:

$$PE = K \frac{A D H}{E_i E_p} \quad (7)$$

where PE is the pumping energy, K is the conversion factor depending on the units used, A is the area irrigated, D is the net depth of irrigation requirement or crop evapotranspiration, H is the pumping head or the sum of elevation differences, operating pressure, and

TABLE 2.-- Expected Peak Overall Plant Efficiencies. (29).

Motor Size (HP) (1)	OPE (2)
5	50%
7 1/2	55%
10 - 15	60%
20 - 40	65%
40 - Up	65 - 70%

TABLE 3.-- Assumed Motor Efficiencies for use in Figuring BHP and Percent of Load. (29).

Motor Size (HP) (1)	Motor Efficiency (%) (2)
5	83
7 1/2	83
10	85
15	86
20	87
25	88
30 - 50	89
60 - 75	90
100 - 200	91

friction and minor losses, E_i is the irrigation efficiency or the percentage of water applied that is stored in the root zone, expressed as a percentage; and E_p is the pumping efficiency, expressed as a percentage.

From this equation, the irrigation efficiency (E_i) was calculated for the areas irrigated from each pump since all other values of this equation were known. The pumping energy (PE) was taken from power billings kept by U.P. & L., most irrigators could approximate the area (A) they were irrigating. An estimation of evapotranspiration or irrigation requirement (D) was made according to the crop type and locality. The pumping head (H) and the pumping efficiency (E_p) were taken from the pump test results.

Thus, irrigation efficiencies were compared for different systems and different irrigation districts in the same manner that pumping plant efficiencies were compared to determine where improvements might be made in order to save water and energy. Irrigators with inefficient systems could then be encouraged to consult an irrigation design company to improve their systems in the same manner that they were referred to their pump dealers to improve inefficient pumping plants.

Irrigation Load Management

The following is a discourse of the methodology which would need to be employed in order to implement a complete irrigation load management program. Thus far, only a pilot program in irrigation load

management has been tested similar to the pilot program in pump testing just described.

An effective load management program must satisfy both the power supplier and the irrigator. In scheduling irrigation during off-peak periods, crop yields must not be decreased. Thus, load management will necessarily involve the incorporation of some irrigation water management techniques in order to achieve these goals.

Power Supply Analyses.--Demand records need to be studied to determine the relative costs to the power supplier of the irrigation load. This demand-cost study helps determine the amount of effort and funds which can be expended to control future demand costs (2).

Most rural power suppliers maintain summaries of the total connected horsepower they serve for irrigation. Power supply personnel also know which substations or sections of their service area contain most of the irrigation loads. Off-peak irrigation scheduling begins at this point. Hourly demand records of substations should be analyzed to develop daily and seasonal load patterns in relation to the total load of the system. Three or four years of data help to better determine the load patterns during the irrigation season.

If the power supply analysis reveals a need for demand control, the magnitude and timing of control must be established. Next, key areas or substations should be selected for control. Some areas or substations within a service area may be easier to control than others. A substation peak or the peak demand of one or more substations may be controlling the total peak demand of the system. Irrigated areas served by certain substations may have larger motors

or finer-textured soils that will lend themselves more readily to off-peak irrigation scheduling.

Sprinkler systems are much easier to shut off for a few hours than surface irrigation systems, although both sprinkler and surface systems can be scheduled off on selected days in a given time period.

After the areas of control have been selected, a method of control and some kind of inducement for irrigators' cooperation must be developed (2).

System Analyses.--Before a load management program can be implemented, some kind of criterion must be devised to determine whether or not a particular irrigation system has the flexibility to be regulated without depreciating crop yields. System analysis is required before a sound decision can be reached concerning off-peak irrigation scheduling.

Stored soil moisture is the key to effective off-peak irrigation scheduling. Many irrigation systems are designed to meet the peak water-use requirements of the crop. However, if the irrigation system does not continuously operate during the peak water-use period, the crop may withdraw some moisture from the soil profile to supplement the irrigation water applied. All of this assumes that off-peak irrigation scheduling is required during the period of peak water-use for the crop. This will probably be the case for most summer peaking utilities since crop peak water-use periods and temperature, hence air-conditioning, occur spontaneously. In other situations, off-peak irrigation scheduling will not be as critical.

The amount of moisture that the crop can withdraw from the soil profile without decreasing yields depends upon the type of crop, stage of growth, type of soil, and the available soil moisture at the time irrigation is interrupted. In some areas, the probability of rainfall can also be considered in an overall plan of scheduled interruption. If the system capacity will allow a nearly full soil moisture profile before interruption, then an off-peak scheduling program can include that system without causing a reduction in crop yields. Research has shown that when water or pumping time is limited, moisture stress at certain crop stages is not as critical as at other stages (2).

Addink, et al. (1 , 2) have conducted research in Nebraska to determine minimum irrigation capacity for maximum corn yields with center-pivot systems. In this study, a computer model was developed to estimate system capacity requirements (nine out of ten years) which would not limit corn production because of a soil moisture deficit. Results of this modeling are shown in Fig. 5 along with examples. These results can be used to: (1) design irrigation systems with limited pumping capacities, or (2) operate irrigation systems with excess capacity for fewer hours. Both of these utilizations can save water and energy. Similar methods can be employed to evaluate other types of irrigation systems, crops, and climatological regions.

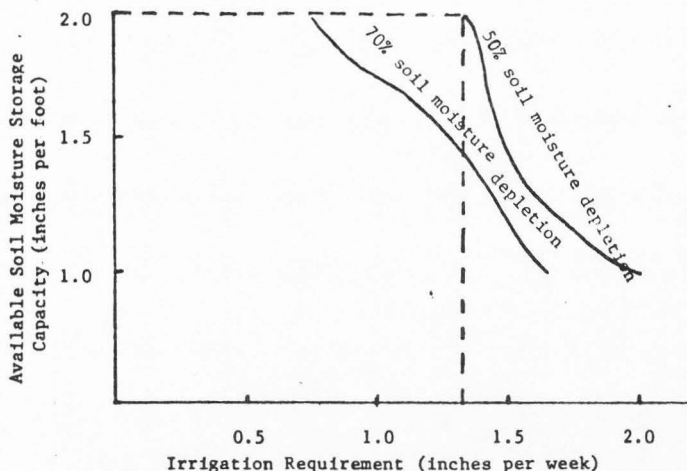


FIG. 5.--Irrigation Requirements vs. Available Soil Moisture for Two Soil Moisture Depletions Based Upon Computer Modeling Using 58 Years of Weather Data at North Platte, Nebraska (1).

