ACT^2 Agricultural Irrigation Pumping Demo

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A California utility is sponsoring the Advanced Customer Technology Test (ACT^2) project involving demonstrations at customer facilities. To represent agricultural customers, the project selected deep-well irrigation pumping because it dominates the utility's agriculture load.

The selected demonstration site is a 288 acre (1,165.5 km^2) vineyard in the Salinas Valley. It uses a single 250 horsepower (186.5 kW) pump to provide water from a stable 260 foot (79 meter) deep aquifer. The pump supplies water directly to the vines through drip emitters and into a sprinkler system to irrigate the vineyard's cover crop and wind break trees. Utility measured overall pumping efficiency (OPE) for this site has been 51% over the last ten years.

An experienced consulting engineering firm (CE) was hired to design and install pumping system energy efficiency measures (EEMs). Each approved EEM had to be competitive with the cost of new electric supply options and acceptable to the customer. When the pump's discharge piping was modified, so flow could be accurately measured, OPE increased to 61%. The CE and site manager attribute this to improved flow accuracy.

The pump was pulled to determine its characteristics and condition and then closely monitored for one season. The resulting data helped calibrate a pumping energy simulation model. With this tool, the CE designed a package of EEMs projected to save 24% of the pumping energy. This package was approved and installed. Initial results of the EEMs energy use are promising but inconclusive.

Introduction

The utility established the ACT^2 Project to determine whether utility investments in customer energy efficiency measures were more cost effective than investments in new electric supply. These measures had to be acceptable to the customer The project selected nine demonstration sites to represent all its non-industrial customers. They included four single family residences, three office buildings, one sit-down restaurant and one deep well agricultural irrigation pumping system.

Agricultural energy use comprises about five percent of the utility's electric load and has been largely overlooked by most Demand Side Management (DSM) and Customer Energy Efficiency (CEE) studies. With food processing excluded, the dominant agricultural energy use in California is irrigation pumping. This includes both low lift pumping from reservoirs or canals and deep well pumping. Deep well pumping was more attractive because it uses more energy and is less affected by drought conditions.

The ACT^2 project has demonstrated measured energy savings in excess of 50% in buildings (Brohard 1992) through the use of integrated designs. However, because most of the energy used in deep well pumping is required just to lift the water, this pumping demonstration is only targeted to save about 25% of current energy use. Demand reduction, while not a goal of this project is important to the utility. It is monitored as a potentially serendipitous benefit.

The sponsoring utilities choose to focus on hardware efficiency improvement and avoid the appearance of telling its agricultural customers how to conduct their business. Energy and water savings through better irrigation management practices are outside the scope of this demonstration.

Methodology

General. The project classifies all sites as either "new" or "retrofit." New sites have no energy use history so improvements must be compared to the energy use predicted by a computerized energy simulation model of the original design. Retrofit sites are monitored for one year, before they are modified, to obtain data to calibrate the preconditions energy simulation model. This allows retrofit site energy impact assessments to be based on two calibrated energy simulation models.

To enhanced the credibility of the findings, all demonstrations are conducted at actual customer facilities and adjusted for the impact of changes in weather and usage. Where possible, the energy impact of each individual EEM was sought. This was more complex than simply comparing total site energy usage before modification with total energy usage after installation of the EEMs. The methodology chosen was to use an energy simulation model for each site. Each building site uses the Department of Energy, DOE-2 building computer program. The agricultural irrigation pumping site required development of a comparable energy use simulation model. This model development was assigned to the CE.

The final evaluation phase of the project will require a base case model and a model of the site as modified with EEMs. Much of the site data monitoring is to calibrate these models against actual energy use to improve credibility of the results. The reported energy savings will be the energy use as simulated by the preconditions model less the energy use simulated by the model modified for the EEMs under typical weather and use. This will be disaggregate through the models to individual EEMs.

Demonstration Site Selection. The project decided to focus on deep well pumping for the agricultural irrigation demonstration because it is the most energy intense and predictable. Most low lift water from rivers and canals is allocated by government agencies. The other agricultural site selection characteristics desired included: growing a major California crop that is not rotated and is in a major California agricultural area.

The first agricultural demonstration site was chosen in 1990. The customer proposed replacing a planned sprinkler irrigation system with drip irrigation to save energy. Further investigation revealed that the principal reason the customer selected a drip irrigation system was that the poor quality of soil at the proposed site required it. Participation as a project demonstration site would substantially subsidize the installation cost of the drip system. This experience led the project to disallow any energy savings based on changed irrigation practices. The agricultural demonstration site manager looked for a customer who was satisfied with their existing agricultural management practices related to irrigation.

