ENERGY EFFICIENCY IMPROVEMENTS IN AGRICULTURAL PUMPS

DRAFT REPORT

A Study on Options & Techno-Economic Feasibility

For CIMATE WORKS FOUNDATION

Contract No.DAT-11-517

DATAMATRIX

Optimizing Energy and Water

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Summary Report

This document is prepared based on the study for improving the energy efficiency in Agricultural Pumps in India and the evaluation of its techno-economic feasibility under the Contract No. DAT-11-517 for Climate Works Foundation. The scope of the study covers the techno economic feasibility of energy efficiency improvement in agricultural pumps at five locations across four states in India. The states selected for the study are Maharashtra, Karnataka, Gujarat and Punjab having significant agricultural pump usage. The following figure depicts an overview of the findings against the back drop of the water stress across India.

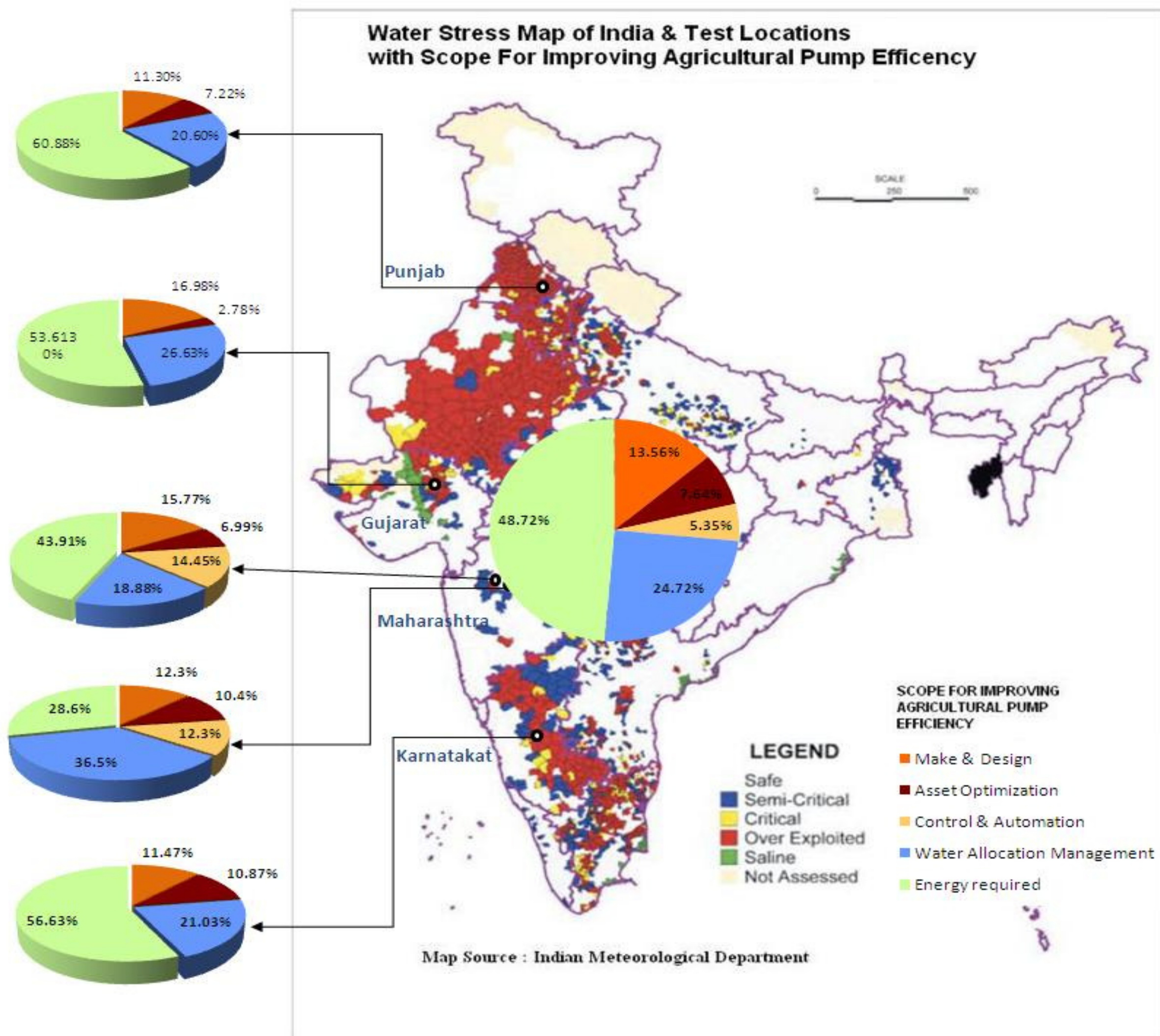

FIGURE 1: SCOPE FOR IMPROVING AGRICULTURAL PUMP EFFICIENCY

The study mainly involves the analysis of the characteristic behavior of selected pump sets and evaluation of various options for improving the performance of agricultural pumps. The scope for improved performance is analyzed against the following options and the findings from various states are tabulated below.

Efficiency improvement opportunities are assessed based on the following options under each village. Improvement scope indicated is the net achievable improvements within each village.

TABLE 1: SCOPE FOR IMPROVING AGRICULTURAL PUMP EFFICIENCY

A	Manufacturing & Design	Scope for Improvement (%) in Agricultural Pump Efficiency					
		Maharashtra Buchkewadi (Surface Water)	**Maharashtra** Gunjalwadi (Ground Water)	**Karnataka** Nagnur (Ground Water)	**Gujarat** Mehsana (Ground Water)	**Punjab** Patiala (Ground Water)	**Average**
1	Use Best Locally Available Design (Higher BEP)	9.82%	9.00%	2.75%	14.73%	5.32%	8.32%
2	Additional gain using BEE Star Rated Pumps	5.40%	0.40%	2.16%	4.43%	0%	2.48%
3	Scope for Improved Metallurgy	0.39%	1.56%	3.81%	Already Addressed	7.04%	2.56%
4	Scope for higher Operating Efficiency at points away from BEP	3.22%	2.25%	0.93%	0.37%	0.38%	1.43%
5	Scope for Improved Efficiency of the Motor	Not Studied Separately	Not Studied Separately	Not Studied Separately	Not Studied Separately	Not Studied Separately	
6	Enhanced Guarantee for the Pump set	2.28%	5.90%	4.30%	2.00%	1.00%	3.10%
B	**Asset Optimization**						
1	Pump Selection with Accurate Estimation of Head & Deterioration	6.55%	15.49%	6.77%	3.79%	0.38%	6.60%
2	Replacement of pumps after 10 years	2.07%	0.81%	6.99%	No scope	8.71%	4.65%
C	**Control & Automation**						
1	Use of Multi speed motors	17.81%	No Scope	No Scope	No Scope	No Scope	3.56%
2	Use of Level Based Controls	Negligible Scope	19.39%	Negligible Scope	Negligible Scope	Negligible Scope	3.88%

D	**Performance Management**						
1	Water Allocation Management	18.88%	36.46%	21.39%	26.63%	Cannot be estimated	25.84%
2	Integrated Approach	Optimum of all above	Optimum of all above	Optimum of all above	Optimum of all above	Optimum of all above	
	OVERALL IMPROVEMENT SCOPE	***56.09%***	***71.43%***	***43.37%***	***46.39%***	***39.12%***	***51.28%***

The net gain from improved energy efficiency of pumping system indicated above will be reduced to the extent of reduced water requirements through water allocation management.

The following pie diagram indicates knowledge based opportunities and material input based opportunities for improving the efficiency, against the energy required. Fresh material inputs are essential for the additional improvement using the BEE Star rated pumps and improved control and automation.

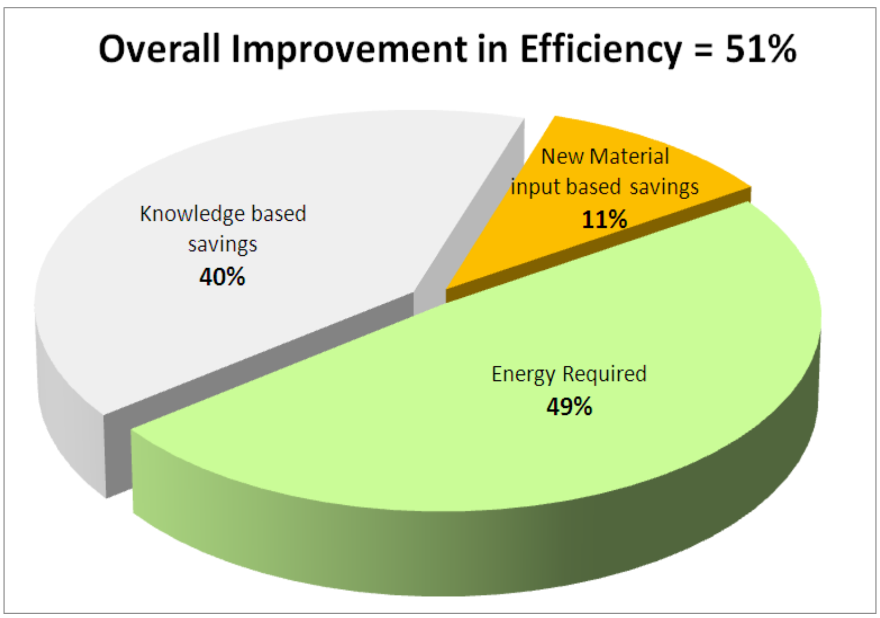

FIGURE 2: KNOWLEDGE BASED SAVINGS AGAINST NEW MATERIAL BASED SAVINGS

The above figure revels that the knowledge based inputs are most critical for improving the agricultural pumping efficiency across India. The findings calls for a distinct shift from the present replacement oriented approach to a knowledge based approach.

The key observations based on this study for improving the agricultural pump efficiency in India are detailed below.

KEY OBSERVATIONS FOR IMPROVING THE AGRICULTURAL PUMP EFFICIENCY IN INDIA

A. Improved Manufacturing & Design

1. **Design efficiency (BEP):** Better design efficiency in agricultural pumps can be easily availed by using the best locally available pumps with higher efficiency. This survey indicates that the dealer relationship, after-sales support and the ability of the pump to withstand the adverse power supply conditions are the critical factors influencing the pump sale and each village has their own favorite brands. The actual pump efficiency is yet to be a prime consideration in the buying decision and the national campaigns for higher efficiency pumps need to be realigned to target the Indian villages through innovative advertizing, campaigning and incentive schemes.
2. **BEE Star Rated Pumps:** The Star Rating program of BEE is an effective method of recognizing the efficient agricultural pumps. The opportunity for further improving the efficiency above the best brand in use at site using BEE Five Star rated pump for the rated conditions is explored in this report.
3. **Scope for Improved Metallurgy:** The study indicates that the pumps of different makes and models deteriorate at different rates resulting in lower operating efficiencies. Selection of the pumps with appropriate metallurgy suiting the local conditions is a key factor contributing to better operating efficiency during the life cycle of the pump, due to lower rate of deterioration.
4. **Operating Efficiency at different points:** The current pump performance criteria assess the performance only at one specified operating point; while the agricultural pumps are subject to varying heads with multiple operating points. A performance criteria as the average efficiency of the operating head range (at 80%, 90%, 100% and 110% of the rated Head) will be a better criteria to encourage better design of pumps to improve operational efficiency of the pumps. Using pumps with flatter efficiency curves leads to better operating efficiency as pumps operate at various operating points other than the BEP.
5. **Motor Efficiency:** Improvement scope in motor efficiency is not separately studied. The overall efficiency benchmark of the Star Ratings of BEE will address the performance of the motors in agricultural pumping.
6. **Enhanced Guarantee of the Pump Set:** There is frequent burning of the motor windings in several test sites primarily on account of the unstable power supply conditions. Manufactures have improved the motor design to address this challenge. The increasing trend of rewinding and deterioration with the age is adversely affecting the pump efficiency. Extended guarantee can encourage faster replacements of pump sets that indirectly results in improvement of efficiency, avoiding loss on account of excessive deterioration.

B. Asset Optimization

1. **Correct Estimation of Head:** Correct estimation of Head is critical for pump performance. The deterioration in pump performance and depletion of the ground water levels over a period are also critical factors to be considered. The data required for this is fragmented and inaccurate at present and there is a pressing need for compiling the data on ground water levels and recommended pump sizing based on specific criteria. An approval procedure for the new pumps can also be considered, under a subsidy scheme to ensure the optimum design criteria of the pump.

2. **Replacement of Pump after a specified age:** Replacement of Pump after a specified age will improve the overall pumping efficiency. The pump performance steadily declines over a period and several inefficient pumps are likely to be in service. The simplest way to improve the efficiency of the old pumps would be to influence the farmers through an appropriate incentive or penalty to replace the pump beyond a certain age.

C. **<u>Control & Automation</u>**

1. **Use of multi speed motors:** Multi speed motors are useful for low Head pumps with significant variation of water levels during the seasons. It can save sizable energy during the low head operations. This will also save water as the excessive discharge is avoided during the wet seasons when levels are high.
2. **Use of level based controls:** Level based controls can save energy, if the drawdown levels of the bore well is significant. The bore well pumps shall be ideally designed to balance the yield of the well against the pump discharge. However in reality there could be significant draw down of the water level and the pumps need to lift more head as the time of pumping increases, depending on the aquifer properties. The pumps can be switched off beyond a permissible level variation.

D. **<u>Performance Management</u>**

1. **Water Allocation Management:** Water allocation is the need of the hour for improving the pumping efficiency, as it can save both water and energy. The measurement of water is crucial for water allocation management. A metered regime aimed at equity in water supply based on the irrigated area will avoid the excess water usage and wastage. This will need a management process to allocate and monitor the water usage involving the farmers and the community. Water can be directly metered or indirectly measured using calibrated simulations.
2. **IWERM:** Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agricultural Water-Energy resource management, as the issues are intrinsically interlinked.

The detailed studies in the subsequent individual reports elaborate the derivations of the facts and figures outlined in the summary report. Further inferences specific to each site can be derived from the individual reports. Other perspectives which are not specifically covered in this summary such as the availability of efficient brands of pumps, location wise deterioration trends, voltage profile of different regions and the relative impact of pump failure, etc. can be derived based on the detailed reports.

This study is confined to the demand side management and supply side improvements are not considered under this study.

DISCLAIMER

This document does not intend to compare the performance of different manufacturers. The data is based on the site test data and can vary from the manufacturers claims on account of various factors at site. The name of the manufacturers will be deleted from the final document to be published.

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TERMS	DESCRIPTION
BEE	Bureau Of Energy Efficiency
BEP	Best Efficiency Point
MI	Minor Irrigation

1 Introduction

1.1 Background

This study is being carried out under the Contract No.DAT-11-517 for the Climate Works Foundation. The project was conceived and developed in close interaction with Prayas Energy Group, Pune (India).

1.2 Objective

The objective of this study is to identify and evaluate various options for improving the energy efficiency in Agricultural Pumps in India and evaluate its techno-economic feasibility.

1.3 Scope of the Study

The scope of the study mainly involves detailed testing of the pumps at site, analysis of the characteristic behavior curves of the pump sets in use for the selected samples.

The data is further simulated to arrive at the actual operating scenarios using Datamatrix Virtual Pump station. The scope for improved performance is analyzed against the following options:

A. Improve Manufacturing & Design
B. Asset Optimization
C. Control & Automation
D. Performance Management

The following tables summarize various options considered under this study

TABLE 2: PERFORMANCE IMPROVEMENT OPTIONS

A	**Improved Manufacturing & Design**
1	Use Best Locally Available Design (Higher BEP)
2	Additional gain using BEE Star Rated Pumps
3	Scope for Improved Metallurgy
4	Scope for higher Operating Efficiency at points away from BEP (Flatness of efficiency curves)
5	Scope for Improved Efficiency of the Motor
6	Enhanced Guarantee for the Pump set
B	**Asset Management**
1	Pump Selection with Accurate Estimation of Head & Deterioration during the service
2	Replacement of pumps after 10 years
C	**Control & Automation**

1	Use of Multi speed motors
2	Use of Level Based Controls
D	**Performance Management**
1	Water Allocation Management
2	Integrated Approach

1.4 Coverage

A survey will be carried out at four major agricultural zones of the country in the states of Maharashtra, Gujarat, Karnataka and Punjab. This report compiles the analysis of four zones in the state of Maharashtra, Karnataka, Gujarat and Punjab for the pumps as detailed below.

TABLE 3: VILLAGE DETAILS OF ZONE 1

Sr. No.	State	Name of Village	No. of Pumps in the Village	Pumps Included in the Detailed Survey	Pumps taken up for Detailed Testing	Remark
1	Maharashtra	Buchkewadi Village at Junnar	18	18	18	18 Pumps are used for the complete Irrigation of Buchkewadi Village from an MI Dam by 7 Co-operative Societies
2	Maharashtra	Gunjalwadi Village at Sangamner	73	4	4	The Village has 52 Bore wells, 21 Open wells with electrically driven Pumps. Four bore well are selected for the study.
3	Karnataka	Nagnur in Dharwad district	56	32	19	The village has 56 bore wells and all are used to irrigate the field using drip irrigation
4	Gujarat	Mehsana District	337	28	14	14 bore well pumps ranging from 12.5 HP to 40 HP at Mehsana are brought under the study for detailed testing and analysis.
5	Punjab	Mohali & Patiala	16	16	16	16 Bore well pumps are with capacity of 15HP and 20HP are selected for detailed testing.

The pumps under the study in Maharashtra are brought under the continuous monitoring of power supply conditions, water levels and the real time pump performance.

1.5 Pumps brought under the study

The pumps brought under the study were selected at random. The pumps brought under testing at various locations are classified under various categories A, B & C with the suffix such as A1, A2 and so on according to the descending order of manufacturer's best efficiency. The makers of the pumps will not be disclosed in public domain and it will be deleted from the final document to be published.

TABLE 4: MAKES AND CLASSIFICATION OF PUMPS TESTED

Sr No.	MAKE	Classification	HP	Type of Pump	Star rated pumps by BEE (Yes/No)
1	SHAKTI	A1	15	BOREWELL	Yes
2	KSB	A2	15	BOREWELL	Yes
3	CRI	A3	5	OPENWELL	Yes
4	Duke	A4	15	BOREWELL	Yes
5	Oswal	A5	15	BOREWELL	Yes
6	Kalsi	A6	15	BOREWELL	Yes
7	Sabar	B1	15,20,35	BOREWELL	Yes
8	Aroma	B2	15,20	BOREWELL	Yes
9	Calama	B3	5	BOREWELL/OPENWELL	No
10	Texmo	B4	5,7.5,10,15	BOREWELL/MONOBLOCK	Yes
11	PHILIPS	B5	10	BOREWELL	No
12	TULSI	B6	5	BOREWELL	No
13	Apara	C1	5	OPENWELL	No
14	TRIMURTI	C2	15	BOREWELL	No
15	KOHINOOR	C3	5	OPENWELL	No
16	USHA	C4	10	BOREWELL	No
17	APOLO	C5	15	BOREWELL	No
18	KAVERI	C6	15	BOREWELL	No
19	Ajanta	C7	15	OPENWELL	No
20	VIMAL	C8	15	BOREWELL	No
21	INDORA	C9	30	BOREWELL	No
22	TURBO	C10	40	BOREWELL	No

2 Approach and Methodology

2.1 Selection of the study location / village

The villages for detailed study were selected at random, within Maharashtra, Karnataka, Gujarat and Punjab; the four dominant states of agricultural pump usage in India.

2.2 Common characteristics of the village

Each village seems to be dominated by certain make of pumps according to the pump dealers, vendors and the support systems easily accessible to the village.

Each village has common factors that influence the energy usage and efficiency. The following points highlight the common factors that influence the Energy Usage in the village.

TABLE 5: FACTORS INFLUENCING THE ENERGY USE EFFICIENCY

- Rain fall
- Crop Pattern
- Water table
- Aquifer characteristics
- Water management practices
- Suppliers & Service support easily accessible

In view of the above common factors that influence the performance across the villages, the study is primarily grouped into different villages and further integrated for common analysis. Using this approach we are able to analyze the energy losses under each village cluster and attribute these losses against the improvement options.

2.3 The challenges

The major challenge for conducting this study is the availability of the pump data in terms the complete performance characteristics, a critical input for this detailed study. Almost all manufacturers in India provide only the Head Vs Flow characteristics data, while the Power Vs Flow characteristics are not published. Manufacturers are reluctant to offer this data for any study or analysis and the only feasible way is to test the pump at site. Detailed analyses where conducted at site capturing the complete characteristic behavior of each pump brought under testing. A survey conducted during the test at site collected the data on the age and the major failures, power supply conditions and other relevant information.

2.4 Tools used for the projects

This project is executed with the help of the following technology, tools and instruments.

TABLE 6: TOOLS FOR THE PROJECT

Type of Tool	Name of Tool	Usage
Testing Instrument Platform	Testing Rig with flow & Pressure Gauge & Throttling arrangement	Site test of Pumps Head v/s Flow
Level Gauge	Bore Well Water Level Gauge	Measurement of Bore well Water Level
Energy Meter	Energy Meter with Data Loggers	Site test of Motor Power v/s Flow
Software	Datamatrix Virtual Pump Station (Version 2.2)	Performance Modeling and Simulation of the Pumping System based on the test data

2.5 Testing of pumps

The testing of pumps is carried out in accordance with the standard engineering practices and the methods adopted by the energy auditors. However the test procedure is enhanced to pick up the complete head versus flow and power versus flow characteristics of the Pump using the throttling facility provided in the test Rig.

The open well pumps are tested for the full range from shut off to the fully open position of the delivery valve. The submersible bore well pumps are tested in the field from the operating head towards the shut off. Bore well pumps being a high head pump, excessive throttling towards the shut off can damage the well through pipe burst (PVC Pipes) and other complications. Hence the following method is derived for picking up the operating characteristic of the bore well pumps.

The bore well pumps are throttled to the extent of 20 % above the operating head in 3 to 5 steps and the head v/s flow and power v/s flow readings are recorded. This data is used in the Datamatrix Virtual Pump Station to simulate the full behavior curves of the pump. The characteristic behavior of each pump is unique and 3 test points can identify the full curve using the Datamatrix software. More points will help to validate the accuracy and reliability of the test data by examining the points falling out of the curves

2.6 Performance Analysis

Datamatrix virtual pump station software is used to simulate varying scenarios under real time operating conditions.

Datamatrix Virtual Pump Station is built against each village brought under the study. The Datamatrix It is configured with the site test data of each motor pump system. The Datamatrix virtual pump station is capable of simulation and modeling the performance of the pumping systems under varying operating scenarios with change in water levels, supply conditions, usage patterns etc.

