Appendix C

Klamath CAPP Private Pumps Field Testing Technical Memorandum

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RH2 TECHNICAL

Memorandum

Client: CDM Smith

Project: Klamath CAPP Engineering Support Services

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Subject: **Klamath CAPP Private Pumps Field Testing**

Date: May 7, 2015

Executive Summary

This study evaluates the efficiency and energy consumption of the pumping equipment in the Klamath Basin's private irrigation systems. The Klamath Water and Power Authority (KWAPA) issued surveys to each of the basin's private pump owners to determine pump and motor properties and irrigation characteristics. Of the approximately 2,500 pumps in the Klamath Basin owned by 355 private pump owners, KWAPA received responses for approximately 150 pumps and motors which are owned by 45 private pump owners (approximately a 13 percent response rate). The information received was evaluated and filtered by RH2 Engineering, Inc., (RH2) to identify a representative sample of 15 facilities for field testing.

This study was conducted by:

1) Performing field pump tests at 15 representative facilities (21 pumps tested in total), based on the age, motor size, and irrigation schedule of the facilities;
2) Determining the energy signatures for the pumps and motors;

3) Analyzing the system in order to recommend:
    a. Improved pump sequencing to minimize the energy consumed with the existing equipment.
    b. Replacement equipment at facilities with inefficient equipment.
    c. Improved irrigation management practices.
4) Estimating the energy consumption and projected energy savings for the remaining private pumps and motors.

Based on the findings of the representative facilities, the average wire-to-water efficiency of the field-tested equipment is 60 percent. However, if the three pumps and motors with potentially artificially high wire-to-water efficiencies (Facility 2 – Pump 1, Facility 10 – Pump 2, and Facility 15 – Pump 1) are not considered, the average wire-to-water efficiency of the remaining 18 pumps and motors is 54 percent (with 86 percent of all tested equipment having wire-to-water efficiencies between 24 and 76 percent).

A summary of the estimated energy consumption at each field-tested facility, and the estimated annual energy savings, is shown in **Table ES-1**. The results of these analyses indicate that nine of the 21 field-tested pumps and motors are recommended for replacement. If these nine pumps and motors are replaced, the annual energy consumption of the field-tested facilities can be reduced by 14.7 percent, which is equivalent to 100,480 kilowatt-hours (kWh) and an annual energy cost savings of $9,043.

Table ES-1
Energy Consumption and Savings Summary with New Equipment

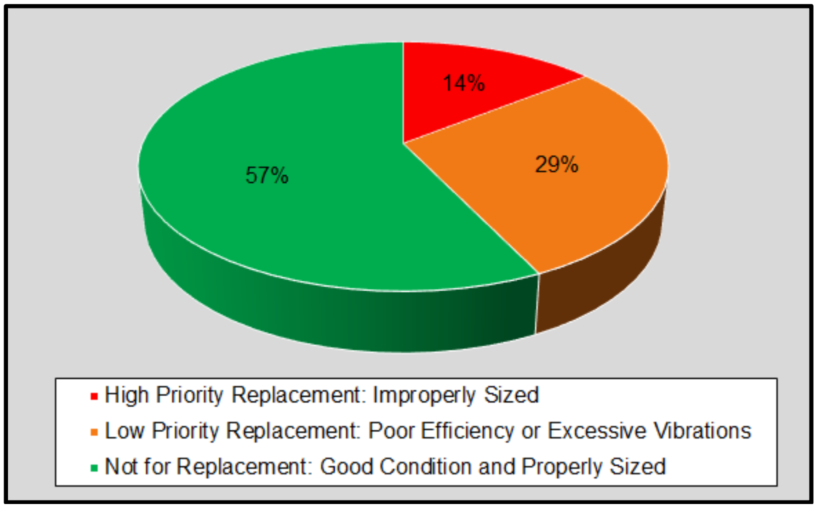
Facility	Facility Name	Annual Energy Consumption (kWh)		Estimated Annual Energy Savings (kWh)
		Existing Equipment and Sequences	New Equipment and Sequences	
Facility 1	**BPS - Pump 1**	**111,800**	**89,440**	**22,360**
	BPS - Pump 2	33,850	16,925	16,925
Facility 2	Submersible Well Pump	10,071	10,071	0
Facility 3	Surface Pump	75,197	70,475	4,722
Facility 4	**Submersible Well Pump**	**23,331**	**9,685**	**13,646**
Facility 5	**Surface Pump**	**46,224**	**30,862**	**15,362**
Facility 6	**Submersible Well Pump**	**101,808**	**87,216**	**14,592**
	Surface Pump	**38,808**	**22,971**	**15,837**
Facility 7	Surface Pump - 1	35,672	35,672	0
	Surface Pump - 2	33,573	33,573	0
	Vertical Turbine Well Pump	82,979	82,979	0
Facility 8	**Vertical Turbine Well**	**33,998**	**24,778**	**9,221**
Facility 9	Vertical Turbine Well	56,678	46,504	10,175
Facility 10	Hot Well Pump 1	47,053	82,344	-35,290
	Hot Well Pump 2	81,789	40,895	40,895
Facility 11	**Surface Pumps**	**69,627**	**62,167**	**7,460**
Facility 12	**Surface Pumps**	**5,026**	**4,306**	**720**
Facility 13	**Surface Pumps**	**3,477**	**2,196**	**1,281**
Facility 14	Surface Pump - 1	48,911	41,046	7,865
	Surface Pump - 2	47,774	41,046	6,728
Facility 15	Surface Pump	51,349	51,349	0
Totals (All Pumps)		**1,038,996**	**886,499**	**152,498**
Totals (Pump Recommended for Replacement)		**434,100**	**333,620**	**100,480**

BPS = booster pump station
NOTES:

- Pumps shown in **bold** text are recommended for replacement.
- Components may not sum to totals due to rounding.

Based on the results of these analyses, which comprise a representative sample of the private on-Project and off-Project private pumps and motors in the Klamath Basin, 43 percent of the private pumps and motors are recommended for replacement. Approximately 14 percent of the private pumps and motors are improperly sized for their existing pumping application, and have significant vibration amplitude concerns and are a high priority for replacement. For the pumps and motors tested, 29 percent were classified as low-priority replacements, either based on poor wire-to-water efficiency or excessive vibration amplitudes, as shown in **Chart ES-1**. Extrapolating the field-tested facility energy reduction of 14.7 percent to the 2,500 pumps in the Klamath Basin, 11.9 gigawatt-hours (11,900,000 kWh) of annual energy savings could be realized if 43 percent of the pumps and motors Basin-wide are in need of replacement, resulting in approximately $1,000,000 of annual energy cost savings.

Chart ES-1
Private Pump Improvement Recommendations



Due to data collection inaccuracies, conservative estimates for total dynamic head and flow were estimated based on known parameters and pump owner knowledge[1]. It is expected that the minimum annual energy savings is 12 percent (on average for all private pumps and motors), and may be as high as 30 percent (on average) if the high and low priority equipment is replaced. The remaining 57 percent of private pumps and motors are believed to be in generally good condition and are properly sized for their existing pumping application.

Variable frequency drives (VFDs) are not recommended for installation on most of the private pumps and motors. Only 14 percent of the field-tested equipment is improperly sized for their existing pumping application, and the equipment at each of these facilities has significant vibration amplitude concerns that are unlikely to be resolved with installation of a VFD. Replacing the existing pump and motor with properly sized equipment will result in significant energy savings (on a percentage basis) at these facilities. The remaining 86 percent of pumps and motors are believed to be properly sized and operate at or near the pump design point during peak irrigation season.

Installation of a VFD on improperly sized equipment will result in minimal energy savings that will only be realized during periods of low irrigation water supply. Of the 2,500 pumps in the Klamath Basin, it is estimated that less than 5 percent of the pumps have operating conditions during normal water years that would benefit from installation of a VFD.

[1] Suction and/or discharge head was not measureable for all pumps, and existing flow meters or exposed piping for a strap-on flow meter did not exist at all pumping facilities. Conservative estimates for total dynamic head and flow were estimated at these locations based on known parameters and pump owner knowledge.

Overview of Existing System

The United States Bureau of Reclamation's (Reclamation) Klamath Project provides irrigation water to approximately 210,000 acres in the Klamath Basin, which includes areas in Klamath County, Oregon, and Siskiyou and Modoc Counties in California. The Klamath Project is supplied with water from Upper Klamath Lake, Clear Lake Reservoir, and Gerber Reservoir. Water is distributed throughout the Klamath Project via the Lost River, Miller Creek, and numerous canals throughout the Klamath Basin. There are more than 350 private pump owners located both on the Klamath Project and off the Klamath Project (on-Project and off-Project, respectively), many of whom own and operate multiple pumps to convey surface or groundwater to private property for irrigation.

Introduction

This technical memorandum evaluates pump and motor efficiency and power consumption for 21 private pumps and motors within the Klamath Basin. KWAPA issued surveys to each of the Basin's private pump owners to determine pump and motor properties and irrigation characteristics. KWAPA received responses for approximately 150 pumps and motors, which are owned by 45 private pump owners (approximately a 13 percent response rate). Many private pump owners did not respond to KWAPA's request for information, leaving the study without information regarding approximately 310 private pump owners, who own an estimated 2,350 pumps and motors.

Reclamation and KWAPA provided the private pump owner responses to RH2. RH2 reviewed and incorporated the responses into a database to determine basic private pump characteristics such as age, motor size, and irrigation schedules. RH2 identified 21 pumps that potentially make up a representative sample of the approximately 2,500 private pumps using methodology similar to that used for the Reserved and Transferred Works pumps in RH2's May 20, 2014, *Klamath CAPP Recommended Testing Facilities* technical memorandum. The methodology was based on the following criteria.

- Test pumping plants that have not been tested as part of previous studies by Energy Trust of Oregon or Pacific Power.
- Test pumping plants in both Oregon and California for both geographic diversity and to recognize the difference in tariff rates between Oregon and California.
- Test a diversity of pumping plants that have a variety of motor sizes, flow rates, total dynamic head conditions, physical condition, type of service (irrigation or drainage), and facility age.

The field testing results from the 21 representative pumps was used to estimate total possible energy efficiency improvements for all private pumps. The pumps tested as part of this project are summarized in **Table 1**. **Charts 1** and **2** show the age and motor size of the field-tested equipment and other information requested as part of the survey. As can be seen from **Charts 1** and **2**, the tested pumps generally reflect the overall distribution of pump age and pump size for all Basin pumps.

Table 1
Field-tested Private Pumps

Facility	Facility Name	Pump No.	Rated Pump Capacity (gpm)	Motor Horsepower (hp)	Existing Variable Frequency Drive?	Installation Year
Facility 1	BPS	1	3,100	75	No	Unknown
		2	5,000	125	Yes	2011
Facility 2	Submersible Well Pump	1	450	30	No	1996/2012
Facility 3	Surface Pump	1	ND	30	No	2011
Facility 4	Surface Pump	1	500	25	No	1960s
Facility 5	Submersible Well Pump	1	700	40	No	2004
Facility 6	Submersible Well Pump	1	800	40	No	2007
	Surface Pump	1	ND	40	No	2004
Facility 7	Surface Pump	1	4,000	100	No	2004
		2	5,000	125	Yes	2004
	Vertical Turbine Well Pump	1	ND	150	Yes	2003
Facility 8	Vertical Turbine Well	1	1,000	75	No	1993
Facility 9	Vertical Turbine Well	1	1,000	60	No	2001
Facility 10	Hot Well 1	1	950	50	No	1975
	Hot Well 2	1	1,600	30	No	1985
Facility 11	Surface Pump	1	1,250	100	Yes	1985
Facility 12	Surface Pump	1	ND	20	No	2003
Facility 13	Surface Pump	1	1,700	15	No	2005
Facility 14	Surface Pumps	1	ND	50	No	2002
		2	ND	50	No	2002
Facility 15	Surface Pump	1	1,200	60	No	1980

gpm = gallons per minute
hp = horsepower
BPS = booster pump station
ND = no data

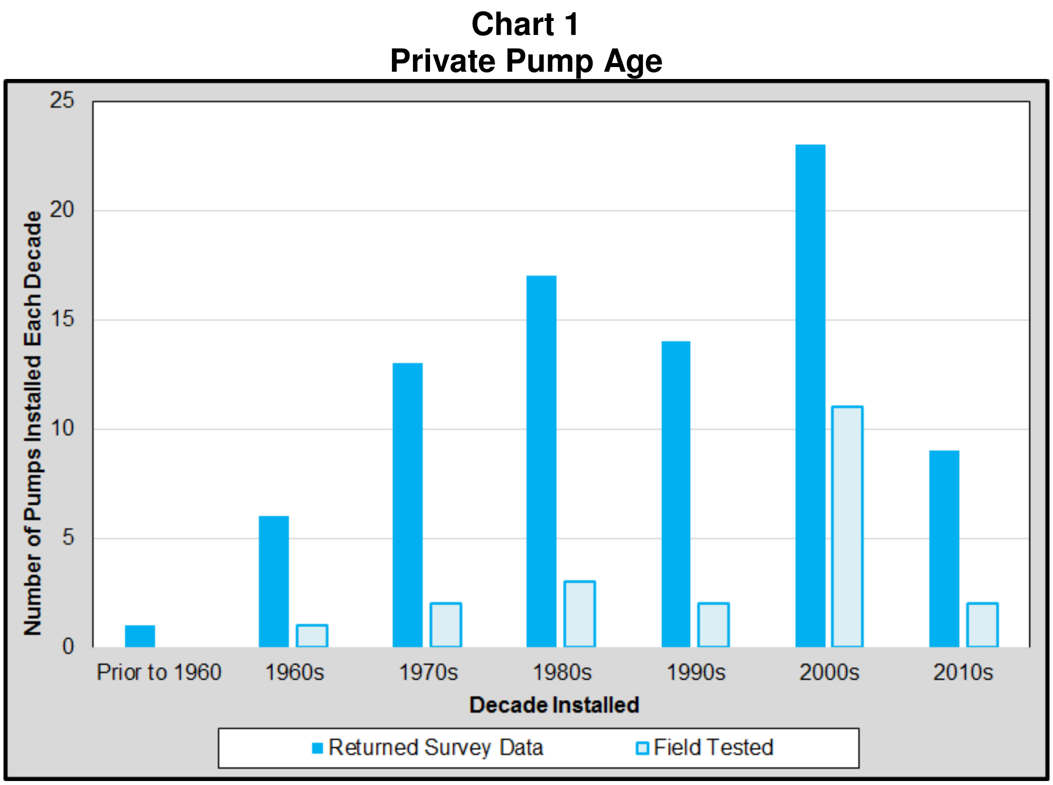


Chart 1
Private Pump Age
Number of Pumps Installed Each Decade
0
5
10
15
20
25
Prior to 1960
1960s
1970s
1980s
1990s
2000s
2010s
Decade Installed
Returned Survey Data
Field Tested