After reviewing data from several sites, the site manager choose a four year old, 288 acre (1,165,500 m^2) vineyard, near Gonzales in the Salinas Valley. The vineyard layout is shown in Figure 1. To mitigate afternoon wind chilling of the vines, it uses a grain cover crop and wind break tree. A single electrically driven pump delivers water either directly to the grape vines by above ground drip

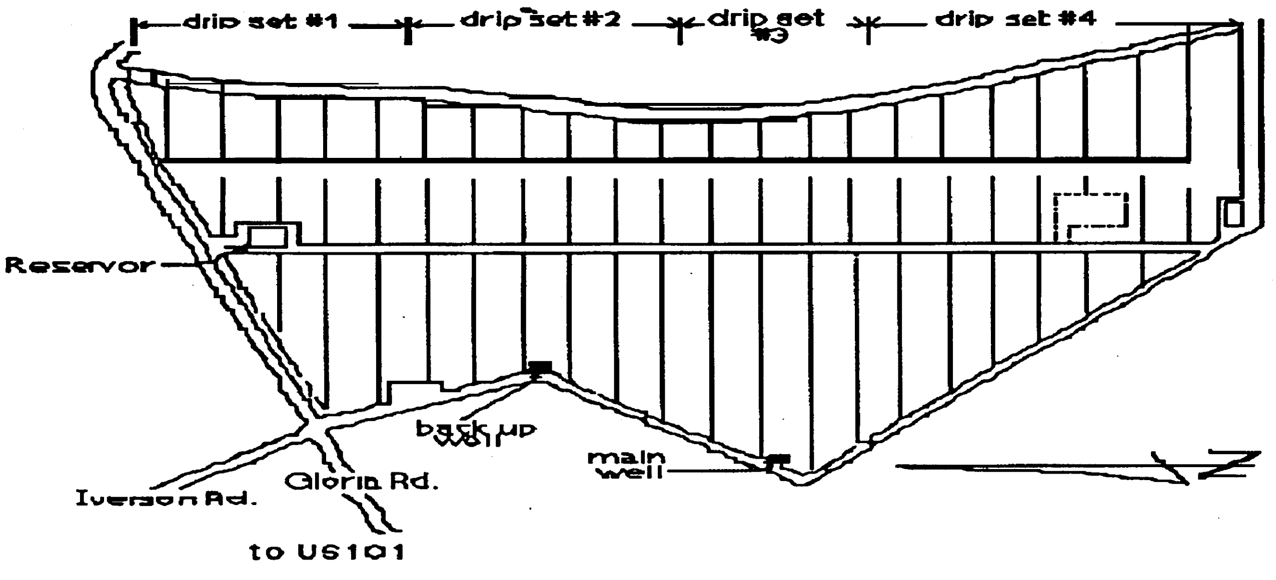


Figure 1. Gonzales Agricultural Demonstration Site Plan View

emitters or to a reservoir. Water from the reservoir is then either pumped to another vineyard or into a sprinkler system to irrigate the cover crop and wind break tree. A butterfly valve, near the pump discharge, allows selection between drip application and reservoir delivery. Figure 2 depicts this irrigation system.

Site Audit Results. The site manager, with the assistance of the selected CE, audited the site to determine the characteristics and conditions of the irrigation system. This included pulling the existing pump for inspection and video taping the well casing including the intake (perforation) section. The audit identified the pumping components shown in Table 1.

Before an agreement was executed, the customer advised the site manager that additional vineyard development was being planned that would be irrigated by this pump. Plans, however, were on hold because investment capital was scarce.

The utility offers “wire-to-water” overall pumping efficiency (OPE) testing, at no cost, to its agricultural customers. Almost ten years of these test reports showed the demonstration pump consistently operating near 51% efficiency.

While the motor was in the shop being inspected, a test of its field windings showed a very low impedance to ground. The customer elected to pay to have the field windings heated to drive off moisture and then revarnished. This type of repair carries no warrantee. The pump and motor were reinstalled in as close to the same condition as they were found. After about one week of pump operation, the motor field winding shorted out. This required returning the motor to the shop for complete rewinding at the customer’s expense.