The Datamatrix virtual pump station is capable of modeling the real time pumping scenarios that simulate all the operating parameters against the energy input to the motor. The sample study conducted in Maharashtra is put under real time, monitoring, and analysis, using continuous logs of energy data of the connected pumps. The study carried out in Maharashtra is validated against real time operational data.

2.7 Performance Simulations

The modeling facility of the system is also used for analyzing the optimum solutions against various performance improvements options as discussed in Table 2.

Performance Simulations are carried out on all pumps brought under this study, duly configured with the Site test data against the respective village. The test data from various test locations are subjected to calibrated simulations to accurately analyze the performance under varying scenarios.

Following Screen Views shows Real Time Performance Simulation Pump No.4 at Gunjalwadi, Maharashtra, using Datamatrix Virtual Pump Station.

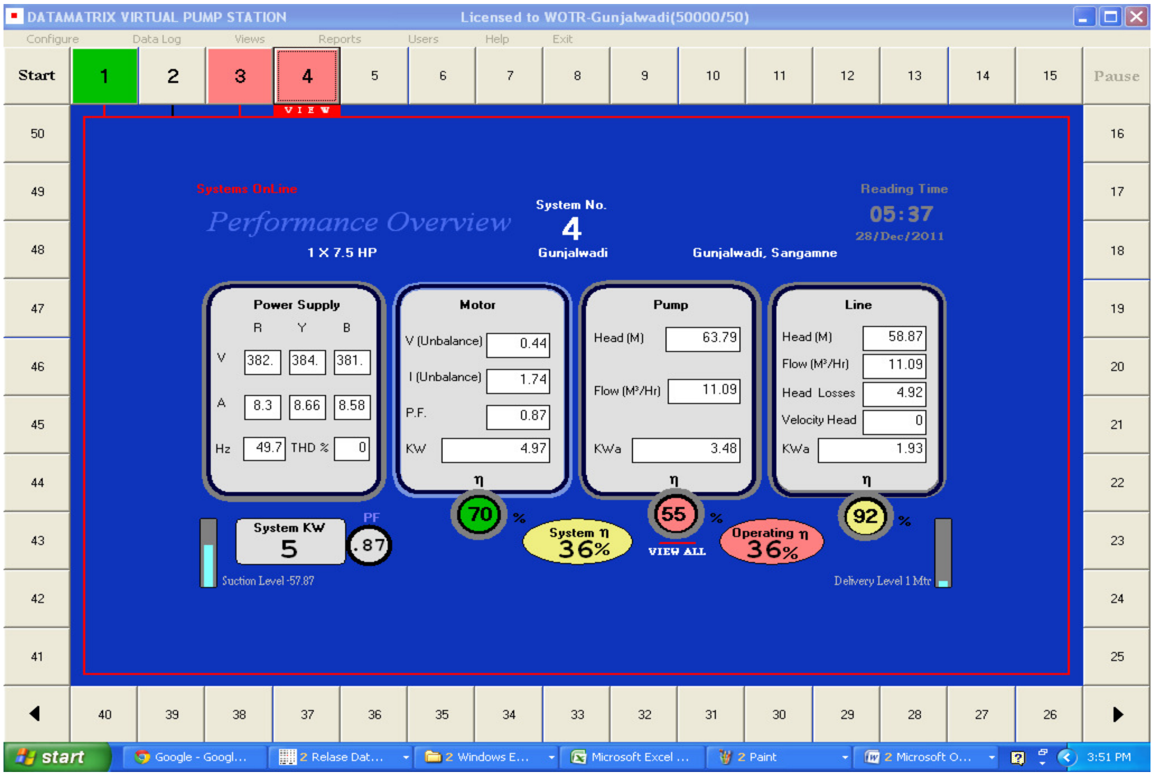


FIGURE 3: PERFORMANCE OVERVIEW DASHBOARD

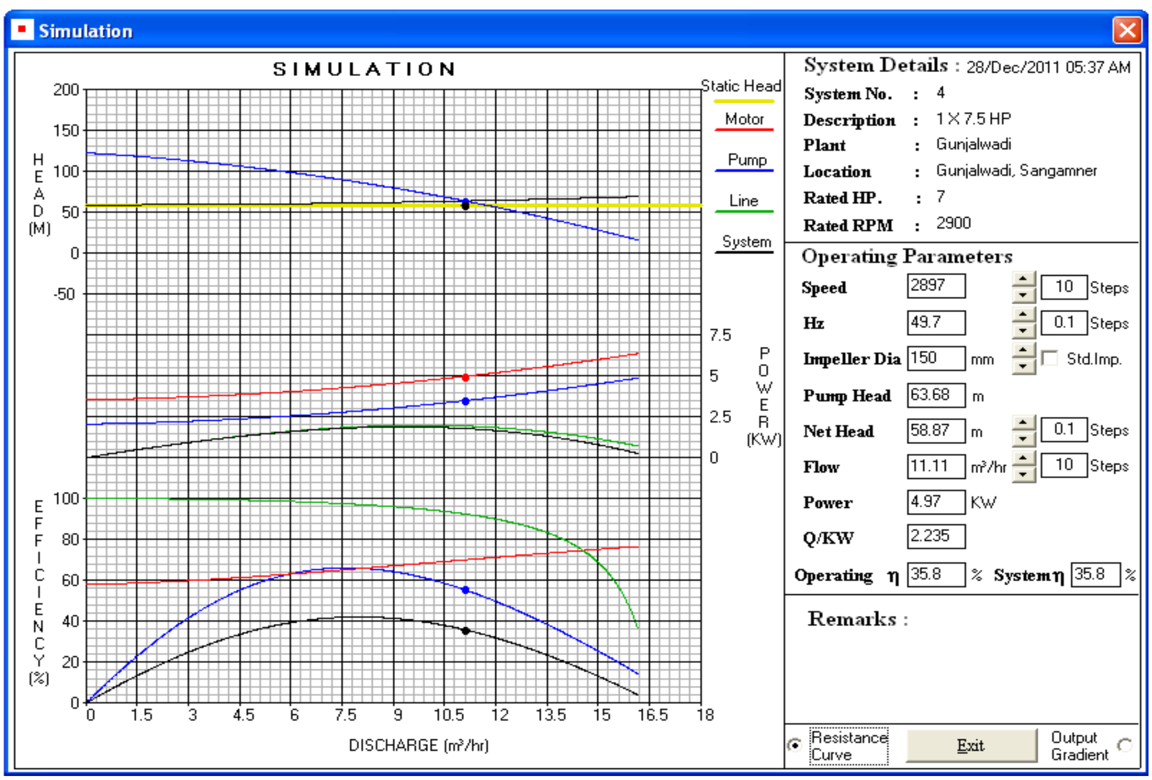


FIGURE 4: PERFORMANCE SIMULATION FOR AN OPERATING INSTANT OF PUMP 4

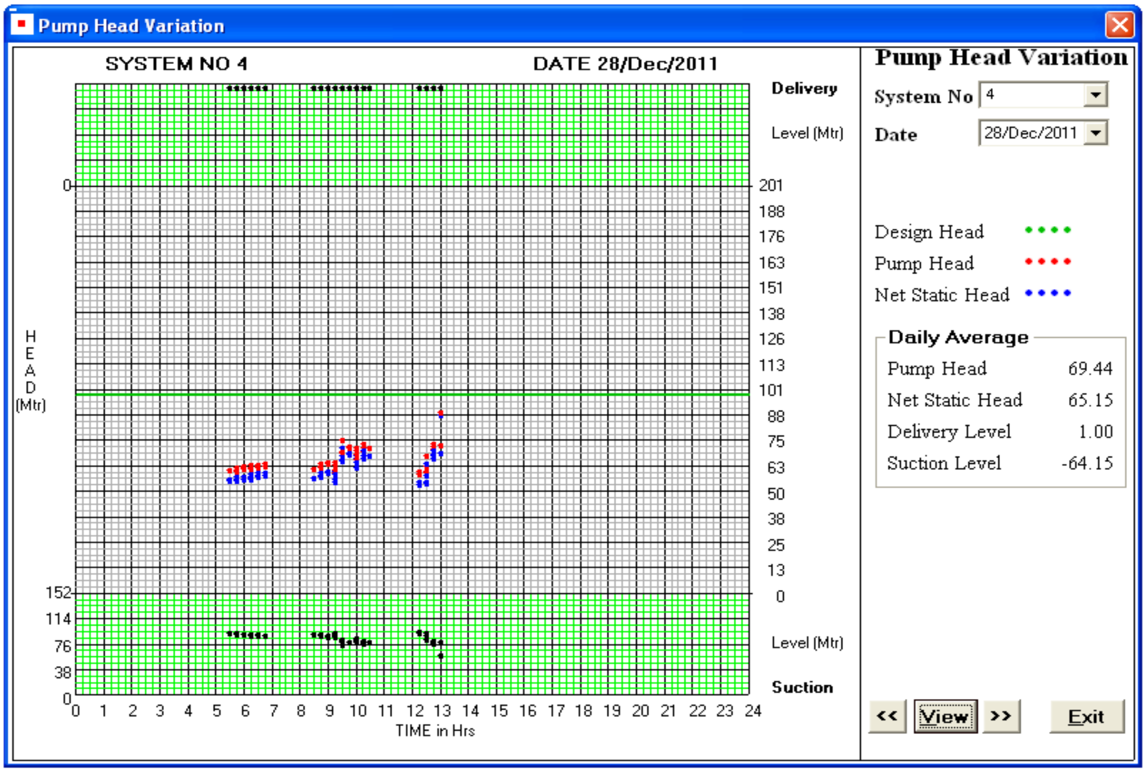
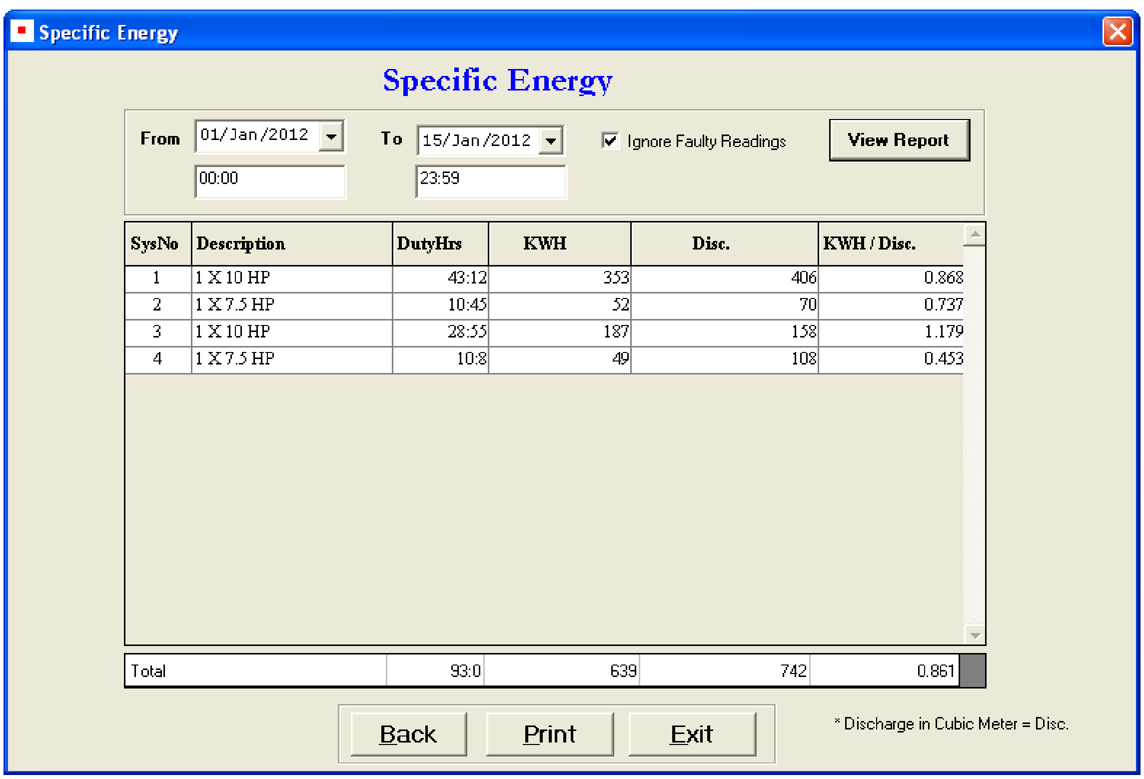


FIGURE 5: DAILY PUMP OPERATION WITH PUMP HEAD AND GROUND WATER LEVEL FOR PUMP NO. 4



SysNo	Description	DutyHrs	KWH	Disc.	KWH / Disc.
1	1 X 10 HP	43:12	353	406	0.868
2	1 X 7.5 HP	10:45	52	70	0.737
3	1 X 10 HP	28:55	187	158	1.179
4	1 X 7.5 HP	10:8	49	108	0.453
Total		93:0	639	742	0.861

FIGURE 6: SPECIFIC ENERGY CONSUMPTION OF GUNJALWADI PUMPS

3 Buchkewadi Village

Buchkewadi Village with a population of 1625 is located in Junner taluka, Maharashtra. The water requirement of the entire village is met through a minor irrigation dam built under a US-AID program. 18 Pumps ranging from 5 to 15 HP irrigate the entire village, under eight cooperative societies.

FIGURE 7: BUCHKEWADI PUMP TESTING

The site survey was conducted in mid October and detailed tests were conducted at site from 10th November 2011 to 22nd November 2011. We are thankful to Ms. Asha Tai Buchke the elected member of the block, Mr. Suresh Gaikwad, the Panchayat president and water committee for their full support and cooperation for the program.

The water allocation is done under the Village Panchayat through the cooperative societies and the farmers get the water supply by rotation. According to a sharing arrangement under the US AID Program, Buchkewadi is entitled for 40% of water and the nearby villages share 60% of the water through a controlled water canal. The pumps at Buchkewadi will irrigate nearby fields and are allowed to use them only for a period of six months and the remaining time in year the pumps are disabled to preserve water for the drinking water and live stock needs of the village.

The following Table lists the pumps surveyed and subjected to extensive testing at Buchkewadi village.

TABLE 7: LIST OF PUMPS SURVEYED & TESTED AT BUCHKEWADI

Sr. No	Pump No	Name of Village	HP	Type of Pump	Year of installation	Age	Pump reference
1	Pump1	Buchkewadi	10	SUBMERSIBLE	2008	4	B4
2	Pump2	Buchkewadi	10	SUBMERSIBLE	2006	6	B4
3	Pump3	Buchkewadi	7.5	SUBMERSIBLE	2007	5	B4
4	Pump4	Buchkewadi	5	SUBMERSIBLE	2002	10	A3
5	Pump5	Buchkewadi	5	SUBMERSIBLE	2011	1	C7
6	Pump6	Buchkewadi	7.5	MONOBLOCK	2006	6	B4
7	Pump7	Buchkewadi	5	SUBMERSIBLE	2009	3	B4
8	Pump8	Buchkewadi	12.5	MONOBLOCK	2009	3	B4
9	Pump9	Buchkewadi	5	SUBMERSIBLE	1990	22	?
10	Pump10	Buchkewadi	12.5	MONOBLOCK	1990	22	B4
11	Pump11	Buchkewadi	12.5	MONOBLOCK	2007	5	B4
12	Pump12	Buchkewadi	5	SUBMERSIBLE	2009	3	B4
13	Pump13	Buchkewadi	15	MONOBLOCK	1990	22	B4
14	Pump14	Buchkewadi	5	SUBMERSIBLE	2009	3	C3
15	Pump15	Buchkewadi	10	SUBMERSIBLE	2008	4	B4
16	Pump16	Buchkewadi	7.5	SUBMERSIBLE	2004	8	B4
17	Pump17	Buchkewadi	5	MONOBLOCK	2009	4	B4
18	Pump18	Buchkewadi	5	SUBMERSIBLE	2007	6	C1

The following figure indicates the simulated water usage at Buchkewadi throughout the year.

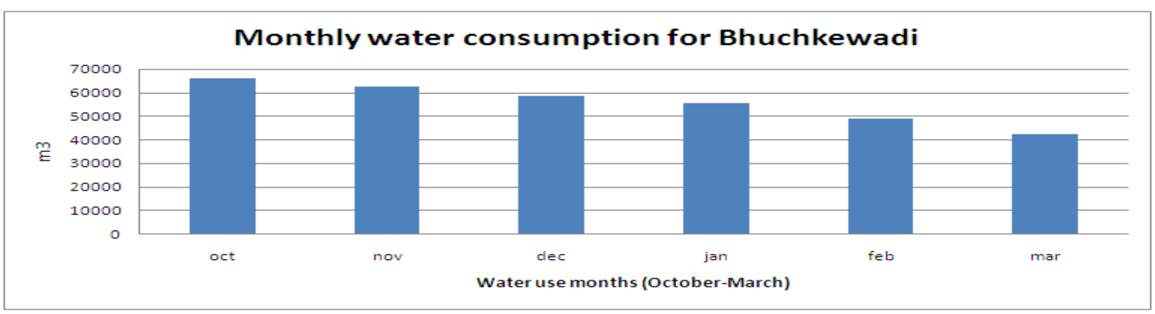


FIGURE 8: MONTH WISE WATER CONSUMPTION

The pumping systems of Buchkewadi are brought under the study with detailed testing and analysis. The total water usage and the depletion of the water levels are available from the water level measurements at the dam site. The energy and water consumption, operating efficiency of the pump sets during the wet and dry season and the water use efficiency, as per the water levels recorded are simulated using Datamatrix Virtual Pump Station.

The following figure highlights the water and energy consumption as well as the performance levels of the pumping systems during the year for an operating cycle of six months, from Dry to wet season.

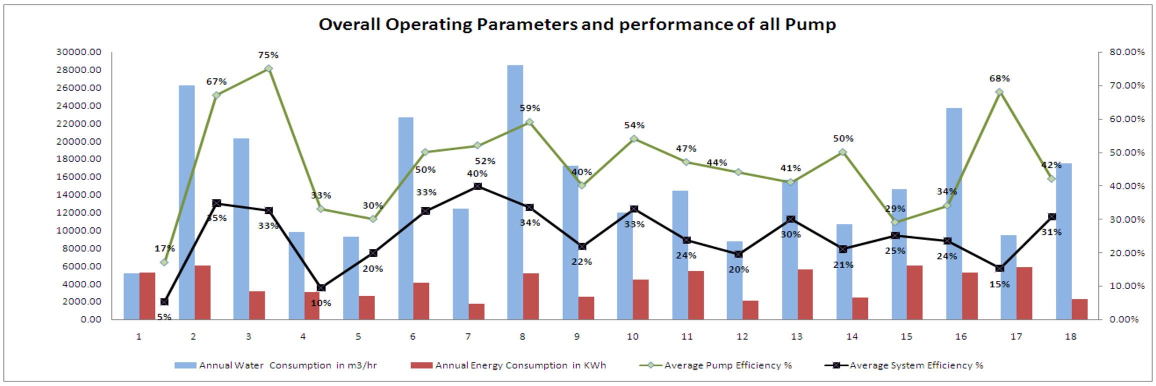


FIGURE 9: OVERALL ANNUAL PUMP PERFORMANCE OF BUCHKEWADI PUMPS

Following performance improvement options are evaluated under this study.

3.1 Scope for Improved Manufacturing Design

The scope for improved manufacturing design for the pump sets studied in the village has been assessed from the following perspectives.

1. Use Best Locally Available Design (Higher BEP)
2. Scope for Improved Metallurgy
3. Scope for higher Operating Efficiency at points away from BEP
4. Improved Efficiency of the Motor
5. Enhanced Guarantee for the Pump set
6. Additional gain using BEE Star Rated Pumps

3.1.1 Use Best Locally Available Design (Higher BEP)

The design efficiency/best efficiency of the pump set varies from manufacturer to manufacturer for each pump model based on the rated head and flow of each pump.

The manufacturers of the agricultural pumps in India publish only head flow characteristics, while the power consumption data is not provided. The pump curves are constructed based on the site test data by plotting the characteristics of each pump set and assessing the actual deterioration of pumps at site, to extrapolate the original conditions. The following figure shows the BEP of each pump plotted against its corresponding age for two major makes of similar ratings of the pumps at site.

The majority of the pumps used in the Buchkewadi village are of make classification B4 open well submersible and monoblock type. The following figure depicts the deterioration in efficiency over the age of the pump.

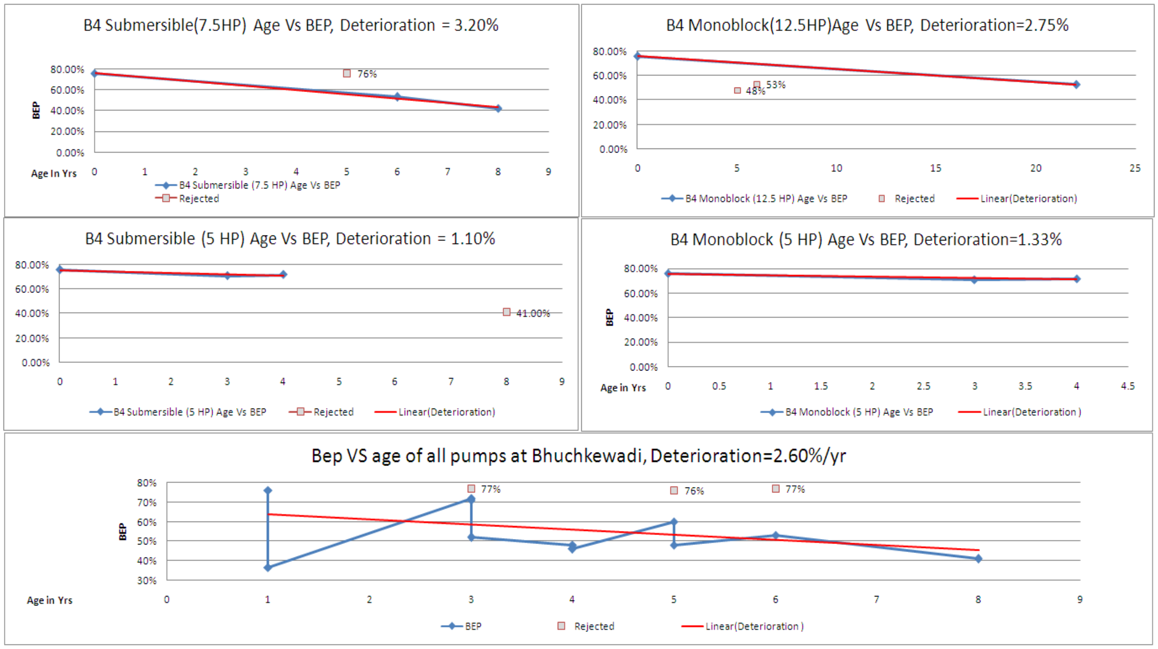


FIGURE 10: BEP OF EACH PUMP PLOTTED AGAINST ITS CORRESPONDING AGE

The above figure indicates the average deterioration rate of B4 make of pumps is 2.32% per year slightly better than other locally available pumps at 2.6%. The data provides a critical insight into the life of the pump under the site conditions and also enables to estimate the efficiency the pump across different time zones during its life cycle.