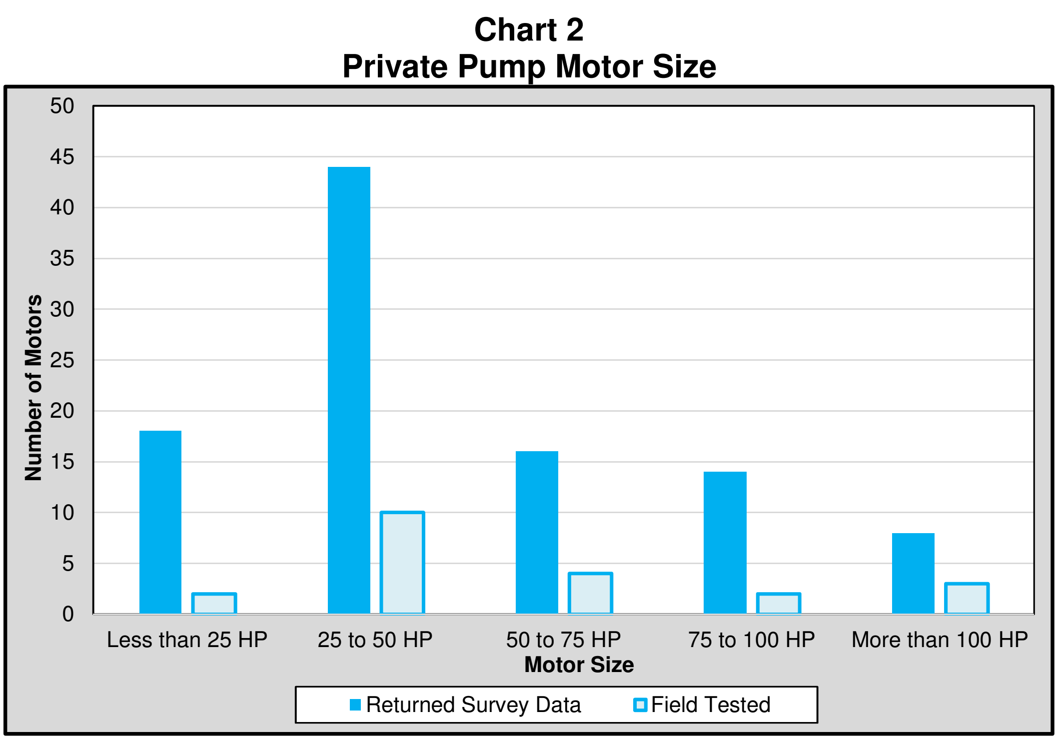


Chart 2
Private Pump Motor Size
Number of Motors
0
5
10
15
20
25
30
35
40
45
50
Less than 25 HP
25 to 50 HP
50 to 75 HP
75 to 100 HP
More than 100 HP
Motor Size
Returned Survey Data
Field Tested

Data Collection

Mechanical and electrical data were collected for 19 pumps and motors owned by 8 different entities between October 6, 2014, and October 8, 2014. Data from the Facility 1 BPS that was collected on June 5, 2014, is included in **Table 1** because the facility is considered an off-Project facility. Therefore, 21 pumps and motors were tested as part of this project. The field data collected are included as **Attachment A**.

For pumps and motors with VFDs, data were collected with the pump and motor operating at three different speeds within the normal operating range of the equipment. For pumps and motors with a valve downstream of the pump, data was collected with both the valve fully open and partially closed to determine the pump and motor characteristics at various flow rates and total dynamic head (TDH) conditions.

Mechanical Data

The mechanical data collected for each pump included the pump manufacturer, model number, suction and discharge hydraulic elevations, and flow meter readings during pumping. For well pumps, the static and pumping depths to the groundwater level were recorded using well sounding equipment. Suction and discharge hydraulic elevations were measured with a Trimble GeoExplorer XH6000 global positioning system. If piping was located immediately upstream or downstream of the pump, the head losses between the water level and the pump were estimated and considered as part of the TDH calculations for each pump. Suction and/or discharge head was not able to be measured for all pumps. TDH was estimated at these locations based on known parameters and pump owner knowledge.

Flow readings were measured by existing meters located within the pump stations or by a strap-on Fuji Portaflow-C ultrasonic flow meter. Existing flow meters or exposed piping for the strap-on flow meter did not exist at all pumping facilities. Flows were estimated at these locations based on pump curves or pump owner knowledge.

Electrical Data

The electrical data collected for each motor included the motor manufacturer, model number, and rated motor size. A power and energy analyzer was connected to the testing motor's electrical cabinet by an electrician from Pacific Electrical Contractors, Incorporated, and the following measurements were recorded: pump power consumption; voltage on all phases; motor current; and the supply power factor.

Vibration Data

Pump vibration data were collected for each of the pumps and motors at the same time as the mechanical and electrical data. A vibration data collector was connected to each pump and motor to measure the total and average (root mean square) velocity of the vibrations.

A vibration spectral analysis was also performed on each pump and motor. The vibration spectra were evaluated to determine specific characteristics that indicate the current condition for the pumps and motors. For the purposes of this technical memorandum, RH2 identified the average vibration amplitude (or magnitude) and compared it with the International Organization for Standardization (ISO) standard 10816, which is reproduced as **Table 2**. The

ISO standard is more stringent than the Hydraulic Institute standard for vibration, and is used in this technical memorandum to determine the acceptability of vibrations in each pump and motor. The vibration data and a summary of the results are included in **Attachment B**.

Table 2
ISO Standard 10816, Mechanical Vibration

<table>
<tr><th colspan="2" rowspan="2">ISO 10816</th><th colspan="2">Machinery
Groups 2 and 4</th><th colspan="2">Machinery
Groups 1 and 3</th></tr>
<tr><th colspan="4">Rated Power</th></tr>
<tr><th colspan="2">Velocity</th><th colspan="2">Group 2: 20 HP - 400 HP Motors
(16 kW - 300 kW)
6.2" ≤ H ≤ 12"</th><th colspan="2">Group 1: 400 HP - 67,000 HP Motors
(300 kW - 50 MW)
12" ≤ H</th></tr>
<tr><th>in/sec peak</th><th>mm/s rms</th><th colspan="2">Group 4 : Pumps ≥ 20 HP (15 kW)
Integrated Driver</th><th colspan="2">Group 3: Pumps ≥ 20 HP (15 kW)
External Driver</th></tr>
<tr><td>0.61</td><td>11.0</td><td rowspan="3"></td><td colspan="2" rowspan="2">Damage Occurs</td><td></td></tr>
<tr><td>0.39</td><td>7.1</td><td></td></tr>
<tr><td>0.25</td><td>4.5</td><td colspan="2">Restricted Operation</td><td rowspan="3"></td></tr>
<tr><td>0.19</td><td>3.5</td><td rowspan="2"></td><td colspan="2" rowspan="3">Unrestricted Operation</td></tr>
<tr><td>0.16</td><td>2.8</td></tr>
<tr><td>0.13</td><td>2.3</td><td rowspan="2"></td><td rowspan="4"></td></tr>
<tr><td>0.08</td><td>1.4</td><td colspan="2" rowspan="3">Newly Commissioned Pumps</td></tr>
<tr><td>0.04</td><td>0.7</td><td rowspan="2"></td></tr>
<tr><td>0</td><td>0</td></tr>
<tr><th colspan="2">Foundation</th><th>Rigid</th><th>Flexible</th><th>Rigid</th><th>Flexible</th></tr>
</table>

kW = kilowatts
H = shaft height
in/sec = inches per second
mm/sec = millimeters per second

Data Analysis

Energy signature, wire-to-water efficiency, estimated energy consumption, and vibration results are summarized in the following sections for each tested pump. The measured energy signature in kilowatt-hours per million gallons (kWh/MG) for each pump was calculated using the mechanical and electrical data collected in the field. The measured energy signature is a function of the measured flow rate and the measured power. Lower energy signatures require less energy to pump a given volume of water, and are therefore preferable to higher energy signatures.

Wire-to-water efficiency is a metric that identifies the efficiency of the entire pump and motor system, including the pump efficiency, motor efficiency, and VFD efficiency (when applicable). Wire-to-water efficiency for newly installed pumps and motors operating at their design points can be as high as 80 percent.

Irrigable acreage data were obtained from the pump owners to estimate the energy consumption of each pump. The estimated values (not actual power bills) were used as the baseline to determine the potential energy savings described in the following sections. Pumps typically operate at different points on their pump curve when multiple pumps are operated simultaneously at a facility, thus consuming varying amounts of energy compared to just a single pump operating at a facility. The energy signature of each pump with varying pump combinations operating at a facility with multiple pumps was not evaluated. Therefore, the actual energy signatures of the equipment at facilities with multiple pumps may differ slightly from those presented in this evaluation. Depending on the operating points and best efficiency points of the pumps, the energy signatures of the equipment at facilities with multiple pumps may be better or worse than presented in this evaluation.

<u>Irrigation Management Practices</u>

The irrigable acreage and irrigation practices were described by each facility owner during the field testing. The irrigation rates provided by each facility owner ranges from 0.8 to 9.7 acre-feet per year per acre (AFY/ac) for the field-tested facilities, with a weighted average of 2.8 AFY/ac. The weighted average considered the irrigable acreage supplied by each facility, (i.e., irrigation rates provided by owners with larger irrigable acreage contributed more than those with smaller irrigable acreage). The irrigation rate of 9.7 AFY/ac appears to be an outlier, as the second highest irrigation rate of the field tested facilities is 5.4 AFY/ac. Similarly, the 0.8 AFY/ac irrigation rate is based on the owner typically performing flood irrigation, thereby decreasing the irrigation water needed for the property.

Analyzed differently, the weighted average of the irrigation rates based on a total irrigable area of 2,637 acres that are supplied by the field-tested facilities is 2.8 AFY/ac. Compared to the evapotranspiration data presented in Table 4-3 of the April 2012 *Irrigation and Water Requirements/Demands for the On-Project Plan Area: Technical Memorandum 3* (OPP TM3), the irrigation rate of the field tested facilities is between the low and average (2.7 and 3.1 AFY/ac, respectively) irrigation rates expected in the Klamath Basin for similar crops.

Although the average and weighted average irrigation rates of the field-tested facilities are within an acceptable range, there are some facilities that appear to be irrigating excessively. Four of the 21 field-tested pumps are providing more than 4.0 AFY/ac, with a weighted average irrigation rate of 5.4 AFY/ac. If these facilities reduced the irrigation duration and frequency to 3.3 to 4.0 AFY/ac, (considered high irrigation rates based on Table 4-3 in the OPP TM3), the annual energy consumption at these facilities could decrease by 25 to 38 percent. This correlates with an annual energy consumption reduction of 1 to 2 percent for all private pumping facilities in the Klamath Basin with improved irrigation management practices, based on the weighted average irrigation rate of the field-tested facilities decreasing to 2.74 to 2.77 AFY/ac.

Facility 1 BPS

Background

The Facility 1 BPS pumps water out of the Lost River and into a canal, typically between May and October. Pump 2 has a VFD and is the lead pump. The VFD allows the system to supply customers during low demand periods by matching the supply flow rate with the customers' demands. As demands increase, the operators can turn on Pump 1 and use Pump 2's VFD to meet demands. The existing sequences for the Facility 1 BPS pumps are shown in **Table 3**.

Table 3
Existing Facility 1 Pump Sequence and Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)
Pumps on as needed to fill canal, typically at least 1 pump on 24 hours per day.	Facility 1 BPS - 2 @ 60 Hz	5,000	52	57%	287
	Facility 1 BPS - 2 @ 55.8 Hz	4,650	52	66%	249
	Facility 1 BPS - 1	2,445	53	36%	462

Hz = Hertz

Vibration Analysis

Pump 1 has vibration levels in the yellow "unrestricted operation" section of the ISO standard (see **Table 2**). This pump may continue to be operated normally. Pump 2 has vibration levels in the orange "restricted operation" section of the ISO standard.

Existing Equipment Assessment

The wire-to-water efficiency of Pump 1 is significantly lower than expected and is likely a result of the pump being significantly undersized for the application. The rated TDH of the pump is 42 feet, but the TDH measured during field testing was 53 feet. It is likely that the significant difference in rated and field-measured TDH is causing increased vibrations and wear in the equipment.

The wire-to-water efficiency of Pump 2 is slightly lower than expected based on the pumping application and age of the equipment, however the vibration levels and characteristics are significantly worse than anticipated. It is likely that the vibrations are causing a decrease in wire-to-water efficiency that will continue to worsen as the equipment ages.