Example 1.--System Design

A farmer has a silty clay loam soil. Climate conditions are similar to North Platte. He wants to irrigate 130 acres, and keep soil moisture depletion less than 50% nine out of ten years.

Available soil moisture storage capacity must first be determined to be 2.0 inches per foot for silty clay loam. From Fig. 5, 1.35 inches per week is required for a soil holding 2.0 inches per foot to prevent depleting soil moisture more than 50%. Allowing 10% downtime would require 1.48 inches system capacity per week. A 130 acre center-pivot would require 520 gpm to provide 1.48 inches per week. If irrigation efficiency is less than 90%, additional capacity is required.

Example 2.--Off-Peak Irrigation

A farmer has a 800 gpm center-pivot irrigating 130 acres. He is willing to cooperate with the power company to reduce peak power loads during the summer. His soil is a silt loam which has an available soil moisture storage capacity of 2.0 inches per foot. According to Fig. 5, 1.35 inches per week is required if soil moisture depletion of 50% or less is acceptable nine of ten years. If a maximum soil moisture depletion of 70% or less was acceptable, it would require 0.70 inches per week. This would decrease corn yields, very little, if any.

However, the farmer decides to use 50% depletion which requires 1.35 inches per week. Applying 1.35 inches per week on 130 acres requires 470 gpm. Since he has 800 gpm available, he could shut off his system 40% of the time each day. Most years he could be shut down more than 40% of the time during the peak-use period without exceeding 50% soil moisture depletion.

Irrigation Scheduling.--Irrigation scheduling or soil moisture monitoring is required to determine which irrigation systems can be shut down without causing crop damage. If electrical load reduction is required, a system which operates on soils with high amounts of available moisture storage will be shut down sooner than one which operates on soils of low available moisture storage (2).

Proper scheduling of irrigation requires careful monitoring of soil moisture in the plants effective root zone and a prediction of the amount of water that the plant uses. Keeping tabs on the status of the soil moisture reservoir is like balancing a checkbook. The amount of irrigation water applied is added in (less inefficiency of water application), and the effective rainfall received and the amount of water used by the crop is subtracted out (11).

Probably the greatest benefit the irrigator obtains from scheduling irrigations is not so much the timing of irrigations, but the amount of water to be applied each irrigation. This relates directly to the irrigation efficiency at which water is used (which was discussed in the Irrigation Water Management subsection). As an example, in Central Nebraska irrigation scheduling has reduced the amount of water applied from 24 inches to 15 inches per season. This is a 38% saving of water and energy for irrigators who scheduled irrigations over those who did not (11).

Refilling the root zone from each irrigation can waste fertilizer, water, and pumping energy. If rainfall occurs soon after the field is irrigated, water will percolate below the root zone carrying with it soluble nutrients, thus wasting fertilizers, water, and energy. It

is important that plant nutrients, applied as soluble fertilizers, not be leached from the soil during the growing season. (Yet, rainfall would not be as dependable in Utah and Idaho.)

In summary, irrigation scheduling not only is an important part of any effective load management program, but also serves to be an integral part of an effective irrigation water management program in conserving water and energy.

Pilot Program.--A pilot program in off-peak control is initially most desirable in order to give district personnel and irrigators the feel of off-peak scheduling and to obtain experience in monitoring and controlling loads. Electrical loads should be monitored at key substations or for the total system, depending upon the effect desired. Irrigation should be scheduled off only when demands reach a predetermined level. The demand analysis of previous years will help to evaluate this parameter (2).

During the summer of 1977, a pilot program in load management was initiated near Rexburg in the Rexburg division of U.P. & L. The Smith South Circuit Substation was chosen for load scheduling on a voluntary basis. One-fifth of the irrigators on this circuit were asked to defer irrigating on a particular day of the week for a ten-hour period. The experiment was conducted during the last week of June, the first week of July, and the last week of July.

RESULTS AND DISCUSSION

If a utility's expenditures can be deferred, then rate increases can also be deferred since utilities are only allowed to increase rates in proportion to increased expenses incurred. Thus, it is desired to determine if various energy management programs could appreciably alleviate pumping demands on the U.P. & L. Co., thereby deferring expenditures for the company and rate increases for the customers.

Fig. 6 shows peak load and peaking capability projections for the U.P. & L. Co. As can be seen, required capability during the winter lull periods equals or exceeds the summer peaks which occur about a year and a half, or 18 months, prior to this time. Thus, the longest the company could expect to defer capital expenditures would be about 18 months.

The irrigation kilowatt-hour consumption in 1977 for each division of U.P. & L. is shown in Table 4. Note that Idaho irrigators consume 77% of all energy used for irrigation within the company.

The 1977 load-duration curve for the U.P. & L. system is shown in Fig. 7. This curve indicates the length of time that a given load must be annually supplied to meet system requirements. For example, a load of approximately 1480 megawatts must be supplied for 100 hours during the year, and a peak load of 1887 megawatts must be supplied for approximately one hour annually.

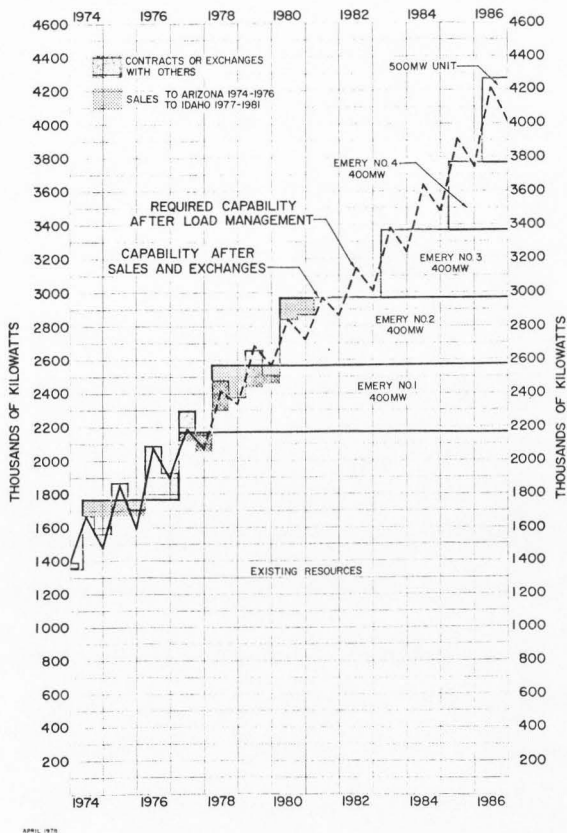


FIG. 6.--Utah Power and Light Company Peak Load and Peaking Capability.