The following table compares the Best Efficiency and the deterioration of the dominant make of pump sets (B4) in the region against the average deterioration rate of other makes.

TABLE 8: SCOPE FOR IMPROVEMENT IN DESIGN EFFICIECNY

Make code	Average Age in yrs	Average Current Overall BEP eff.	Deterioration rate of BEP Efficiency Per year	Manufacturers Overall BEP (Extrapolated)
B4	4.54	61.91%	2.32%	72.44%
Others	2.5	56.13%	2.60%	62.62%

Observations

- The Scope for improvement in higher BEP for the pumps according to the best available pump in the village is 72.44% -62.62% = 9.82%

3.1.2 Scope for improved Metallurgy

The deterioration of a pump is largely dependent on its metallurgy and the pump operating conditions. A better understanding of the pump performance deterioration enables selection of the optimum pump for the optimum performance across its life cycle.

The following analysis on pump deterioration is based on the preceding section (3.1.1). The projected efficiency of the major brand B4 against the other pumps brought under the study is tabulated in the following table. The effective improvement in efficiency is considered over its Life Cycle of 10 years with the impact of deterioration (Refer to Figure 9).

TABLE 9: SAVINGS ON ACCOUNT OF IMPROVED METALLURGY

Make of Pump	Deterioration rate of BEP Efficiency	Initial BEP Efficiency at the start of operation	Final BEP Efficiency at the end of 10th year	Losses on account of machine deterioration at 10th year
B4	2.32%	72.44%	49.24%	23.20%
Others	2.60%	62.63%	36.63%	26.00%
Savings	**0.28%**	**-9.81%**	**-12.61%**	**2.80%**

The rate of deterioration is mainly dependent on the metallurgy of the pumps used in a similar operating environment. It is quite evident that B4 group of pumps have better metallurgy to withstand deterioration in efficiency under the specific conditions in the village. Replacing all other pumps by the same make as that of B4 would yield an estimated 2.80% increase in efficiency.

Coating of pump interior with special coating material that gives a smooth and tough surface resisting abrasion will reduce the deterioration rate. None of the Buchkewadi pumps where internally coated and this aspect could not be studied.

Observations

- The saving during a life span of 10 years is estimated as (2.80%/2) = 1.40%.
- The average gain in efficiency on 18 pumps by replacing 5 pumps by B4 pumps would be (2.80% x 5/18).= 0.39%

3.1.3 Scope for higher Operating Efficiency at points away from BEP (Flatness of efficiency curves)

The following figure shows the variation in efficiency from tested BEP for -50% to 50% head variation from the best efficiency point of various pumps at Buchkewadi.

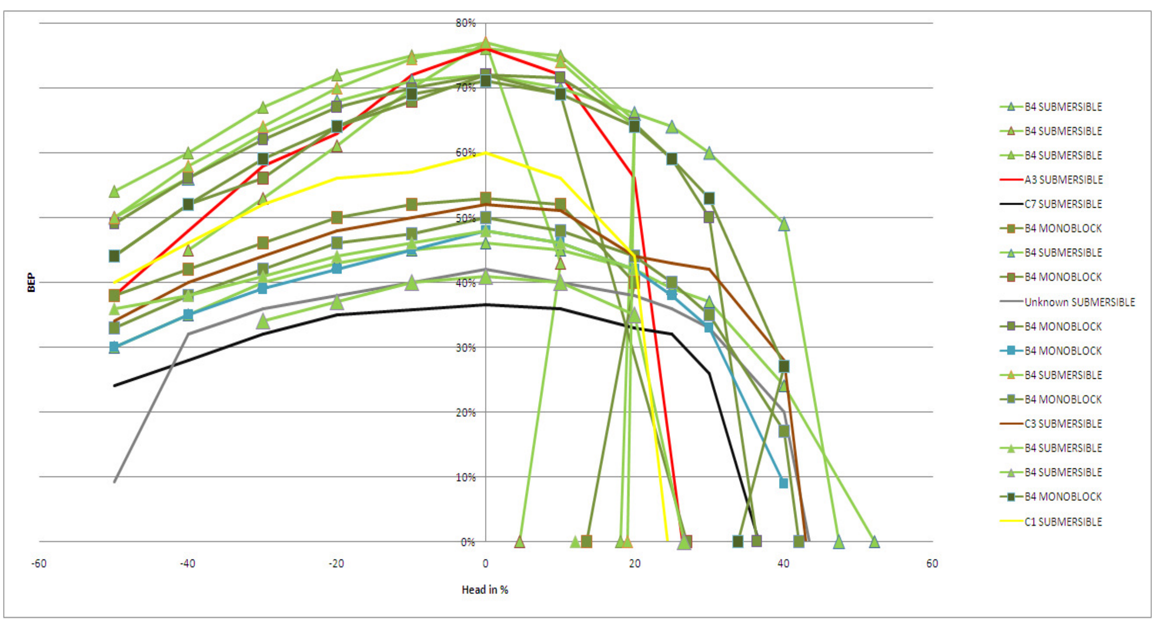


FIGURE 11: EFFICIENCY VS % VARIATION OF BEP HEAD

Observations:

- The drop in efficiency is more drastic when the head increases beyond BEP head.
- Flatness of the efficiency curves depends on a particular pump model and design of the manufacturer for a specified duty requirement (Head & Flow).
- Considering multiple operating heads (Design Point +10%, -10% and -20% of Head) for a cluster of pumps having almost same BEP the savings on account of variation in heads in terms of pump efficiency would be 3.22 % (i.e. difference between most flat curve and average flatness of remaining pumps in the same cluster)
- The flatness of the efficiency curves will be improved by manufacturers, if the criteria for fixing the performance of the pump only at one point are changed to performance at multiple operating points.
- The criteria for performance may be the average operating efficiency across an operating range.

3.1.4 Scope for improved efficiency in Motor

The pump sets used in Buchkewadi village are either mono block or submersible pumps. The detailed testing of the motor is not possible at the field conditions.

3.1.5 Enhanced Guarantee for the Pump set

The survey conducted at Buchkewadi reveals that the pump is generally taken out of service for repairs mainly for rewinding. The pump failures were analyzed with regard to the age of the pump and the data is represented in the following chart.

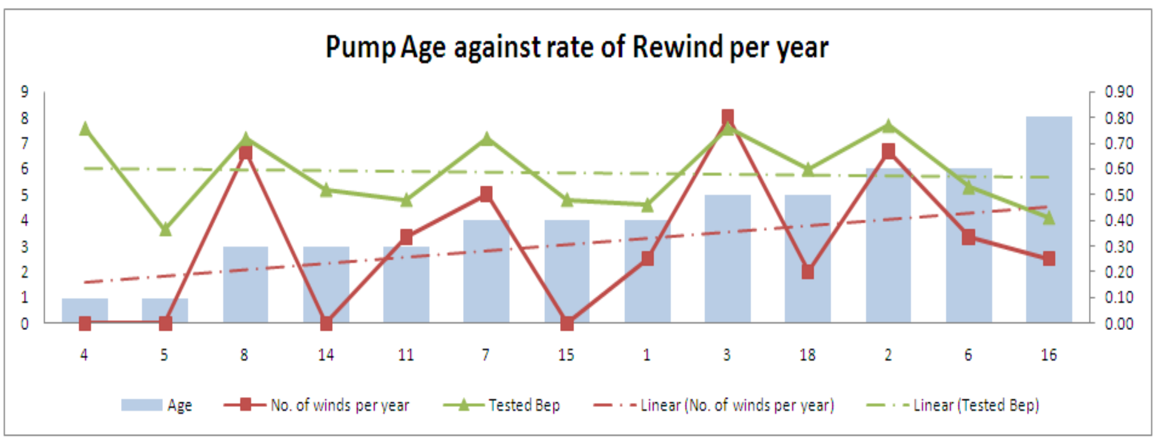


FIGURE 12: PUMP AGE AGAINST RATE OF REWIND PER YEAR

The Y- axis represents the age of the pumps (scale to the left) and X-axis represents the pumps in use with their age represented by the bar graph. The failure rate is represented as the average rate of rewinding per year as indicated by the dark dotted lines.

From the above figure it is clear that the rate of failure at Buchkewadi has an increasing trend against age of the pump. The following table indicates the average rewinding rate of motors per year per pump.

TABLE 10: AVERAGE RATE OF FAILURE OF PUMPS AT BHUCHKEWADI

Total No. of pumps at Buchkewadi	Average age of Pumps at Buchkewadi	Average Number of Failures per pump/year
18	7.4	0.3

The failure rate is also greatly influenced by the power supply conditions at site. The following table represents the average fluctuations in power supply conditions observed along the peak power supply variation for Buchkewadi, with the corresponding failure rate.

TABLE 11: CORRELATION OF FAILURE RATE AGAINST SUPPLY CONDITIONS

Project	No. of Pumps	Average Age (Yrs)	Average failure Time(Yrs)	Average Voltage variation (%)	Peak Voltage Variation (%)
Buchkewadi	18	7.4	0.5	22.58%	52.95%

To be compared against the study on other villages.

Observations:

- The slope of the trend line in figure12 indicates the rate of failure at Buchkewadi increases by 2.10% every year while the effective efficiency of the pump decreases by 0.18%.
- Extended guarantee will encourage advancement of replacement of pumps.
- The overall advancement of procurement on pump by 10% will give an overall gain of (2.10% + 0.18%) = 2.28%; considering that the cost of down time and repairs are comparable with the energy cost paid by the farmers.

3.1.6 Additional gain using BEE Star Rated Pumps

The Star Rating program of BEE is an effective method of recognizing the efficient agricultural pumps. Majority of the pumps found at Buchkewadi Village are of B4 Brand, which is among the Star rated brand by the BEE. The opportunity for further improving the efficiency above the best brand in use (B4) by using BEE Five Star rated pump for the rated conditions is tabulated below.

TABLE 12: OVERALL EFFICIENCY COMPARISON WITH RATED BEE PUMPS

Make Code	Overall Efficiency of Best Pump At Site (B4 Pump). (a)	Overall Efficiency of Five star rated Pump (b)	Scope of improvement in efficiency (b)-(a)
B4	53.90%	59.30%	5.40%

Observation

- BEE has several pumps with different performance levels (Efficiency) in the rated conditions of the pump considered. The weighted average efficiency of the available Five Star pumps is considered for the benchmark.
- The net scope of improvement in efficiency over best locally available pump (B4) and BEE five star rated pumps is 5.40%.

3.2 Asset Optimization

Each pump is designed to work for a specific design head and flow requirement. If there is a mismatch in the range in which the pump is operating against its design head, the performance of the pump will drop dramatically. Thus imperative for optimum efficiency is selecting the right pump for a well defined head and flow range.

The above factors greatly influence the performance of the pumps over a period of time. The pump performance can be improved by appropriate decision making by precise selection of the pump for optimum performance, considering the duty conditions during its life cycle. The following sections evaluate the opportunities to improve the energy efficiency by various asset management options.

3.2.1 Pump Selection with Accurate Estimation of Head & Deterioration During the service

The following figure represents the change in efficiency plotted against the operating head. The new pumps are represented in darker colors and the older pumps are in light colors. The deterioration of pumps has a tendency to compress the performance curves towards the Zero Head & Efficiency. The efficiency drop suddenly, after the pump operating point crosses over the BEP towards the shut off (on the right side of the following figure).

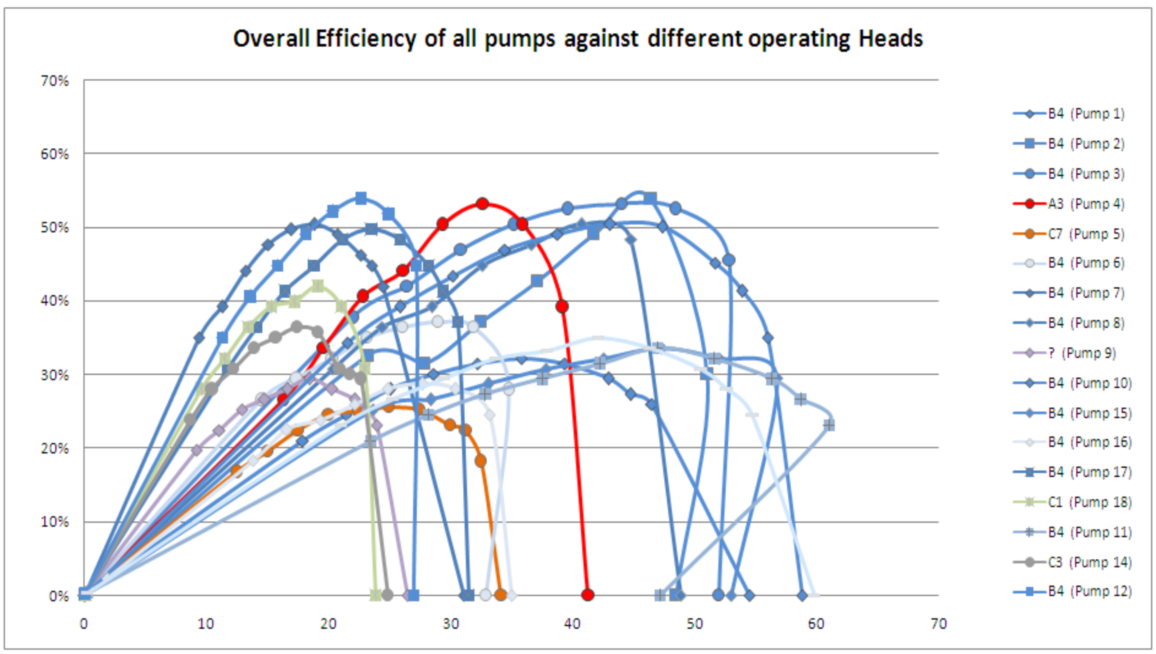


FIGURE 13: EFFICIENCY OF ALL PUMPS AGAINST OPERATING HEADS

The current practice of selecting the pump in the village is based on the feedback on the pumps used by other farmers in the vicinity. Some of the farmers select a pump based on the initial feel on the water level and head as advised by the local dealer, based on this preliminary information. This approach grossly ignores many factors influencing the performance of the pumps over a period of time leading to huge losses incurred on account of inappropriate selection of pumps.

The following figure represents the present losses on account of pump operation away from the BEP resulting in operation at considerably lower BEP of the pump.

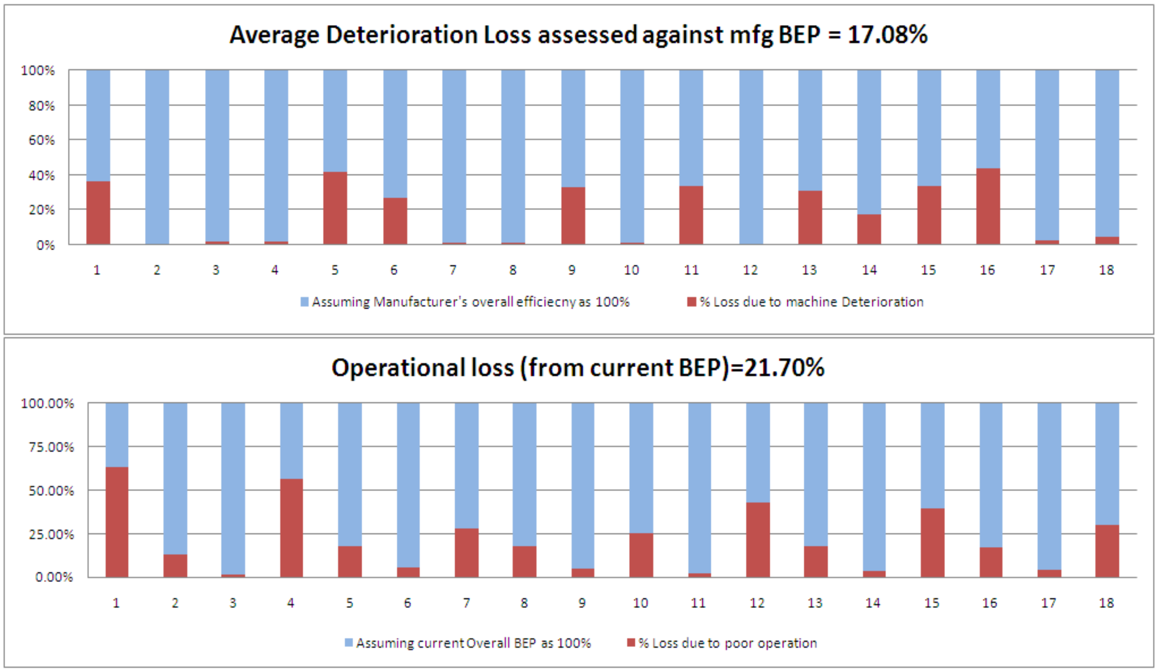


FIGURE 14: SCOPE FOR ASSET MANAGEMENT

Going only by the current situation would be misleading, as all pumps are subjected to continuous deterioration. The challenge here is to accurately select a pump which will operate at the best possible efficiency during its lifecycle.

The following Figure indicates the BEP of installed pumps at Buchkewadi with its corresponding efficiency (operating efficiency in blue). The graph also indicates the BEP against the proposed head of (excess 30% head above BEP suggested) indicated in Red. The current BEP efficiency levels are indicated in green.

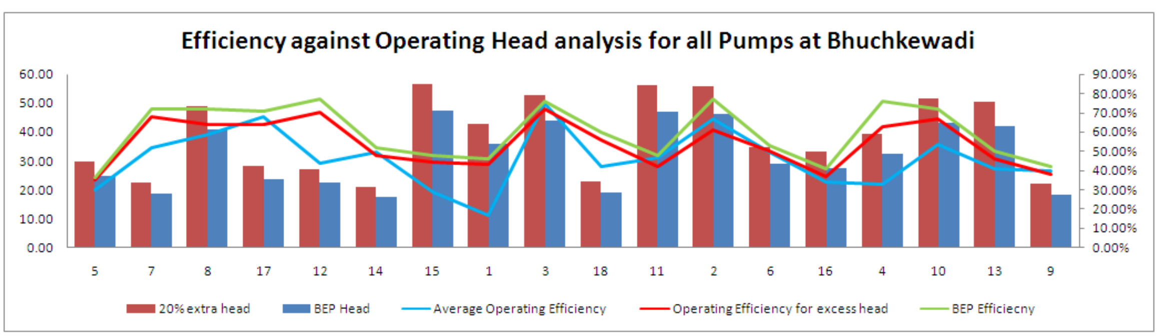


FIGURE 15: AGE-WISE DETERIORATION OF CURRENT BEP AND PROPOSED BEP PUMPS

The existing scenario has an average 13.19% operational loss (due to operations away from BEP). Incase if the pumps are selected with 30% higher head from the BEP, it will have an operational loss of 5.64% (due to operations away from BEP), effectively across the entire operating life.

Observations

- It is observed that the head producing ability of a pump drops as its age increases causing the operating point to shift away from its BEP.
- Now if we select a pump having 30% more head producing capacity, it will run more efficiently over the operating years as shown in the above figure.
- From the above figure, the current operating efficiency (indicated in Blue) is operating at an average of 13.19% away from the BEP (indicated in Green) while the proposed 30% excess head (indicated in Red) will be is only 5.64% away from BEP.
- It is estimated that the operating point of oversized pumps will be only 5.64% below BEP as compared to 13.19% below BEP on the current situation.
- The improvement in efficiency on account of selecting pumps 30% additional head from BEP is estimated as (13.19% - 5.64%) 6.55%.

3.2.2 Replacement of pumps after 10 years

Pump replacement is the easiest way to achieve better efficiencies. However the gains from replacement is influenced by many factors such as the pump deterioration, the variation in the water tables, shift in the operating point due to these factors and the analysis can be quite complex. To strike a golden mean between the ad hoc pump selections as practiced today and a complex analysis as carried out here, a simplistic approach can be derived. This may be tackled in the next stage of this research program.

The deterioration factors and the increasing maintenance cost over the time, studied under this report emphasis the need for a periodical replacement of the pumps. Ideally the periodical replacements shall be according to the deterioration rate in each location. However an upper limit shall be determined to limit the age of a pump. The government policies and programs shall be aligned to address this aspect as well.

Observations:

- It can be observed from the figure13 that the pump performance drops drastically as the operating point of the pump shifts from BEP towards the shut off. As the pump deteriorates, the ability of the pump to lift water is affected, resulting in substantial reduction in flow rate and efficiency.
- The suggested age of replacement of inefficient pumps by locally available best performing pumps is 10 years i.e. those pumps older than 10 years are to be replaced best by the best performing brand (B4) of new pumps, available in the locality.

TABLE 13: SAVINGS ON ACCOUNT OF MACHINE REPLACEMENT AFTER 10 YEARS

Average Age of the Pumps	Number of Pumps older than 10 years	Average age of these pumps older than 10 years	Average overall efficiency of these pumps(A)	Manufacturers overall BEP Efficiency (Extrapolated) (B)	Savings on account of replacement of machines after 10 years (B-A)
7.4	3	22	38.27%	50.71%	12.44%

- The effective gain on entire Buchkewadi site by replacing 3 low efficiency pumps older than 10 years is (12.44% x 3/18) = 2.07%

3.3 Use of multi speed motors

Buchkewadi village water requirements are met through a Minor Irrigation Dam. There is a substantial variation in the operating head during the seasons.

The following figure highlights the speed reduction and its effect on the operating head, flow and the corresponding efficiency of the tested pumps. The speed reduction will be achieved by providing 2 speed motors having 2 pole and 4 pole options.