Existing Equipment Energy Analysis

Pump run time data were not immediately available for the Facility 1 BPS, but the existing pump sequence is the most efficient pump sequence, and no energy savings are anticipated at this facility based on the existing equipment and pump sequence. Based on an estimate of

1,300 annual pumping hours for Pump 2 and 500 annual pumping hours for Pump 1, the existing annual energy consumption is estimated to be 145,650 kWh.

New Equipment Energy Analysis

If new pumps and motors with the same capacity are installed to replace the existing equipment, the wire-to-water efficiency of the equipment would be approximately 75 percent and the energy signature of the equipment would be approximately 230 kWh/MG, which represents an improvement of approximately 50 percent for Pump 1 and approximately 20 percent for Pump 2. If new pumps and motors with the same capacity are installed to replace the existing equipment, the estimated annual energy consumption is estimated to be 106,365 kWh, which represents a 39,285 kWh savings (27.0 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing system is $13,109. The estimated annual energy cost can be reduced to $9,573 if new (more efficient) equipment with the same capacity as the existing equipment is installed. The results of the estimated annual energy cost calculations are shown in **Table 4**.

Table 4
Summary of Facility 1 BPS Energy and Cost Savings

Description	Existing System	Existing System with Resequencing	New Equipment (Same Capacity)
Annual kWh	145,650 kWh	145,650 kWh	106,365 kWh
Annual kWh Savings[1]	---	0 kWh	39,285 kWh
Energy Cost ($/kWh)	$0.09	$0.09	$0.09
Annual Energy Cost	$13,109	$13,109	$9,573
Annual Energy Cost Savings[1]	---	$0	$3,536

(1) Compared to the existing system.

<u>Facility 2 – Well Pump</u>

Background

The Facility 2 well has a submersible 450 gallon per minute (gpm) pump and 30 HP motor that pumps groundwater into sprinkler lines that are used to irrigate a combined 18 acres of pasture and alfalfa fields, typically between May and October. The owner has the ability to open and close sprinkler lines as needed to meet the irrigation needs of the system. These needs typically require operating the pump for 10 hours per day for 4 or 5 days, and then keeping the pump off for 10 days.

Vibration Analysis

A vibration analysis was not performed because the well has a submersible pump and motor, making it impossible to connect the vibration monitoring equipment to the pump or motor.

Existing Equipment Assessment

A new pump and motor were installed in 2012, but the new motor continually caused blown breakers in the electrical panel. The original motor, which was originally installed in 1996, was reinstalled with the new pump and this configuration has remained in place since 2012. Three sprinkler lines were open during field testing, which reduced the pumping flowrate to 335 gpm and increased discharge pressure to 88 pounds per square inch (psi). The measured wire-to-water efficiency of the well pump is higher than expected, likely due to the pump providing less flow and more TDH than the design point of the pump. The results of the analyses indicate that the efficiency of the pump and motor would still be high had testing occurred during irrigation season with the pump operating at (or closer to) the design point. Similarly, the energy signature of the pump and motor would improve (decrease) during normal system operations with the pump operating at (or closer to) the design point. A summary of the existing equipment assessment results is shown in **Table 5**.

Table 5
Facility 2 Well Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on 10 hours per day for 4 to 5 days, then off for 10 days. Repeat.	Submersible Well Pump	335	282	88%	1,000	22.4	10,071

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 10,071 kWh based on 5 months of pump operation each year.

New Equipment Energy Analysis

No energy savings are anticipated for the Facility 2 submersible well pump and motor with new equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.13 per kWh, the estimated annual energy cost for the existing well pump is $1,309, and additional savings are not anticipated through reoperation or with new equipment. The results of the estimated annual energy cost calculations are shown in **Table 6**.

Table 6
Summary of Facility 2 Well Pump Energy Cost

Description	Existing System
Annual kWh	10,071 kWh
Energy Cost ($/kWh)	$0.13
Annual Energy Cost	$1,309

NOTE: $0.13/kWh used for California pumps and motors, compared to $0.09/kWh for Oregon pumps and motors.

Facility 3 – Surface Water Pump

Background

The Facility 3 surface water pump is powered by a 30 HP motor that pumps surface water from a canal into hand and wheel lines that are used to irrigate a combined 80 acres of pasture and oat/alfalfa fields, typically between May and October. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system. These needs typically were assumed to require operating the pump non-stop for 14 days, then keeping the pump off for 14 days.

Vibration Analysis

The pump is vibrating in the orange "restricted operation" section of the ISO standard and the motor is vibrating in the yellow "unrestricted operation" section of the ISO standard.

Existing Equipment Assessment

A valve downstream of the pump discharge was throttled during testing, allowing three sets of data to be collected for this pump. Discharge pressure readings were not available for this pump, but the owner indicated that pressures in the hand line range from 20 to 70 psi. Based on this information, the calculations that follow assume a discharge pressure of 45 psi, and that the additional headloss introduced by the throttling valve has a linear relationship with the reduction in flow for each of the two throttled data sets. The measured wire-to-water efficiency of the pump is good based on the valve being in the fully open position, but the wire-to-water efficiency could decrease significantly if the discharge pressure of the system during testing was less than 45 psi. A summary of the existing equipment assessment results is shown in **Table 7**.

Table 7
Facility 3 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on 14 hours per day for 14 days, then off for 14 days. Repeat.	Surface Pump - Fully Open	675	109	66%	521	22.4	75,197
	Surface Pump - Minimal Throttling	650	105	48%	690		
	Surface Pump - Additional Throttling	425	173	64%	851		

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 75,197 kWh based on 5 months of pump operation each year.

Because there is only one pump to supply the system, no energy savings are anticipated at this facility based on the existing equipment and pump sequence.

New Equipment Energy Analysis

If a new pump and motor with the same capacity (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to at least 70,475 kWh. This decrease represents a 4,722 kWh savings (6.3 percent) compared to the existing pumping equipment. If the discharge pressure during testing was less than 45 psi, the energy savings with new equipment would improve.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $6,768. With a new pump and motor, the annual energy cost can be decreased by at least $425 (to $6,343), and, as previously described, the cost savings would increase if the discharge pressure during testing was less than 45 psi. The results of the estimated annual energy cost calculations are shown in **Table 8**.

Table 8
Summary of Facility 3 Surface Water Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	75,197 kWh	70,475 kWh
Annual kWh Savings	---	4,722 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$6,768	$6,343
Annual Energy Cost Savings	---	$425

Facility 4 – Surface Water Pump

Background

The Facility 4 surface water pump has a rated capacity of 500 gpm and is powered by a 25 HP motor. The pump conveys surface water from a canal into hand and wheel lines that are used to irrigate 25 acres of organic grass, clover, and alfalfa fields, typically between May and October. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system. These needs typically require operating the pump non-stop for five to six days, then keeping the pump off for approximately two weeks.

Vibration Analysis

The pump is vibrating in the orange "restricted operation" section of the ISO standard and the motor is vibrating in the green "newly commissioned machinery" section of the ISO standard.

Existing Equipment Assessment

A valve downstream of the pump discharge was throttled during testing, allowing three sets of data to be collected for this pump. Discharge pressure readings were not available for this pump, but the owner indicated that pressures in the wheel line are approximately 60 psi. It was also assumed that additional headloss introduced by the throttling valve has a linear relationship with the reduction in flow for each of the three throttled data sets. The measured wire-to-water efficiency of the pump is very poor based on the valve being in the fully open position, but the wire-to-water efficiency could increase slightly if the discharge pressure of the system during testing was more than 60 psi. A summary of the existing equipment assessment results is shown in **Table 9**.

Table 9
Facility 4 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on for 5 to 6 days every 2.5 weeks.	Surface Pump - Fully Open	220	142	29%	1,530	20.2	23,331
	Surface Pump - Minimal Throttling	186	168	31%	1,723		
	Surface Pump - Additional Throttling	161	194	32%	1,876		

The results of the field testing and the pump operation characteristics described by the owner indicate that the pump is providing flows that are significantly less than the rated capacity of the pump. The owner indicated that the typical pumped flowrate is 224 to 336 gpm, but the pump is rated for 500 gpm. The field-measured flowrate without throttling was 220 gpm. A pump with a rated capacity of 224 to 336 gpm should be considered when a replacement pump is needed. A smaller motor should also be considered, as a 15 or 20 HP motor will be sufficient to provide 224 or 336 gpm to the system while providing TDH equal to that of the existing pump.

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 23,331 kWh based on 5 months of pump operation each year.

New Equipment Energy Analysis

If a new 350 gpm pump and 20 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 9,685 kWh. This decrease represents a 13,646 kWh savings (58.4 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $2,100. With a new pump and motor, the annual energy cost is estimated to decrease by $1,228 (to $872). The results of the estimated annual energy cost calculations are shown in **Table 10**.

Table 10
Summary of Facility 4 Surface Water Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	23,331 kWh	9,685 kWh
Annual kWh Savings	---	13,646 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$2,100	$872
Annual Energy Cost Savings	---	$1,228

<u>Facility 5 – Well Pump</u>

Background

The Facility 5 well has a submersible 700 gpm pump and 40 HP motor that pumps groundwater into sprinkler and hand lines that are used to irrigate a combined 20 acres of pasture, hay and grass fields, typically between May and October. The owner has the ability to open and close sprinkler lines as needed to meet the irrigation needs of the system. These needs typically require operating the pump for 24 hours per day for 6 days, and then keeping the pump off for approximately 10 days. The system can also be irrigated with water from a ditch that can be boosted from the ditch into the Facility 5 system with a 500 gpm, 20 HP pump and motor. This surface water booster pump is the owner's preferred pump to supply the system, but recent dry years have made supply to this pump unreliable. Supply to this pump was not available during field testing and therefore it was not tested.

Vibration Analysis

A vibration analysis was not performed because the well has a submersible pump and motor, making it impossible to connect the vibration monitoring equipment to the pump or motor.

Existing Equipment Assessment

Although the existing submersible well pump is rated for 700 gpm, only 250 to 300 gpm is required to meet the peak irrigation needs of the system. The pump typically provides discharge pressures that exceed 150 psi, and the owner throttles a valve downstream of the pump discharge to reduce pressures to 65 to 75 psi. This valve was throttled during field testing, allowing two sets of data to be collected for this pump. The measured wire-to-water efficiency of the pump is poor based on the system configuration during field testing. A summary of the existing equipment assessment results is shown in **Table 11**. A field test with the system fully open could not be completed due to the minimal irrigation needs during field testing.

Table 11
Facility 5 Well Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on 24 hours per day for 6 days, then off for approximately 10 days. Repeat.	Submersible Well Pump - Partial Throttling	210	427	53%	2,548	32.1	46,224
	Submersible Well Pump - Additional Throttling	150	437	44%	3,144		

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 46,224 kWh based on 5 months of pump operation each year, and without supplemental water from the surface water booster pump. Typically, the owner will utilize the surface water booster pump to supply the system during portions of the irrigation season when the ditch has sufficient water, which likely reduces the energy required to supply the system.

New Equipment Energy Analysis

If a new 300 gpm pump and 25 HP motor (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption for the submersible well pump is estimated to decrease to 30,862 kWh based on no supplemental supply from the surface water booster pump. This decrease represents a 15,362 kWh savings (33.2 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $4,160. With a new pump and motor, the annual energy cost is estimated to decrease by $1,383 (to $2,778). The results of the estimated annual energy cost calculations is shown in **Table 12**.

Table 12
Summary of Facility 5 Well Pump Energy Cost

Description	Existing System	Future System with New Equipment
Annual kWh	46,224 kWh	30,862 kWh
Annual kWh Savings	---	15,362 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$4,160	$2,778
Annual Energy Cost Savings	---	$1,383

Facility 6 – Well and Surface Pumps

Background

The Facility 6 well has a submersible 800 gpm pump and motor that pumps groundwater into sprinkler lines that are used to irrigate a combined 126 acres of pasture, grain, and alfalfa fields, typically between May and October. The owner also flood irrigates the pasture and fields, and can open and close sprinkler lines as needed to meet the irrigation needs of the system. Water from the submersible well pump can be boosted by an adjacent surface water booster pump when extra pressure is needed during peak irrigation. During typical years, water is available in a ditch adjacent to the surface water booster pump and the owner can pump the surface water to meet the irrigation needs of the system without needing to operate the submersible well pump. Operational characteristics of the system vary on an annual basis depending on the acreage that is flood irrigated and the quantity of water in the ditch.

Vibration Analysis

A vibration analysis was not performed on the submersible well pump and motor because the vibration monitoring equipment could not be connected to the pump or motor. Vibration data was collected for the surface water booster pump, which revealed that the pump and motor are both vibrating in the red "damage occurs" section of the ISO standard.

Existing Equipment Assessment

Although the existing submersible well pump is rated for 800 gpm, the pump is limited to approximately 450 gpm during peak irrigation season due to drawdown in the well. Valves downstream of the pumps were throttled during field testing, allowing three sets of data to be collected for each pump. The valve between the well and surface water pump was fully open during field testing of the surface water booster pump. The measured wire-to-water efficiency of both pumps is poor based on the system configuration during field testing. A summary of the existing equipment assessment results is shown in **Table 13**.

Table 13
Facility 6 Well and Surface Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Used if limited or no KID water in ditch.	Submersible Well Pump - Fully Open	400	194.852	48%	1,263	30	101,808
	Submersible Well Pump - Minimal Throttling	330	238.376	49%	1,523		
	Submersible Well Pump - Additional Throttling	220	296.893	44%	2,106		
Pumps from KID to irrigate at various intervals via gravity or sprinklers.	Surface Pump - Fully Open	440	115.47	41%	875	23	38,808
	Surface Pump - Minimal Throttling	440	145.474	50%	920		
	Surface Pump - Additional Throttling	400	177.775	54%	1,029		

Existing Equipment Energy Analysis

Due to the varying nature of the system operation, the following assumptions were made to estimate the pump's annual energy consumption shown in **Table 13**. The well pump was assumed to operate 24 hours per day for 1 week, every other week. The surface water booster pump was assumed to operate half the time that the well pump is operating. Both pumps were assumed to operate for five months each year. Based on these operation characteristics, the estimated annual energy consumption for both pumps is 140,616 kWh, and the breakdown of estimated annual energy consumption for each pump is shown in **Table 13**. Actual annual energy consumption is likely less than this during typical years due to supplemental surface water being provided.

