Deep Well Agricultural Pump Repair Evaluation Using Pre and Post Pump Efficiency Tests

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ABSTRACT

Pumping from deep wells can be a large portion of the operating cost of an agricultural business. A deep well pump repair increases the efficiency of the pumping system yielding energy and dollar savings. Utility DSM programs promote savings by offering information on, or incentives for, deep well pump repair. To assess the savings from these programs, a typical evaluation often uses engineering estimates of savings and/or billing data. However, in the agricultural sector, annual pump energy use is influenced by a myriad of factors that are difficult, if not impossible, to capture with an engineering, statistical, or combined approach. The most direct approach is to do field measurement of the pre-repair efficiency and the post-repair efficiency of the pumping system. This method is time consuming and expensive. However, after previous evaluations where an engineering and statistical methodology were used with some success, it was decided to use the more direct field measurement approach to generate estimates of gross savings. This paper presents the gross impact evaluation estimates for the pump repair portion of PG&E's 1996 and 1997 Agricultural Programs. These two evaluations are the first time that direct field measurements have been used in agricultural sector pumping evaluations within the state of California. The authors present evaluation results along with the pros and cons of using field measurements to assess pump repair energy savings. The information presented in this paper will be of interest for any energy efficiency pumping programs within the agricultural sector.

Introduction

The impact evaluation of agricultural demand-side management (DSM) is challenging due to the wide variation in the geologic, geographic, and climatic settings where the measures are implemented. Differences in soil conditions, accessibility to irrigation water, and potentially changing crops from year to year all contribute to variances in energy use. Many of these factors can even vary in the same setting across several years. All of this means that energy savings can be difficult to accurately evaluate.

This paper outlines the evaluation of an agricultural pump repair measure implemented through the Pacific Gas and Electric (PG&E) Energy Efficiency Incentives (EEI) Program. The PG&E EEI program is briefly discussed, the pump repair measure and pump tests are characterized, gross results for the pump repair measure of two impact evaluations are provided, and the pros and cons of the specific evaluation method of pre and post pump efficiency testing are discussed.

PG&E Agricultural Programs

Pacific Gas & Electric has offered agricultural measures in the EEI program for over 20 years. From 1994 through 1997, these measures (including pump repairs, pump adjustments, low-pressure sprinkler nozzles, micro irrigation conversion, and custom measures) have saved over 53,000 MWh of energy and 10 MW[1] in peak demand in their first year of implementation alone. PG&E has also offered free pump testing to their customers since the late 1920's. The pump testing program, offered through the PG&E Energy Management Services program, performs 4,000 to 5,000 pump tests each year throughout the utility service territory. The information gathered during the pump tests have been stored in the same relational database format since 1991, providing a wealth of pump test data.

Since 1994, PG&E has been required to evaluate the impacts of the EEI programs following a strict set of protocols. These protocols set evaluation criteria such as the minimum number of sample points required, the amount of pre- and post-implementation billing data required for a statistical analysis, and specifies the unit of measurement for the measure. The evaluations of the measures implemented by PG&E's agricultural customers have followed these protocols whenever possible, and received special dispensation when the protocols could not be followed. Since 1994, the four evaluations have addressed the difficulties inherent to an agricultural evaluation, with each year's evaluation learning from the previous year and attempting to improve upon the methodology used to estimate the gross impact.

Energy savings estimates from the pump repair measure varied across the four evaluation years from 43% to 79% of the total net energy impact for the end use, as shown in Figure 1. As such, although there were multiple measures in the end use, the pump repair measure (averaging 60% of the impact for the end use) was closely scrutinized each year to determine the most expeditious and accurate method possible for the gross impact estimate. The evaluations in 1994 and 1995 method used a statistically adjusted engineering approach. While the results were reasonable, it was recommended in the 1995 evaluation report that a different approach be used in the future. The 1996 and 1997 evaluations used an engineering approach with direct measurements of the efficiency of post-repaired pumps.