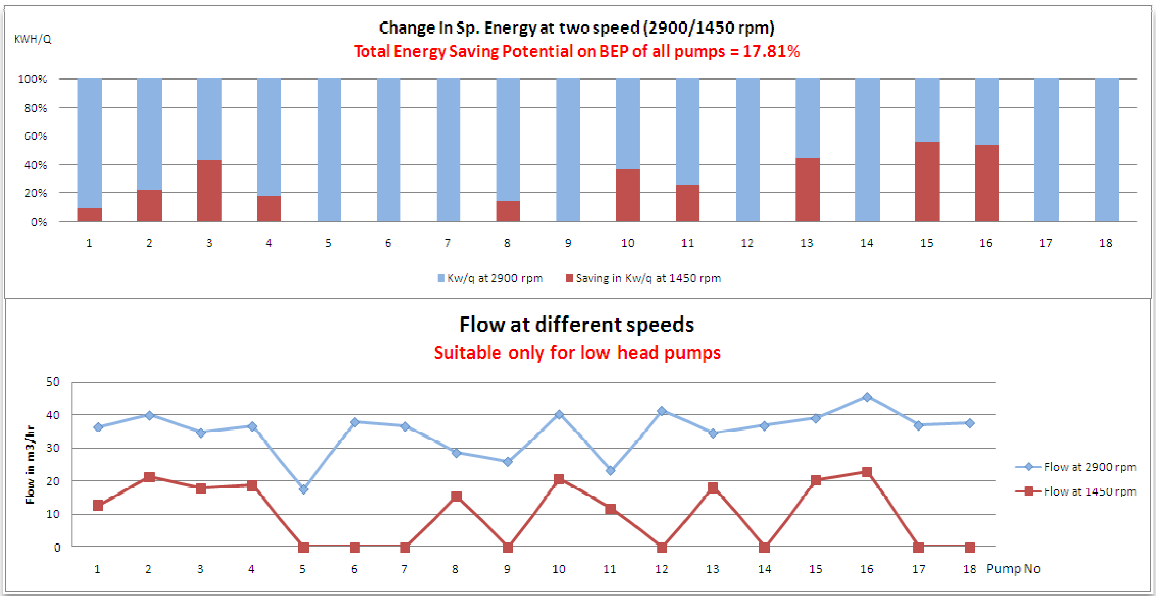


FIGURE 16: EFFECT OF SPEED REDUCTION ON BUCHKEWADI PUMPS

Observations:

- The use of 2-speed motors will bring in a substantial savings for low head pumps
- Two Speed Motors are not suitable for high head pumps
- The low operating head during the wet season has a tendency to discharge more water during wet seasons as against lower water requirements. Use of two speed motors will also correct the reverse trend of water use as against the water need from wet to dry season.
- Power and flow values were simulated for BEP at both 2900 and 1450 rpm (speed) using Datamatrix virtual pump station and the overall saving potential is observed as 17.81%

3.4 Water Allocation Management

The following table shows the water usage against the land holding and water requirements, estimated as a proportion of the cultivated area.

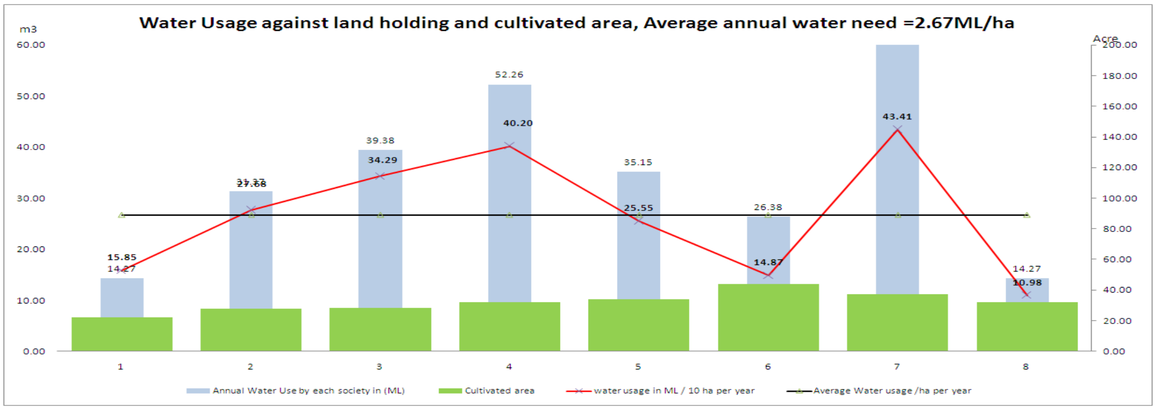


FIGURE 17: WATER DISTRIBUTION PATTERN ACROSS BUCHKEWADI

The above figure indicates the irrigated land and the water usage. The average line is drawn taking into account of the average water use per hector. This excessive water usage above the average is considered as the excessive irrigation.

The water allocation can be done based on the land holding, cultivated portion and the specific 00water need estimated under each pump set. This can lead to substantial water savings with a resultant saving in energy.

Observations:

- The above figure clearly indicates the need for equitable distribution of water.
- Equitable distribution shall save substantial water and energy required to deliver it.
- The annual water usage per society/acre is calculated by taking the ratio of the total amount of water consumed and total irrigated land used by each pump.
- The excess water consumption above the average can be easily avoided.
- The water and the corresponding energy savings (by avoiding the excess water usage from average) through equitable water distribution is estimated to be 18.88%.

3.5 Other Opportunities

The frictional loss in the pipe line is estimated to be less than 3.00% of the total energy usage and do not have any appreciable scope for improvement.

There is an appreciable scope for energy management on the supply side for Buchkewadi village considering the low voltage (Refer to table-5). The saving can be achieved with the present distribution networks by staggering the loading of pumps. The saving opportunity under Supply Side is not covered under this study. There is a pressing need to improve the power distribution network at the feeder level.

Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agriculture Water-Energy resource management, as the issues are intrinsically interlinked.

4 Gunjalwadi Village

Gunjalwadi Village is located in Sangamner taluka, Maharashtra and has a population of 781. It has 21 open wells and 52 bore well pumps out of which four bore well pumps ranging from 5 to 10 HP of Gunjalwadi are brought under the study for detailed testing and analysis. The energy and water consumption, operating efficiency of the pump sets during its operation is simulated on a real time basis using Datamatrix technology.

FIGURE 18: GUNJALWADI PUMP TESTING

The tests were conducted at site from 23th November 2011 to 29th November 2011. We are thankful to Mr. Crispin Lobo, Trustee of WOTR, for organizing the testing of pumps with all local supports required for conducting the detailed testing of pumps at Gunjalwadi. The test data were analyzed in detail for the techno economic feasibility for (A) Improved Manufacturing Design (B) Asset Optimization (C) Control & Automation (D) Performance Management. The detailed analysis and observations for Gunjalwadi against each category is elaborated in this section.

TABLE 14: LIST OF PUMPS SURVEYED & TESTED AT GUNJALWADI

Sr. No	Pump no	Name of Village	HP	Type of Pump	Year of installation	Age	Pump reference
1	Pump1	Gunjalwadi	10	SUBMERSIBLE	2006	6	B3
2	Pump2	Gunjalwadi	7.5	SUBMERSIBLE	2000	12	B5
3	Pump3	Gunjalwadi	10	SUBMERSIBLE	2000	12	B5
4	Pump4	Gunjalwadi	7.5	SUBMERSIBLE	2005	7	C6

4.1 Scope for Improved Manufacturing Design

The scope for improved manufacturing design for the pump sets studied in the village has been assessed from the following perspectives.

1. Use Best Locally Available Design (Higher BEP)
2. Scope for Improved Metallurgy
3. Scope for higher Operating Efficiency at points away from BEP (Flatness of efficiency curves)
4. Improved Efficiency of the Motor
5. Enhanced Guarantee for the Pump set
6. Additional gain using BEE Star Rated Pumps

4.1.1 Use Best Locally Available Design (Higher BEP)

The design efficiency/best efficiency of the pump set varies from manufacturer to manufacturer for each pump model based on the rated head and flow of each pump.

The manufacturers of the agricultural pumps in India publish only head flow characteristics, while the power consumption data is not provided. We have evolved the pump curves based on the site test data by plotting the characteristics of each pump set and assessing the actual deterioration of pumps at site, to extrapolate the original conditions. The following figure shows the BEP of each pump plotted against its corresponding age for two popular makes of similar ratings of the pumps at site. The following figure depicts the deterioration in efficiency over the age of the pump.

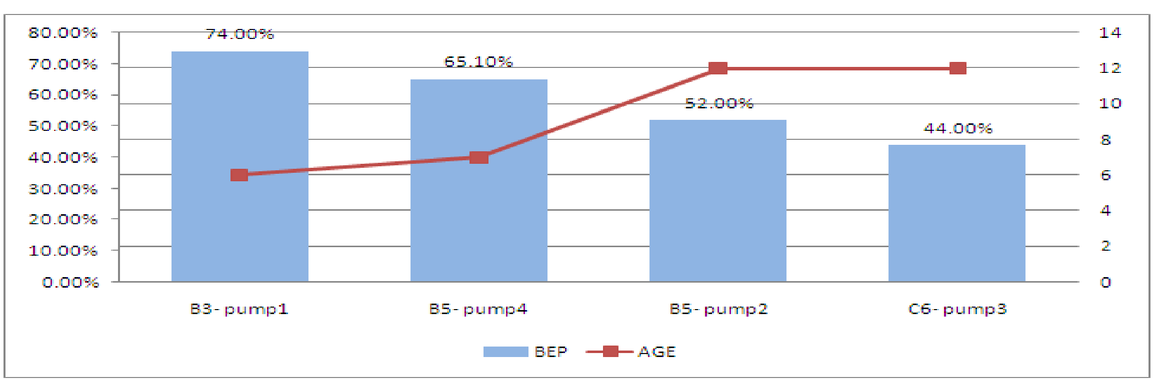


FIGURE 19: BEP OF EACH PUMP PLOTTED AGAINST ITS CORRESPONDING AGE

The above figure indicates the average deterioration rate of B3 makes of pumps is slightly better than other locally available pumps at Gunjalwadi. The data provides a critical insight into the life of the pump under the site conditions and also enables to estimate the efficiency the pump across different time zones during its life cycle.

The following table compares the Best Efficiency and the deterioration of the two prominent make of pump sets in the region having the similar ratings at Gunjalwadi Village.

TABLE 15: SCOPE FOR IMPROVEMENT IN DESIGN EFFICIECNY

Make Code	Average Age in yrs	Average Current BEP eff.	Deterioration rate of BEP Efficiency Per year	Manufacturers BEP (Extrapolated)
B3	6	73.00%	0.67%	77.00%
Others	10.33	68.00%	1.08%	68.00%

Observations

- The Scope for improvement in higher BEP for the pumps available in the village is 77.00% -68.00% = 9%

4.1.2 Scope for improved Metallurgy

The deterioration of a pump is largely dependent on its metallurgy and the pump operating conditions. A better understanding of the pump performance deterioration enables selection of the optimum pump for the optimum performance across its life cycle.

The following analysis on pump deterioration is based on the preceding section (4.1.1). The projected efficiency of the major brand B3 against the other pumps brought under the study is tabulated in the following table. The effective improvement in efficiency is considered over its Life Cycle of 10 years with the impact of deterioration.

TABLE 16: SAVINGS ON ACCOUNT OF IMPROVED METALLURGY

Make Code	Deterioration rate of BEP Efficiency	Initial BEP Efficiency at the start of operation	Final BEP Efficiency at the end of 10th year	Losses on account of machine deterioration at 10th year
B3	0.67%	77.00%	70.33%	6.67%
Others	1.08%	68.00%	57.17%	10.83%
Savings	**0.42%**	**-9.00%**	**-13.17%**	**4.17%**

The rate of deterioration is mainly dependent on the metallurgy of the pumps used in a similar operating environment, on similar operating conditions. It is quite evident that B3 make of pump has better metallurgy to withstand deterioration in efficiency under the specific conditions in the village. Replacing all other pumps by B3 would yield an estimated 4.17% increase in efficiency.

Coating of pump interior with special coating material that gives a smooth surface resisting abrasion will reduce the deterioration rate, depending on the life of the coatings. None of the Gunjalwadi pumps where internally coated and this aspect could not be studied.

Observations

- The average saving over a period of 10 years would be half of the indicated value i.e. (4.17%/2) = 2.08%.
- The average gain in efficiency on 4 pumps by replacing 3 pumps by Calama make would be (2.08% x 3/4).= 1.56%

4.1.3 Scope for higher Operating Efficiency at points away from BEP (Flatness of efficiency curves)

The following figure shows the variation in efficiency from tested BEP for -50% to 50% head variation from the best efficiency point of various pumps at Gunjalwadi.

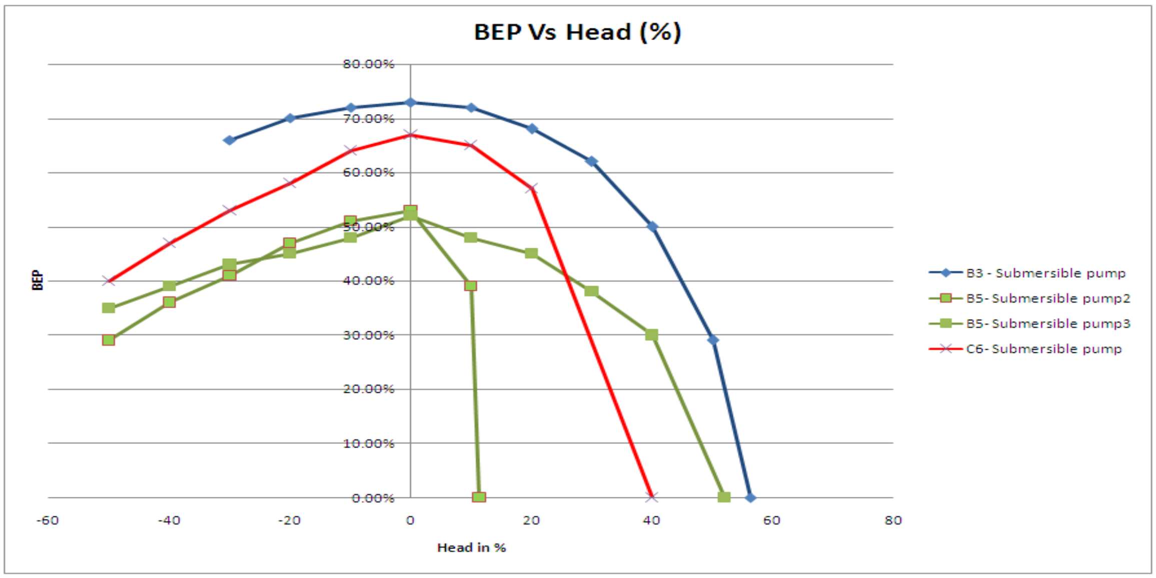


FIGURE 20: EFFICIENCY VS % VARIATION OF BEP HEADS

Observations:

- The drop in efficiency is more drastic when the head increases beyond BEP head.
- Flatness of the efficiency curves depends on a particular pump model and design of the manufacturer for a specified duty requirement (Head & Flow).
- Considering multiple operating heads (Design Point +10%, -10% and -20% of Head) for a cluster of pumps having almost same BEP the savings on account of variation in heads in terms of pump efficiency would be 2.25 % (i.e. difference between most flat curve and average flatness of remaining pumps in the same cluster)
- The flatness of the efficiency curves will be improved by manufacturers, if the criteria for fixing the performance of the pump only at one point are changed to performance at multiple operating points.
- The criteria for performance may be the average operating efficiency across an operating range.

4.1.4 Scope for improved efficiency in Motor

The pump sets used in Gunjalwadi village are all bore well pumps. The detailed testing of the motor is not possible at the field conditions.

4.1.5 Enhanced Guarantee for the Pump set

The survey conducted at Gunjalwadi reveals that the pump is generally taken out of service for repairs mainly for rewinding. The pump failures were analyzed with regard to the age of the pump and the data is represented in the following chart.

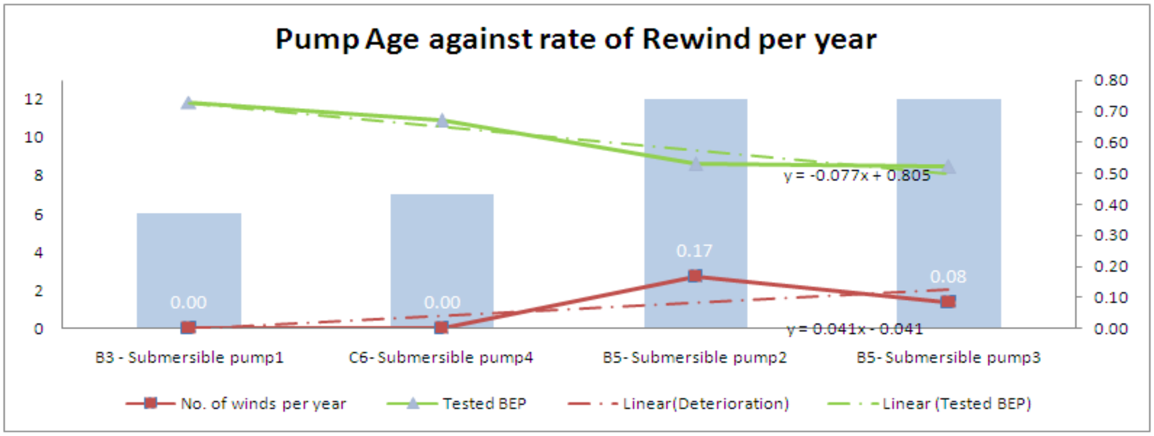


FIGURE 21: PUMP AGE AGAINST RATE OF REWIND PER YEAR

The Y- axis represents the age of the pumps (scale to the left) and X-axis represents the pumps in use with their age represented by the bar graph. The failure rate is represented as the average rate of rewinding per year as indicated by the dark dotted lines.

From the above figure it is clear that the rate of failure at Gunjalwadi has an increasing trend against age of the pump. The following table indicates the average rewinding rate of motors per year per pump

TABLE 17: AVERAGE RATE OF FAILURE OF PUMPS AT GUNJALWADI

Total No. of pumps at Gunjalwadi	Average age of Pumps at Gunjalwadi	Average Number of Failures per pump/year
4	9.25	0.24

The failure rate is also greatly influenced by the power supply conditions at site. The following table represents the average fluctuations in power supply conditions observed along the peak power supply variation for Gunjalwadi, with the corresponding failure rate.

TABLE 18: CORRELATION OF FAILURE RATE AGAINST SUPPLY CONDITIONS

Project	No. of Pumps	Average Age (Yrs)	Average failure Time(Yrs)	Average Voltage variation (%)	Peak Voltage Variation (%)
Gunjalwadi	4	9.25	12.33	3.13%	19.52%

To be compared against the study on other villages.

Observations:

- The slope of the trend lines in figure21 indicates the rate of failure at Gunjalwadi increases by 2. 05% every year while the effective efficiency of the pump decreases by 3.85%.
- Extended guarantee will encourage advancement of replacement of pumps.

- The overall advancement of procurement on pump by 10% will give an overall gain of (2.05% + 3.85%) = 5.90%; considering that the cost of down time and repairs are comparable with the energy cost paid by the farmers.

4.1.6 Additional gain using BEE Star Rated Pumps

The Star Rating program of BEE is an effective method of recognizing the efficient agricultural pumps. The pumps found at Gunjalwadi are of B3, B5 and C6 Brand and none of them is Star rated brand by the BEE. The opportunity for further improving the efficiency above the best brand in use (B3) by using BEE Five Star rated pump for the rated conditions is tabulated below.

TABLE 19: OVERALL EFFICIENCY COMPARISON WITH RATED BEE PUMPS

Make Code	Overall Efficiency of Best Pump level At Site (B3 Pump). (a)	Overall Efficiency of Five star rated Pump-set after 10 years. (b)	Scope of improvement in efficiency by replacement of the pumps by BEE five star rated pumps (b)-(a)
B3	51.10%	51.50%	0.40%

Observation

- BEE has several pumps with different performance levels (Efficiency) in the rated conditions of the pump considered. The weighted average efficiency of the available Five Star pumps is considered for the benchmark.
- The net scope of improvement in efficiency by replacement of the B3 pumps by BEE five star rated pumps is 0.40%.

4.2 Asset Optimization

Each pump is designed to work for a specific design head and flow requirement. If there is a mismatch in the range in which the pump is operating against its design head, the performance of the pump will drop dramatically. Thus imperative for optimum efficiency is selecting the right pump for a well defined head and flow range.

The above factors greatly influence the performance of the pumps over a period of time. The pump performance can be improved by appropriate decision making by precise selection of the pump for optimum performance, considering the duty conditions during its life cycle. The following sections evaluate the opportunities to improve the energy efficiency by various asset management options.

4.2.1 Pump Selection with Accurate Estimation of Head & Deterioration During the service

The current practice of selecting the pump in the village is based on the feedback on the pumps used by other farmers in the vicinity. Some of the farmers select a pump based on the initial feel on the water level and head as advised by the local dealer, based on this preliminary information. This approach grossly ignores many factors influencing the performance of the pumps over a period of time leading to huge losses incurred on account of inappropriate selection of pumps

The following figure represents the present losses on account of pump operation away from the BEP resulting in operation at considerably lower BEP of the pump.

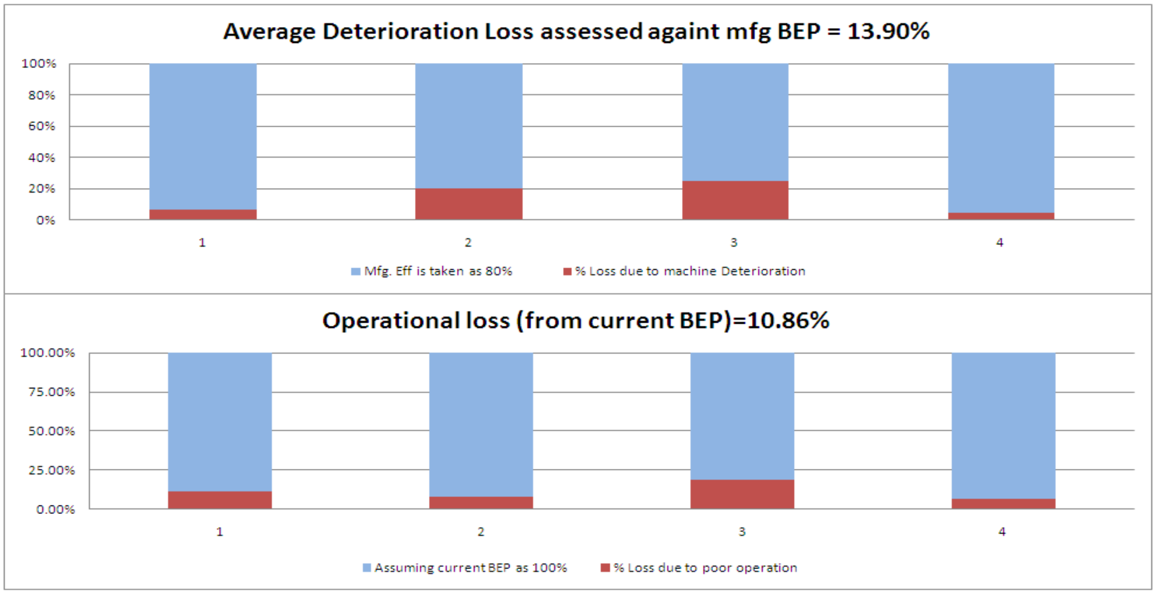


FIGURE 22: SCOPE FOR ASSET MANAGEMENT

Going only by the current situation would be misleading, as all pumps are subjected to continuous deterioration. The challenge here is to accurately select a pump which will operate at the best possible efficiency during its life. In order to do so it is necessary to know at what rate the head producing capacity of a pump is falling and what is the working life of a pump under the scenario, besides knowledge on the decline of water table during its life cycle.