New Equipment Energy Analysis

If a new 450 gpm submersible well pump and 40 HP motor (and an assumed 70 percent wire-to-water efficiency) is installed to replace the existing well equipment, the annual energy consumption is estimated to decrease to 87,216 kWh, which represents a 14.3 percent (14,592 kWh) savings. If a new surface water booster pump with the same capacity (and an assumed 70 percent wire-to-water efficiency) were to replace the existing equipment, the annual energy consumption is estimated to decrease to 22,971 kWh, which represents a 40.8 percent (15,837 kWh) savings. The decreases in energy consumption assume there is no supplemental supply.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of \$0.09 per kWh, the estimated annual energy cost for the existing well pump is \$9,163 and is \$3,493 for the surface water pump. With new equipment, the annual energy cost is estimated to decrease by \$1,313 to \$7,849 for the well pump and by \$1,425 to \$2,067 for the surface water pump. The results of the estimated annual energy cost calculations are shown in **Table 14**.

Table 14
Summary of Facility 6 Well and Surface Pump Energy Cost

Description	Existing System	Future System with New Equipment
Submersible Well Pump		
Annual kWh	101,808 kWh	87,216 kWh
Annual kWh Savings	---	14,592 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$9,163	$7,849
Annual Energy Cost Savings	---	$1,313
Surface Water Booster Pump		
Annual kWh	38,808 kWh	22,971 kWh
Annual kWh Savings	---	15,837 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$3,493	$2,067
Annual Energy Cost Savings	---	$1,425

<u>Facility 7 – Well and Two Surface Pumps</u>

Background

Facility 7's two vertical turbine surface water pumps convey water from the B Canal to a private canal at a higher elevation that provides the primary supply of irrigation water for 1,300 acres of alfalfa and grass fields. A vertical turbine well pump supplements the surface water, pumping water directly into the private canal as needed to meet the irrigation demands of the system. The surface water pumps typically operate 24 hours per day during peak irrigation season. The well pump and one surface water pump are equipped with VFDs to allow the owner to supply the canal during low demand periods by matching the supply flow rate with the irrigation demands.

Vibration Analysis

The Surface Pump 1 pump and motor are vibrating in the yellow "unrestricted operation" section of the ISO standard and the Surface Pump 2 pump and motor are vibrating in the green "newly commissioned machinery" section of the ISO standard. The well pump is vibrating in the yellow "unrestricted operation" section of the ISO standard and the well motor is vibrating in the green "newly commissioned machinery" section of the ISO standard.

Existing Equipment Assessment

The wire-to-water efficiency of the two surface pumps and motors is good (at or above 70 percent) based on the results of the field testing. This energy signature is likely due to the pumps being only 10 years old and properly sized for the pumping application, and having a roof to protect the equipment from weathering.

The well pump and motor also have a good energy signature based on an estimated TDH of 129 feet when operating at 60 Hz. Suction head was not able to be measured in the field due to the owner's well sounder being stuck in the well column, and discharge pressure was not able to be measured because the owner's pressure gauge was broken and standard fittings could not be used to connect the testing pressure gauge to the discharge pipe. The owner indicated that the well's static water depth was 42 feet. RH2 estimated the pumping water depth to be 60 feet and the discharge pressure to be 30 psi, resulting in a TDH of 129 feet when head losses are considered. A summary of the existing equipment assessment results is shown in **Table 15**.

Table 15
Facility 7 Well and Surface Pumps Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Convey water from KID's B Canal to private canal. During peak irrigation, pumps operate day and night non-stop.	Surface Pump - 1	4,000	42	70%	186	45	35,672
	Surface Pump - 2 @ 60 Hz	4,700	42	75%	178	50	33,573
	Surface Pump - 2 @ 55 Hz	4,000	42	76%	173	41	
	Surface Pump - 2 @ 50 Hz	3,100	41	70%	185	34	
Supplements supply from surface pumps as needed for irrigation needs.	Vertical Turbine Well @ 60 Hz	4,000	129	76%	537	129	82,979
	Vertical Turbine Well @ 55 Hz	3,600	124	81%	479	104	
	Vertical Turbine Well @ 50 Hz	3,100	119	88%	423	79	

Existing Equipment Energy Analysis

Due to the varying nature of the system operation, the following assumptions were made to estimate the pump's annual energy consumption shown in **Table 15**. Each pump was assumed to operate 16 hours per day, with 5 days off each month. The two pumps with VFDs were assumed to operate at varying speeds between 50 and 60 Hz. All three pumps were assumed to operate for five months each year. Based on these operation characteristics, the estimated annual energy consumption for both pumps is 152,224 kWh, and the breakdown of estimated annual energy consumption for each pump is shown in **Table 15**. Actual annual energy consumption will vary based on the quantity of water available in the B Canal.

New Equipment Energy Analysis

No energy savings are anticipated for Facility 7's well or surface pumps through reoperation or with new equipment due to the better-than-expected wire-to-water efficiency of the existing equipment. The well pump and motor have a significantly worse energy signature than the surface water pumps, and therefore it should continue to be used only on an as-needed basis to supplement supply from the B Canal.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the pumping equipment is as follows.

- Surface water pump without a VFD: $3,210
- Surface water pump with VFD: $3,022
- Well pump: $7,468.

Additional savings are not anticipated through reoperation or with new equipment, other than continuing to limit use of the well pump to only when needed to supplement the surface water. The results of the estimated annual energy cost calculations are shown in **Table 16**.

Table 16
Summary of Facility 7 Well and Surface Pumps Energy Cost

Description	Existing System
Surface Water Pump - 1 (No VFD)	
Annual kWh	35,672 kWh
Energy Cost ($/kWh)	$0.09
Annual Energy Cost	$3,210
Surface Water Pump - 2 (With VFD)	
Annual kWh	33,573 kWh
Energy Cost ($/kWh)	$0.09
Annual Energy Cost	$3,022
Well Pump (With VFD)	
Annual kWh	82,979 kWh
Energy Cost ($/kWh)	$0.09
Annual Energy Cost	$7,468

<u>Facility 8 – Well Pump</u>

Background

The Facility 8 well, located adjacent to an irrigation ditch, is a vertical turbine pump with a rated capacity of 1,000 gpm and is powered by a 75 HP motor. The well provides supplemental water as needed to irrigate 58 acres of pasture and alfalfa fields. Depending on the irrigation system demands and quantity of water available in the irrigation ditch, the well is used as much as 30 percent of the time during the irrigation season. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system.

Vibration Analysis

The pump is vibrating in the yellow "unrestricted operation" section of the ISO standard and the motor is vibrating in the orange "restricted operation" section of the ISO standard.

Existing Equipment Assessment

The existing system does not have a valve downstream of the pump discharge for throttling and suction and discharge pressure readings were not available for this pump. RH2 estimated the water level in the well during pumping to be 60 feet and the discharge pressure to be 40 psi at the wellhead. These assumptions are based on typical well drawdown and discharge pressures for similar irrigation system configurations in the Klamath Basin. The wire-to-water efficiency of the pump and motor is directly impacted by these suction and discharge pressure assumptions. If the TDH of the pump is more than these assumptions, the actual wire-to-water efficiency of the equipment is higher. Conversely, if the TDH of the pump is less than these assumptions, the actual wire-to-water efficiency of the equipment is lower. A summary of the existing equipment assessment results is shown in **Table 17**.

Table 17
Facility 8 Well Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on as much as 30% of irrigation season as needed to meet the irrigation needs of the system.	Vertical Turbine Well Pump	540	153	49%	972	31.5	33,998

The results of the field testing and the pump operation characteristics described by the owner indicate that the pump is providing significantly less flow than the rated capacity of the pump. Additionally, the rated TDH of the pump is only 50 feet, which is likely significantly less than the TDH required by the pump. Based on conservative estimates, if the groundwater level during pumping is 20 feet below the ground surface and the discharge pressure at the pump is 20 psi, the required TDH of the pump is at least 66 feet, plus system headlosses. A smaller motor should also be considered, as a 30 or 40 HP motor will be sufficient to provide the field-measured flow and TDH (540 gpm and 153 feet TDH) to the system.

Existing Equipment Energy Analysis

Based on the pump operating 30 percent of the irrigation season, the existing annual energy consumption is estimated to be 33,998 kWh based on 5 months of pump operation each year. It is recommended that the owner continue to use the well only as a supplemental source of supply for the system when sufficient surface water in the irrigation ditch is not available. No measureable energy savings are anticipated at this facility based on the results of the field testing.

New Equipment Energy Analysis

If a new 540 gpm pump and 40 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 24,778 kWh. This decrease represents a 9,221 kWh savings (27.1 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $3,060. With a new pump and motor, the annual energy cost is estimated to decrease by $830 to $2,230. The results of the estimated annual energy cost calculations are shown in **Table 18**.

Table 18
Summary of Facility 8 Well Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	33,998 kWh	24,778 kWh
Annual kWh Savings	---	9,221 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$3,060	$2,230
Annual Energy Cost Savings	---	$830

Facility 9 – Well Pump

Background

The Facility 9 well is a vertical turbine pump with a rated capacity of 1,000 gpm and is powered by a 60 HP motor. The well is located near the D Canal, and provides supplemental water as needed to supply wheel and hand lines that irrigate 112 acres of fields consisting mostly of alfalfa and potatoes. Depending on the irrigation system demands and quantity of water available in the D Canal, the well is used approximately 30 percent of the time during the irrigation season. A 40 HP booster pump is located at the same site as the well pump, and can be used to boost pressures during peak irrigation system demands. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system.

Vibration Analysis

The pump is vibrating in the green "newly commissioned machinery" section of the ISO standard and the motor is vibrating in the yellow "unrestricted operation" section of the ISO standard.

Existing Equipment Assessment

Suction pressure readings were not available during field testing, and the owner's discharge pressure gauge was reading only 4 psi during testing which was far too low to be an accurate measurement. RH2 attempted to temporarily remove the owner's pressure gauge and install an RH2 gauge, but standard fittings could not be used to connect the RH2 pressure gauge to the discharge pipe. RH2 estimated the water level in the well during pumping to be 60 feet and the discharge pressure to be 20 psi at the wellhead. These assumptions are based on typical well drawdown and discharge pressures for similar irrigation system configurations in the Klamath Basin. The wire-to-water efficiency of the pump and motor is directly impacted by these suction and discharge pressure assumptions. A summary of the existing equipment assessment results is shown in **Table 19**.

Table 19
Facility 9 Well Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on as much as 30% of irrigation season as needed to meet the irrigation needs of the system.	Vertical Turbine Well Pump	1,500	113	61%	583	52.5	56,678

The results of the field testing and the pump operation characteristics described by the owner indicate that the pump is providing significantly more flow than the rated capacity of the pump; therefore, there is significantly less TDH in the system than the rated capacity of the pump. A new pump should be considered that is more accurately sized to meet the needs of the system.

During field testing, the booster pump was turned on in an effort to assess the pump and motor condition, but the booster pump caused the well to dry out and unstable pumping conditions ensued. No additional data was obtained with the booster pump operating.

Existing Equipment Energy Analysis

Based on the well pump operating 30 percent of the time during the irrigation season, the existing annual energy consumption is estimated to be 56,678 kWh based on 5 months of pump operation each year. It is recommended that the owner continue to use the well only as a supplemental source of supply for the system when sufficient surface water in the D Canal is not available.

New Equipment Energy Analysis

If a new 1,000 gpm pump and 60 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 46,504 kWh. This decrease represents a 10,175 kWh savings (17.9 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $5,101. With a new pump and motor, the annual energy cost is estimated to decrease by $916 (to $4,185). The results of the estimated annual energy cost calculations are shown in **Table 20**.

Table 20
Summary of Facility 9 Well Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	56,678 kWh	46,504 kWh
Annual kWh Savings	---	10,175 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$5,101	$4,185
Annual Energy Cost Savings	---	$916

NOTE: Components may not sum to totals due to rounding.

<u>Facility 10 – Hot Well Pumps No. 1 and No. 2</u>

Background

The two Facility 10 hot well pumps are vertical turbine groundwater pumps that pump water in excess of 195 degrees Fahrenheit to a steel tank at a higher elevation, which then gravity feeds multiple organic vegetable greenhouse heaters. Hot Well Pumps 1 and 2 are 30 and 50 HP, respectively, and operate year-round on an as-needed basis, which includes less pumping during the summer months due to the hotter temperatures naturally providing heat to the greenhouses. There is a third hot well pump that can also provide heat to the greenhouses, but the pump was piped to a canal for supplemental irrigation water in 2014. Hot Well Pump No. 3 was not tested due to degraded wiring in the motor's electrical panel that was in need of repair.

Vibration Analysis

The Hot Well Pump No. 1 pump and motor are both vibrating in the orange "restricted operation section of the ISO standard. The Hot Well Pump No. 2 pump is vibrating in the green "newly commissioned machinery" section of the ISO standard and the motor is vibrating in the yellow "unrestricted operation" section of the ISO standard.

Existing Equipment Assessment

The wire-to-water efficiency of Hot Well Pumps 1 and 2 is good (at or above 70 percent) based on the results of the field testing. The wire-to-water efficiency of pump 2 exceeds 100 percent and is likely artificially high based on poor TDH data available during testing. Due to the high temperature of the well water, suction head was not able to be measured in the field with standard well sounding equipment. The owner indicated the static water depth of each well was 45 feet and the dynamic water level during pumping was approximately 47 feet. Both Hot Well Pumps 1 and 2 are located within structures to protect the equipment from the elements. A summary of the existing equipment assessment results is shown in **Table 21**.