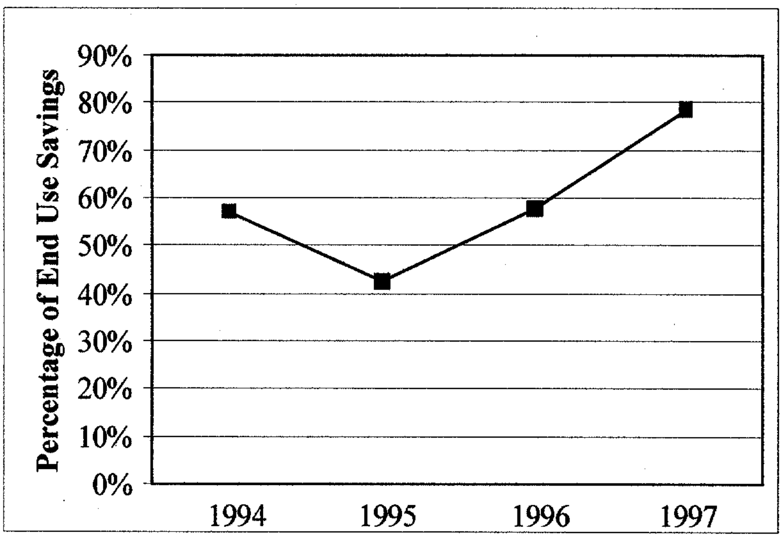

Figure 1. Pump Repair Savings Percentage of End Use

Pump Repairs

As a pump is used, sand and small rocks that are pulled through the system along with the water erode the metal of the bowls and impeller. In addition, bearing wear, corrosion, and possible deterioration due to cavitation, cause pump efficiency to drop over time. These phenomena cause a decrease in the output from the pump and a resultant decrease in the pump motor load. Simultaneously, the pump efficiency, flow-rate, and pressure drop. A pump repair most often refurbishes the bowl/impeller system to the original specifications. The repair of a pump differs from the replacement of

[1] This is the total first year evaluated net impacts for the program years 1994-97, pumping and related end use.

a pump. In a pump repair for a deep well turbine pump (often used in the agricultural sector and shown in Figure 2), the motor is removed from the top of the pump and the pump column is brought up to the surface. The bowl and impeller assemblies, located at the bottom of the pump column, are removed and taken to a shop where a machinist removes the scrapes and dents in the bowls caused by the sand and soil. Since there is generally more than one bowl/impeller assembly in a pump, the machinist smoothes these imperfections in each bowl. An impeller is installed that is either new or repaired in each newly smoothed bowl. The repaired bowl/impeller assemblies now have a closer fit and allow the pump to more efficiently create the pressure needed to lift the water to the surface and distribute it to the crops. This procedure is less expensive than a replacement since there is no cost to purchase the new bowls or impellers. When the pump system is brought back to the original specifications, the flow and pressure increases, as does the pump motor load. For example, a pump with an eroded bowl/impeller system may draw only 85% of the rated motor horsepower, while the same system after repair will most likely draw 110% of the rated horsepower, resulting in an increase in flow of perhaps 35%.

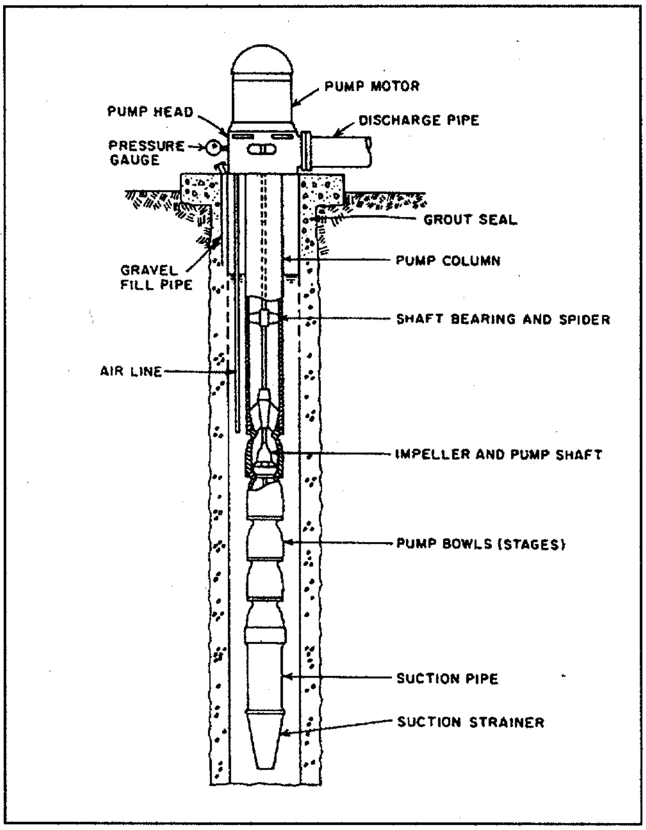

Figure 2 Deep-Well Turbine Pump (Hanson 1994)