The following Figure indicates the BEP of installed pumps at Gunjalwadi with its corresponding efficiency (operating efficiency in blue). The graph also indicates the BEP against the proposed head of (excess 20% head above BEP suggested) indicated in Red. The current BEP efficiency levels are indicated in green.

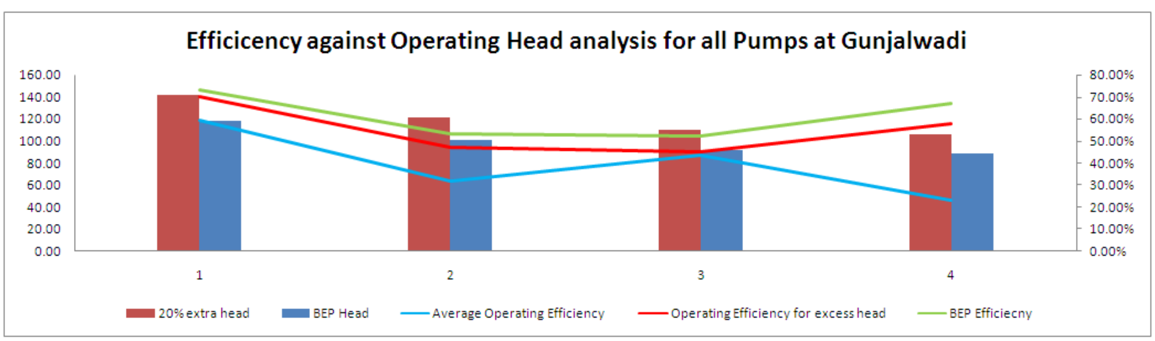


FIGURE 23: AGE-WISE DETERIORATION OF CURRENT BEP AND PROPOSED BEP PUMPS

The existing scenario has an average 21.74% operational loss (due to operations away from BEP). Incase if the pumps are selected with 20% higher head from the BEP, it will have will have an operational loss of 6.25% (due to operations away from BEP), effectively for the entire operating life.

Observations

- It is observed that the head producing ability of a pump drops as its age increases causing the operating point to shift away from its BEP.
- Now if we select a pump having 30% more head producing capacity then what is required we realize that this pumps average operating efficiency point stays close to the BEP and will run more efficiently over the operating years as shown in the above figure.
- From the above figure, the current operating efficiency (indicated in Blue) is operating at an average of 21.74% away from the BEP (indicated in Green) while the proposed 30% excess head (indicated in Red) will be is only 6.25% away from BEP.
- It is estimated that the operating point of oversized pumps will be only 6.25% below BEP as compared to 21.74% below BEP on the current situation.
- The improvement in efficiency on account of selecting pumps 20% additional head from BEP is estimated as (21.74% - 6.25%) 15.49%.

4.2.2 Replacement of pumps after 10 years

Pump replacement is the easiest way to achieve better efficiencies. However the gains from replacement is influenced by many factors such as the pump deterioration, the variation in the water tables, shift in the operating point due to these factors and the analysis can be quite complex. To strike a golden mean between the ad hoc pump selections as practiced today and a complex analysis as carried out here, a simplistic approach can be derived. This may be tackled in the next stage of this research program.

The deterioration factors and the increasing maintenance cost over the time, studied under this report emphasis the need for a periodical replacement of the pumps. Ideally the periodical replacements shall be according to the deterioration rate in each location. However an upper limit shall be determined to limit the age of a pump. The government policies and programs shall be aligned to address this aspect as well.

Observations:

- It can be observed from the figure 20 that the pump performance drops drastically as the operating point of the pump shifts from BEP towards the shut off. As the pump deteriorates, the ability of the pump to lift water is affected, resulting in substantial reduction in flow rate and efficiency.
- The suggested age of replacement of inefficient pumps by locally available best performing pumps is 10 years i.e. those pumps older than 10 years are to be replaced best by the best performing brand (B3) of new pumps.

TABLE 20: SAVINGS ON ACCOUNT OF MACHINE REPLACEMENT AFTER 10 YEARS

Average age of the pumps in years	Number of Pumps older than 10 years	Average age of pumps older than 10 years	Average overall efficiency of these pumps (A)	Manufacturers overall BEP Efficiency (Extrapolated) (B)	Savings on account of replacement of machines after 10 years (B-A)
9.25	2	12	39.00%	40.63%	1.63%

- The effective gain on entire Gunjalwadi site by replacing 2 low efficiency pumps older than 10 years is (1.63% x 2/4) = 0.815%

4.3 Use of level based controls

Gunjalwadi village has a terrain with hard rock and is known to have confined aquifers and these well may have significant draw down level, in this scenario the bore well pumps requires more energy to pump water from greater depths. The draw down level is as a result of faster withdrawal of ground water than recoup rate. The energy usage of the pump can be reduced by interrupting operations as against continuous operation of the pump. The process can be automated with an energy based sensing mechanism to stop the pump beyond a prescribed water level and allow the water to recoup before starting he pump.

The following figure represents the actual energy savings recorded by restricting the draw down levels up to 25%.

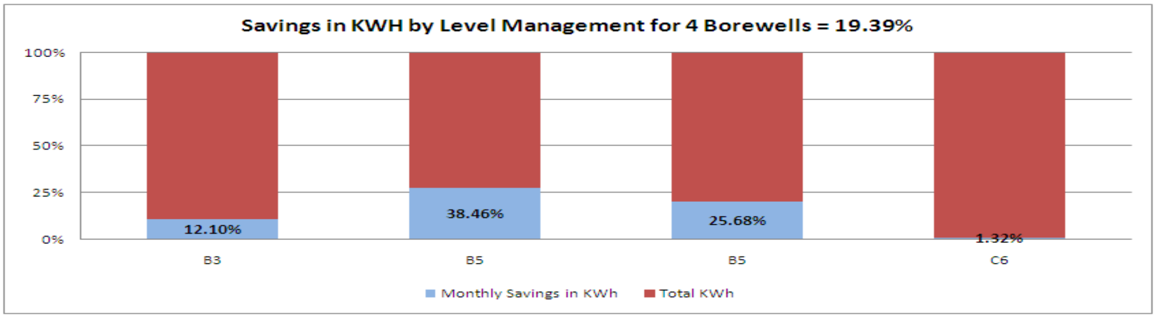


FIGURE 24: DRAW DOWN LEVEL MANAGEMENT

Observation:

- The use of level base control for saving energy can be beneficial for high head variation pumps such as bore well pumps.
- The pumps at Gunjalwadi have a 19.39 % scope for improvement in energy efficiency using level based controls

4.4 Water Allocation Management

The water allocation can be done based on the land holding, cultivated portion and the specific water need estimated under each pump set. The following table shows the water usage against the water requirements for the village based on the cultivated land.

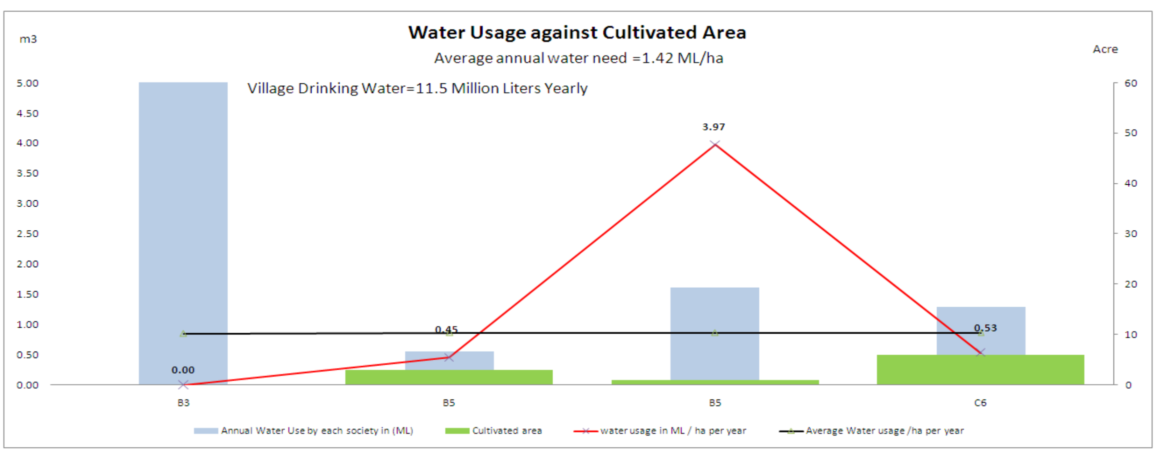


FIGURE 25: WATER DISTRIBUTION PATTERN ACROSS GUNJALWADI

As observed, Pump 1 caters only to the drinking water requirements of the village. The above figure indicates the irrigated land and the water usage. The average line is drawn taking into account of the average water use per hector. This excessive water usage above the average is considered as the excessive irrigation.

Observations:

- The above figure highlights the critical need for equitable distribution of water.
- Equitable distribution saves substantial water along with the energy required.
- The annual water usage per pump/acre is calculated by taking the ratio of the total amount of water consumed and total irrigated land used by each farmer. The water and the corresponding energy savings (by avoiding the excess water usage from average) through equitable water distribution is estimated to be 36.46%.

4.5 Other Opportunities

The frictional loss in the pipe line is estimated to of a trivial value of the total energy usage and do not have any appreciable scope for improvement.

Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agriculture Water-Energy resource management, as the issues are intrinsically interlinked.

5 Nagnur Village

Nagnur is a village in the southern state of Karnataka, India. It is located in the Kalghatgi Taluka of Dharwad district in Karnataka. The village has a population of 1343. The survey data indicates that the village has 56 bore well pumps. The village has negligible ground water level variation during the pumping season. Out of these, 19 bore well pumps ranging from 5 & 7.5 HP pumps are brought under the study for detailed testing and analyses.

FIGURE 26: NAGNUR PUMP TESTING

The tests were conducted at site from 21st April 2012 to 3rd May 2012. We are thankful to the Mayor of Hubli Dharward Mrs. Poorna Patil and Mr. Sudhir Patil for extending all necessary support at site and convincing the villagers to subject their pumps to extensive testing.

The test data were analyzed in detail for the techno economic feasibility for (A) Improved Manufacturing Design (B) Asset Optimization (C) Control & Automation (D) Performance Management. The detailed analysis and observations for Nagnur village against each category is elaborated in this section.

TABLE 21: LIST OF PUMPS SURVEYED AT NAGNUR

Survey Ref.	Tested Pump No	Pum p no	Name of Village	HP	Type of Pump	Year of installation	Age (Yrs)	Make Reference No.
16	Pump1	B-16	Nagnur	5	SUBMERSIBLE	1998	14	B3
15	Pump2	B-15	Nagnur	7.5	SUBMERSIBLE	2008	4	C4
19	Pump3	B-19	Nagnur	5	SUBMERSIBLE	2005	7	B5
17	Pump4	B-17	Nagnur	7.5	SUBMERSIBLE	2005	7	B5
11	Pump5	B-11	Nagnur	5	SUBMERSIBLE	2010	2	B5
27	Pump6	B-27	Nagnur	7.5	SUBMERSIBLE	2007	5	B5
6	Pump7	B-6	Nagnur	5	SUBMERSIBLE	1999	13	B3
7	Pump8	B-7	Nagnur	5	SUBMERSIBLE	1997	15	B3
30	Pump9	B-30	Nagnur	5	SUBMERSIBLE	2004	8	B3
2	Pump10	B-2	Nagnur	5	SUBMERSIBLE	1993	19	B3
24	Pump11	B-24	Nagnur	5	SUBMERSIBLE	1992	20	B5
31	Pump12	B-31	Nagnur	5	SUBMERSIBLE	1992	20	B3
32	Pump13	B-32	Nagnur	5	SUBMERSIBLE	2002	10	B5
20	Pump14	B-20	Nagnur	5	SUBMERSIBLE	1998	14	B3
21	Pump15	B-21	Nagnur	5	SUBMERSIBLE	2002	10	B5
12	Pump16	B-12	Nagnur	5	SUBMERSIBLE	2005	7	B5
26	Pump17	B-26	Nagnur	5	SUBMERSIBLE	2002	10	B3
33	Pump18	B-33	Nagnur	5	SUBMERSIBLE			NA
10	Pump19	B-10	Nagnur	5	SUBMERSIBLE	2000	12	B5
1		B-1	Nagnur	7.5	SUBMERSIBLE	1989	23	B3
3		B-3	Nagnur	5	SUBMERSIBLE	1998	14	B3
4		B-4	Nagnur	7.5	SUBMERSIBLE	2000	12	B3
5		B-5	Nagnur	6	SUBMERSIBLE	2003	9	NA
8		B-8	Nagnur	5	SUBMERSIBLE	1997	15	NA
9		B-9	Nagnur	5	SUBMERSIBLE	2007	5	B5
13		B-13	Nagnur	5	SUBMERSIBLE	2001	11	NA
14		B-14	Nagnur	5	SUBMERSIBLE	2002	10	NA
18		B-18	Nagnur	5	SUBMERSIBLE	2003	9	NA
22		B-22	Nagnur	5	SUBMERSIBLE	2000	12	NA
23		B-23	Nagnur	5	SUBMERSIBLE	1989	23	NA
25		B-25	Nagnur	5	SUBMERSIBLE	1996	16	NA
28		B-28	Nagnur	5	SUBMERSIBLE	2002	10	B3
29		B-29	Nagnur	6	SUBMERSIBLE	1981	31	NA

The scope of survey at Nagnur is widened to study the multiplicity of pumps in use and its consistency in the research samples. The survey indicates that the percentage population of A, B, C, & D category pumps are 0, 66%, 3% & 30.30% respectively.

5.1 Scope for Improved Manufacturing Design

The scope for improved manufacturing design for the pump sets studied in the village has been assessed from the following perspectives.

1. Improved Design efficiency of Pump Sets (Higher BEP)
2. Scope for Improved Metallurgy
3. Higher Operating Efficiency at points away from BEP
4. Improved Efficiency of the Motor
5. Enhanced Guarantee for the Pump set

5.1.1 Use Best Locally Available Design (Higher BEP)

The design efficiency/best efficiency of the pump set varies from manufacturer to manufacturer for each pump model based on the rated head and flow of each pump.

The manufacturers of the agricultural pumps in India publish only head flow characteristics, while the power consumption data is not provided. We have evolved the pumps curves based on the site test data by plotting the characteristics of each pump set and assessing the actual deterioration of pumps at site, to extrapolate the original conditions. The following figure shows the BEP of each pump plotted against its corresponding age for two major makes of similar ratings of the pumps at site.

The majority of the pumps used in the Nagnur village are B6 and B3 which are reputed brands. The following figure depicts the deterioration in efficiency over the age of the pump.

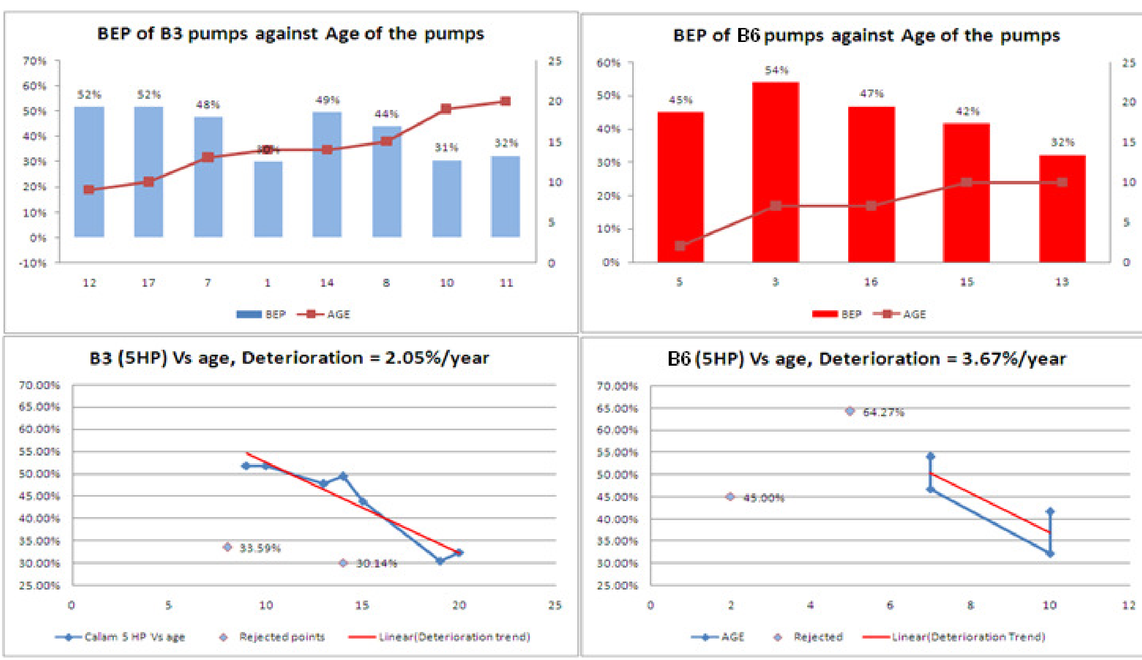


FIGURE 27: BEP OF EACH PUMP PLOTTED AGAINST ITS CORRESPONDING AGE

The above figure indicates the deterioration rate of two makes of pumps with the same rating. The data provides critical insight into the life of the pump under the site conditions and also enables to estimate the efficiency the pump across different time zones during its life cycle.

The following table compares the Best Efficiency and the deterioration of the two prominent make of pump sets in the region having the same ratings at Nagnur Village.

TABLE 22: SCOPE FOR IMPROVEMENT IN DESIGN EFFICIECNY

Make Code	Average Age in yrs	Average Current BEP eff.	Deterioration rate of BEP Efficiency Per year	Manufacturers BEP (Extrapolated)
B6	6.83	42.65%	3.67%	67.73%
B3	14.25	41.27%	2.05%	70.48%

Observations

- The Scope for improvement in higher BEP for the pumps available in the village is 70.48% -67.73% = 2.75%

5.1.2 Scope for improved Metallurgy

The deterioration of a pump is largely dependent on its metallurgy and the pump operating conditions. A better understanding of the pump performance deterioration enables selection of the optimum pump for the optimum performance across its life cycle.

The following analysis on pump deterioration is based on the preceding section (5.1.1). The projected efficiency of the major brand B4 against the other pumps brought under the study is tabulated in the following table. The effective improvement in efficiency is considered over its Life Cycle of 10 years with the impact of deterioration (Refer to Figure 27).

TABLE 23: SAVINGS ON ACCOUNT OF IMPROVED METALLURGY

Make Code	Deterioration rate of BEP Efficiency	Initial BEP Efficiency at the start of operation	Losses on account of machine deterioration	Final BEP Efficiency at the end of 10^{th} year
B6	3.67%	67.73%	36.70%	31.03%
B3	2.05%	70.48%	20.50%	49.98%
Savings	**1.62%**	**-2.75%**	**16.20%**	**-18.95%**

The rate of deterioration is mainly dependent on the metallurgy of the pumps used in a similar operating environment. It is quite evident that B3 has better metallurgy to withstand deterioration in efficiency under the specific conditions in the village. Using B3 pumps instead of B6 would have yielded an estimated 16.20% increase in efficiency.

Coating of pump interior with special coating material that gives a smooth surface resisting abrasion will reduce the deterioration rate, depending on the life of the coatings. None of the Nagnur pumps where internally coated and this aspect could not be studied.

Observations

- As per the survey, the average age of the pump at Nagnur village surveyed is 10.2 years.
- B3 pumps can give an advantage of lower deterioration rate over B6 at the site conditions of Nagnur village, The average saving over a period of 10 years would be half of the indicated value i.e. (16.20%/2) = 8.10%.
- The average gain in efficiency on 17 pumps by replacing eight B6 pumps would be (8.10% x 8/17).= 3.81%

5.1.3 Improved design efficiency at operating points

The improved design efficiency at operating points away from BEP will result in flatter performance characteristics of the pump efficiency. The following figure shows the variation in efficiency from tested BEP for -50% to 50% head variation from the best efficiency point.

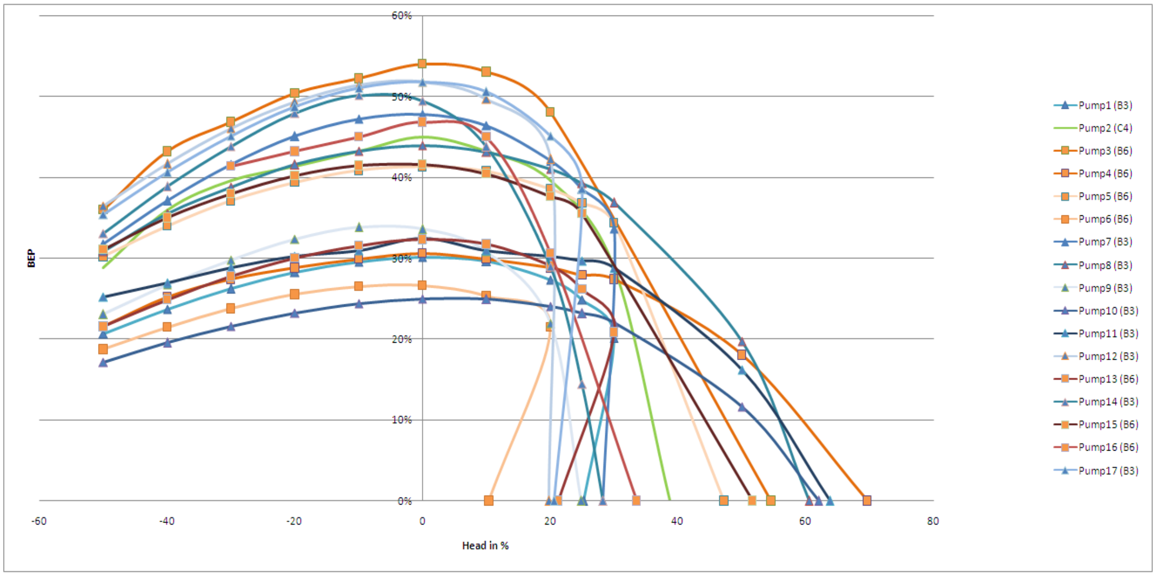


FIGURE 28: EFFICIENCY VS % VARIATION OF BEP HEADS

Observations:

- The drop in efficiency is more drastic when the head increases beyond BEP head.
- Flatness of the efficiency curves depends on a particular pump model and design of the manufacturer
- Considering multiple operating heads (Design Point +10%, -10% and -20% of Head) for a cluster of pumps having similar BEP, the savings on account of variation in heads in terms of pump efficiency would be 0.93 % (i.e. difference between most flat curve and average flatness of remaining pumps in the same cluster) for the pumps tested at Nagnur.
- This indicates the close similarity between the characteristics of the pumps.
- The flatness of the efficiency curves will be improved by manufacturers, if the criteria for fixing the performance of the pump only at one point are changed to performance at multiple operating points.
- The criteria for performance may be the average operating efficiency across an operating range.