TABLE 4.--1977 Irrigation Energy Consumption of the Utah Power and Light Company by Division and State (17).

Division (1)	KWHR (2)	% Total (3)
Rexburg Division	362,481,752	66
Preston Division	60,640,176	11
Salt Lake Division	24,843,587	5
Ogden Division	10,675,397	2
Telluride Division	57,594,824	10
Southern Division	32,777,252	6
Company Total	549,012,988	

Total Idaho Kwh	= 414,338,120	75.5% of Total
Total Utah Kwh	= 133,120,130	24.2% of Total
Total Wyoming Kwh	= 1,554,738	0.3% of Total

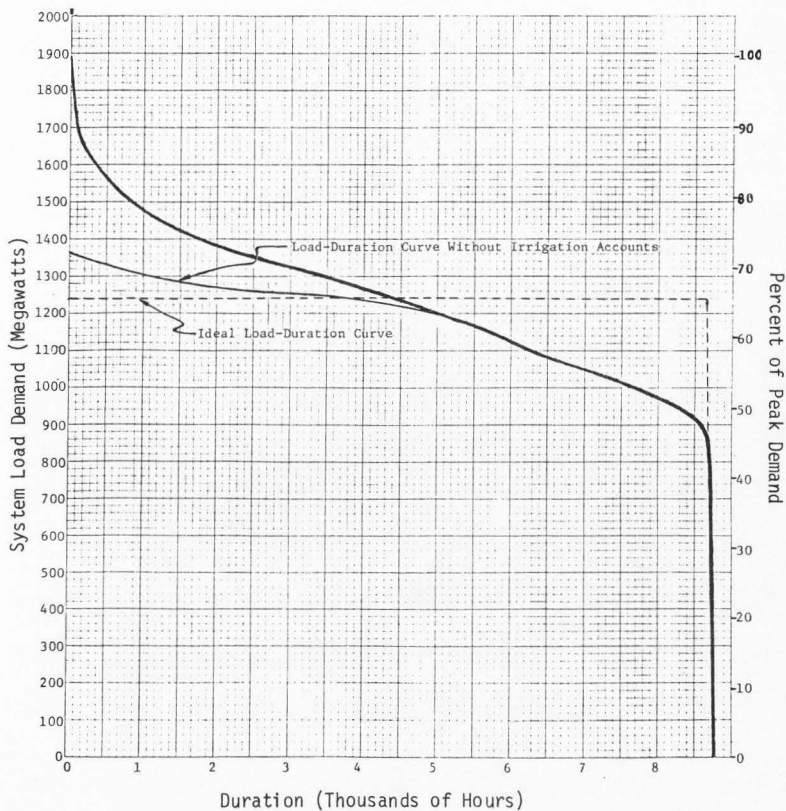


FIG. 7.-- 1977 Load-Duration Curve, Ideal Load-Duration Curve, and the 1977 Load-Duration Curve Without Irrigation Loads for the Utah Power and Light Company.

The integration of the load-duration curve over the year, or the area below the curve, represents the annual kilowatt-hour sales for U.P.& L. of nearly 1.09×10^{10} Kwh. Note that each small square on the graph represents 2.00×10^6 Kwh. The ideal load-duration curve would be constant throughout the year having the same area below the curve. As shown in Fig. 7, by the dashed line, this would produce a continuous base load of about 1240 Mw. Fundamentally, the area below the curve represents sales where the company makes a greater return on investment and the height of the curve reflects capital investments that must be made to provide for demand. Therefore, it is desirable to maximize the area under the curve while minimizing the height of the curve.

The scale at the right of the graph gives the percentage of the peak demand. From the graph, it can be seen that 700 hours of generation will take care of 20% of the total capacity requirement, whereas only 80 hours of operation will take care of 10% of the peak requirement. The load is never less than 45% of the annual peak. Consequently, 45% of the total peaking capacity can be considered base load generation, operating more or less around the clock, while approximately 35% is mixed or intermediate capacity. The remaining 20% of generating capacity could be classified as peaking requirement.

Total company consumption for irrigation in 1977 was 549,012,988 Kwh (Table 4) and comprises about 5% of all energy sold by U.P.& L. Since these loads occur for approximately 4000 hours or less each irrigation season, the companies load-duration curve would look

something like that shown by the thin solid line in Fig. 7 if all irrigation loads were completely eliminated. Thus, it can be seen that although irrigation loads comprise only 5% of all energy sales by the company, these loads produce about 30% of the peak kilowatt demand.

Pump Testing

It is important to note that all of the assets of a pump testing program cannot be converted into economic parameters. For instance, P.G.& E. believes that its pump testing program serves as a valuable public relations instrument (29). Since this kind of program can help irrigation customers save money, they are naturally more partisan towards the power company.

The relationship between overall pumping plant efficiency and Kwh consumption per acre foot per foot lift is shown in Fig. 8. It can be seen that the lower the pumping plant efficiency, the more critical power consumption becomes. From Fig. 8, cost can be substituted for kilowatt-hour consumption and the effect of pumping plant efficiency on power cost at various power rates can be seen in Fig. 9. Thus, the higher the price per Kwh, the more critical the cost becomes for decreasing efficiency. Further analysis reveals a linear function between the present efficiency of a pumping plant and the potential percent of energy savings that can be expected by upgrading the system to a higher overall efficiency, see Fig. 10.

Many of the pumping plant installations tested during this study involved two pumps in series, i.e., a primary pump used to lift