During the site audit, a project sponsored by the California Institute of Energy Efficiency (CIEE) titled, “Field Determination of Agricultural Pumping Plant Electric Motor Efficiencies” was beginning (Soloman and Zoldoske 1994). It was triggered by a 1989 test report (Lobodovsky et al. 1989) of industrial motors that found many were operating 6% to 23% below their rated efficiencies due to poorly matched loads. Supplemental finding was provided to this project to obtain expedited efficiency data on thirty large (>75 hp/56 kW) deep well irrigation pump motors. This was used to determine whether the demonstration site pump motor efficiency was typical of those in the utility’s service territory. The draft report, by Solomon and Zoldoske, concluded that California’s large irrigation pumping motors operate within a few percentages of their rated efficiency, even after long periods of field use. The demonstration site pump motor was in fact typical, testing at 90.6% efficient after more than 20 years of field use.

Pumping Operations. The existing pumping system was capable of supplying almost 1600 gpm (5835 lpm) with a total head of 460 feet (140.2 m). Water delivery to the drip system was limited to 600 gpm (2200 lpm) by the

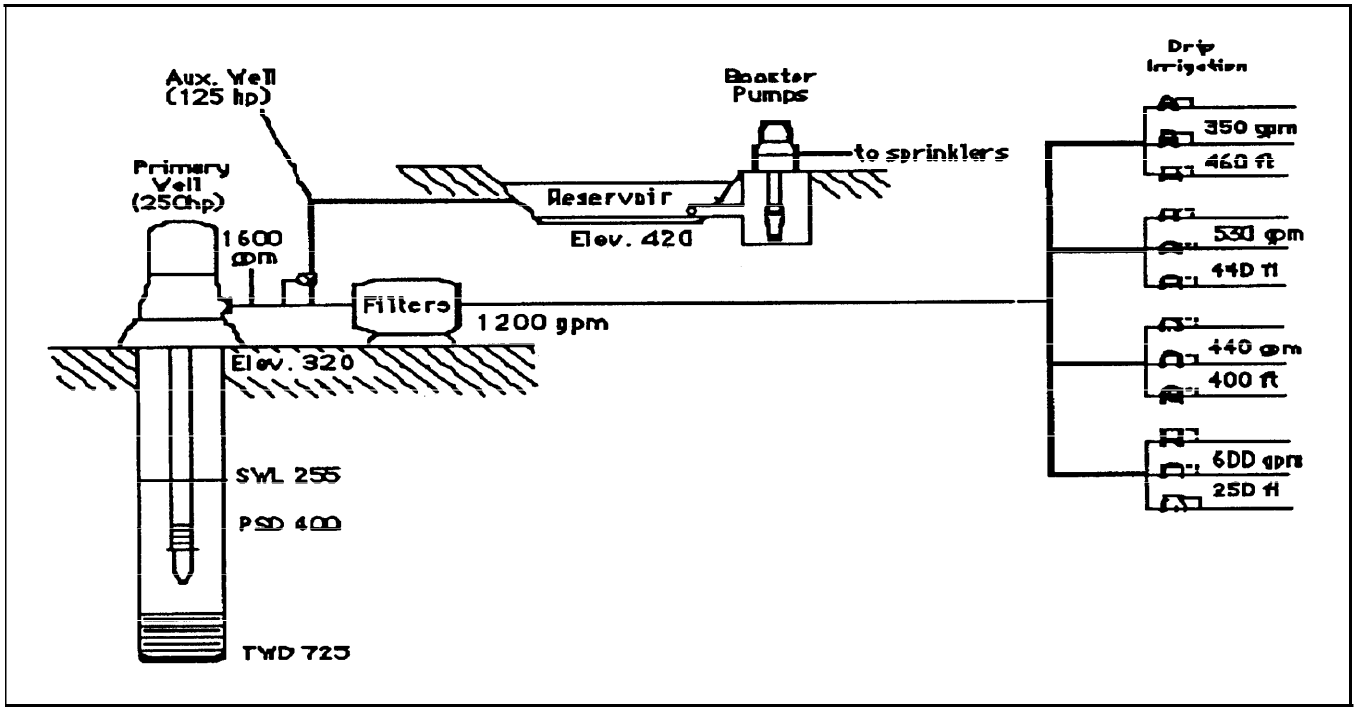
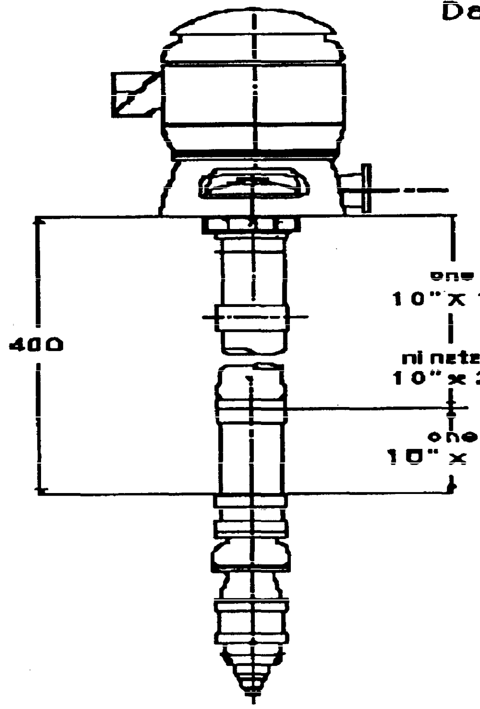