5.1.4 Improved Motor Efficiency

The pump sets used in Nagnur village are submersible pumps. The detailed testing of the motor is not possible at the field conditions. However the performance of the motor at each site is reflected in our data and analysis, as all tests are conducted at site with the combined motor pump set.

5.1.5 Enhanced Guarantee for the Pump set

The survey conducted at Nagnur Village reveals that the pump is generally taken out of service for repairs mainly for rewinding. The pump failures were analyzed with regard to the age of the pump and the data is represented in the following chart.

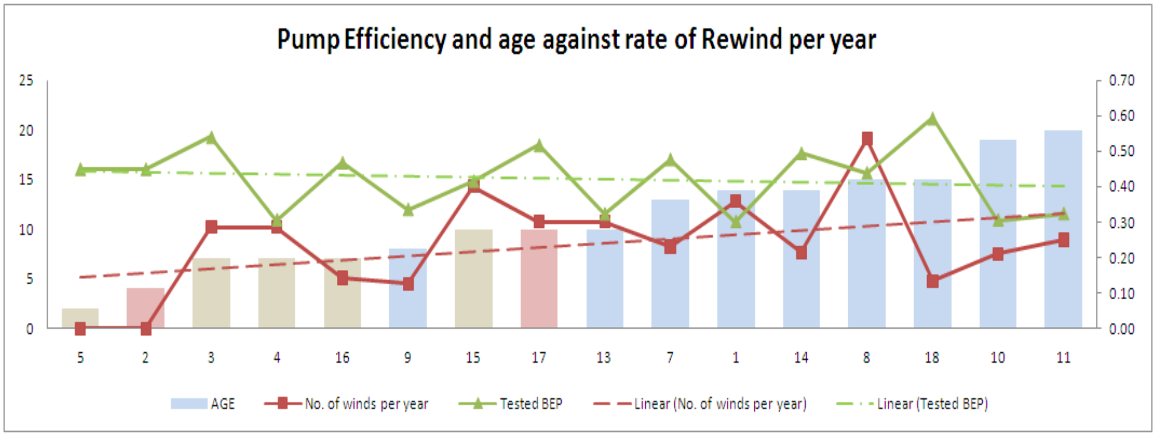


FIGURE 29: PUMP AGE AGAINST RATE OF REWIND PER YEAR

The Y- axis represents the age of the pumps (scale to the left) and X-axis represents the pumps in use with their age represented by the bar graph. The failure rate is represented as the average rate of rewinding per year as indicated by the dark dotted lines.

From the above figure it is clear that the rate of failure at Nagnur Village has an increasing trend against age of the pump. The following table indicates the average rewinding rate of motors per year per pump

TABLE 24: AVERAGE RATE OF FAILURE OF PUMPS AT NAGNUR

Total No. of pumps at Nagnur	Average age of Pumps at Nagnur	Average Number of Failures per pump/year
17	10.23	0.34

The failure rate is also greatly influenced by the power supply conditions at site. The following table represents the average fluctuations in power supply conditions observed along the peak power supply variation for Nagnur Village, with the corresponding failure rate.

TABLE 25: CORRELATION OF FAILURE RATE AGAINST SUPPLY CONDITIONS

Project	No. of Pumps	Average Age (Yrs)	Average failure Time (Yrs)	Average Voltage variation (%)	Peak Voltage Variation (%)
Nagnur	17	10.23	3.4	7.92%	19.28%

To be compared against the study on other villages.

Observations:

- The rate of major failure of pumps mainly due to burning of motors at Nagnur increases at the rate of 1.44% along with deterioration in BEP at the rate of 2.86% per year.
- Extended guarantee will encourage advancement of replacement of pumps.
- Considering the cost in making good the failures, the overall advancement of procurement on pump by 10% will give an overall gain of (1.44% + 2.86%) = 4.30%.

- If the above figure is read in conjunction with figure 32 then it is observed that the rate of rewinding has increased when pumps operate away from the BEP

5.1.6 Additional gain using BEE Star Rated Pumps

The Star Rating program of BEE is an effective method of recognizing the efficient agricultural pumps. Majority of the pumps found at Nagnur Village are of B3 and B6 Brand. The opportunity for further improving the efficiency above the best brand in use (B3) by using BEE Five Star rated pump for the rated conditions is tabulated below.

TABLE 26: OVERALL EFFICIENCY COMPARISON WITH RATED BEE PUMPS

Make Code	Overall Efficiency of Best Pump level At Site (B3 Pump). (a)	Overall Efficiency of Five star rated Pump-set after 10 years. (b)	Scope of improvement in efficiency by replacement of the pumps by BEE five star rated pumps (b)-(a)
B3	49.34%	51.50%	2.16%

Observation

- BEE has several pumps with different performance levels (Efficiency) in the rated conditions of the pump considered. The weighted average efficiency of the available Five Star pumps is considered for the benchmark.
- The net scope of improvement in efficiency by replacement of the B3 pumps by BEE five star rated pumps is 2.16%.

5.2 Asset Optimization

Each pump is designed to work for a specific design head and flow requirement. If there is a mismatch in the range in which the pump is operating against its design head, the performance of the pump will drop dramatically. Thus imperative for optimum efficiency is selecting the right pump for a well defined head and flow range.

The above factors greatly influence the performance of the pumps over a period of time. The pump performance can be improved by appropriate decision making by precise selection of the pump for optimum performance, considering the duty conditions during its life cycle. The following sections evaluate the opportunities to improve the energy efficiency by various asset management options.

5.2.1 Pump Selection with Accurate Estimation of Head & Deterioration During the service

The following figure represents the change in efficiency plotted against the operating head. The new pumps are represented in darker colors and the older pumps are in light colors. The deterioration of pumps has a tendency to compress the performance curves towards the Zero Head & Efficiency. The efficiency drop suddenly, after the pump operating point crosses over the BEP towards the shut off (on the right side of the following figure).

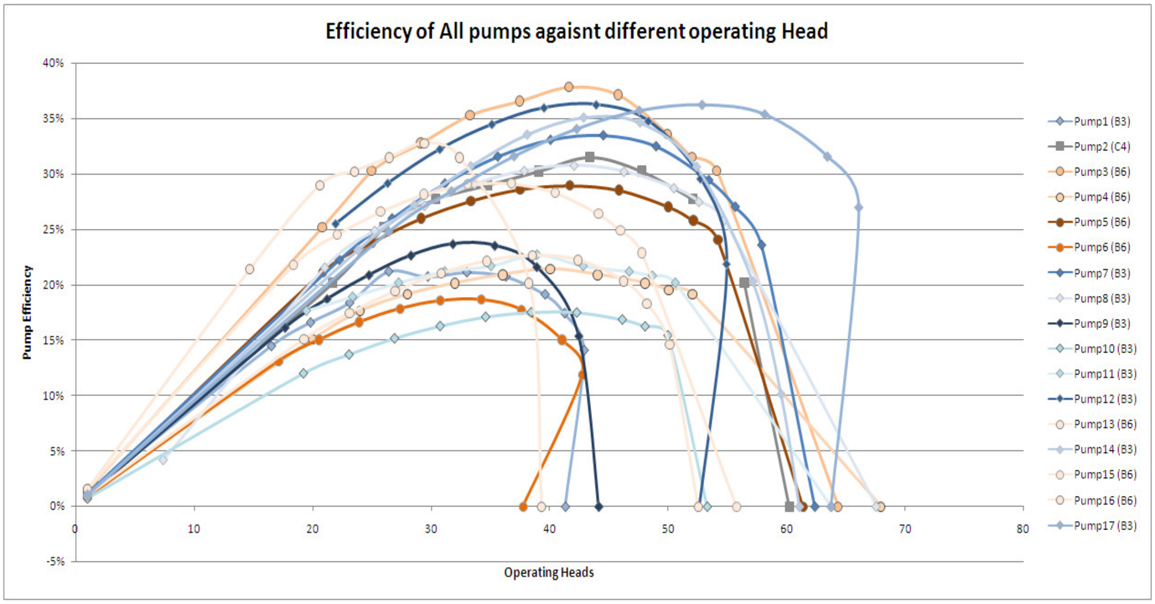


FIGURE 30: EFFICIENCY OF ALL PUMPS AGAINST OPERATING HEADS

The current practice of selecting the pump in the village is based on the feedback on the pumps used by other farmers in the vicinity. Some of the farmers select a pump based on the initial feel on the water level and head as advised by the local dealer, based on this preliminary information. This approach grossly ignores many factors influencing the performance of the pumps over a period of time leading to huge losses incurred on account of inappropriate selection of pumps

The following figure represents the present losses on account of pump operation away from the BEP resulting in operation at considerably lower BEP of the pump.

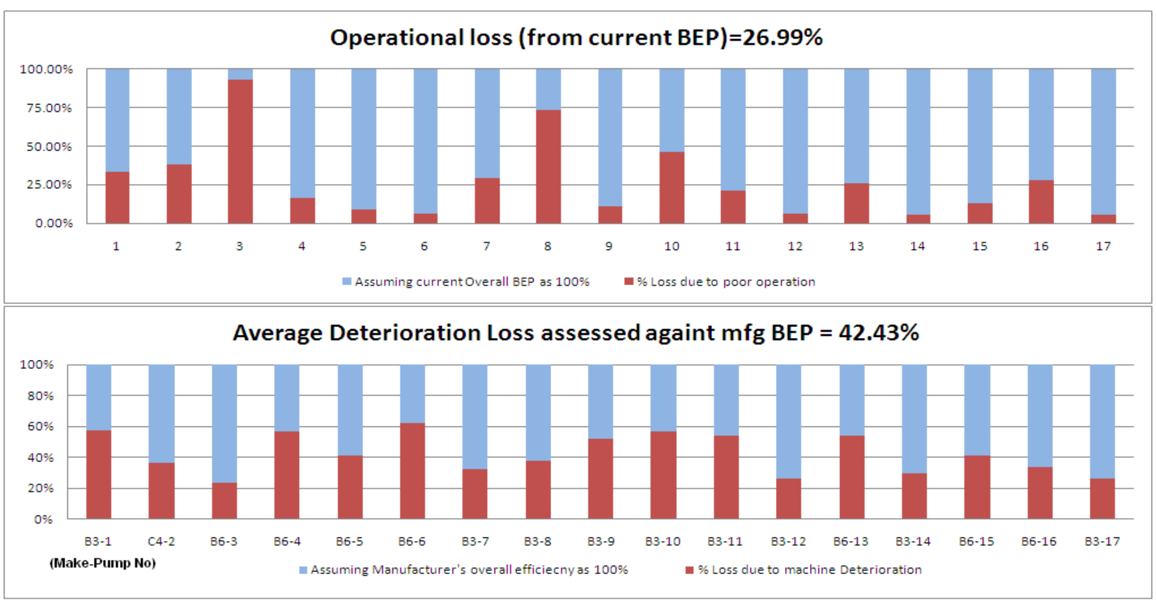


FIGURE 31: SCOPE FOR ASSET MANAGEMENT

Going only by the current situation would be misleading, as all pumps are subjected to continuous deterioration. The challenge here is to accurately select a pump which will operate at the best possible efficiency during its life. In order to do so it is necessary to know at what rate the head producing capacity of a pump is falling and what is the working life of a pump under the scenario, besides knowledge on the decline of water table during its life cycle.

The following Figure indicates the BEP of installed pumps at Nagnur with its corresponding efficiency (operating efficiency in blue). The graph also indicates the BEP against the proposed head of (excess 30% head above BEP suggested) indicated in Red. The current BEP efficiency levels are indicated in green.

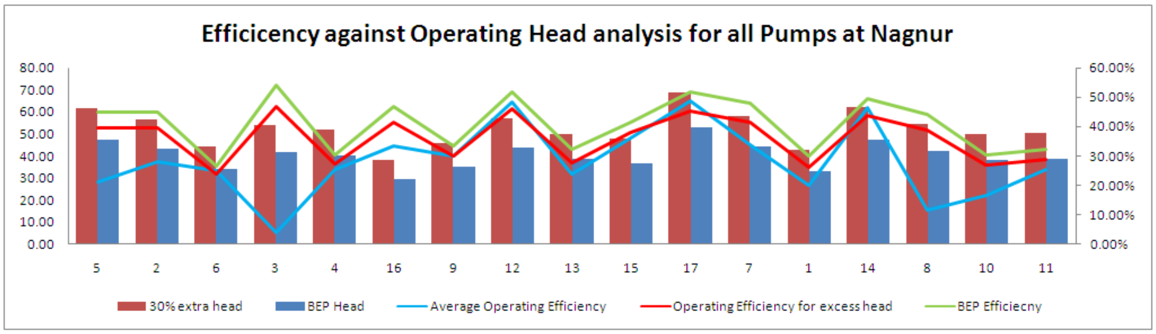


FIGURE 32: AGE-WISE DETERIORATION OF CURRENT BEP AND PROPOSED BEP PUMPS

The existing scenario has an average 11.38% operational loss (due to operations away from BEP). Incase if the pumps are selected with 30% higher head from the BEP, it will have will have an operational loss of 4.61% (due to operations away from BEP), effectively for the entire operating life.

Observations

- It is observed that the head producing ability of a pump drops as its age increases causing the operating point to shift away from its BEP.
- Now if we select a pump having 30% more head producing capacity then what is required we realize that this pumps average operating efficiency point stays close to the BEP and will run more efficiently over the operating years as shown in the above figure.
- From the above figure, the current operating efficiency (indicated in Blue) is operating at an average of 14.83% away from the BEP (indicated in Green) while the proposed 30% excess head (indicated in Red) will be is only 5.23% away from BEP.
- It is estimated that the operating point of oversized pumps will be only 5.23% below BEP as compared to 14.68% below BEP on the current situation.
- The improvement in efficiency on account of selecting pumps 30% additional head from BEP is estimated as (11.38% - 4.61%) 6.77%.

5.2.2 Replacement of pumps after 10 years

Pump replacement is the easiest way to achieve better efficiencies. However the gains from replacement is influenced by many factors such as the pump deterioration, the variation in the water tables, shift in the operating point due to these factors and the analysis can be quite complex. To strike a golden mean between the ad hoc pump selections as practiced today and a complex analysis as carried out here, a simplistic approach can be derived. This may be tackled in the next stage of this research program.

The deterioration factors and the increasing maintenance cost over the time, studied under this report emphasis the need for a periodical replacement of the pumps. Ideally the periodical replacements shall be according to the deterioration rate in each location. However an upper limit shall be determined to limit the age of a pump. The government policies and programs shall be aligned to address this aspect as well.

Observations:

- It can be observed from the figure 30 that the pump performance drops drastically as the operating point of the pump shifts from BEP towards the shut off. As the pump deteriorates, the ability of the pump to lift water is affected, resulting in substantial reduction in flow rate and efficiency.
- At Nagnur the suggested age of replacement of inefficient pumps by locally available best pumps is 10 years i.e. those pumps older than 10 years (B3 pumps) are to be replaced best by B3 make new pumps.
- The suggested age of replacement of inefficient pumps by locally available best performing pumps is 10 years i.e. those pumps older than 10 years are to be replaced best by the best performing brand (B3) of new pumps.

TABLE 27: SAVINGS ON ACCOUNT OF MACHINE REPLACEMENT AFTER 10 YEARS

Average age of pumps in years	Number of B3 Pumps older than 10 years	Average age of B3 pumps older than 10 years	Average overall efficiency of these pumps (A)	Manufacturers overall BEP Efficiency (Extrapolated) (B)	Savings on account of replacement of machines after 10 years (B-A)
10.23	6	15.83	24.61%	44.40%	19.79%

Observation

- The effective gain on entire Nagnur site by replacing 6 low efficiency pumps older than 10 years is (19.79% x 6/17)=6.99%

5.3 Use of multi speed motors

Considering the fact that the use of step down synchronous speed (i.e. from 2900 rpm to 1480 rpm) using a multi speed motor will substantially reduce the head and flow generation capacity of pump. The feasibility for using multi speed motors for Nagnur is nil, as these pumps would not be able to generate the required head

Observation:

- It is not feasible to use multi speed motors for high head bore well pumps.

5.4 Use of level based controls

The ground water level at Nagnur village is found to be plentiful. The test was carried out in mid-summer and the results showed good water levels at all bore wells. The result clearly indicates a negligible scope for savings on account of level control.

5.5 Water Allocation Management

The following table shows the water usage against the land holding and water requirements, estimated as a proportion of the cultivated area.

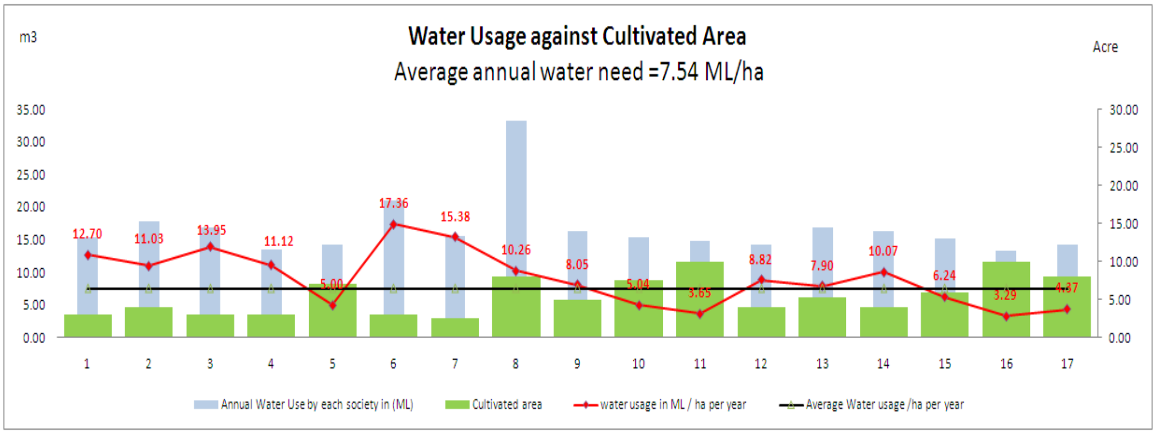


FIGURE 33: WATER DISTRIBUTION PATTERN ACROSS NAGNUR

The above figure indicates the irrigated land and the water usage. The average line is drawn taking into account of the average water use per hector. This excessive water usage above the average is considered as the excessive irrigation.

Observations:

- The above figure clearly indicates the need for equitable distribution of water.
- Equitable distribution shall save substantial water and energy required to deliver it.
- The annual water usage per farmer/acre is calculated by taking the ratio of the total amount of water consumed and total irrigated land used by each farmer. The water and the corresponding energy savings (by avoiding the excess water usage from average) through equitable water distribution is estimated to be 21.39%.
- The 17 pumps brought under detailed testing is estimated to pump 284.23 Million Liters of water annually and the scope for annual saving in water is estimated to be 60.80 Million Liters (21.39%).

5.6 Other Opportunities

The frictional loss in the pipe line is estimated to of a trivial value of the total energy usage and do not have any appreciable scope for improvement.

Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agriculture Water-Energy resource management, as the issues are intrinsically interlinked

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6 Mehsana

Mehsana district in Gujarat state is located at a distance of 74 km from Ahmadabad. The district has a population of over 18 lakhs, covering an area of over 4,500 km^2. There are over 600 villages in this district. The survey is conducted in Sobhasan, Ransipur, Fudeda, Sardarpur, Gunjha-Kosha and Lilapur-Kahipur villages. Testing of pumps is conducted in Sobhasan, Ransipur, Fudeda, Sardarpur and Gunjha-Kosha villages. The village has negligible ground water level variation during the pumping season. The irrigation infrastructure of these villages consists of approximate 337 bore well pumps ranging from 12.5 HP to 75 HP. The average age of the pumps surveyed is 6.6 years. Out of this 14 bore well pumps ranging from 12.5 HP to 40 HP at Mehsana are brought under detailed testing and analysis.

FIGURE 34: MEHSANA PUMP TESTING

The tests were conducted at site during 5th May 2012 to 16th May 2012. We are thankful to the Dr. Tushar Shah (Principal Researcher, IWMI) and Mr. Mohan Sharma (Director programmes, DSC) for extending us the all necessary support at site and convince the villagers to subject their pumps for extensive testing.

The test data where analyzed in detail for the techno economic feasibility for (A) Improved Manufacturing Design (B) Asset Optimization (C) Control & Automation (D) Performance Management. The detailed analysis and observations is elaborated in this section.

TABLE 28: LIST OF PUMPS SURVEYED AT MEHSANA

Sr. No	Pump no	Name of Village	HP	Type	Year of installation	Age	Pump Configuration No	Make Reference No.
1	B-1	Lilapur	30hp	SUBMERSIBLE	2002	10		Unknown
2	B-2	Lilapur	30hp	SUBMERSIBLE	2005	7		A2
3	B-4	Kahipur	m-52 , p-40	SUBMERSIBLE	2008	4		Unknown
4	B-5	Fudeda	20 hp	SUBMERSIBLE	1992	20	1	A2
5	B-6	Fudeda	40 hp	SUBMERSIBLE	2003	9	2	C10
6	B-7	Fudeda	20 hp	SUBMERSIBLE	2002	10		C8
7	B-8	Sardarpur	25 hp	SUBMERSIBLE	2010	2		A4
8	B-10	Ransipur	20 hp	SUBMERSIBLE	2002	10		Unknown
9	B-11	Ransipur	20 hp	SUBMERSIBLE	1987	25	7	C8
10	B-12	Ransipur	20 hp	SUBMERSIBLE	2009	3	6	A1
11	B-13	Fudeda	35 hp	SUBMERSIBLE	2010	2	3	A1
12	B-16	Unjha	50 hp	SUBMERSIBLE	2003	9		Unknown
13	B-17	Unjha	75 hp	SUBMERSIBLE	2000	12		A2
14	B-18	Unjha	62 hp	SUBMERSIBLE	1996	16		Unknown
15	B-19	Sobhasan	12.5 hp	SUBMERSIBLE	2012	0	8	C2
16	B-20	Ransipur	20hp	SUBMERSIBLE	2001	11	5	B1
17	B-22	Sobhasan	20 hp	SUBMERSIBLE	2012	0	4	C5
18	B-23	Sobhasan	20 HP	SUBMERSIBLE	2011	1	9	B1
19	B-24	Sobhasan	15 hp	SUBMERSIBLE	2011	1	10	B1
20	B-25	Sobhasan	15 hp	SUBMERSIBLE	2011	1	11	B1
21	B-26	Sobhasan	15 hp	SUBMERSIBLE	2012	0	14	A4
22	B-27	Sobhasan	30 hp	SUBMERSIBLE	2011	1	13	C9
23	B-28	Sobhasan	15 hp	SUBMERSIBLE	2012	0	12	A4

6.1 Scope for Improved Manufacturing Design

The scope for improved manufacturing design for the pump sets studied in the village is assessed from the following perspectives.