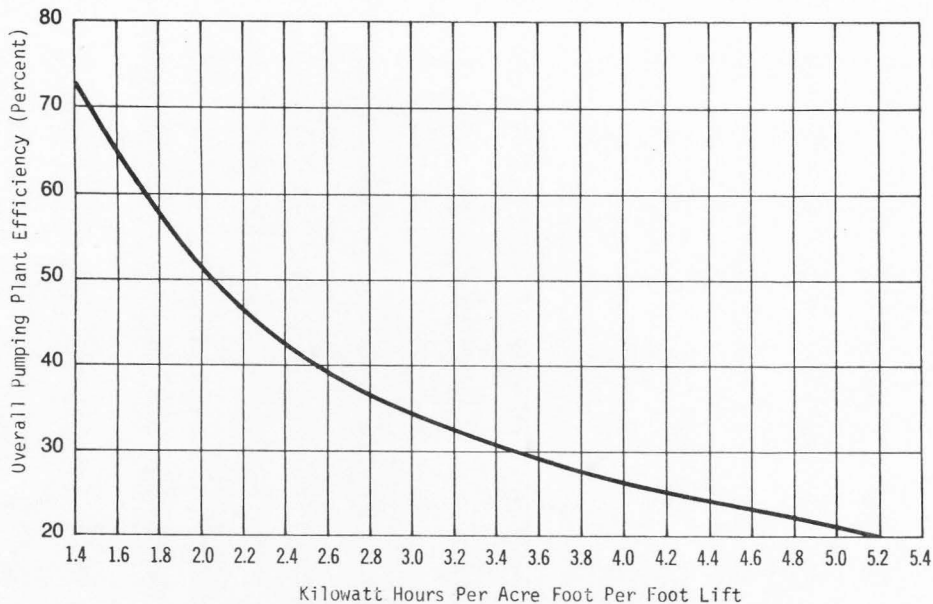


Fig. 8.--Relationship Between Overall Pumping Plant Efficiency and Kilowatt-Hour Consumption per Acre Foot Per Foot Lift.

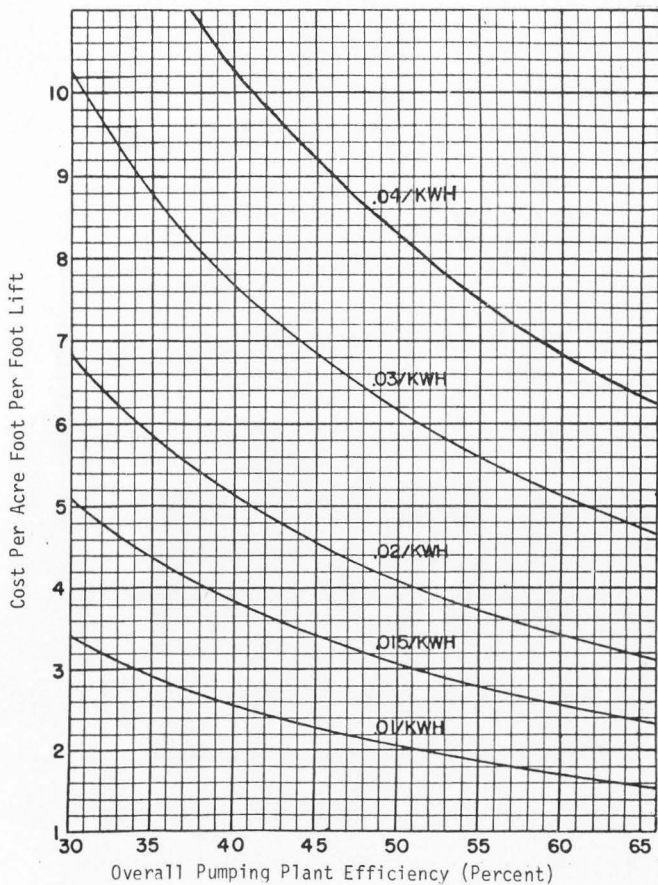


FIG. 9.--The Effect of Efficiency on Power Cost for Irrigation Pumps at Various Power Rates.

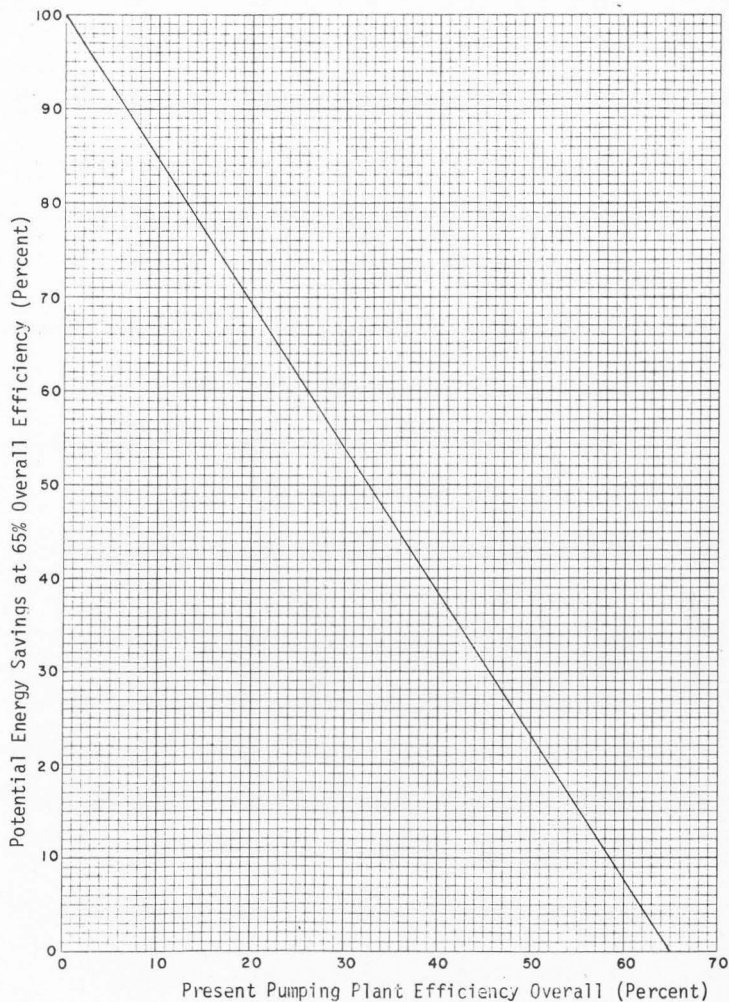


FIG. 10.--Relationship Between Present Pumping Plant Efficiency and Potential Energy Savings Available by Upgrading Plant to a 65% Overall Efficiency.

underground water to the surface and a booster pump used to provide additional head to operate sprinkler systems. Two tests were conducted on this type of installation. One was conducted when both the primary and booster pumps were operating, and the second with only the primary pump. With these two tests, it was possible to determine which pump might have been contributing most to the overall plant inefficiency. In the following analysis of the pumping plant efficiency results, only the overall (primary and booster) pumping plant efficiencies are examined in order to eliminate redundancies.

Results.--Pump testing results show that the Ogden, Southern, and Telluride divisions have lower pumping efficiencies ranging on the average from 54% to 57%, whereas, the Rexburg and Preston divisions have higher efficiencies averaging 62% to 63%.