Table 21
Facility 10 Hot Well Pumps Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pumps on as needed year-round.	Hot Well No. 1	950	94	72%	409	23.3	47,053
	Hot Well No. 2	1,600	139	103%	423	40.6	81,789

Existing Equipment Energy Analysis

Due to the varying nature of the system operation, assumptions were made to estimate the pump's annual energy consumption shown in **Table 21**. Each pump was assumed to operate six hours per day, year-round. Based on these operation characteristics, the estimated annual energy consumption for both pumps is 128,843 kWh, and the breakdown of estimated annual energy consumption for each pump is shown in **Table 21**. The power consumption of Hot Well Pump No. 2 is approximately twice as much as Hot Well Pump No. 1, but Hot Well No. 2 provides 50 to 60 percent more supply than Hot Well No. 1. It is recommended that Hot Well Pump No. 1 be utilized more frequently than Hot Well Pump No. 2 to reduce energy consumption. If Hot Well Pump No. 2's runtime was reduced by 50 percent, and Hot Well Pump No. 1's runtime increased to maintain the same supply to the system, it is estimated that the annual energy consumption of the two well pumps would decrease 5,604 kWh to 123,238 kWh.

New Equipment Energy Analysis

No energy savings are anticipated for the Hot Well No. 1 or No. 2 pumps with new equipment due to the better-than-expected wire-to-water efficiency of the existing equipment. However, energy savings can be realized if Hot Well Pump No. 1 is utilized more frequently than Hot Well Pump No. 2.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the Hot Well No. 1 and No. 2 pumps is $11,596. With the revised sequencing, the annual energy cost is estimated to decrease by $504 (to $11,091). The results of the estimated annual energy cost calculations are shown in **Table 22**.

Table 22
Summary of Facility 10 Hot Well Pumps Energy Cost and Savings

Description	Existing System	Existing Equipment with Resequencing
Annual kWh	128,843 kWh	123,238 kWh
Annual kWh Savings	---	5,604 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$11,596	$11,091
Annual Energy Cost Savings	---	$504

NOTE: Components may not sum to totals due to rounding.

<u>Facility 11 –Surface Water Pump</u>

Background

The Facility 11 surface water pump has a rated capacity of 1,250 gpm and is powered by a 100 HP motor with a VFD. The pump conveys surface water from a canal into wheel lines that are used to irrigate 300 acres of grass, hay, and alfalfa fields, typically between May and October. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system. These needs typically require operating the pump non-stop for five to six days, then keeping the pump off for approximately two weeks.

Vibration Analysis

The pump is vibrating in the orange "restricted operation" section of the ISO standard and the motor is vibrating in the yellow "unrestricted operation" section of the ISO standard.

Existing Equipment Assessment

Pump and motor speed was varied during testing, allowing three sets of data to be collected for this pump. A strap-on flow meter was used to measure the flow from the pump, and the owner's pressure transducer was used to determine the TDH of the pump during testing. The pump was not able to be run at full speed during testing, as the system is set to provide a maximum of 62 psi to the system, but only 515 gpm was able to be pumped at 62 psi during field testing due to limited wheel lines being needed during the field testing. Therefore, the pump could not operate at speeds in excess of 52 Hz without potentially damaging the system. The measured wire-to-water efficiency of the pump is satisfactory at all three tested speeds, and is likely better when operating at faster speeds. A summary of the existing equipment assessment results is shown in **Table 23**.

Table 23
Facility 11 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on for 5 to 6 days every 2.5 weeks.	Pump @ 44 Hz	420	106	48%	696	60.3	69,627
	Pump @ 48.5 Hz	490	129	52%	779		
	Pump @ 52 Hz	515	146	52%	873		

Note: During normal operation, the pump provides 1,200 gpm at 62 psi to irrigate 4 wheel lines. During testing, only 1.5 wheel lines were open, resulting in low flows. The average power consumption was estimated based on the normal operation properties of the pump and an estimated 60 percent wire-to-water efficiency.

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 69,627 kWh based on 5 months of pump operation at full speed each year.

New Equipment Energy Analysis

If a new 1,250 gpm pump and 100 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 62,167 kWh. This decrease represents a 7,460 kWh savings (10.7 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $6,266. With a new pump and motor, the annual energy cost is estimated to decrease by $671 to $5,595. The results of the estimated annual energy cost calculations are shown in **Table 24**.

Table 24
Summary of Facility 11 Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	69,627 kWh	62,167 kWh
Annual kWh Savings	---	7,460 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$6,266	$5,595
Annual Energy Cost Savings	---	$671

Facility 12 – Surface Water Pump

Background

The Facility 12 surface water pump is a vertical turbine pump that is powered by a 20 HP motor. The pump conveys surface water from a canal into pipes that irrigate 8.21 acres of pasture with flood valves. Irrigation is typically between May and October, taking place for two days every three weeks. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system.

Vibration Analysis

The pump is vibrating in the green "newly commissioned machinery" section of the ISO standard and the motor is vibrating in the orange "restricted operation" section of the ISO standard.

Existing Equipment Assessment

The pump configuration during field testing was similar to the configuration during normal irrigation operations. No throttling valve exists for the pump, so only one data point was collected during the field visit. The measured wire-to-water efficiency of the pump is satisfactory based on the field data. A summary of the existing equipment assessment results is shown in **Table 25**.

Table 25
Facility 12 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on for 2 days every 3 weeks.	Vertical Turbine Surface Water Pump	1,000	42	50%	263	15.7	5,026

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 5,026 kWh based on 5 months of pump operation each year.

New Equipment Energy Analysis

If a new 1,000 gpm pump and 20 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 4,306 kWh. This decrease represents a 720 kWh savings (14.3 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $452. With a new pump and motor, the annual energy cost is estimated to decrease by $65 to $388. The results of the estimated annual energy cost calculations are shown in **Table 26**.

Table 26
Summary of Facility 12 Surface Water Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	5,026 kWh	4,306 kWh
Annual kWh Savings	---	720 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$452	$388
Annual Energy Cost Savings	---	$65

Facility 13 – Surface Water Pump

Background

The Facility 13 surface water pump is a vertical turbine pump with 1,700 gpm capacity that is powered by a 15 HP motor. The pump conveys surface water from a canal into pipes that irrigate 25 acres of pasture with flood valves. Irrigation is typically between May and October, taking place for two days every three weeks. The owner has the ability to open and close lines as needed to meet the irrigation needs of the system.

Vibration Analysis

The pump and motor are both vibrating in the green "newly commissioned machinery" section of the ISO standard.

Existing Equipment Assessment

The pump configuration during field testing was similar to the configuration during normal irrigation operations. No throttling valve exists for the pump, so only one data point was collected during the field visit. The measured wire-to-water efficiency of the pump is very poor based on the field data. A summary of the existing equipment assessment results is shown in **Table 27**.

Table 27
Facility 13 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on for 2 days every 3 weeks.	Vertical Turbine Surface Water Pump	1,550	9	24%	117	10.9	3,477

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 3,477 kWh based on 5 months of pump operation each year.

New Equipment Energy Analysis

If a new 1,700 gpm pump and 15 HP motor with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 2,196 kWh. This decrease represents a 1,281 kWh savings (36.8 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of \$0.09 per kWh, the estimated annual energy cost for the existing pump and motor is \$313. With a new pump and motor, the annual energy cost is estimated to decrease by \$115 to \$198. The results of the estimated annual energy cost calculations are shown in **Table 28**.

Table 28
Summary of Facility 13 Surface Water Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	3,477 kWh	2,196 kWh
Annual kWh Savings	---	1,281 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$313	$198
Annual Energy Cost Savings	---	$115

Facility 14 – Surface Water Pumps

Background

The Facility 14 pumps are two identical vertical turbine pumps with 50 HP motors that pump surface water from a canal into 8 and 10-inch-diameter irrigation mains that supply three pivots. The pivots combine to irrigate 415 acres of pasture, typically operating for 2 to 3 days each week (1 inch of water per week) between May and October. The owner has the ability to open and close lines and pivots as needed to meet the irrigation needs of the system.

Vibration Analysis

The south pump and motor are both vibrating in the yellow "unrestricted operation" section of the ISO standard and the north pump and motor are both vibrating in the green "newly commissioned machinery" section of the ISO standard.

Existing Equipment Assessment

The pump configuration during field testing was similar to the configuration during normal irrigation operations. No throttling valve exists for the pumps, so only one data point for each pump was collected during the field visit. The measured wire-to-water efficiency of the pumps is average based on the field data. A summary of the existing equipment assessment results is shown in **Table 29**.

Table 29
Facility 14 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pumps on for 2 to 3 days each week.	South Pump	1,025	124	59%	660	40.8	48,911
	North Pump	1,025	124	60%	650	39.8	47,774

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 96,685 kWh based on 5 months of pump operation each year. Because the pumps have nearly identical wire-to-water efficiencies and energy signatures, no energy savings are anticipated at this facility based on the existing equipment and pump sequence.

New Equipment Energy Analysis

If new 1,025 gpm pumps with 50 HP motors with the capacity required to meet the irrigation needs of the system (and an assumed 70 percent wire-to-water efficiency) are installed to replace the existing equipment, the annual energy consumption is estimated to decrease to 82,092 kWh. This decrease represents a 14,592 kWh savings (15.1 percent) compared to the existing pumping equipment.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $8,702. With a new pump and motor, the annual energy cost is estimated to decrease by $1,313 (to $7,388). The results of the estimated annual energy cost calculations are shown in **Table 30**.

Table 30
Summary of Facility 14 Surface Water Pumps Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	96,685 kWh	82,092 kWh
Annual kWh Savings	---	14,592 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$8,702	$7,388
Annual Energy Cost Savings	---	$1,313

NOTE: Components may not sum to totals due to rounding.

Facility 15 Surface Water Pump

Background

The Facility 15 surface water pump is a centrifugal pump that is powered by a 60 HP motor. The pump conveys surface water from a canal into an eight-inch-diameter irrigation main that supplies one pivot. The pivot irrigates 150 acres of grain or hay, typically operating for 1 week every 3 weeks for grain, and 4 to 8 hours each week for hay between May and October. The land is typically pre-flooded in the winter to saturate the soil.

Vibration Analysis

The pump and motor are both vibrating in the orange "restricted operation" section of the ISO standard.

Existing Equipment Assessment

The pump configuration during field testing was similar to the configuration during normal irrigation operations. No throttling valve exists for the pump, so only one data point was collected during the field visit. Flow and discharge pressure data was not able to be measured during field testing. Instead, estimates of 1,200 gpm and 55 psi at the pivot were made based on the owner's knowledge of the system. The measured wire-to-water efficiency of the pump is very good based on the field data. A summary of the existing equipment assessment results is shown in **Table 31**.

Table 31
Facility 15 Surface Water Pump Assessment Results

Operation Characteristics	Pump	Flow (gpm)	TDH (ft)	Wire-to-water Efficiency	Energy Signature (kWh/MG)	Average Power Consumption (kW)	Estimated Annual Power (kWh)
Pump on for 1 week every 3 weeks for grain.	Centrifugal Surface Water Pump	1,200	175	86%	639	45.8	51,349

Existing Equipment Energy Analysis

Based on the operation characteristics described previously, the existing annual energy consumption is estimated to be 51,349 kWh based on 5 months of pump operation each year, during years where grain is planted in the field.

New Equipment Energy Analysis

No energy savings are anticipated for the Facility 15 pump with new equipment due to the good wire-to-water efficiency of the existing equipment based on 1,200 gpm and 175 feet of TDH (55 psi at the pivot) being provided by the pump. Based on the operation characteristics described previously, new equipment is not likely to result in energy savings at this facility.

Energy Cost Analysis

Based on the estimated annual energy consumption values and an assumed energy rate of $0.09 per kWh, the estimated annual energy cost for the existing pump and motor is $4,621 when grain is planted in the field. The estimated annual energy consumption and cost when hay is planted in the field is approximately 10 percent of that estimated for grain due to the difference in irrigation rates and frequencies between the two crops. Additional savings are not anticipated through reoperation or with new equipment. The results of the estimated annual energy cost calculation for grain is shown in **Table 32**.

Table 32
Summary of Facility 15 Surface Water Pump Energy Cost and Savings

Description	Existing System	Future System with New Equipment
Annual kWh	51,349 kWh	51,349 kWh
Annual kWh Savings	---	0 kWh
Energy Cost ($/kWh)	$0.09	$0.09
Annual Energy Cost	$4,621	$4,621
Annual Energy Cost Savings	---	$0

Summary

An inventory of the field-tested facilities is shown in **Table 33**, presenting the wire-to-water efficiency, energy signature, and vibration amplitude data calculated in this study. The calculated data and possible vibration-related problems were evaluated quantitatively to determine the overall condition of each pump and motor in a numerical ranking. **Table 34** lists the criteria used to determine the overall condition of each pump and motor. The criteria are arranged in two different categories with a weighting factor assigned to each category. Two-thirds of the overall condition rating was based on wire-to-water efficiency and one-third of the overall condition rating was based on vibration amplitude. The overall pump and motor ratings are numerical values ranging from 1 (best rating) to 10 (worst rating).