Figure 2. Water Supply and Distribution System Schematic

Table 1. Original Pumping Equipment

Date re-installed: February 24, 1994



MOTOR

Mfg'r U.S. , HP 250 , RPM 1800

PH 3 , CY 60 , YDll 460

Y H S , S/N CC1010398, Frame 1505PH

DISCHARGE HEAD

Mfg'r L & B , Type CL , Size 10"

PUMP

Mfg'r L & B , Type RXL , Size 14"

No. Stages 7 , Setting Depth 400 ft

Column Size 10" , Length

Tube Size 3 - 3/16 , TMD --

No. Spiders --

Head Tube Size -- , Length -- , THD --

Suction Length 10'. Size 10" . Strainer NO

Discharge Length -- , Size --

capacity of the drip filters. This required the grapevines to be irrigated in four sets. While the pump discharge piping was being modified, the customer increased filter capacity to 1200 gpm (4380 lpm) which now allows irrigation of the grape vines in two sets. This provides increased flexibility because the customer prefers to conduct all drip irrigation during daylight because leaks could go undetected after dark. The customer estimated that almost half of the pumped water went to the vineyard's drip irrigation system.

Monitoring

General. The project installs permanent sensors at each site to monitor the actual energy consumed by various system components and the conditions that influence energy use. These sensor signals are fed into a data logger where they are converted to fifteen minute average values and stored. These data are downloaded with a modem daily during the week and on Monday mornings for Friday through Sunday.

The agricultural demonstration site manager choose to focus on minimizing the energy consumed per quantity of water supplied by the pump rather than the more obvious parameter, OPE. This is because OPE accepts well drawdown as a given and assumes that all discharge pressure is useful. Drawdown is actually a function of the pumping flow rate, aquifer characteristics, and well design. Good pumping practice reduces drawdown which reduces the total lift needed and correspondingly the energy consumed. Also, increased discharge pressure often results from throttling to control flow rate. This was typical at the demonstration site before the drip filter capacity was doubled. The energy to produce discharge head is in the numerator of the OPE formula that means it is considered as productive.

Monitoring energy consumed per quantity of water delivered required only two data points: energy to the motor, in kWh, and a time integration of discharge flow rate, in feet per second. Energy is easily monitored but accurate measurement of flow rates over 1000 gpm (3650 lpm) requires reasonably undisturbed flow. This normally requires a straight section twenty times the pipe diameter in length or ten times the pipe diameter with straightening vanes. An examination of the existing pump discharge piping shown on Figure 3 revealed that this did not exist.

To rectify this, the pump discharge piping was modified as shown in Figure 4 at a cost of over $15,000 before monitoring began.