The distribution of individual pumping plant efficiencies for all divisions of U.P. & L. are shown in Table 5, based on the sample of pumps tested during 1977. As shown, 4% of all pumps tested had efficiencies of 40% or less, and 10% of all pumps tested had efficiencies of 45% or less, etc. It is interesting to note that 19% of the pumping plants tested had efficiencies greater than 65%. This emphasizes that realistically, pumping plant installations can be upgraded to at least a 65% efficiency and this should be an absolute minimum for new installations of 20 hp and above.

Column 3 shows the percent of potential energy savings that can be expected by upgrading the given pumping plant efficiencies to 65%. Fig. 10 can be used to obtain these values.

TABLE 5.--Distribution of Individual Pumping Plant Efficiencies and Economic Effect of Improving All Pumps in the Utah Power and Light Service Area, Based on the Sample of Pumps Tested During 1977.

Percent of Pumps Tested Less Than Given Efficiency (1)	Given Pumping Plant Efficiency (2)	Percent Potential Energy Savings (3)	Potential Kwh Reductions (4)	Potential kw Demand Reductions (5)	Potential kwh Revenue Reductions (6)	Potential Reduced Variable Operating Expenses (Fuel + O&M) (7)	Potential Deferred Capital Expense Reductions (8)	Potential Net Marginal Benefit (9)
4	40	39.4	12,977,000	4,950	234,000	117,000	652,000	535,000
10	45	31.8	39,180,000	14,940	705,000	353,000	1,967,000	1,615,000
21	50*	24.2	81,104,000	30,920	1,460,000	730,000	4,071,000	3,341,000
32	55	16.7	125,025,000	47,670	2,250,000	1,125,000	6,277,000	5,152,000
58	60	9.1	168,447,000	64,220	3,032,000	1,516,000	8,456,000	6,940,000
81	65	11.5	178,554,000	68,080	3,214,000	1,607,000	8,964,000	7,357,000

* Probable operating efficiency where irrigators could economically justify upgrading pumping plant efficiencies to 65%.

Column 4 represents the kilowatt-hour reductions that would occur for U.P. & L. during 18 months if all pumping plants operating at or below the efficiency given in Column 2 were upgraded to 65%. Column 4 is somewhat conservative since all of the pumping plants in each category were assumed to be operating at the stated efficiency. For example, the pumping plants operating between 40% and 45% efficiency were all assumed to be operating at 45% efficiency.

Column 5 estimates the kilowatt demand reduction based upon an annual weighted average plant operation time of 3115 hours in Utah and 1546 hours in Idaho. These figures were obtained from averaging U.P. & L. billing records. This column was calculated assuming that kilowatt demand reduction occurs from upgrading pumping plant efficiency either by decreasing the power demand required by the pump installation or by decreasing the pumping time required for each irrigation.

In column 6, the revenue reduction from decreased kwh sales during the first 18 months is calculated by multiplying the kwh reduction in column 4 by a price per kwh of \$.018, which is estimated from the company's irrigation rate schedules. Any kwh reductions will result in reduced sales in the less expensive blocks of the declining energy rate structure. The reduction in expenses such as fuel, operation, and maintenance costs due to decreased kwh sales is shown in Column 7. U.P. & L. attributes approximately \$.009 per kwh to these expenses (17).

The reduction in capital expenditures for new generation is shown in column 8 based upon a cost of \$650,000 per kilowatt (17).

This column considers the savings which could be realized by deferring expenses for 18 months if this capital were invested at a 20% fixed cost with an anticipated 9% rate of inflation. Again, this figure is conservative since the cost of new transmission and distribution facilities is not included.

Column 9 of Table 5 shows the net marginal benefit between reduced revenue due to the decrease in kwh sales and the savings in capital expenditures that can be deferred for the first 18 months due to the reduction in kilowatt demand.

It can be seen that if all irrigators brought their pumping plant efficiencies up to 65%, the company would realize a benefit of about \$7,357,000 the first 18 months or about \$4,905,000 annually at 1977 power rates. However, for all practical purposes, this is not feasible since it is uneconomical for many irrigators to upgrade their plants.

Although an individual economical analysis must be made for each pumping plant, estimates reveal that most irrigators with pumping plants operating at or below 50% efficiency could economically justify upgrading their plants. This figure may be slightly conservative, but as power rates continue to rise, the efficiency at which it becomes economical to upgrade a given pumping plant will also rise in an exponential manner as shown in Fig. 9. Therefore, at a pumping plant efficiency of 50% or less, 21% of the company's irrigators might be economically induced to upgrade their pumping plants. This would result in savings of about \$3,341,000 for the company the first 18 months or about \$2,227,000 annually, and savings of about \$1,460,000

the first 18 months or about \$973,000 annually for irrigation customers. This type of analysis suggests that U.P. & L. would economically benefit from any kind of reduction in irrigation load since their rate of return for this service is unfavorable.

It is very important to realize that the figures presented in Table 5 assume that all pumping plants could have been tested and upgraded before the 1977 irrigation season. This is not practical by any means, therefore the financial benefits shown in column 8 would be spread over several years during which the program functioned.

Discussion.--Since the irrigators who volunteered to participate in the pump testing study were probably more conscientious about maintenance than many irrigators, the pump efficiency results may not reflect a true picture of the potential problems associated with each division. Consequently, the pump efficiencies generated in this study are likely to be higher than average since pumping plant efficiency can be directly related to the quality and quantity of service maintenance provided by the irrigator. It is difficult if not impossible to determine the extent of the difference attributable to this incongruity.

There are many reasons why pumping efficiencies may be sub-standard. The first possibility is that the pumping plant was poorly designed or installed. This appeared to be the case for several pumps tested. Only a pump test made immediately after installation could disclose this problem. There was much evidence that wells were not properly developed and, consequently the sand which is normally removed during well development was excessively eroding impeller

blades which decreased efficiency. Solution to these problems required educational training since most farmers and some pump dealers are not familiar with the development of irrigation wells and the technicalities of pumping plant system design and selection. At today's costs for well drilling, irrigation equipment, and operation, capital investments are lifetime expenditures and farmers cannot afford to patronize inferior service or equipment.

In the Benson area of the Preston division and the Tremonton area of the Ogden division, many of the pumps are centrifugal pumps which utilize water from rivers or unlined canals. This water is particularly silty and deteriorates impeller blades much like sand, and in turn, lowers the pump efficiency.

As previously noted, even if a farmer is provided an efficient pumping plant installation, poor maintenance and no service adjustments will soon result in low efficiencies.