Table 33
Private and Off-Project Field Tested Facilities

Facility	Facility Name	Pump No.	Rated Pump Capacity (gpm)	Motor Horse-power (hp)	Install-ation Year	Energy Analysis: Wire-to-water Efficiency	Energy Analysis: Energy Signature (kWh/MG)	Vibration Analysis: Pump Vibration Amplitude RMS (mm/s)	Vibration Analysis: Motor Vibration Amplitude RMS (mm/s)	Overall Pump and Motor Rating
Facility 1	BPS	1	3,100	75	Unknown	36%	462	N/A	1.93	9.0
		2	5,000	125	2011	57%	287	N/A	2.78	4.7
Facility 2	Submersible Well Pump	1	450	30	1996/ 2012	88%	1,000	N/A	N/A	0.7
Facility 3	Surface Pump	1	ND	30	2011	66%	521	3.26	2.54	3.8
Facility 4	Submersible Well Pump	1	500	25	1960s	29%	1,530	3.76	1.77	8.0
Facility 5	Surface Pump	1	700	40	2004	53%	2,548	N/A	N/A	3.3
Facility 6	Submersible Well Pump	1	800	40	2007	48%	1,263	N/A	N/A	4.7
	Surface Pump	1	ND	40	2004	41%	875	12.94	6.55	8.0
Facility 7	Surface Pumps	1	4,000	100	2004	70%	186	1.99	2.59	2.0
		2	5,000	125	2004	75%	178	0.72	1.00	1.0
	Vertical Turbine Well Pump	1	ND	150	2003	76%	537	1.42	1.14	1.5
Facility 8	Vertical Turbine Well	1	1,000	75	1993	49%	972	1.45	2.69	6.5
Facility 9	Vertical Turbine Well	1	1,000	60	2001	61%	583	1.19	1.89	2.8
Facility 10	Hot Well 1	1	950	50	1975	72%	409	2.88	4.69	3.0
	Hot Well 2	1	1600	30	1985	103%	423	1.18	1.98	1.5
Facility 11	Surface Pump	1	1,250	100	1985	52%	873	3.11	2.30	5.2
Facility 12	Surface Pump	1	ND	20	2003	50%	263	1.19	3.38	4.7
Facility 13	Surface Pump	1	1,700	15	2005	24%	117	0.99	1.33	7.0
Facility 14	Surface Pump	1	ND	50	2002	59%	660	1.47	1.81	4.7
	Surface Pump	2	ND	50	2002	60%	650	0.28	0.41	3.7
Facility 15	Surface Pump	1	1,200	60	1980	86%	639	3.35	3.25	3.0

Wire-to-water Efficiency Legend	Vibration Amplitude RMS Legend	Overall Pump and Motor Rating
Greater than 70%	Newly Commissioned	Excellent
Greater than 60%	Unrestricted Operation	Good
50% to 60%	Restricted Operation	Average
40% to 50%	Damage Occurs	Fair
Less than 40%		Poor

Table 34
Overall Pump and Motor Rating Criteria

Points	Category	Weighting Factor	Weighted Points
	Wire-to-water Efficiency		
1	Wire-to-water Efficiency Greater than 70%	0.67	0.67
3	Wire-to-water Efficiency Greater than 60%		2.01
5	Wire-to-water Efficiency 50% to 60%		3.35
7	Wire-to-water Efficiency 40% to 50%		4.69
10	Wire-to-water Efficiency Less than 40%		6.70
	Vibration Characteristics		
1	Operating in Green "Newly Commissioned Machinery" Section	0.33	0.33
4	Operating in Yellow "Unrestricted Operation" Section		1.33
8	Operating in Orange "Restricted Operation" Section		2.64
10	Operating in Red "Damage Occurs" Section		3.30

Overall pump and motor condition varies significantly (24 to 103 percent) between the 21 pumps and motors tested as part of this study. The average wire-to-water efficiency of the field-tested equipment is 60 percent, but if the three pumps and motors with potentially artificially high wire-to-water efficiencies (Facility 2 – Pump 1, Facility 10 – Pump 2, and Facility 15 – Pump 1) are not considered, the average wire-to-water efficiency of the remaining 18 pumps and motors is 54 percent. Twelve of the 21 pumps and motors have wire-to-water efficiencies greater than 54 percent. Improvement recommendations for each pump and motor are shown in **Table 35**.

Table 35
Facility Improvement Recommendations

Facility Owner	Facility Name	Pump No.	Improvement Recommen-dation	Priority	Rationale
Facility 1	BPS	1	Replace	High	Poor energy signature due to pump design points differing significantly from field-measured conditions. Significant vibration amplitude and secondary vibration characteristic concerns.
		2	Monitor - Do Not Replace	Medium	Performance is poor based on age of pump and motor. Re-evaluate energy and vibration characteristics in 3 to 5 years.
Facility 2	Submersible Well Pump	1	Monitor - Do Not Replace	Low	Efficient pump and motor, but no vibration data collected. Based on pump and motor efficiency, no need for improvements.
Facility 3	Surface Pump	1	None - No Concerns	Medium	Efficient pump and motor and minimal vibration concerns.
Facility 4	Submersible Well Pump	1	Replace	Medium	Poor pump and motor efficiency, but no vibration data collected. Significant energy savings can be realized with new equipment.
Facility 5	Surface Pump	1	Replace	High	Poor pump and motor efficiency likely due to improperly sized pump. Extreme vibration concerns. Significant energy savings can be realized with new equipment.
Facility 6	Submersible Well Pump	1	Replace	High	Very poor pump and motor efficiency likely due to improperly sized pump. Significant vibration concerns. Significant energy savings can be realized with new equipment.
	Surface Pump	1	Replace	Low	Average pump and motor efficiency, but no vibration data collected. Significant energy savings can be realized with new equipment.
Facility 7	Surface Pumps	1	Monitor - Do Not Replace	Medium	Efficient pump and motor with minor vibration concerns.
		2	None - No Concerns	Low	Efficient pump and motor and no vibration concerns.
	Vertical Turbine Well Pump	1	None - No Concerns	Low	Efficient pump and motor and minimal vibration concerns.
Facility 8	Vertical Turbine Well	1	Replace	Medium	Below average pump and motor efficiency with minor to significant vibration concerns.
Facility 9	Vertical Turbine Well	1	None - No Concerns	Medium	Efficient pump and motor and minimal vibration concerns.
Facility 10	Hot Well 1	1	Monitor - Do Not Replace	Medium	Efficient pump and motor but significant vibration concerns.
	Hot Well 2	1	Monitor - Do Not Replace	Low	Efficient pump and motor and minimal vibration concerns.
Facility 11	Surface Pump	1	Replace	Low	Average pump and motor efficiency with minor to significant vibration concerns.
Facility 12	Surface Pump	1	Replace	Low	Average pump and motor efficiency with minor to significant vibration concerns.
Facility 13	Surface Pump	1	Replace	Medium	Very poor pump and motor efficiency likely due to improperly sized pump. Minimal vibration concerns, but significant energy savings can be realized with new equipment.
Facility 14	Surface Pump	1	Monitor - Do Not Replace	Medium	Average pump and motor efficiency with minor vibration concerns.
	Surface Pump	2	Monitor - Do Not Replace	Low	Average pump and motor efficiency with minimal vibration concerns.
Facility 15	Surface Pump	1	Monitor - Do Not Replace	Medium	Efficient pump and motor but significant vibration concerns.

Based on the data presented in **Table 35**, three of the 21 field-tested pumps and motors have a high priority replacement recommendation. These pumps and motors have poor wire-to-water efficiencies and significant energy savings can be realized if replacement equipment is installed. These high priority pumps and motors also have significant vibration concerns that have and will continue to shorten the life of the equipment and are reduce the efficiency of the equipment.

An additional six pumps are also recommended for replacement in **Table 35**, but are lower priority than the three high priority pumps. The remaining 12 pumps and motors are not recommended for replacement but should be monitored by the facility owners and be reevaluated in 3 to 5 years as part of a standard preventative maintenance program. The pump sequences at each facility should be resequenced as described in the **Data Analysis** section for each facility until pump and motor replacements take place.

A summary of the estimated energy consumption at each facility with replacement pumps and motors at each facility is shown in **Table 36**. Based on the estimated annual energy consumption values shown in **Table 36** and an assumed energy rate of $0.09 per kWh in Oregon and $0.13 per kWh in California, the annual energy cost savings is $9,043 if nine of the of the 21 field-tested pumps and motors are replaced as recommended in **Table 35**. If these nine pumps and motors are replaced, the annual energy consumption can be reduced by 23.1 percent at the nine facilities, which is equivalent to 100,480 kWh. These reductions equate to a 14.7 percent reduction in energy consumption when all 21 field-tested pumps are considered.

Table 36
Same Capacity Replacement Equipment Energy Consumption and Savings Summary

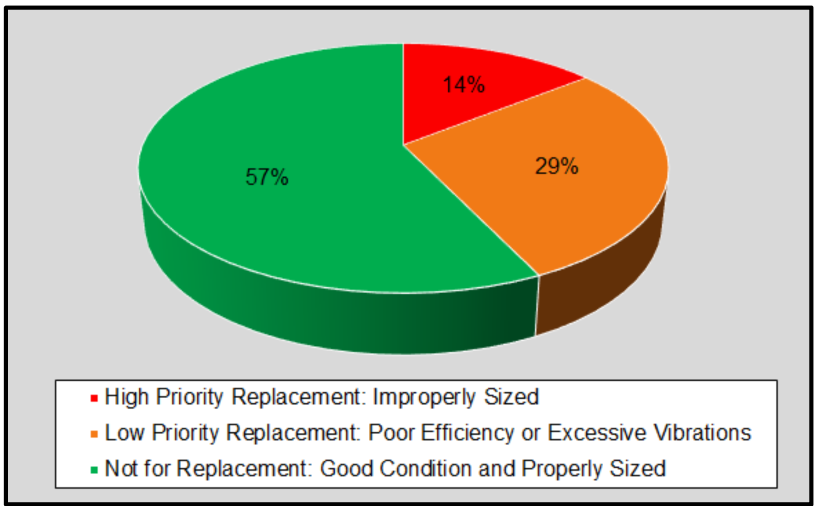
Facility	Facility Name	Annual Energy Consumption (kWh) Existing Equipment and Sequences	Annual Energy Consumption (kWh) New Equipment and Sequences	Estimated Annual Energy Savings (kWh)
Facility 1	**BPS - Pump 1**	**111,800**	**89,440**	**22,360**
	BPS - Pump 2	33,850	16,925	16,925
Facility 2	Submersible Well Pump	10,071	10,071	0
Facility 3	Surface Pump	75,197	70,475	4,722
Facility 4	**Submersible Well Pump**	**23,331**	**9,685**	**13,646**
Facility 5	**Surface Pump**	**46,224**	**30,862**	**15,362**
Facility 6	**Submersible Well Pump**	**101,808**	**87,216**	**14,592**
	Surface Pump	**38,808**	**22,971**	**15,837**
Facility 7	Surface Pump - 1	35,672	35,672	0
	Surface Pump - 2	33,573	33,573	0
	Vertical Turbine Well Pump	82,979	82,979	0
Facility 8	**Vertical Turbine Well**	**33,998**	**24,778**	**9,221**
Facility 9	Vertical Turbine Well	56,678	46,504	10,175
Facility 10	Hot Well Pump 1	47,053	82,344	-35,290
	Hot Well Pump 2	81,789	40,895	40,895
Facility 11	**Surface Pumps**	**69,627**	**62,167**	**7,460**
Facility 12	**Surface Pumps**	**5,026**	**4,306**	**720**
Facility 13	**Surface Pumps**	**3,477**	**2,196**	**1,281**
Facility 14	Surface Pump - 1	48,911	41,046	7,865
	Surface Pump - 2	47,774	41,046	6,728
Facility 15	Surface Pump	51,349	51,349	0
Totals (All Pumps)		**1,038,996**	**886,499**	**152,498**
Totals (Pump Recommended for Replacement)		**434,100**	**333,620**	**100,480**

NOTES:

- Pumps shown in **bold** text are recommended for replacement.
- Components may not sum to totals due to rounding.
- Energy savings can be realized at Facility 10 if Hot Well Pump No. 1 is utilized more frequently than Hot Well Pump No. 2. The negative energy savings for Hot Well Pump No. 1 reflect these operational changes, and the annual energy consumption for the two wells is equivalent to that presented in Table 22.

Based on the results of these analyses, which comprise a representative sample of the private pumps and motors in the Klamath Basin, the average private pump and motor has a wire-to-water efficiency of 54 percent (with 86 percent of all tested equipment having wire-to-water efficiencies between 24 and 76 percent), and has pump and motor vibration levels that are within the yellow "unrestricted operation" section of the ISO standard. Approximately 14 percent of the private pumps and motors are improperly sized for their existing pumping application, and have significant vibration amplitude concerns. These 14 percent of pumps and motors are a high priority for replacement. An additional 29 percent of the private pumps and motors are low-priority replacements, either based on poor wire-to-water efficiency or excessive vibration amplitudes, as shown in **Chart 3**.

Chart 3
Private Pump Improvement Recommendations



If the high and low priority replacement equipment is replaced with new equipment, an estimated 11.8 to 15.2 percent energy savings can be realized on an annual basis. Due to data collection inaccuracies, conservative estimates for total dynamic head and flow were estimated based on known parameters and pump owner knowledge. It is expected that the minimum annual energy savings is 11.8 percent (on average for all private pumps and motors), and annual energy savings may be as high as 30 percent (on average) if the high and low priority equipment is replaced.

The remaining 57 percent of private pumps and motors are believed to be in generally good condition and are properly sized for their existing pumping application. An additional one to two percent reduction in annual energy consumption can be achieved with improved irrigation management practices throughout the private pumping facilities in the Klamath Basin. This results in an estimated range of 12.8 to 17.2 percent overall energy savings with replacement equipment and improved irrigation management practices, with up to 32 percent energy savings possible if very conservative assumptions are removed. Assuming the field-tested data set is representative of all 2,500 private pumps and motors in the Basin, energy savings of 13 to 17 percent, with a maximum savings of 32 percent, could be realized Basin-wide. Extrapolating the field-tested facility energy reduction of 14.7 percent to the 2,500 pumps in the Klamath Basin, 11.9 gigawatt-hours (11,900,000 kWh) of annual energy savings could be realized if 43 percent of the pumps and motors Basin-wide are in need of replacement, resulting in approximately $1,000,000 of annual energy cost savings.