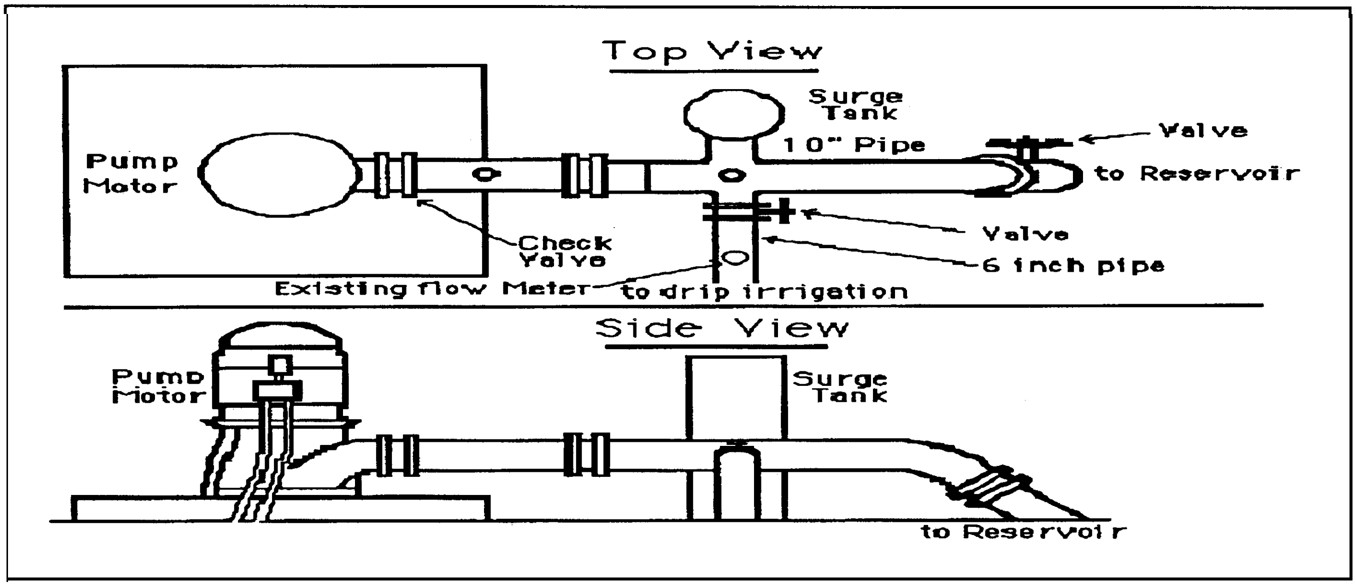


Figure 3. Existing Pump Discharge Piping

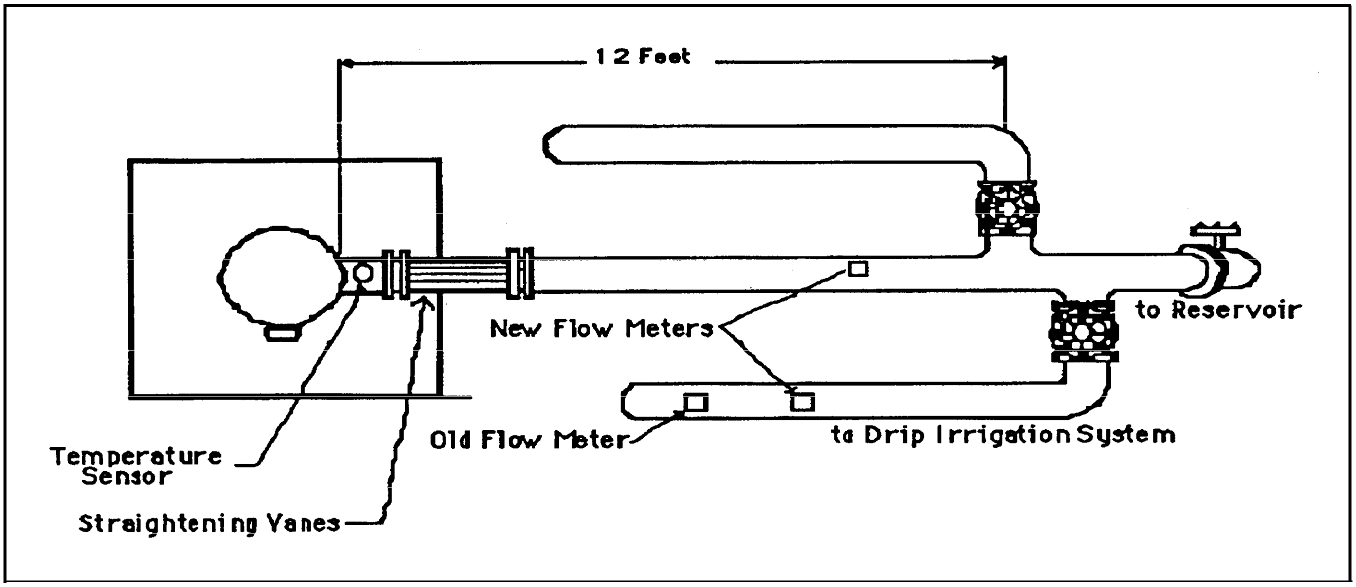


Figure 4. Modified Pump Discharge Piping

Precondition Data. No actual weather parameters are monitored at the Gonzales site. They do not factor directly into the pumping energy use model. However, a file of hourly weather data from two existing nearby weather stations is collected each month and stored with the other Gonzales site data.