The efficiency of the pumping plant can only be measured by a pump test. While a decrease in flow from the pump is an indicator that the pump is performing poorly, a pump test is necessary to assess the possible savings from repairing the bowl/impeller assembly.

Pump Tests

A pump test can be performed on a variety of pumps under many conditions. To perform the pump test, a hole is usually drilled in the pump discharge pipe. A pressure gauge provides the discharge pressure of the pump and the well water level is measured with a special plumb line. The discharge pressure added to the height the water is lifted (determined from the water level in the well) is the total pressure (total lift) produced by the pumping system. A Pitot tube type flowmeter is used to determine the flow rate in gallons per minute and the input kW of the pump motor is measured. The irrigation system is turned on and the values measured. There may be one or more tests at different system configurations (i.e., a single set of sprinklers may be turned on or multiple sets). All these inputs are used to determine the overall pumping plant efficiency (OPE) as shown in Figure 3.

$$OPE = \frac{(Flowrate)(TotalLift)}{(3960)(InputHorsepower)}$$

Figure 3. Overall Pumping Plant Efficiency Algorithm

As in the case of all measurement, certain conditions can occur in the field that can cause poor pump test results. The flow meter requires a laminar flow with little to no turbulence to properly measure flow. If the length of pipe available is short, turbulent flow results and can cause the test to be poor or invalid. Another common problem is that it is not always possible to measure the depth of the water in the well, thus making it impossible to accurately estimate total lift. Additionally, there are measurement errors in the pressure and power values. Because of these factors, an evaluation using pump tests should have the pump tester provide a estimate of accuracy of their measurements, if only on a simple scale such as good, fair, and poor.

The OPE of a pump can also depend on weather and season. In California, changes in the water table can occur seasonally. In the spring, the runoff from the mountains and the winter rains bring the water table higher than in the summer after no rain. Since the total lift of the pump motor varies by season, the OPE is also seasonally dependent. Therefore, a pump test performed on the same pump in the spring versus the fall would show a different efficiency.

The difficulties inherent with pump testing need to be acknowledged during an evaluation, and accommodated to the best degree possible. However, there is always a non-quantifiable level of uncertainty in the results of a pump test.

The PG&E pump test database has been a repository for the results of the 4,000 or more pump tests performed throughout the PG&E service territory each year. Many of the pump tests in the database are tests on the same pump over time. Growers often have PG&E come out on a regular basis to test their pumps. There is a variable in the database indicating if the test is routine, a new installation, or after a pump repair. This explanatory variable is crucial in the use of the database for evaluation purposes. If it is known that the test was done after a pump repair, the database can be searched for a test on the same pump at a previous date, thereby supplying pre- and post-repair OPEs.

Evaluation of the Pump Repair Measure – Methodology

The evaluation of the pump repair measure for the 1996 and 1997 agricultural (Ag) sector EEI program used an engineering approach based on field measurements in an effort to provide accurate findings. Additionally, these two program years saw a drop in pump repair participation that precluded a statistical approach. The number of pump repair measure applications (generally with one pump per application) rebated by the 1994 through 1997 PG&E Ag EEI program are shown in Table 1.

Table 1. Number of Pump Repair Rebates by Program Year

Program Year	Number of Pump Repair Applications Rebated
1994	807
1995	295
1996	67
1997	111

Both the energy and demand impacts of the pump repair measure were evaluated. The analysis of the energy impact for both the 1996 and 1997 program years consisted of determining the OPE of pumps pre- and post-repair and applying an OPE ratio to the annual kWh usage. The algorithm used to calculate the energy savings is shown in Figure 4.

$$\text{kWh Savings} = \text{Annual kWh} * \text{OPE Ratio}$$

$$\text{OPE Ratio} = \left(1 - \frac{\text{OPEpre}}{\text{OPEpost}}\right)$$

Figure 4. kWh Savings Algorithm

Essentially, there are two pieces of information required to estimate the impact algorithm to each pump repaired. First, the annual kWh must be known for only the specific pump repaired. Second, the pump type and horsepower must be known to properly apply the OPE ratio. The original assumption was that there was one pump per metered account. This turned out to be incorrect, especially for the district water pumps using axial pumps to move large amounts of water with a low pressure differential, but it was fairly accurate for irrigation pumps which formed the majority of the participant accounts.