Based on the pumps and motors inspected, VFDs are not recommended for installation on most of the private pumps and motors. Only 14 percent of the field-tested equipment is improperly sized for their existing pumping application, and the equipment at each of these facilities has significant vibration amplitude concerns that are unlikely to be resolved with installation of a VFD. Replacing the existing pump and motor with properly sized equipment will result in significant energy savings (on a percentage basis) at these facilities. The remaining 86 percent of pumps and motors are believed to be properly sized and operate at or near the pump design point during peak irrigation season.

Installation of a VFD on the improperly sized equipment will result in minimal energy savings that will only be realized during periods of low irrigation water supply. Of the 2,500 pumps in the Klamath Basin, it is estimated that less than 5 percent of the pumps have operating conditions during normal water years that would benefit from installation of a VFD. The most favorable application of VFD equipment is on facilities that have the ability and need to irrigate a smaller portion of the land during low irrigation water supply periods. For example, a farm with multiple wheel lines is likely to realize energy savings by installing a VFD on a pump where fewer wheel lines are run to match available supplies.

Monitoring Recommendations

It is recommended that the wire-to-water efficiency, energy signature, and vibration characteristics of each pump and motor be retested and reevaluated every three to five years as part of a standard preventative maintenance program. The data contained in this technical memorandum provides a baseline that can be used as a comparison to evaluate pump and motor degradation as the service life of the equipment increases. The ability to monitor this data over time can assist an owner with prioritizing operations and maintenance tasks. A decreasing wire-to-water efficiency, increasing energy signature, or increasing vibration amplitude may be indicative of a pump in need of maintenance or beginning to fail, providing the opportunity to troubleshoot and repair the pump and/or motor prior to failure.

Attachments

Attachment A – Off-Project and Private Pump and Motor Field Data and Analysis
Attachment B – Pump and Motor Ratings

ATTACHMENT A

OFF-PROJECT AND PRIVATE PUMPS FIELD DATA AND ANALYSIS

Klamath CAPP
Off-project and Private Pumps
Field Data Collection

Test Information/Pump Data

Owner	Site - Pump #	Pump Test No.	Date (mm/dd/yy)	Time	Well or BPS?	VFD?	Suction Zone HGL (ft)	Discharge Zone HGL (ft)	Pump MFG	Pump Model No.	Motor MFG	Motor Model No.	Rated Pump Flow (gpm)	Rated Pump TDH (ft)	Rated Motor Size (hp)
Facility 1	BPS - 1	1	06/05/14	1:30 PM	BPS	No	4,103	4,154			US Electrical	No Data	3,100	42	75
Facility 1	BPS - 2	1	06/05/14	1:45 PM	BPS	Yes	4,103	4,154			US Electrical	P12 20084 661-0001R 0001	5,000		125
Facility 1	BPS - 2	2	06/05/14	1:45 PM	BPS	Yes	4,103	4,154			US Electrical	P12 20084 661-0001R 0001	5,000		125
Facility 2	Submersible Well	1 - Avg.	10/07/14	8:45 AM	W	No	4,002	4,270	Well # 46NO5E24P002M				450		30
Facility 2	Submersible Well	2 - Low	10/07/14	8:45 AM	W	No	4,007	4,270					450		30
Facility 2	Submersible Well	3 - High	10/07/14	8:45 AM	W	No	3,992	4,270					450		30
Facility 3	Surface Pump	1	10/06/14	3:25 PM	BPS	No	4,126	4,235	Cornell	3RB-30-3-4	Baldor	A17387T-55			30
Facility 3	Surface Pump	2	10/06/14	3:30 PM	BPS	No	4,126	4,235	Cornell	3RB-30-3-4	Baldor	A17387T-55			30
Facility 3	Surface Pump	3	10/06/14	3:35 PM	BPS	No	4,126	4,235	Cornell	3RB-30-3-4	Baldor	A17387T-55			30
Facility 6	Submersible Well	1	10/06/14	10:45 AM	W	No	3,957	4,192					800		
Facility 6	Submersible Well	2	10/06/14	10:50 AM	W	No	3,980	4,275					800		
Facility 6	Submersible Well	3	10/06/14	11:00 AM	W	No	3,965	4,155					800		
Facility 6	Surface Pump	1	10/06/14	11:10 AM	BPS	No	4,116	4,262	Berkeley	B3ZPBH	Baldor	JPM2538T			40
Facility 6	Surface Pump	2	10/06/14	11:15 AM	BPS	No	4,116	4,232	Berkeley	B3ZPBH	Baldor	JPM2538T			40
Facility 6	Surface Pump	3	10/06/14	11:17 AM	BPS	No	4,116	4,294	Berkeley	B3ZPBH	Baldor	JPM2538T			40
Facility 4	Surface Pump	1	10/06/14	7:42 AM	BPS	No	4,104	4,245	Berkeley	B3ZPL			500	175	25
Facility 4	Surface Pump	2	10/06/14	7:56 AM	BPS	No	4,104	4,245	Berkeley	B3ZPL			500	175	25
Facility 4	Surface Pump	3	10/06/14	8:00 AM	BPS	No	4,104	4,245	Berkeley	B3ZPL			500	175	25
Facility 5	Submersible Well	1	10/06/14	9:00 AM	W	No	4,092	4,529	Well # L48779						40
Facility 5	Submersible Well	2	10/06/14	9:11 AM	W	No	4,084	4,510							40
Facility 7	Surface Pump - 1	1	10/07/14	2:45 PM	BPS	No	4,150	4,191			GE	BAG52935A	4,000		100
Facility 7	Surface Pump - 2	1	10/07/14	3:05 PM	BPS	Yes	4,150	4,191			GE	BAG52934A	5,000		125
Facility 7	Surface Pump - 2	2	10/07/14	3:12 PM	BPS	Yes	4,150	4,191			GE	BAG52934A	5,000		125
Facility 7	Surface Pump - 2	3	10/07/14	3:15 PM	BPS	Yes	4,150	4,191			GE	BAG52934A	5,000		125
Facility 7	Vertical Turbine Well	1	10/07/14	3:58 PM	W	Yes	4,129	4,258	National		US Electrical	G05-BF75-MC1			150
Facility 7	Vertical Turbine Well	2	10/07/14	4:02 PM	W	Yes	4,134	4,258	National		US Electrical	G05-BF75-MC1			150
Facility 7	Vertical Turbine Well	3	10/07/14	4:04 PM	W	Yes	4,139	4,258	National		US Electrical	G05-BF75-MC1			150
Facility 8	Vertical Turbine Well - 1	1	10/07/14	12:11 PM	W	No	4,076	4,228	Johnston	45948	GE	5K6258XH1A	1,000	50	75
Facility 9	Vertical Turbine Well - 2	1	10/07/14	12:41 PM	W	No	4,027	4,133	Goulds		US Electrical	E03-S318A-M E14	1,000		60
Facility 9A	VT Well - 2 Booster Pump	1	10/07/14	12:45 PM	BPS	No	4,133	4,138	Cornell	5RB-CC 40-4	US Electrical	D0701058570-201R-01			40
Facility 11	Surface Pump	1	10/08/14	8:26 AM	BPS	Yes	4,090	4,196	Berkeley	E6EXPBL		404TTDS7661AA	1,250	210	100
Facility 11	Surface Pump	2	10/08/14	8:35 AM	BPS	Yes	4,090	4,219	Berkeley	E6EXPBL		404TTDS7661AA	1,250	210	100
Facility 11	Surface Pump	3	10/08/14	8:45 AM	BPS	Yes	4,090	4,235	Berkeley	E6EXPBL		404TTDS7661AA	1,250	210	100
Facility 12	Surface Pump	1	10/08/14	9:10 AM	BPS	No	4,092	4,127	National	M12	US Electrical	H020S2BLG*			20
Facility 13	Surface Pump	1	10/08/14	9:32 AM	BPS	No	4,107	4,115	Goulds	14RHMC	US Electrical	H10-BF88-H	1,700	28	15
Facility 14	Surface Pump	1	10/08/14	10:05 AM	BPS	No	4,086	4,194	Goulds		US Electrical	G07-BF54A-MA8			50
Facility 14	Surface Pump	1	10/08/14	10:15 AM	BPS	No	4,086	4,194	Goulds		US Electrical	G09-BF54A-MC13			50
Facility 15	Surface Pump	1	10/08/14	10:45 AM	BPS	No	4,084	4,214			US Electrical	9703594-130 C0490260S	1,200		60
Facility 10	Vertical Turbine Well	1	10/08/14	11:56 AM	W	No	4,051	4,137	American	3053	GE	112103	950		30
Facility 10	Vertical Turbine Well	1	10/08/14	11:25 AM	W	No	4,057	4,137				326TPHDD27K2PB	1,600		50

Hydraulic Data

Owner	Site - Pump #	Pump Test No.	Wells: Pumping Depth to Groundwater Level (ft)	Wells: Discharge HGL (ft)	Booster Pumps: Suction HGL (ft)	Booster Pumps: Discharge HGL (ft)	Headloss and Flow: Distance Between Suction and Discharge (ft)	Piping Headloss (ft)	Flap Gate?	Discharge Pipe Diameter (in)	Pipe Velocity (fps)	Flap Gate Open Angle	Flap Gate K-value	Exit Loss K-value	Discharge Headloss (ft)	Flow Meter Reading (gpm)
Facility 1	BPS - 1	1		51.0	4,103.4	4,154.4	487	1	Y	18	3.1	30	4.0	1.0	0.4	2,445
Facility 1	BPS - 2	1			4,103.4	4,154.4	487	1	N	24	3.5	30	4.0	1.0	0.6	5,000
Facility 1	BPS - 2	2			4,103.4	4,154.4	487	1	N	24	3.3	30	4.0	1.0	0.5	4,650
Facility 2	Submersible Well	1 - Avg.	4,002.0	4,270.1			142.0	9	N	4	8.6	---	---	4.0	4.6	335
Facility 2	Submersible Well	2 - Low	4,007.0	4,270.1			142.0	9	N	4	8.6	---	---	4.0	4.6	335
Facility 2	Submersible Well	3 - High	3,992.0	4,270.1			142.0	9	N	4	8.6	---	---	4.0	4.6	335
Facility 3	Surface Pump	1			4,126.0	4,234.9			N							650
Facility 3	Surface Pump	2			4,126.0	4,234.9			N							675
Facility 3	Surface Pump	3			4,126.0	4,234.9			N							425
Facility 6	Submersible Well	1	3,957.0	4,192.3			253.0	2	N	6	3.7	---	---	3.6	0.8	330
Facility 6	Submersible Well	2	3,980.0	4,275.4			253.0	1	N	6	2.5	---	---	3.6	0.3	220
Facility 6	Submersible Well	3	3,965.0	4,155.4			253.0	3	N	6	4.5	---	---	3.6	1.1	400
Facility 6	Surface Pump	1			4,116.2	4,261.6	2.0	0	N	8	2.8	---	---	0.5	0.1	440
Facility 6	Surface Pump	2			4,116.2	4,231.6	2.0	0	N	8	2.8	---	---	0.5	0.1	440
Facility 6	Surface Pump	3			4,116.2	4,293.9	2.0	0	N	8	2.6	---	---	0.5	0.1	400
Facility 4	Surface Pump	1			4,104	4,244.7	88.0	0	N	6	2.5	---	---	1.5	0.1	220
Facility 4	Surface Pump	2			4,104	4,244.7	88.0	0	N	6	2.1	---	---	1.5	0.1	186
Facility 4	Surface Pump	3			4,104	4,244.7	88.0	0	N	6	1.8	---	---	1.5	0.1	161
Facility 5	Submersible Well	1	4,092.2	4,528.9			160.0	0	N	6	1.7	---	---	3.5	0.2	150
Facility 5	Submersible Well	2	4,084.2	4,510.4			160.0	1	N	6	2.4	---	---	3.5	0.3	210
Facility 7	Surface Pump - 1	1			4,150	4,190.6	913.0	1	N	24	2.8	---	---	1.5	0.2	4,000
Facility 7	Surface Pump - 2	1			4,150	4,190.6	913.0	2	Y	24	3.3	30	4.0	1.2	0.5	4,700
Facility 7	Surface Pump - 2	2			4,150	4,190.6	913.0	1	Y	24	2.2	30	4.0	1.2	0.2	3,100
Facility 7	Surface Pump - 2	3			4,150	4,190.6	913.0	1	Y	24	2.8	30	4.0	1.2	0.3	4,000
Facility 7	Vertical Turbine Well	1	4,129.0	4,258.2					N							4,000
Facility 7	Vertical Turbine Well	2	4,134.0	4,258.2					N							3,600
Facility 7	Vertical Turbine Well	3	4,139.0	4,258.2					N							3,100
Facility 8	Vertical Turbine Well - 1	1	4,076.0	4,228.3			60.0	0	N							540
Facility 9	Vertical Turbine Well - 2	1	4,027.0	4,133.2			60.0	2	N	8	9.6	---	---	3.3	4.7	1,500
Facility 9A	VT Well - 2 Booster Pump	1			4,133	4,138.2	10.0	0	N	10	6.1	---	---	1.9	1.1	1,500
Facility 11	Surface Pump	1			4,090	4,195.7	10.0	0	N	12	1.2	---	---	2.2	0.0	420
Facility 11	Surface Pump	2			4,090	4,218.8	10.0	0	N	12	1.4	---	---	2.2	0.1	490
Facility 11	Surface Pump	3			4,090	4,235.0	10.0	0	N	12	1.5	---	---	2.2	0.1	515
Facility 12	Surface Pump	1			4,092	4,126.9	340.0	5	N	8	6.4	---	---	3.2	2.0	1,000
Facility 13	Surface Pump	1			4,107	4,115.2	120.0	1	N	12	4.4	---	---	2.4	0.7	1,550
Facility 14	Surface Pump	1			4,086	4,194.4	1,880.0	12	N	10	4.2	---	---	13.5	3.7	1,025
Facility 14	Surface Pump	1			4,086	4,194.4	1,880.0	12	N	10	4.2	---	---	13.5	3.7	1,025
Facility 15	Surface Pump	1			4,084	4,213.9	1,800.0	40	N	8	7.7	---	---	6.4	5.8	1,200
Facility 10	Vertical Turbine Well	1	4,051.3	4,137.1			470.0	7	N	8	6.1	---	---	2.5	1.4	950
Facility 10	Vertical Turbine Well	1	4,056.8	4,137.1			1,350.0	57	N	10	6.5	---	---	2.9	1.9	1,600