Because the motor field windings were rewound, pump efficiency was re-tested. Surprisingly, the OPE now tested at 61%. This 10% improvement was much larger than what could be attributed to rewinding the motor. A review of the test data showed the measured flow rate had also increased almost 200 gpm (727 lpm) at a constant discharge pressure. This could only mean that the modification to the discharge piping to improve the accuracy of flow measurement had been justified. OPE apparently had previously been reported at near 51% because the flow rate had been under stated by about 15%. This was probably due to the proximity of the flow sensor to the 90 degree discharge bend and disturbance caused by the discharge check valve.

The CE evaluated early site data and concluded that the pumping system could best be characterized as functioning in one of four modes. The average fifteen-minute data records are sorted and aggregated by pumping mode in monthly data reports. Table 2 below shows these four pumping modes.

Mode 1 delivers the most water but mode 3 clearly has the highest OPE. Table 3 gives the total kilowatt-hours consumed for an acre-foot of water delivered in each mode and as a composite at the Gonzales site in June 1993. This clearly shows that OPE by itself is not the best measure of pumping energy efficiency.

This data showed that over three quarters of the pumped water was supplied to the reservoir. The site manager asked the customer about this discrepancy from the earlier estimate that half the water went to the reservoir. The customer replied that he had obtained the necessary venture capital and was installing the new vineyard. This new vineyard was the destination of the additional water going to the reservoir.

The relatively low composite kWh required per acre-foot is due entirely to the fact that pumping to the reservoir, using Mode 1, is the least energy intensive.

Energy Efficiency Measures (EEMs)

Design Process. The CE's work experience had been primarily on municipal and irrigation district pumps because there is very little market for engineering services to optimize agricultural pumping efficiency. One reason for the CE's selection was their existing spreadsheet simulation of pumping energy efficiency. The contract assigned the CE to convert this spreadsheet into a computer model of pumping energy efficiency. This tool was to facilitate analysis of the monitored site data and allowed evaluation and selection of proposed EEMs. The project requires that the mature market cost[2] of each installed EEM be less than the value of the energy saved.

The CE plans are to add a module to the computer simulation model that would allow the mathematical approximation of a pump curve to interact with other parameters so that dynamic shifts can be made in the pump's operating point.

The potential EEMs considered were:

1. Separate booster pump for the drip system
2. Variable Speed Drive (VSD) for the motor,
3. High efficiency pump bowls,
4. Smoothed impeller and bowl surfaces, add skirts,
5. High efficiency vertical hollowshaft motor,
6. 300% thrust bearing for the vertical shaft motor,
7. Low absorption motor casing color,
8. Increase column pipe diameter,
9. Coat column pipe
10. Smaller composite material drive shaft,
11. Ceramic surfaced spider bearings,
12. Drag reducing additives (DRA),
13. Replace reservoir/drip system selection valve,
14. Increase filter cross-sectional area,
15. Increase size of drip system distribution piping,
16. Increase power conductor size, and
17. Replace motor control center.

Selection of EEMs. Because of the difference in motor loading of the three operating modes, the use of a variable speed drive (VSD) or a dual well and booster pump motor combination were considered potentially attractive.

Table 2. Description of Pumping Modes

Mode	Water Use Characterized By	Flow Rate-gpm (lps)	Discharge Pressure-psi (kPa)	Water Depth-ft (meter)	Overall Pumping Eff. (%)
0	Pump off	0	0	250-260 (76-79)	NA
1	To reservoir	1450-1690 (5272-6145)	50-55 (345-379)	345-355 (105-108)	57-59
2	To lower drip set	1330-1450 (4836-5272)	70-104 (483-717)	335-345 (102-105)	60-61
3	To upper drip set	1100-1330 (4000=4836)	120-140 (827-965)	311-335 (95-102)	62-63

Table 3. June 1993 kWh per Acre-foot of Water Delivered

Mode 1:	delivered 78.56 acre feet of water using 63,972 kWh of electricity	= 814.3 kWh/AF
Mode 2:	delivered 5.72 acre feet of water using 5,181 kWh of electricity	= 905.8 kWh/AF
Mode 3:	delivered 12.2 acre feet of water using 12,434 kWh of electricity	= 1,019.2 kWh/AF
Composite:	delivered 96.48 acre feet of water using 81,586.7 kWh of electricity	= 845.6 kWh/AF

However, because the site data reports showed that over three-fourths of pumping energy was used in mode 1, the VSD application offered only marginal energy savings. This coupled with high initial capital costs and potentially high maintenance requirements eliminated VSD's from consideration. The dual pump option looked attractive because a smaller well pump would reduce flow and thus draw down. The booster pump would then provide the pressure needed by the drip system. This option was eliminated when monitored data showed that the irrigation peak demand required the existing motor to run continuously for up to six days. A comparison of the observed operating modes with modern high efficiency pump curves showed several could operate near peak efficiently for all three modes. As a result, the option chosen was to replace the twenty year old motor that operated at 90.6% efficiency with a new one that operates near 95% efficiency.