Air bubbles were seen in the discharge water from several pumps, and may have been introduced into the system by several different processes. For instance, in the Milford area of the Telluride division, many of the older wells have casings which were perforated above the predominate water bearing aquifer. This results in "cascading water," i.e., water that falls from a perched aquifer to the normal pumping level. This falling water entrains air and the bubbles are drawn into the impeller. Another undesirable effect from shallow casing perforations is the lower quality of water which flows into the well nearer to the surface.

Falling water can also be generated when column pipes rust and

deteriorate above the pumping level, allowing some of the pumped water to fall back into the well. Another process by which air was introduced into the impeller occurred when the normal water table dropped near the intake of the column and air and water were alternately sucked into the impeller, breaking pump suction. This problem was encountered in the Santaquin area of the Southern division and if the water table continues to drop in this region, flowrates will continue to drop off until many pumps will cease to pump altogether unless the columns are extended and the bowls lowered.

These air bubbles are undesirable because as they move into the higher pressure regions of the impeller, they suddenly collapse and cause a phenomena similar to cavitation. The implosion which occurs during cavitation can be so violent that it eats away the impeller blades.

Another common reason for low efficiencies was the addition of a booster pump or other hydraulic alteration in the original system. These alterations changed the head from that for which the pumping plant was designed and, therefore may have lowered the pumping plant efficiency. This was one of the major contributions to low pumping plant efficiencies as cited by Longenbaugh (19). As sprinkler irrigation systems are becoming more popular, many of the older irrigation pumps used for surface irrigation are being converted for use with sprinkle systems with the addition of booster pumps. Such hydraulic alteration, adding valves, or changing pipe sizes may reduce the efficiency of the original system considerably.

On many systems, throttling valves were used to operate pumping plants at different flowrates, such as for running different numbers of sprinkler lateral lines. In such situations, a throttling valve controls flow by creating an artificial increase in the discharge head. These throttling valves were used to dissipate energy not required to operate the system, thereby wasting power. Along with this hydraulic loss, there is another energy loss associated with valve control. As flow decreases below the design point on the H-Q curve, pump efficiency also decreases causing an additional waste of power. This is what can happen for any hydraulic alteration. For many systems of this kind, variable frequency drives may help conserve considerable amounts of energy (9).

The Rexburg and Northern Preston divisions had pumps with higher efficiencies mainly because most of the plants are larger and newer. Larger pumping plants are usually more efficient because they are built to meet better tolerances. Also, newer systems should be expected to be more efficient since improved technology and engineering advancements have provided greater efficiencies in hydraulic design. It is also possible that pump dealers and well testers are more conscientious or proficient in Idaho.

In summary, it appears that implementation of a pump testing program in the U.P.& L. Co. may reduce kwh sales for irrigation by about 10% and reduce kw demand for irrigation by 6%. Overall, this would result in 0.5% reduction in total kwh sales and a 1.6% reduction in total kw demand for the company. This would affect the 1977 load-duration curve as shown in Fig. 11. Economically, it would

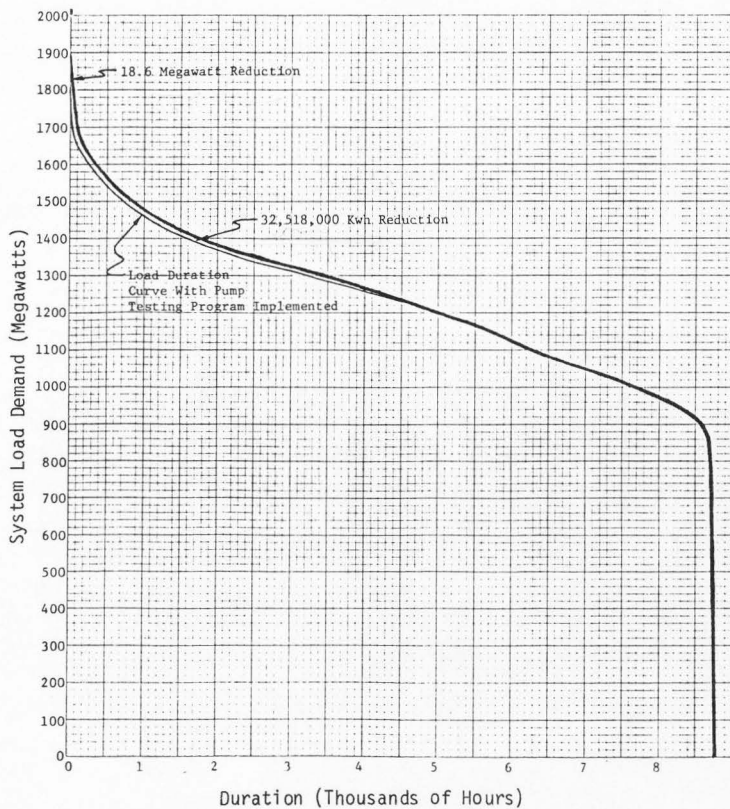


FIG. 11.--1977 Load-Duration Curve for the Utah Power & Light Company with Implementation of Pump Testing Program Based Upon the Sample of Pumps Tested in 1977 if Pumps with Efficiencies of 50% and Less Were Upgraded.

appear that both U.P. & L. and their irrigation customers would benefit financially from a program which improved irrigation pumping plant efficiencies.

Irrigation Water Management

The irrigation efficiencies could not be calculated for all of the pumps tested in determining pump efficiencies since many pumps irrigated fields which supplied only a portion of the total seasonal irrigation.

The net seasonal evapotranspiration requirements were determined through the use of the Soil Conservation Service's Irrigation Guides in both Utah and Idaho. The Modified Blaney Criddle Formula was used to develop these guides and the present consensus of many reputable irrigation experts is that evapotranspiration estimates for alfalfa using this equation may be substantially higher than those actually occurring. Therefore, there may be greater error introduced into the computation of the irrigation efficiency at those fields growing alfalfa.

Results.--Although the sampling of irrigation efficiencies is rather small, the results indicate definite trends associated with the irrigation efficiencies in each division. Higher irrigation efficiencies appear to prevail throughout the Rexburg, Ogden, and southern Preston divisions, while lower irrigation efficiencies seem to be associated with the northern Preston, Southern, and Telluride divisions.

Discussion.--If irrigation water management proves to be as successful as the initial results obtained in the Nebraska irrigation scheduling programs, irrigators might easily expect to save at least 15% of the water and energy presently being used if such a program could be provided to them.

A 15% reduction in irrigation energy consumption due to implementation of an irrigation water management program would affect the 1977 load-duration curve as shown in Fig. 12. Again, this would reduce both the kwh sales and also the kw peak demand.