Since the annual kWh of just the repaired pump was required, the evaluation disaggregated the billing data for multiple pump accounts based on the horsepower and run time of the pumps on the account. For example, some irrigation systems used both a deep well pump and a booster pump. The booster pump was accounted for by separating out the percentage of time that the booster pump ran (e.g., the deep well pump runs by itself 60% of the time, and together with the booster 40% of the time). The horsepower of the booster pump was determined during the on-site audit. The load factor of the pumps was assumed to be 1.0. The billing data was apportioned to the pump based upon the deep well horsepower, booster pump(s) horsepower, and the operating schedule determined while on site. Similarly, if the repaired pump was one of many on an account, horsepower and time-of-use data were collected to perform a similar disaggregation of the account's billing data and energy use to each pump.

The second piece of data required for the evaluation was the OPE ratio. The OPE ratio was obtained through pre- and post-repair pump tests of the same well. The potential savings from the repair of a pump can vary by pump type (i.e., turbine, centrifugal, axial) and pump size. There will always be pumps that cannot be tested for one reason or another. Therefore, to apply an average OPE ratio for these non-tested pumps, it is best to have robust data for a variety of pump types and sizes. This means that both the pre- and post-repair OPE must be known. While the 1996 and 1997 program evaluations performed pump tests on a census of pump repair sites to obtain a post-repair OPE, the pre-repair OPE was more difficult to determine.

The 1996 Ag EEI program did not require proof of poor efficiency prior to obtaining a rebate for the pump repair. Therefore, the evaluation team used the PG&E pump test database to find those pumps with rebates that also had a pre-repair pump test. Based on results from the 1996 program evaluation, the 1997 Ag EEI program did require pumps between 20 and 75 horsepower to show that the efficiency of the pump was less than 50% in order to qualify for the program. Therefore, for 1997, a pre-repair pump test was required in order to obtain a rebate for pumps in that range of horsepower. The evaluation team expected to have a greater percentage of pre/post repair OPE values during the evaluation of the 1997 program due to this restriction. Additionally, the 1997 program evaluation also analyzed six years of pump test data to obtain the most pre/post OPE results possible.

It was assumed there would be some degradation of pump efficiency over time; however, it was also assumed that the measurement error bounds around any determination of pump efficiency would encompass the original pump efficiency value. Therefore, the impact estimates were considered conservative and did not account for possible pump efficiency degradation within the impact measurement. The impact was the same as the change in efficiency.

The demand impact analysis compared the difference in motor load for the 1996 program evaluation and the kW input for the 1997 program evaluation. The pre- and post-repair motor load and kW values were determined from the same sources as the OPE. Both the 1996 and 1997 program evaluations determined if the standard deviation of the average difference between the pre- and post-repaired pump motor load or kW included zero. Additionally, the 1997 program evaluation compared the pre- and post-repair kW input using the statistical t-test. .

1996 Evaluation Results

During the 1996 program year evaluation, pump tests were done on both pump repair participants and nonparticipants. The plan was to use the nonparticipant test data as a baseline. There were 134 total pump tests performed for this evaluation (66 participants and 68 nonparticipants). It was known before going into the field that over 30% of the rebated pumps had pump tests in the PG&E pump test database. With this large percentage of the participant group planned to have both a pre- and post-repair test, the analysis plan appeared robust. Since the rebate application did not require the date of the pump repair, when in the field, the date of the pump test repair was gathered to the best of the auditors' ability. Unfortunately, over half of the expected pre/post repair test pairs turned out to have had the pump test performed <u>after</u> the pump repair, and were subsequently lost for analysis. Additionally, 35% of all the pump tests were lost due to poor tests (e.g., turbulent flow or inability to measure the depth of the water). The analysis plan required re-thinking in the middle of the evaluation. The final analysis was bolstered by using the most recent year of the PG&E pump test database and pulling out pre/post repair pump test pairs.