1. Improved Design efficiency of Pump Sets (Higher BEP)
2. Scope for Improved Metallurgy
3. Higher Operating Efficiency at points away from BEP
4. Improved Efficiency of the Motor
5. Enhanced the Guarantee for the Pump set

6.1.1 Use Best Locally Available Design (Higher BEP)

The design efficiency/best efficiency of the pump set varies from manufacturer to manufacturer for each pump model based on the rated head and flow of each pump.

The manufacturers of the agricultural pumps in India publish only head-flow characteristics, while the power consumption data is not provided. We have evolved the manufacture curves based on the site test data by plotting the characteristics of each pump set and assessing the actual deterioration of pumps at site, to extrapolate the original conditions.

The following figure shows the BEP of each pump plotted against its corresponding age for two major makes of similar ratings of the pumps at site.

The following figure depicts the current BEP of all pumps selected for detailed testing against age of the pump.

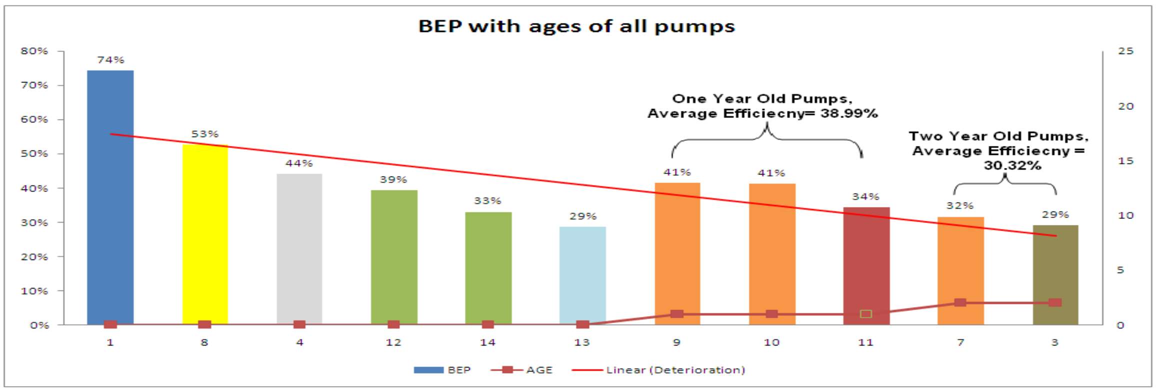

FIGURE 35: BEP OF EACH PUMP PLOTTED AGAINST ITS CORRESPONDING AGE

Most of the pumps have been newly installed. Hence the BEP of these pumps indicated in the figure are almost manufacturer's Best efficiency values, considering deterioration effect to be of a trivial value.

Since most of the pumps are of 15 and 20 HP, they can be grouped into a these two categories and the manufacturer's Best efficiency can be compared as shown in the following table.

TABLE 29: SCOPE FOR IMPROVEMENT IN DESIGN EFFICIECNY

Number of pumps	HP	Average Efficiency in the same HP range	Manufacturer's Best Efficiency of the pump in the HP range Tested	Best Performing pump in the same HP range at site	Savings
6	20	49.49%	74.36%	A2	24.87%
5	15	40.05%	52.68%	C2	12.63%
Overall		44.77%	63.52%	-	18.75%

Observations

- The average gain in efficiency on 14 pumps by replacing 11 pumps by A2 make would be (18.75% x 11/14).= 14.73%
- Most of the pumps tested at Mehsana are within one year from their installation date and the pump deterioration is not considered.

6.1.2 Scope for improved Metallurgy

The deterioration of a pump is largely dependent on its metallurgy and the pump operating conditions. A better understanding of the pump performance deterioration enables selection of the optimum pump for the optimum performance across its life cycle.

The following analysis on pump deterioration is based on the preceding section (6.1.1). The projected efficiency of the major brand A2 against the other pumps brought under the study is tabulated in the following table. The effective improvement in efficiency is considered over its Life Cycle of 10 years with the impact of deterioration (Refer to Figure 35).

TABLE 30: COMPUTING PUMP DETERIORATION RATE AT GUJRAT

Number of Pumps	Average efficiency after 1st year (A)	Average efficiency after 2nd year (B)	Deterioration of pumps at Mehsana district (B-A)/2
12	38.99%	30.32%	4.34%

Mehsana is characterized by heavy sand deposits and with alkaline water resulting in accelerated deterioration in pumps. This result in frequent repair activities to be carried out and often impeller of the pumps are replaced in 3 years on an average.

The high deterioration rate of 4.34% indicates that there is a huge scope for savings on account for improved metallurgy. From the survey it is clear that the pump needs frequent maintenance for the upkeep of the pumps to meet the duty requirements, demanding frequent refurbishment of the impeller. The current practice at Mehsana of replacing / retrofitting pump impellers frequently has well taken care of this opportunity. As such there is no scope in improved metallurgy.

6.1.3 Improved design efficiency at operating points

The improved design efficiency at operating points away from BEP will result in flatter performance characteristics of the pump efficiency. The following figure shows the variation in efficiency from tested BEP for -50% to 50% head variation from the best efficiency point.

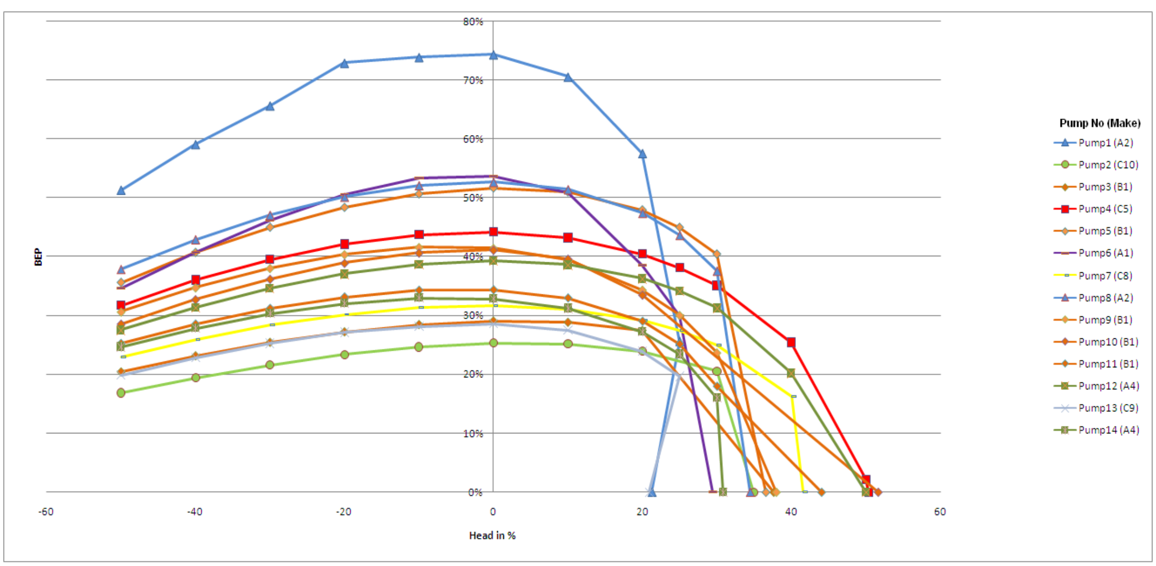

FIGURE 36: EFFICIENCY VS % VARIATION OF BEP HEADS

Observations:

- The drop in efficiency is more drastic when the head increases beyond BEP head.
- Flatness of the efficiency curves depends on a particular pump model and design of the manufacturer
- Considering multiple operating heads (Design Point +10%, -10% and -20% of Head) for a cluster of pumps having similar BEP, the savings on account of variation in heads in terms of pump efficiency would be 0.37 % (i.e. difference between most flat curve and average flatness of remaining pumps in the same cluster)
- This indicates the close similarity between the characteristics of the pumps; except A2 pumps which is out performing others.
- The flatness of the efficiency curves will be improved by manufacturers, if the criteria for fixing the performance of the pump only at one point are changed to performance at multiple operating points.
- The criteria for performance may be the average operating efficiency across an operating range.

6.1.4 Improved Motor Efficiency

The pump sets used in Mehsana district are submersible pumps. The detailed testing of the motor is not possible at the field conditions. However the performance of the motor at each site is reflected in our data and analysis, as all tests are conducted at site with the combined motor pump set.

6.1.5 Enhanced Guarantee for the Pump set

The survey conducted at Mehsana district reveals the pump is generally taken out of service for repairs mainly for rewinding. The Pump 1 brought under the survey was the only pump to be retrofitted with new impellers after the drop in efficiency with prolonged use over the years and currently shows the best efficiency among all pumps. The pump failures were analyzed with regard to the age of the pump and the data is represented in the following chart.

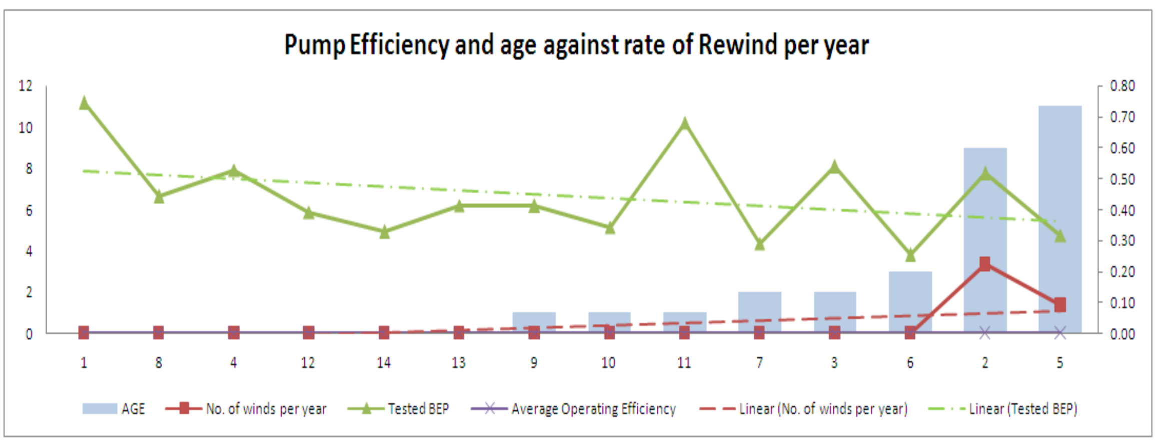

FIGURE 37: PUMP AGE AGAINST RATE OF REWIND PER YEAR

The Y- axis represents the age of the pumps (scale to the left) and X-axis represents the pumps in use with their age represented by the bar graph. The failure rate is represented as the average rate of rewinding per year as indicated by the dark dotted lines.

From the above figure it is clear that the rate of failure at Mehsana has an increasing trend against age of the pump. The following table indicates the average rewinding rate of motors per year per pump

TABLE 31: AVERAGE RATE OF FAILURE OF PUMPS AT MEHSANA

Total No. of pumps at Mehsana	Average age of Pumps at Mehsana	Average Number of Failures in 10 Years	Average number of rewinds per pump/ year
14	5.29	0.49	0.05

The failure rate is also greatly influenced by the power supply conditions at site. The following table represents the average fluctuations in power supply observed along the peak power supply variation for Mehsana district, with the corresponding failure rate.

TABLE 32: CORRELATION OF FAILURE RATE AGAINST SUPPLY CONDITIONS

Project	No. of Pumps	Average Age (Yrs)	Average failure Time(Yrs)	Average Voltage variation (%)	Peak Voltage Variation (%)
Mehsana	14	5.29	0.05	6.12%	26.51%

To be compared against the study on other villages.

Observations:

- The slope of the trend line in figure12 indicates the rate of failure at Mehsana increases by 0.80% every year while the effective efficiency of the pump decreases by 1.20%.
- Extended guarantee will encourage advancement of replacement of pumps.
- The overall advancement of procurement on pump by 10% will give an overall gain of (0.80% + 1.20%) = 2.00%; considering that the cost of down time and repairs are comparable with the energy cost paid by the farmers.

6.1.6 Additional gain using BEE Star Rated Pumps

Since most of the pumps are newly installed the current BEP of pumps are considered to be close to manufacturer's BEP. The overall system efficiency of these pumps is tabulated below.

The overall efficiency of A2 pumps from BEE star rated list is reported to be 60%. The average replacement life is of A2 pumps with stainless-steel impeller is observed to be 6.6 years while the replacement rate of other pumps is 3 years.

The scope of savings in efficiency by replacing the best performing pump locally available make against BEE's best star rated make for the same rating is tabulated below.

TABLE 33: OVERALL EFFICIENCY COMPARISON WITH RATED BEE PUMPS

Make Code	Overall Efficiency of Best Pump level At Site (A2 Pump). (a)	Overall Efficiency of Five star rated Pump-set after 10 years. (b)	Scope of improvement in efficiency by replacement of the pumps by BEE five star rated pumps (b)-(a)
A2	55.77 %	60.20%	4.43%

Observation

- BEE has several pumps with different performance levels (Efficiency) in the rated conditions of the pump considered. The weighted average efficiency of the available Five Star pumps is considered for the benchmark.
- The net scope of improvement in efficiency by replacement of the A2 pumps by BEE five star rated pumps is 4.43%.

6.2 Asset Optimization

Each pump is designed to work for a specific design head and flow requirement. If there is a mismatch in the range in which the pump is operating against its design head, the performance of the pump will drop dramatically. Thus imperative for optimum efficiency is selecting the right pump for a well defined head and flow range.

The above factors greatly influence the performance of the pumps over a period of time. The pump performance can be improved by appropriate decision making by precise selection of the pump for optimum performance, considering the duty conditions during its life cycle.

The following sections evaluate the opportunities to improve the energy efficiency by various asset management options.

6.2.1 Pump Selection with Accurate Estimation of Head & Deterioration During the service

The following figure represents the change in efficiency plotted against the operating head. The new pumps are represented in darker colors and the older pumps are in light colors. The deterioration of pumps has a tendency to compress the performance curves towards the Zero Head & Efficiency. The efficiency drop suddenly, after the pump operating point crosses over the BEP towards the shut off (on the right side of the following figure).

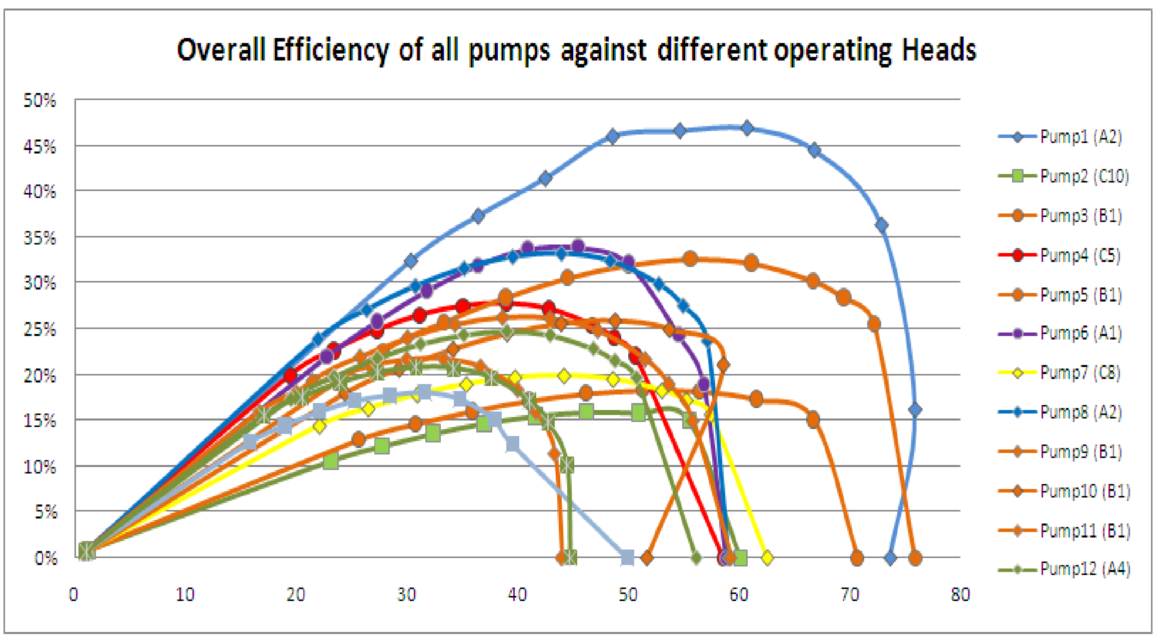

FIGURE 38: EFFICEICNCY OF ALL PUMPS AGAINST OPERATING HEADS

The current practice of selecting the pump in the village is based on the feedback on the pumps used by other farmers in the vicinity. Some of the farmers select a pump based on the initial feel on the water level and head as advised by the local dealer, based on this preliminary information. This approach grossly ignores many factors influencing the performance of the pumps over a period of time leading to huge losses incurred on account of inappropriate selection of pumps

The following figure represents the present losses on account of pump operation away from the BEP resulting in operation at considerably lower BEP of the pump.

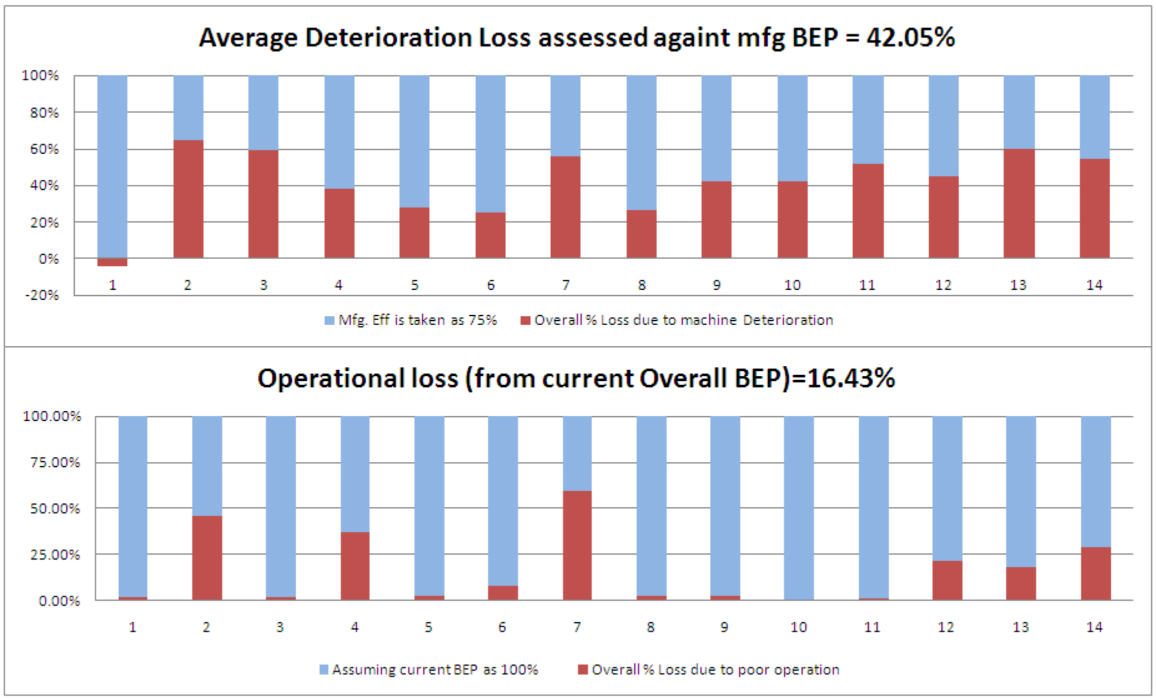

FIGURE 39: SCOPE FOR ASSET MANAGEMENT

Going only by the current situation would be misleading, as all pumps are subjected to continuous deterioration. The challenge here is to accurately select a pump which will operate at the best possible efficiency during its life. In order to do so it is necessary to know at what rate the head producing capacity of a pump is falling and what is the working life of a pump under the scenario, besides knowledge on the decline of water table during its life cycle.

The following Figure indicates the BEP of installed pumps at Mehsana with its corresponding efficiency (operating efficiency in blue). The graph also indicates the BEP against the proposed head of (excess 20% head above BEP suggested) indicated in Red. The current BEP efficiency levels are indicated in green.

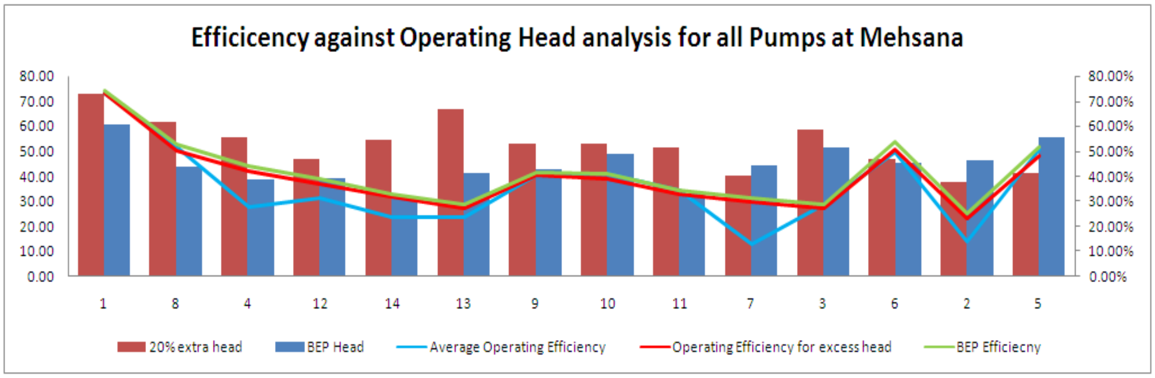

FIGURE 40: AGE-WISE DETERIORATION OF CURRENT BEP AND PROPOSED BEP PUMPS

The existing scenario has an average 5.71% operational loss (due to operations away from BEP). Incase if the pumps are selected with 20% higher head from the BEP, it will have will have an operational loss of 1.92% (due to operations away from BEP), effectively for the entire operating life.

Observations

- The head producing ability of a pump drops as its age increases causing the operating point to shift away from its BEP.
- Now if we select a pump having 20% more head producing capacity then what is required we realize that this pumps average operating efficiency point stays close to the BEP and will run more efficiently over the operating years as shown in the above figure.
- From the above figure, the current operating efficiency (indicated in Blue) is operating at an average of 5.71% away from the BEP (indicated in Green) while the proposed 20% excess head (indicated in Red) will be is only 1.92% away from BEP.
- The improvement in efficiency on account of selecting pumps 20% additional head from BEP is estimated as (5.71% - 1.92%) 3.79%.