Irrigation Load Management

The pilot program in irrigation load management was used to help determine if scheduled irrigation could appreciably reduce system peak demand.

An analysis of the summer system demand for U.P. & L. revealed a period of lower demand between about 4:00 a.m. and 9:00 a.m. for every day of the week and a period of higher demand between about 11:00 a.m. and 7:00 p.m. for every day of the week except Sundays, which had more or less a continuous demand throughout this same period. Analysis of the Smith Substation in the Rexburg division showed that demand for this substation followed total system demand very closely.

Results.--With only part of the irrigators participating, daily peak demand was reduced 14% on the Smith Substation. This represented about 1.65 Mw in demand. With all irrigators participating on a mandatory basis, it was felt that daily peak demand could be reduced by as much as 25% (16).

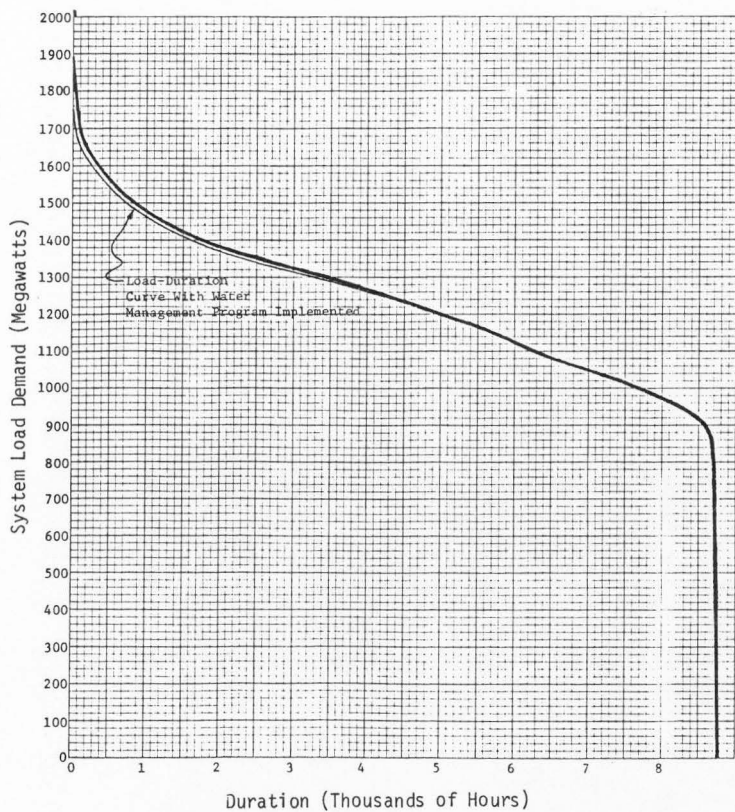


FIG. 12.--Effect of Irrigation Water Management Program on the 1977 Load-Duration Curve for U.P. & L. with Estimated Energy Savings of 15%.

Discussion.--The irrigation load management pilot program did not include all of the irrigators on the Smith Substation, and those that did participate, did so only on a voluntary basis. Approximately 30 irrigation accounts were involved with the program (16).

If 25% of the demand due to irrigation could be eliminated throughout Utah and Idaho, this would represent a demand reduction of about 155 Mw on the U.P. & L. system.

Since Idaho irrigators only operate on the average of about 1550 hours annually, these irrigation systems would lend themselves much more readily to a direct control irrigation load management program than irrigation systems in Utah which operate around 3100 hours annually. The popularity of center-pivot systems in Idaho is probably the reason for this difference. Center-pivot systems are actually the most versatile systems to subject to load scheduling. Thus, it would be much more realistic to involve only Idaho irrigators in a direct control load management program. Utah irrigators might be encouraged to support some kind of indirect control load management program.

If 25% of the demand due to irrigation in Idaho could be eliminated, this would represent a demand reduction of about 115 Mw on the U.P. & L. system. From the experience obtained in the Nebraska irrigation load management programs, it appears that irrigators might be shut down for about 20 days or less annually. Therefore, an irrigation load management program in Idaho might expect to reduce kwh consumption by about 3,000,000 kwh, which would reduce U.P. & L. revenue by about \$98,000 during the first year and a half. However, this assumes that irrigators would not otherwise irrigate at all during off peak periods to make up for the time shut down.

The 115 Mw reduction in demand would save U.P.& L. approximately \$4,746,000 during the first year and a half due to deferred capital expenditures for new generation. This would amount to a gross marginal savings of \$4,649,000 during the first year and a half. The cost of equipment, installation, and operation must be deducted from this amount to determine the net savings over the operational lifetime of the program.

Fig. 13 shows the effect on the U.P.& L. 1977 load-duration curve for the implementation of an irrigation load management program in Idaho with direct control. Implementation of direct control irrigation load management programs in Utah would produce an even more desirable load-duration curve, but this does not appear to be as feasible. Since the irrigation loads in Utah are more spread out, the cost/benefit ratio of expensive control equipment to the load controlled would greatly increase.

In summary, there appears to be substantial savings for U.P.& L. through implementation of an irrigation load management program, but due to the characteristics of the Utah and Idaho irrigation systems, Idaho irrigation loads have a much greater potential for direct control, and Utah irrigation loads would be more suitable for indirect control.

Inequities.--It appears there would be major problems created in offering special rates to irrigators who would subject themselves to irrigation load management due to the difference in the nature of the designs of various systems.