The revised analysis plan also included determining if the pump tests from the nonparticipants really could be used as a baseline. After the data was compiled and prior to any analysis of pre- and post-repair pump tests, the pump test data was compared between the participants and nonparticipants. The statistical t-test (one-tailed) was used to see if the differences between the two groups were significant at the 90% confidence level. The sample points were binned by pump type. (The sample was not big enough to provide more than 10 points when binned by both pump type and size.) Only the turbine pumps had enough points to use the t-test (20 nonparticipants and 16 participants). It did show a significant difference (t=2.108), with a participant OPE of 65.5% and a nonparticipant OPE of 57.7% (for a difference of 7.8%). When all pump types and sizes were taken together and compared, the OPE difference was 8.2% (with the participants having the higher average OPE), and indicated a significant difference at the 90% confidence level (t=2.129). However, after careful consideration, the evaluation team decided that the nonparticipants could not be used as a baseline for the analysis. A baseline is the efficiency that the customer would have gone to without the rebate, and the impact is the difference between that level of efficiency and the current efficiency with the rebate. In the case of a pump repair, the repair is either done or not, there is no efficiency level that represents a point with or without a rebate. The nonparticipant group was considered to be indicative of where the pump population efficiency may be, but not useful in determining the savings due to the repair. Therefore, the energy impact was based on the difference between the pre/post repair OPE values only.

The algorithm used to determine the energy impact for pump repair is shown in Figure 4. There were five participant pump repair sites with both a good pump test and pre-repair pump test data from the PG&E database. Of these, four were deep well turbine pumps and one was a submersible turbine. Since the evaluation could not rest on these few pre- and post-tests, the only other source of pre- and post-data was analyzed. Within the 1995/96 PG&E pump test database, the variable 'Pump Test Type' has multiple choices, two of which are 'routine' and 'after pump repair'. Tests which were made on the same pump and had both a 'routine' and 'after pump repair' designation were pulled from the database and analyzed. The tests were determined to be on the same pump based on the horsepower of the pump and the meter number. Only those pump tests with a 'routine' pump test prior to the 'after pump repair' test were kept.

The submersible and turbine OPEs were taken from the PG&E database for the three submersible and twenty-two turbine pump tests with both a pre- and post-repair. Additionally, three growers with good post-repair pump test data from the evaluation had had pump tests performed on the pumps by independent pump testers prior to the pump repair and they were able to find the results. Table 2 indicates the results of the 1996 analysis.

Table 2. 1996 Evaluation Pre- and Post-OPE

Type of Pump	Source of Data	Number of Points	Pre OPE	Post OPE	OPE Difference	OPE Ratio
Submersible	1996 Evaluation	1	0.54	0.64	0.100	0.16
Submersible	PG&E Database	3	0.34	0.40	0.064	0.15
Weighted Submersible	Both	4	0.39	0.46	0.073	0.16
Turbine	1996 Evaluation	1	0.47	0.65	0.185	0.28
Turbine	1996 Evaluation	1	0.29	0.61	0.319	0.52
Turbine	1996 Evaluation	1	0.47	0.56	0.095	0.17
Turbine	1996 Evaluation	1	0.26	0.63	0.371	0.59
Turbine	1996 Evaluation	1	0.60	0.67	0.069	0.10
Turbine	1996 Evaluation	1	0.61	0.70	0.085	0.12
Turbine	1996 Evaluation	1	0.57	0.60	0.033	0.05
Turbine	PG&E Database	22	0.54	0.60	0.061	0.10
Weighted Turbine	Both	29	0.52	0.61	0.086	0.14

Because there were so few rebated data points with a known pre- and post-repair OPE, the more conservative OPE ratio from the turbine pumps of 0.14 was used to determine the impact of all the pump repair measure in the 1996 program.

The demand analysis used the same pre- and post-pump repair sites as the energy analysis. The three sites with independent pump test information provided by the growers did not have the motor load value provided. Therefore, the pre- and post-motor loads were based on twenty-six turbine pumps.