Electrical Data

Owner	Site - Pump #	Pump Test No.	Pump Current: I Leg A (amps)	I Leg B (amps)	I Leg C (amps)	Voltage: E Leg A (volts)	E Leg B (volts)	E Leg C (volts)	Power: Total Power (kW)	Power Factor: pf Leg A	pf Leg B	pf Leg C	VFD Only: Frequency (Hz)
Facility 1	BPS - 1	1	91	93	93	472			67.7	0.90			
Facility 1	BPS - 2	1	125			482			86.0		0.83		60.0
Facility 1	BPS - 2	2	110			447			69.5		0.82		55.8
Facility 2	Submersible Well	1 - Avg.	42	43	43	467	471	468	20.1	0.58			
Facility 2	Submersible Well	2 - Low	42	43	43	467	471	468	20.1	0.58			
Facility 2	Submersible Well	3 - High	42	43	43	467	471	468	20.1	0.58			
Facility 3	Surface Pump	1	40	39	40	468	471	483	26.9	0.82			
Facility 3	Surface Pump	2	34	32	33	474	478	480	21.1	0.78			
Facility 3	Surface Pump	3	34	33	33	470	477	473	21.7	0.79			
Facility 6	Submersible Well	1	42	43	44	479	481	478	30.2	0.85			
Facility 6	Submersible Well	2	39	40	41	477	480	473	27.8	0.84			
Facility 6	Submersible Well	3	42	43	44	474	479	482	30.3	0.85			
Facility 6	Surface Pump	1	34	34	35	473	475	471	24.3	0.86			
Facility 6	Surface Pump	2	33	32	34	475	475	469	23.1	0.86			
Facility 6	Surface Pump	3	35	34	36	473	472	472	24.7	0.87			
Facility 4	Surface Pump	1	27	27	28	484	480	481	20.2	0.88			
Facility 4	Surface Pump	2	26	27	25	483	478	482	19.2	0.87			
Facility 4	Surface Pump	3	25	25	25	482	478	482	18.1	0.86			
Facility 5	Submersible Well	1	48	46	47	479	480	472	28.3	0.72			
Facility 5	Submersible Well	2	51	50	52	476	477	482	32.1	0.76			
Facility 7	Surface Pump - 1	1	87	86	90	482	481	477	44.6	0.61			
Facility 7	Surface Pump - 2	1	93	88	92	484	486	477	50.1	0.60			60.0
Facility 7	Surface Pump - 2	2	61	61	63	482	484	487	34.4	0.58			50.0
Facility 7	Surface Pump - 2	3	75	75	76	487	488	481	41.4	0.59			55.0
Facility 7	Vertical Turbine Well	1	167	158	162	472	471	477	128.9	0.93			60.0
Facility 7	Vertical Turbine Well	2	132	126	131	478	475	473	103.5	0.92			55.0
Facility 7	Vertical Turbine Well	3	100	93	98	475	474	487	78.8	0.92			50.0
Facility 8	Vertical Turbine Well - 1	1	61	65	61	469	471	477	31.5	0.62			
Facility 9	Vertical Turbine Well - 2	1	75	73	72	475	472	476	52.5	0.87			
Facility 9A	VT Well - 2 Booster Pump	1	26	26	27	243	229	472	87.8	0.71			
Facility 11	Surface Pump	1	29	31	36	506	501	490	17.5	0.47			44.0
Facility 11	Surface Pump	2	38	43	45	496	489	497	22.9	0.50			48.5
Facility 11	Surface Pump	3	45	50	54	493	489	497	27.0	0.51			52.0
Facility 12	Surface Pump	1	48	46	45	235	233	230	15.8	0.84			
Facility 13	Surface Pump	1	17	18	17	473	472	474	10.9	0.77			
Facility 14	Surface Pump	1	56	58	60	475	479	481	40.6	0.85			
Facility 14	Surface Pump	1	56	57	58	473	475	477	40.0	0.85			
Facility 15	Surface Pump	1	68	64	68	472	470	475	46.0	0.84			
Facility 10	Vertical Turbine Well	1	34	35	33	479	483	481	23.3	0.83			
Facility 10	Vertical Turbine Well	1	59	58	57	472	469	462	40.6	0.86			

Hydraulic Calculations / % of Rated Factors / Electrical Calculations

Owner	Site - Pump #	Pump Test No.	Q (gpm)	TDH (ft)	Wire-to-Water Efficiency	Horse-power (hp)	% of Rated Pump TDH	% of Rated Pump Q	% of Rated Motor hp	Average I (amps)	Average E (volt)	Average pf	Calculated Power (kW)	Measured Power (kW)	Measured % of Calculated Power (kW)	Energy Signature (kW-h/MG)
Facility 1	BPS - 1	1	2,445	53	36%	91	127%	79%	121%	92	472	0.90	68	68	100%	462
Facility 1	BPS - 2	1	5,000	52	57%	115		100%	92%	125	482	0.83	86	86	100%	287
Facility 1	BPS - 2	2	4,650	52	66%	93		93%	75%	110	447	0.82	70	70	100%	249
Facility 2	Submersible Well	1 - Avg.	335	282	88%	27		74%	90%	43	469	0.58	20	20	100%	1000
Facility 2	Submersible Well	2 - Low	335	277	87%	27		74%	90%	43	469	0.58	20	20	100%	1000
Facility 2	Submersible Well	3 - High	335	292	92%	27		74%	90%	43	469	0.58	20	20	100%	1000
Facility 3	Surface Pump	1	650	105	48%	36			120%	40	474	0.82	27	27	101%	690
Facility 3	Surface Pump	2	675	109	66%	28			94%	33	477	0.78	21	21	100%	521
Facility 3	Surface Pump	3	425	173	64%	29			97%	33	473	0.79	22	22	101%	851
Facility 6	Submersible Well	1	330	238	49%	40		41%		43	479	0.85	30	30	100%	1523
Facility 6	Submersible Well	2	220	297	44%	37		28%		40	477	0.84	28	28	100%	2106
Facility 6	Submersible Well	3	400	195	48%	41		50%		43	478	0.85	30	30	101%	1263
Facility 6	Surface Pump	1	440	145	50%	33			81%	34	473	0.86	24	24	101%	920
Facility 6	Surface Pump	2	440	115	41%	31			77%	33	473	0.86	23	23	100%	875
Facility 6	Surface Pump	3	400	178	54%	33			83%	35	472	0.87	25	25	100%	1029
Facility 4	Surface Pump	1	220	142	29%	27	81%	44%	108%	27	482	0.88	20	20	100%	1530
Facility 4	Surface Pump	2	186	168	31%	26	96%	37%	103%	26	481	0.87	19	19	102%	1723
Facility 4	Surface Pump	3	161	194	32%	24	111%	32%	97%	25	481	0.86	18	18	102%	1876
Facility 5	Submersible Well	1	150	437	44%	38			95%	47	477	0.72	28	28	101%	3144
Facility 5	Submersible Well	2	210	427	53%	43			108%	51	478	0.76	32	32	100%	2548
Facility 7	Surface Pump - 1	1	4,000	42	70%	60		100%	60%	87	480	0.61	44	45	101%	186
Facility 7	Surface Pump - 2	1	4,700	42	75%	67		94%	54%	91	482	0.60	46	50	110%	178
Facility 7	Surface Pump - 2	2	3,100	41	70%	46		62%	37%	62	484	0.58	30	34	115%	185
Facility 7	Surface Pump - 2	3	4,000	42	76%	55		80%	44%	75	485	0.59	37	41	111%	173
Facility 7	Vertical Turbine Well	1	4,000	129	76%	173			115%	163	473	0.93	124	129	104%	537
Facility 7	Vertical Turbine Well	2	3,600	124	81%	139			92%	129	475	0.92	98	104	106%	479
Facility 7	Vertical Turbine Well	3	3,100	119	88%	106			70%	97	479	0.92	74	79	106%	423
Facility 8	Vertical Turbine Well - 1	1	540	153	49%	42	305%	54%	56%	62	472	0.62	32	31	100%	972
Facility 9	Vertical Turbine Well - 2	1	1,500	113	61%	70		150%	117%	73	474	0.87	52	52	100%	583
Facility 9A	VT Well - 2 Booster Pump	1	1,500	6	2%	118			294%	26	315	0.71	10	88	871%	976
Facility 11	Surface Pump	1	420	106	48%	23	51%	34%	23%	32	499	0.47	13	18	136%	696
Facility 11	Surface Pump	2	490	129	52%	31	62%	39%	31%	42	494	0.50	18	23	128%	779
Facility 11	Surface Pump	3	515	146	52%	36	69%	41%	36%	49	493	0.51	21	27	126%	873
Facility 12	Surface Pump	1	1,000	42	50%	21			106%	46	233	0.84	16	16	101%	263
Facility 13	Surface Pump	1	1,550	9	24%	15	32%	91%	97%	17	473	0.77	11	11	100%	117
Facility 14	Surface Pump	1	1,025	124	59%	54			109%	58	478	0.85	41	41	100%	660
Facility 14	Surface Pump	1	1,025	124	60%	54			107%	57	475	0.85	40	40	100%	650
Facility 15	Surface Pump	1	1,200	175	86%	62		100%	103%	67	472	0.84	46	46	100%	639
Facility 10	Vertical Turbine Well	1	950	94	72%	31		100%	104%	34	481	0.83	23	23	100%	409
Facility 10	Vertical Turbine Well	1	1,600	139	103%	54		100%	109%	58	468	0.86	40	41	100%	423

ATTACHMENT B

PUMP AND MOTOR RATINGS

Facility	Facility Name	Pump No.	Rated Pump Capacity (gpm)	Motor Horse-power (hp)	Install-ation Year	Energy Analysis		Vibration Analysis		Overall Pump and Motor Rating	Wire-to-water Efficiency Rating	Vibration Rating
						Wire-to-water Efficiency	Energy Signature (kWh/MG)	Pump Vibration Amplitude RMS (mm/s)	Motor Vibration Amplitude RMS (mm/s)			
Facility 1	BPS	1	3,100	75	Unknown	36%	462	N/A	1.93	9.0	10.0	7.0
		2	5,000	125	2011	57%	287	N/A	2.78	4.7	5.0	4.0
Facility 2	Submersible Well Pump	1	450	30	1996/ 2012	88%	1,000	N/A	N/A	0.7	1.0	N/A
Facility 3	Surface Pump	1	ND	30	2011	66%	521	3.26	2.54	3.8	3.0	5.5
Facility 4	Submersible Well Pump	1	500	25	1960s	29%	1,530	3.76	1.77	8.0	10.0	4.0
Facility 5	Surface Pump	1	700	40	2004	53%	2,548	N/A	N/A	3.3	5.0	N/A
Facility 6	Submersible Well Pump	1	800	40	2007	48%	1,263	N/A	N/A	4.7	7.0	N/A
	Surface Pump	1	ND	40	2004	41%	875	12.94	6.55	8.0	7.0	10.0
Facility 7	Surface Pumps	1	4,000	100	2004	70%	186	1.99	2.59	2.0	1.0	4.0
		2	5,000	125	2004	75%	178	0.72	1.00	1.0	1.0	1.0
	Vertical Turbine Well Pump	1	ND	150	2003	76%	537	1.42	1.14	1.5	1.0	2.5
Facility 8	Vertical Turbine Well	1	1,000	75	1993	49%	972	1.45	2.69	6.5	7.0	5.5
Facility 9	Vertical Turbine Well	1	1,000	60	2001	61%	583	1.19	1.89	2.8	3.0	2.5
Facility 10	Hot Well 1	1	950	50	1975	72%	409	2.88	4.69	3.0	1.0	7.0
	Hot Well 2	1	1600	30	1985	103%	423	1.18	1.98	1.5	1.0	2.5
Facility 11	Surface Pump	1	1,250	100	1985	52%	873	3.11	2.30	5.2	5.0	5.5
Facility 12	Surface Pump	1	ND	20	2003	50%	263	1.19	3.38	4.7	5.0	4.0
Facility 13	Surface Pump	1	1,700	15	2005	24%	117	0.99	1.33	7.0	10.0	1.0
Facility 14	Surface Pump	1	ND	50	2002	59%	660	1.47	1.81	4.7	5.0	4.0
	Surface Pump	2	ND	50	2002	60%	650	0.28	0.41	3.7	5.0	1.0
Facility 15	Surface Pump	1	1,200	60	1980	86%	639	3.35	3.25	3.0	1.0	7.0

Wire-to-water Efficiency Legend
Greater than 70%
Greater than 60%
50% to 60%
40% to 50%
Less than 40%

Vibration Amplitude RMS Legend
Newly Commissioned
Unrestricted Operation
Restricted Operation
Damage Occurs

Overall Pump and Motor Rating
Excellent
Good
Average
Fair
Poor