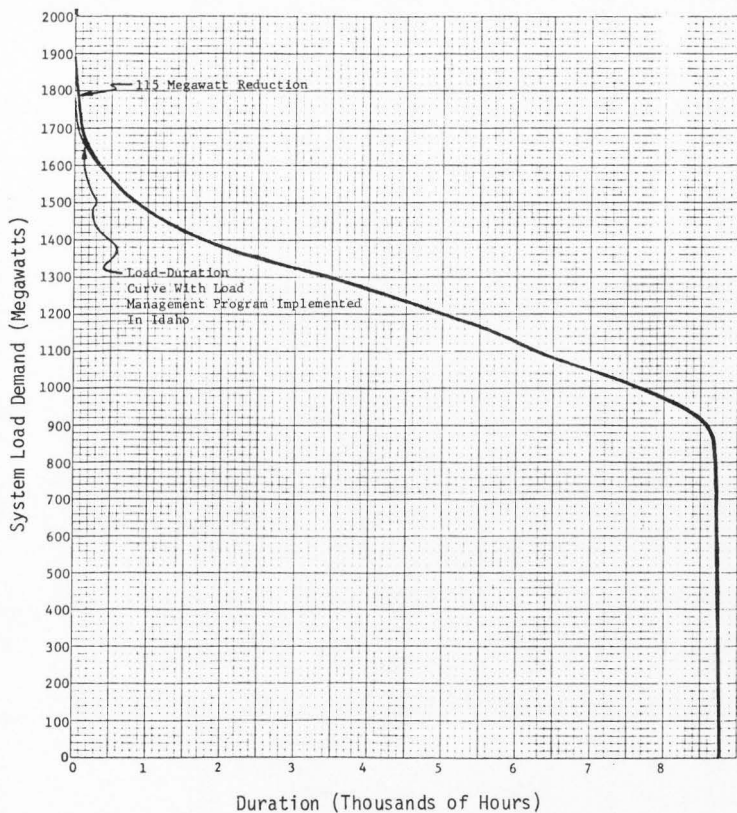


Fig. 13.--Effect of Irrigation Load Management on the 1977 Load Duration Curve for U.P. & L. if Irrigation Load Management is Implemented in Idaho.

Well designed irrigation systems will meet the exact water requirements of a crop during the peak consumptive-use period and will need to operate continuously during this period. Because these systems are not oversized, they will not create unnecessary Kw demand over the minimum requirement. However, these systems will not lend themselves to off-peak scheduling and will therefore, be penalized although their design promotes the more favorable effect of minimum kw demand.

On the other hand, oversized systems create excessive kw demand for the company, but they lend themselves well to off-peak scheduling and would receive the benefits of a special rate.

Another inequity would result among irrigators who pump water from an uncontrolled source such as a private well or reservoir and irrigators who are limited to pumping from canals, pipelines or reservoirs during regulated intervals, as often practiced by irrigation companies. The latter situation may not allow an irrigator the flexibility to participate in the load management program, again penalizing the irrigator with the higher rate schedule.

If special rate structures are to be incorporated into an irrigation load management program, these inconsistencies must be resolved.

Although an energy load management program appears to offer U.P.& L. the most direct means to reduce peak demand due to irrigation, programs in pump testing and irrigation water management will also economically benefit U.P.& L. in two ways. First, by reducing irrigation kwh consumption. Since U.P.& L. receives a lower rate of

return on investment for irrigation, they will benefit by selling irrigation kwh's to some other class of customer at a higher rate of return. Secondly, U.P.& L. would also realize some kw demand reductions from these two programs. Although kw demands usually increase as efficiency is increased, more water would be pumped and pumps could be shut down for longer periods of time. This would actually decrease the overall kw demand due to irrigation.

An effective program in irrigation load management must incorporate, to some extent, some of the data obtained from an irrigation water management program; and a sound irrigation water management program must incorporate some of the data obtained in a pump test. Consequently, these programs are by no means independent.

CONCLUSIONS

There appears to be significant potential for energy conservation through implementation of energy management programs in pump testing and irrigation water management for the U.P. & L. Co. These two programs could potentially save irrigators at least 35% of the energy presently being consumed for irrigation. The economic benefits for the utility are also very favorable. With inflating costs for new generation, transmission, distribution and the increasing cost of capital, these programs will become even more appealing in the future. If U.P. & L. cannot justify the costs incurred through implementing pump testing and irrigation water management programs, it appears that there may be potential for enough energy savings to promote interest in commercial programs within private enterprise.

In addition to this, an irrigation load management program appears to offer U.P. & L. substantial economic benefits which might also be passed on to the irrigator. Unfortunately, irrigation load management essentially conserves no energy.

The probable combined effect of implementing programs in pump testing, irrigation water management, and irrigation load management is shown by the dashed line of the load-duration curve in Fig. 14.

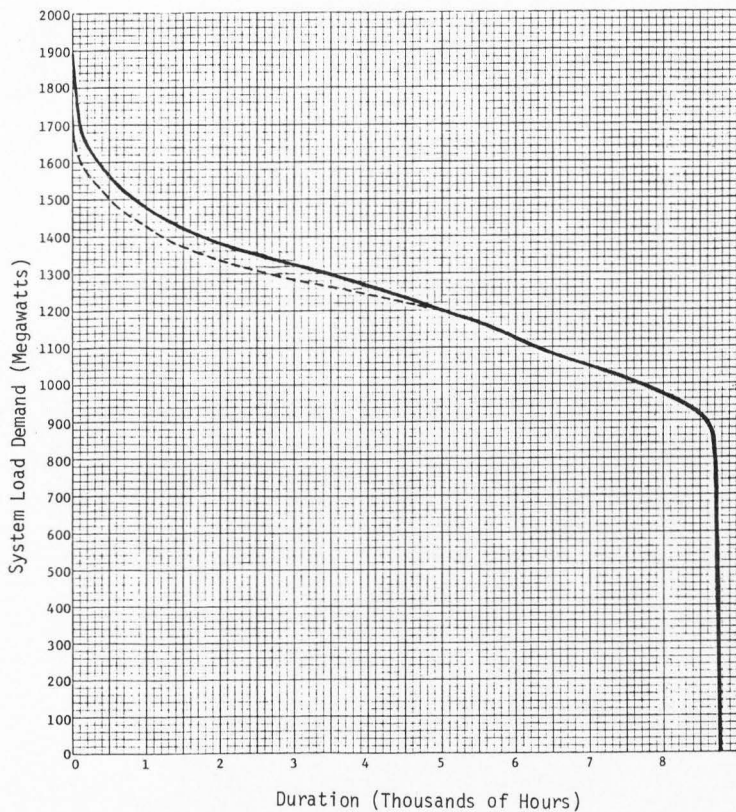


FIG. 14.--Probable Combined Effect of Implementing Programs in Pump Testing, Irrigation Water Management and Irrigation Load Management on the 1977 U.P. & L. Load-Duration Curve.

Presently, there is not sufficient data available to fully evaluate the exact benefits of these programs. It is for this reason that estimates on future load growth in planning resource requirements should not be based upon favorable results revealed in this study. With today's extended periods of power plant siting and construction, a utility could easily find itself substantially short of power, if such projections were overestimated. Already, reductions in orders for new generating equipment such as boilers and turbines (which take a long time to manufacture) indicate that presently, there is not nearly enough generation being added to the country's power reserves to meet future load requirements. Many believe that there will be significant power shortages by the early 1980's.

In this perspective, energy management may well be able to prolong such predicaments, but if these programs are also used to plan resources, the problem may only be compounded.

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