The motor loads were only slightly greater post-repair than pre-repair. The 80% confidence interval around the average included zero. Because of this, the demand impact was set to zero for the evaluation.

1997 Evaluation Results

The 1997 evaluation incorporated the experience from the 1996 evaluation to create a more complete and robust evaluation. The 1997 evaluation approach minimized cost yet continued to provide credible impact results for this measure by using the PG&E pump test database to carefully select accounts for post-repair pump tests. Only if the pump repair measure had a PG&E pump test performed before the repair, as determined from the pump test database, program applications, and discussions with the grower, was a post-installation pump test performed during the on-site audit. Using the date that the incentive check was cut, the analysis of the pump test database identified 43 pump tests that appeared to meet those criteria. A census of these 43 pumps was recruited for pump tests, resulting in 33 completed, good tests. For all other pump repair sites, only energy use information was collected in order to properly disaggregate the billing information for application of the kWh saving algorithm shown in Figure 4.

The evaluation team collected post-repair OPE values from 33 pumps. These pumps had pre-repair OPE values already recorded in the PG&E pump test database or had a pre-repair test in the application. Although the 1997 program had required a pre-repair test from pumps in the 20-75 horsepower range, the evaluation included many 20-75 horsepower pumps that were paid in 1997, but actually applied under the 1996 program. Therefore, there were fewer than expected pre-repair tests based on the horsepower bin. Improving on the 1996 evaluation approach, the 1997 evaluation increased the number actual pre- and post-OPE values by analyzing the 1992-1997 PG&E pump test database to identify pumps with pre- and post-repair test results. Since there is a difference in the pre-to-post efficiency possible based on technology (e.g., turbine, centrifugal, or axial flow pump), this data was also analyzed by pump type. There was a large enough sample in the pump test database to separate the turbine pumps into two bins – 20-75 horsepower and over 75 horsepower. The pre- and post-OPE values for the PG&E pump test database analysis and the evaluation pump tests are shown in Table 3.

Table 3. 1997 Evaluation Pre- and Post-OPE

Data Source	N of Data	Pump Type	hp Bin*	Pre-OPE	Post-OPE	OPE Ratio
1997 Evaluation Pump Tests	7	Axial/Propeller	All	0.38	0.48	0.20
Review of 1992-1997 PG&E Pump Test Database	18			0.45	0.52	0.13
Weighted Average OPE for Axial/Propeller Pumps				**0.43**	**0.51**	**0.15**
1997 Evaluation Pump Tests	2	Centrifugal, Booster	All	0.05	0.25	0.80
Review of 1992-1997 PG&E Pump Test Database	1			0.69	0.74	0.06
Weighted Average OPE for Centrifugal Booster Pumps				**0.26**	**0.41**	**0.36**
1997 Evaluation Pump Tests	3	Submersible	All	0.38	0.47	0.18
Review of 1992-1997 PG&E Pump Test Database	17			0.43	0.53	0.19
Weighted Average OPE for Submersible Pumps				**0.42**	**0.52**	**0.19**
1997 Evaluation Pump Tests	15	Turbine, Well	1	0.38	0.58	0.34
Review of 1992-1997 PG&E Pump Test Database	162			0.52	0.60	0.13
Weighted Average OPE for Deep Well Turbine Pumps from 20-75 hp				**0.51**	**0.60**	**0.15**
1997 Evaluation Pump Tests	6	Turbine, Well	2	0.50	0.64	0.23
Review of 1992-1997 PG&E Pump Test Database	48			0.53	0.63	0.16
Weighted Average OPE for Deep Well Turbine Pumps from Over 75 hp				**0.52**	**0.63**	**0.17**

*1=20-75 hp, 2=Over 75 hp

Because of the use of the multiple years of the pump test database, there was sufficient data to apply the results by pump type, with the exception of centrifugal pumps. The average turbine pre- and post-efficiency for motors under 75 horsepower was applied to centrifugal pumps.

For the 31 pumps with known pre- and post-OPE values (33 evaluated pumps minus the 2 centrifugal pumps), the pump-specific pre- and post-repair OPE values were used to determine the impact. All other pumps (80) used the weighted average OPE ratio shown in Table 3 based on the pump type and horsepower. Therefore, the 1997 program evaluation not only had more data points for application of OPE ratio by pump type, but 28% of the pumps (31/111) had site specific OPE ratios applied. This was an improvement from the 1996 evaluation where all rebated pumps had the same OPE ratio applied regardless of pump type or size.