Since the new motor is rated the same as the one replaced, the nominal demand reduction is zero. However, since the old motor operated at 225 kW (300 hp), if the new motor operates near its rated level (250 hp/186.5 kW), demand may be reduce by 37.5 kW, or 17%.

The CE developed pumping energy simulation model showed that if the existing motor efficiency was 90.6% (per field tests) and the pump bowl efficiency was 80% (as predicted from the pump curve, see Figure 5), the OPE should be about 72%. Several tests, however, showed the actual OPE was nearer 60%. With this given, the model calculated that the pump bowl efficiency was near 67%. No other energy loss mechanism existed to account for this large a discrepancy. The site manager will have confirming factory efficiency tests conducted of the old motor and pump, after the new pumping system is commissioned, to verify the model. [Actual results of these tests will be available by the time of presentation.]

The CE modelled friction losses in the drip system distribution pipes to determine whether increasing their size would reduce energy loss. Actual pipe diameters and lengths were unknown but estimates were provided by the customer. Using this along with known flows and the discharge pressures, the CE was able to correlated the model with observed field conditions. The model showed that friction losses in the drip system were not large enough to justify pipe replacement. Even if this had been cost effective, the customer indicated that digging up the pipe running through the vineyard it would have been prohibitively disruptive.

The EEM to provide ceramic contact surfaces on the spider bearings were ruled out because they were considered too fragile for a deep well pumping operation. Similarly, composite material drive shafts, common for truck drive shafts were ruled out. No suppliers could be found for the 400 foot (122 m) length required.

The final approved package of EEMs included a high efficiency motor with a low absorption coating, new underfiled and slurry polished pump impellers, enameled pump bowls, a refurbished motor control center and larger power cables. In addition, a tank will be added to the low pressure (downstream) side of the drip filters to allow the injection of a drag reducing additives if a suitable one can be found. Details of EEM selection are shown on Table 4, EEM Energy Savings and Cost Effectiveness Table.