The kW difference pre- and post-repair was also analyzed using the 1992-1997 PG&E database information to determine if there were demand impacts. On average, there was an increase of 1.3 kW due to the pump repair. However, the standard deviation around that value was large and included zero. The pre- and post-repair kW values were further analyzed using a single-tailed t-test. At the 90% confidence level, there were no significant differences between the pre- and post-repair kW (t=0.001). Because of the results of both the standard deviation and the t-test, the demand impacts were set to zero for all the pump repair measures. This was consistent with the 1996 PG&E agricultural sector evaluation findings.

Pros and Cons of Pump Tests as an Evaluation Tool

The use of pump tests in an evaluation mean that measured field data is available for determination of savings. However, unless the evaluation can determine both the pre- and post-repair information from a pump, the results are of little use. Pump testing is a good way to get accurate data especially for small populations where a statistical evaluation would probably provide indeterminate results. A positive result of the pump test approach is that the results of the pump tests can be provided to the grower. As such, it is seen as a service by the utility to the customer.

On the negative side of the equation, one of the difficulties in using pump tests is the inability to test all pumps due to piping length or other factors. However, these pumps should be able to be rebated regardless of the configuration of the pump system because they are providing energy savings. The evaluation needs to account for these pumps. Additionally, the evaluation cost of performing pump tests is high compared to a billing analysis, and thus requires careful selection of the sites to be tested.

Recommendations for Use by Other Program Evaluations

The evaluation approach used here will only work if both a pre- and post-repair pump test is available and in sufficient quantity to be meaningful when applied as an average to pumps without pre/post data. Any program providing rebates for a pump repair should require a pre-repair pump test where it is technically feasible. The test should be performed by a qualified pump tester and a level of the accuracy of the results should be provided (i.e., good versus poor test conditions). When coupled with a pre-repair pump test, a post-repair pump test as part of the program would provide the best impact estimates.

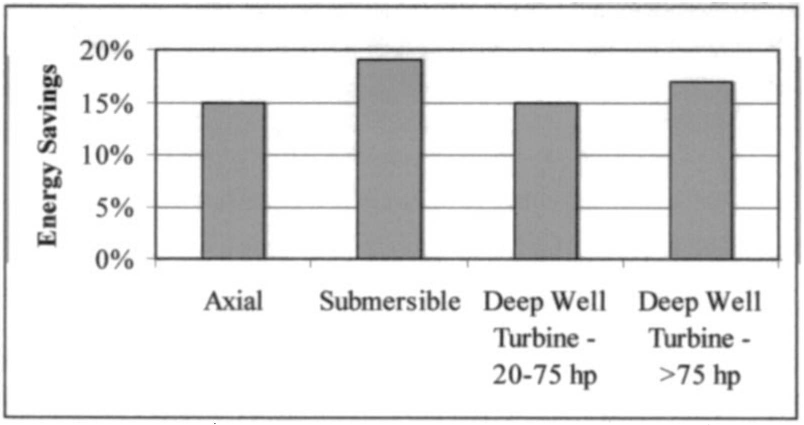

Figure 5. Potential Energy Savings Percentage

The results of these evaluations confirm the engineering estimate that the pump repair measure does not result in a decrease in electrical demand. However, as shown in Figure 5, potential energy savings will be around 15% of the annual use.

If there is no source of pre/post information comparable to the PG&E pump test database, the evaluation team should be prepared to provide results based on a limited number of data points if they use this type of evaluation tool. If there is a comparable source of information, all possible data to should be pooled to obtain the most robust set of pre/post repair data.

The database tracking the program should require that specific fields, such as measure implementation date, pump type, and horsepower of the pump, be filled in for all participants. This would help in the use of pump tests done outside of the evaluation and in applying average efficiencies for all participants.

This paper presented the methodology and results of the most recent PG&E evaluations of the agricultural measure of a pump repair. By providing this information, it was hoped that other utilities program designers and evaluators, when approaching the offering or evaluation of this measure, could have an idea of the type of energy and demand savings possible from a pump repair.

References

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