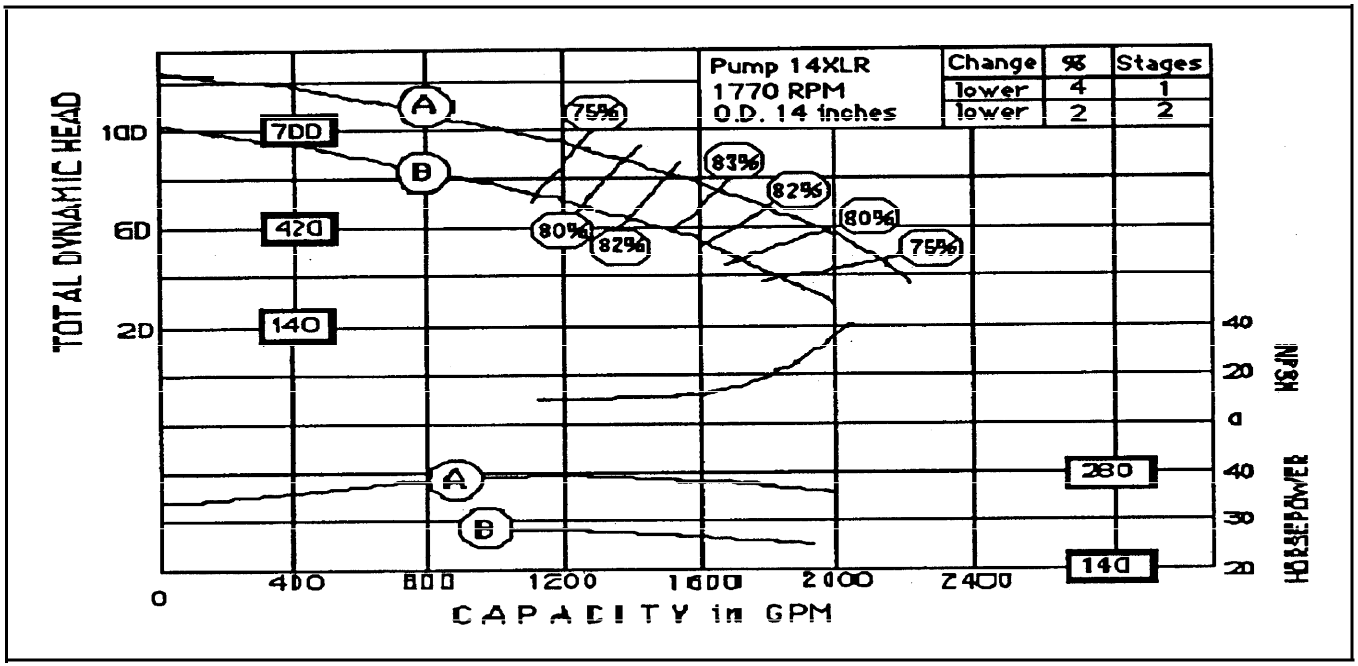


Figure 5. Original Pump Performance Curves

Table 4. EEM Energy Savings and Cost Effectiveness

EEM No.	Description of Energy Efficiency Measures	Overall Pump Eff. (%)	Total Installed Cost ($)	Total Energy Saved (kWh/yr)	Cost of Conserved Energy ($/kWh)	Annual Energy Used (kWh)
0	Base Case (1993 performance	58.6	0	0		434,000
3	Replace pump bowls (67% to 80% eff.)	69.3	15,000	67,000	0.222	367,000
4	Smooth impeller and bowl surfaces, add skirts	71.0	2,000	9,000	0.222	358,000
5,6,7	Replace electric motor (90% to 95+% eff.)	74.2	17,500	19,000	0.921	339,000
8	Replace inner column	74.3	15,000	2,400	6.250	rejected
12	Drag Reducing Additives[(a)]	74.7	1,200	9,500	0.126	329,500
17	Replace Motor Cntl Cntr and oversize wire	75.0	8,000	4,000	2.000	325,500

(a) Conditionally approved until specific additive is identified and evaluated.

Installation. It took two weeks to pull the deep well pump and install the new EEMs. This was scheduled to be completed before April so that normal seasonal irrigation could begin. To meet this deadline the pump supplier needed the motor delivered to their plant by mid-March 1994 so it could be tested with the pump bowls before sending them to the Gonzales site. Both components were delayed. Fortunately, significant rainfall during April 1994 delayed the need to start scheduled irrigation of the vineyard.

The motor control center (MCC) was replaced and new power cables installed the end of March since it did not interrupt irrigation pumping.

When the new pump and motor arrived the last week of April, the old pump was pulled and taken to the contractors shop for inspection. Installation of the new pump and motor was completed Saturday, April 30, 1994. No problems were encountered with the construction work. The CE witnessed shimming of the motor to assure alignment to the pump shaft.

Commissioning. The CE witnessed commissioning tests including: alignment of the pump drive shaft within the hollowshaft of the motor by shimming and filling with hydrophilic grout; tensioning of the shaft casing to prevent sagging; lateral adjustment of the shaft so that the pump impellers have the proper tolerance; motor vibration displacement test in accordance with the Hydraulic Institute; pump capacity head performance to verify the pump curve; and an overall pumping-plant efficiency test. The site manager witnessed the final tests conducted on Friday, May 6, 1994.

The efficiency results calculated while pumping to the reservoir were unbelievable. An OPE of 82% was calculated using the utility's independent measurements. This resulted from a 5% increase in flow concurrent with a 29% reduction in input power. The installed site sensors were disrupted during the installation work and had not been re-calibrated so no means to cross-check of the OPE calculation was available. [Actual performance data will be available by presentation time.]

Preliminary Results

Data from the site monitoring system will not be usable until the all the sensors are calibrated. This is scheduled for June 1, 1994. A formal report will be issued at the end of the first growing season in September 1994. One more growing season of monitoring with the customer fully in control is planned for 1995. A final site report will document how effective the EEMs were and how persistent these energy savings were without close utility control.

Impact Evaluation

The preconditions model of pumping energy use will be calibrated when the factory efficiency test results for the old motor and pump are received. After the first growing season of monitored pumping data is available with the EEMs installed, the energy use simulation model will be re-calibrated. The goal will be to match the energy use in kilowatt-hours per acre-foot of water used in each pumping mode within two percent.

The pumping model will then be used to determine the impact of energy use for each EEM.

Endnotes

1. The formula for Overall Pumping-plant Efficiency (OPE) is:

$$OPE\ (\%) = 100 \times \frac{Flow\ (gpm) \times Total\ Lift\ (feet)}{Input\ horsepower \times 3960}$$

2. Mature market cost is the mean price that a product would sell for if it became the popular technological solution to a common problem and no artificial restrictions limited competition between suppliers.

References

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