6.2.2 Replacement of pumps after 10 years

Pump replacement is the easiest way to achieve better efficiencies. However the gains from replacement is influenced by many factors such as the pump deterioration, the variation in the water tables, shift in the operating point due to these factors and the analysis can be quite complex. To strike a golden mean between the ad hoc pump selections as practiced today and a complex analysis as carried out here, a simplistic approach can be derived. This may be tackled in the next stage of this research program.

The deterioration factors and the increasing maintenance cost over the time, studied under this report emphasis the need for a periodical replacement of the pumps. Ideally the periodical replacements shall be according to the deterioration rate in each location. However an upper limit shall be determined to limit the age of a pump. The government policies and programs shall be aligned to address this aspect as well.

Observations:

- It can be observed from the figure 38 that the pump performance drops drastically as the operating point of the pump shifts from BEP towards the shut off. As the pump deteriorates, the ability of the pump to lift water is affected, resulting in substantial reduction in flow rate and efficiency.

- At Mehsana the suggested age of replacement of inefficient pumps by locally available best pumps is much less than 10 years hence there is no scope for savings at Mehsana.

6.3 Use of multi speed motors

Considering the fact that the use of step down synchronous speed (i.e. from 2900 rpm to 1480 rpm) using a multi speed motor will substantially reduce the head and flow generation capacity of pump.
The feasibility for using multi speed motors for Mehsana is nil, as these pumps would not be able to generate the required head

Observation:

- It is not feasible to use multi speed motors for high head bore well pumps.

6.4 Use of level based controls

The ground water level at Mehsana village is found to be plentiful. The test was carried out in mid-summer and the results showed good water levels at all bore wells. The result clearly indicates a negligible scope for savings on account of level control.

6.5 Water Allocation Management

The following table shows the water usage against the land holding and water requirements, estimated as a proportion of the cultivated area.

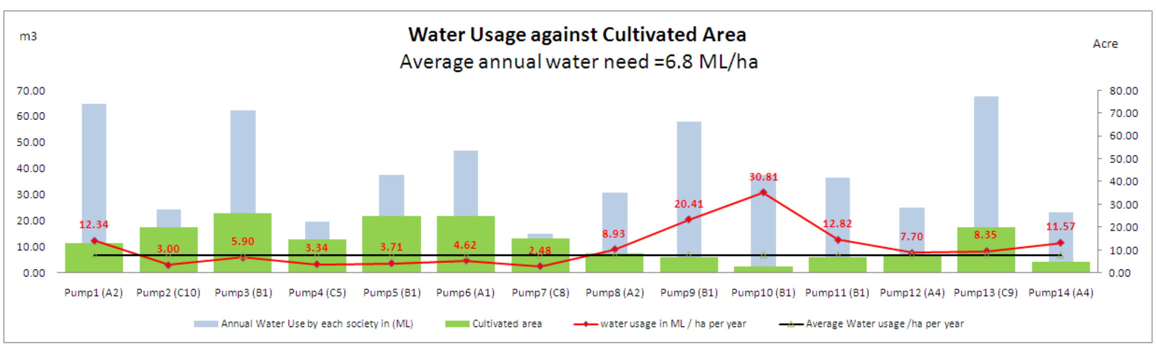

FIGURE 41: WATER DISTRIBUTION PATTERN ACROSS MEHSANA

The above figure indicates the irrigated land and the water usage. The average line is drawn taking into account of the average water use per hector. This excessive water usage above the average is considered as the excessive irrigation.

Observations:

- The above figure clearly indicates the need for equitable distribution of water.
- Equitable distribution shall save substantial water and energy required to deliver it.

- The annual water usage per farmer/acre is calculated by taking the ratio of the total amount of water consumed and total irrigated land used by each farmer. The water and the corresponding energy savings (by avoiding the excess water usage from average) through equitable water distribution is estimated to be 26.63%.
- The 18 pumps brought under detailed testing is estimated to pump 548.36 Million Liters of water annually and the scope for annual saving in water is estimated to be 146.04 Million Liters (26.63%).

6.6 Other Opportunities

The frictional loss in the pipe line is estimated to of a trivial value of the total energy usage and do not have any appreciable scope for improvement.

Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agriculture Water-Energy resource management, as the issues are intrinsically interlinked

7 Mohali and Patiala

Patiala is the administrative capital of Patiala district located in south-eastern Punjab, in northern India. Mohali is a city adjacent to Chandigarh. In 2011, both Patiala & Mohali had a population of 13, 54,686 & 1, 74,000 respectively. Patiala district with an area of 3625 Sq. km was the 5th largest district of the Punjab. Both city Mohali and Patiala has negligible ground water level variation during the pumping season. Out of these 16 bore well pumps ranging from 15 & 20 HP pumps are brought under the study for detailed testing and analysis. The average age of the pumps tested is found to be 13.75 years.

FIGURE 42: PUNJAB PUMP TESTING

The tests were conducted at site from 6th May 2012 to 12th May 2012. We are thankful to Mr. M.C. Jain, President- SEEM (Society for Energy Engineers & Managers) for organizing the local support at Punjab for conducting the detailed testing of pumps at Patiala and Mohali. The test data were analyzed in detail for the techno economic feasibility for (A) Improved Manufacturing Design (B) Asset Optimization (C) Control & Automation (D) Performance Management. The detailed analysis and observations for Mohali and Patiala against each category is elaborated in this section.

List of Pumps Surveyed at Punjab along with Tested pumps

TABLE 34: LIST OF PUMPS SURVEYED AT PUNJAB

Sr. No	Pump no	Name of Village	HP	Make	Year of installation	Age	Pump Configuration No	Pump reference
1	B-1	Mohali	15	SUBMERSIBLE	2009	3	1	A6
2	B-2	Mohali	15	SUBMERSIBLE	2006	6	2	A6
3	B-4	Mohali	15	SUBMERSIBLE	2003	9	3	B4
4	B-5	Mohali	15	SUBMERSIBLE	1998	14	4	B4
5	B-6	Mohali	20	SUBMERSIBLE	2003	9	5	B2
6	B-7	Mohali	15	SUBMERSIBLE	2001	11	6	B4
7	B-8	Mohali	15	SUBMERSIBLE	2002	10	7	B4
8	B-10	Mohali	15	SUBMERSIBLE	2000	12	8	B4
9	B-11	Mohali	20	SUBMERSIBLE	1997	15	9	B2
10	B-12	Mohali	15	SUBMERSIBLE	1999	13	10	B4
11	B-13	Patiala	15	SUBMERSIBLE	1992	20	11	B2
12	B-16	Patiala	15	SUBMERSIBLE	1993	19	12	B2
13	B-17	Patiala	15	SUBMERSIBLE	1992	20	13	B2
14	B-18	Patiala	15	SUBMERSIBLE	1991	21	14	B2
15	B-19	Patiala	15	SUBMERSIBLE	1992	20	15	A5
16	B-20	Patiala	15	SUBMERSIBLE	1994	18	16	A5

7.1 Scope for Improved Manufacturing Design

The scope for improved manufacturing design for the pump sets studied in the cities are assessed from the following perspectives.

1. Improved Design efficiency of Pump Sets (Higher BEP)
2. Scope for Improved Metallurgy
3. Higher Operating Efficiency at points away from BEP
4. Improved Efficiency of the Motor
5. Enhanced Guarantee for the Pump set

7.1.1 Use Best Locally Available Design (Higher BEP)

The design efficiency/best efficiency of the pump set varies from manufacturer to manufacturer for each pump model based on the rated head and flow of each pump.

The manufacturers of the agricultural pumps in India publish only head flow characteristics, while the power consumption data is not provided. We have evolved the manufactures pump curves based on the site test data by plotting the characteristics of each pump set and assessing the actual deterioration of pumps at site, to extrapolate the original conditions. The following figure shows the BEP of each pump plotted against its corresponding age for two major makes of similar ratings of the pumps at site.

The following figure shows the Best Efficiency of all makes along with their deterioration the deterioration in best efficiency (bar graph) of two makes over the age (line graph) of the pump.

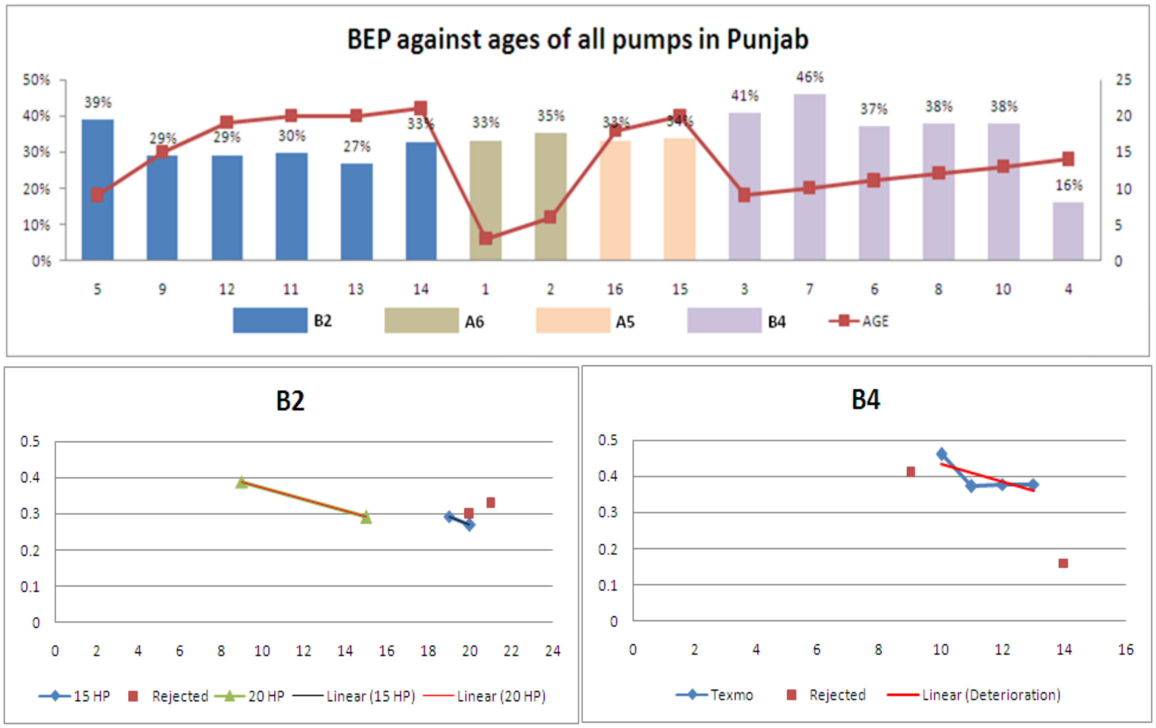

FIGURE 43: BEP OF EACH PUMP PLOTTED AGAINST ITS CORRESPONDING AGE

The above figure indicates the deterioration rate of two makes of pumps at Punjab. The data provides critical insight into the life of the pump under the site conditions and also enables to estimate the efficiency the pump across different time zones during its life cycle.

The following table compares the Best Efficiency and the deterioration of the best make locally available at site and remaining pump sets in the region having the same ratings.

TABLE 35: SCOPE FOR IMPROVEMENT IN DESIGN EFFICIECNY

Make Code	Average Age in yrs	Average Current BEP eff.	Deterioration rate of BEP Efficiency Per year	Manufacturers BEP (From BEE star rated list)
A5	19	33.55%	2.10%	76%
Others	11.11	33.72%	3.71%	69.91%

Observations

- The Scope for improvement in higher BEP for same rating pumps available in the village is 76.00% -69.91% = 6.09%.
- The average gain in efficiency on 16 pumps by replacing 14 pumps by A5 make would be (6.09% x 14/16).= 5.32%

7.1.2 Scope for improved Metallurgy

The deterioration of a pump is largely dependent on its metallurgy and the pump operating conditions. A better understanding of the pump performance deterioration enables selection of the optimum pump for the optimum performance across its life cycle.

The following analysis on pump deterioration is based on the preceding section (7.1.1). The projected efficiency of the major brand B4 against the other pumps brought under the study is tabulated in the following table. The effective improvement in efficiency is considered over its Life Cycle of 10 years with the impact of deterioration (Refer to Figure 42).

TABLE 36: SAVINGS ON ACCOUNT OF IMPROVED METALLURGY

Make Code	Deterioration rate of BEP Efficiency	Initial BEP Efficiency at the start of operation	Final BEP Efficiency at the end of 10th year	Losses on account of machine deterioration at 10th year
A5	2.10%	76.00%	55.00%	21.00%
Others	3.71%	69.91%	32.78%	37.10%
Savings	**1.62%**	**-6.09%**	**-22.22%**	**16.10%**

It is quite evident that A5 has better metallurgy to withstand deterioration in efficiency under the specific conditions in the village. Using A5 pumps instead of other brands would have yielded an estimated 16.10% increase in efficiency would have been achieved in 10 years. However the net gain in efficiency is computed after adjusting the initial higher efficiency of -6.09% (considered in the preceding section).

Coating of pump interior with special coating material that gives a smooth surface resisting abrasion will reduce the deterioration rate, depending on the life of the coatings. None of the pumps tested where internally coated and this aspect could not be studied.

Observations

- A5 pumps can give an advantage of lower deterioration rate over all other brands at the site conditions, with a net gain in efficiency of 16.10% over all other brands of same ratings at the end of life considered as 10years.
- The average saving over a period of 10 years would be half of the indicated value i.e. (16.10%/2) = 8.05%.
- The average gain in efficiency on 16 pumps by replacing 14 pumps by A5 make would be (8.05% x 14/16).= 7.04%

7.1.3 Scope for higher Operating Efficiency at points away from BEP (Flatness of efficiency curves)

The improved design efficiency at operating points away from BEP will result in flatter performance characteristics of the pump efficiency. The following figure shows the variation in efficiency from tested BEP for -50% to 50% head variation from the best efficiency point.

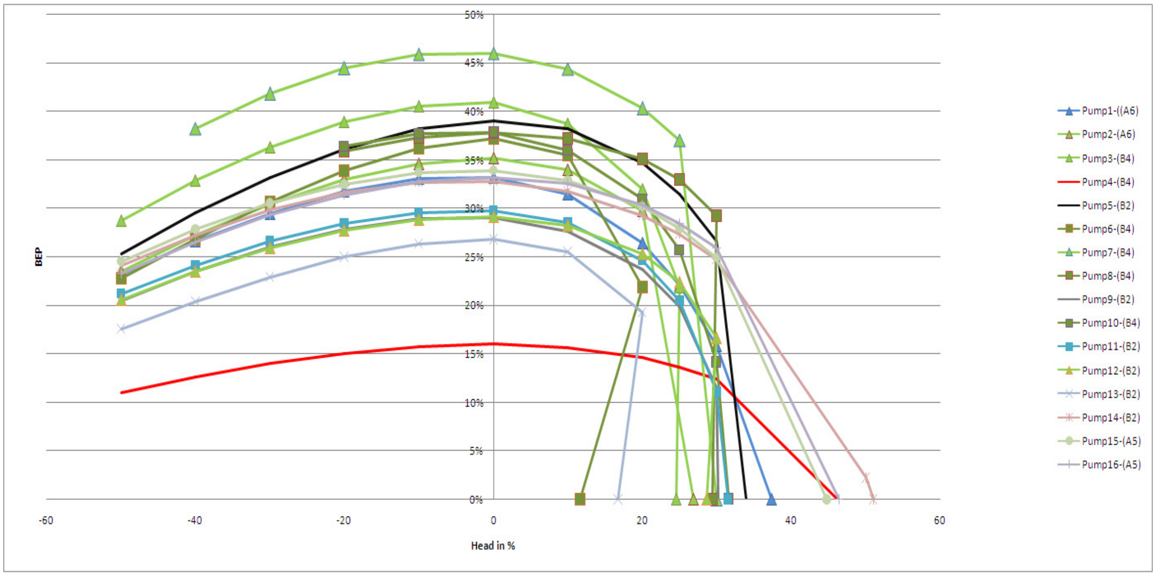

FIGURE 44: EFFICIENCY VS % VARIATION OF BEP HEADS

Observations:

- The drop in efficiency is more drastic when the head increases beyond BEP head.
- Flatness of the efficiency curves depends on a particular pump model and design of the manufacturer
- Considering multiple operating heads (Design Point +10%, -10% and -20% of Head) for a cluster of pumps having similar BEP, the savings on account of variation in heads in terms of pump efficiency would be 0.38 % (i.e. difference between most flat curve and average flatness of remaining pumps in the same cluster) for the pumps tested.
- This indicates the close similarity between the characteristics of the pumps.
- The flatness of the efficiency curves will be improved by manufacturers, if the criteria for fixing the performance of the pump only at one point are changed to performance at multiple operating points.
- The criteria for performance may be the average operating efficiency across an operating range.

7.1.4 Improved Motor Efficiency

The pump sets used in Mohali and Patiala are submersible pumps. The detailed testing of the motor is not possible at the field conditions. However the performance of the motor at each site is reflected in our data and analysis, as all tests are conducted at site with the combined motor pump set.

7.1.5 Enhanced Guarantee for the Pump set

The survey conducted at Mohali and Patiala reveals that the pump is generally taken out of service for repairs mainly for rewinding. The pump failures were analyzed with regard to the age of the pump and the data is represented in the following chart.

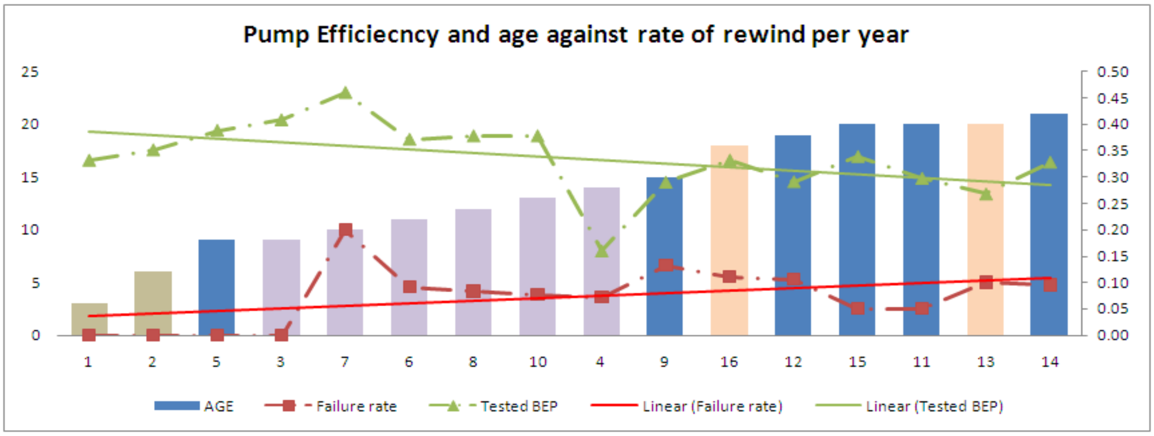

FIGURE 45: PUMP AGE AGAINST RATE OF REWIND PER YEAR

The Y- axis represents the age of the pumps (scale to the left) and X-axis represents the pumps in use with their age represented by the bar graph. The failure rate is represented as the average rate of rewinding per year as indicated by the dark dotted lines.

From the above figure it is clear that the rate of failure at Mohali and Patiala has an increasing trend against age of the pump. The following table indicates the average rewinding rate of motors per year per pump

TABLE 37: AVERAGE RATE OF FAILURE OF PUMPS AT MOHALI AND PATIALA

Total No. of pumps at Mohali and Patiala	Average age of Pumps at Mohali and Patiala	Average number of rewinds per pump/year
16	13.75	0.07

The failure rate is also greatly influenced by the power supply conditions at site. The following table represents the average fluctuations in power supply observed along the peak power supply variation for Mohali and Patiala, with the corresponding failure rate.

TABLE 38: CORRELATION OF FAILURE RATE AGAINST SUPPLY CONDITIONS

Project	No. of Pumps	Average Age (Yrs)	Average failure Time (Yrs)	Average Voltage variation (%)	Peak Voltage Variation (%)
Mohali & Patiala	16	13.75	0.07	10.84%	15.66%

To be compared against the study on other villages.

Observations:

- The slope of the trend line in figure12 indicates the rate of failure at Mohali and Patiala increases by 0.40% every year while the effective efficiency of the pump decreases by 0.60%.
- Extended guarantee will encourage advancement of replacement of pumps.
- Considering the cost in making good the failures, the overall advancement of procurement on pump by 10% will give an overall gain of (0.40% + 0.60%) = 1.00%; considering that the cost of down time and repairs are comparable with the energy cost paid by the farmers.

- If the above figure is read in conjunction with figure 48 then it is observed that the rate of rewinding has increased when pumps operate away from the BEP

7.1.6 Additional gain using BEE Star Rated Pumps

The Star Rating program of BEE is an effective method of recognizing the efficient agricultural pumps. Majority of the pumps found at Punjab Village are Star rated by the BEE. The opportunity for further improving the efficiency above the best brand in use (A5) by using BEE Five Star rated pump for the rated conditions is tabulated below.

TABLE 39: OVERALL EFFICIENCY COMPARISON WITH RATED BEE PUMPS

Make Code	Overall Efficiency of Best Pump level At Site (A5 Pump). (a)	Overall Efficiency of Five star rated Pump-set after 10 years. (b)	Scope of improvement in efficiency by replacement of the pumps by BEE five star rated pumps (b)-(a)
A5	58%	58%	0%

Observation

- BEE has several pumps with different performance levels (Efficiency) in the rated conditions of the pump considered. The weighted average efficiency of the available Five Star pumps is considered for the benchmark.
- The net scope of improvement in efficiency by replacement of the A5 pumps by BEE five star rated pumps 0%.

7.2 Asset Optimization

Each pump is designed to work for a specific design head and flow requirement. If there is a mismatch in the range in which the pump is operating against its design head, the performance of the pump will drop dramatically. Thus imperative for optimum efficiency is selecting the right pump for a well defined head and flow range.

The above factors greatly influence the performance of the pumps over a period of time. The pump performance can be improved by appropriate decision making by precise selection of the pump for optimum performance, considering the duty conditions during its life cycle. The following sections evaluate the opportunities to improve the energy efficiency by various asset management options.

7.2.1 Pump Selection with Accurate Estimation of Head & Deterioration During the service

The following figure represents the change in efficiency plotted against the operating head. The new pumps are represented in darker colors and the older pumps are in light colors. The deterioration of pumps has a tendency to compress the performance curves towards the Zero Head & Efficiency. The efficiency drop suddenly, after the pump operating point crosses over the BEP towards the shut off (on the right side of the following figure).

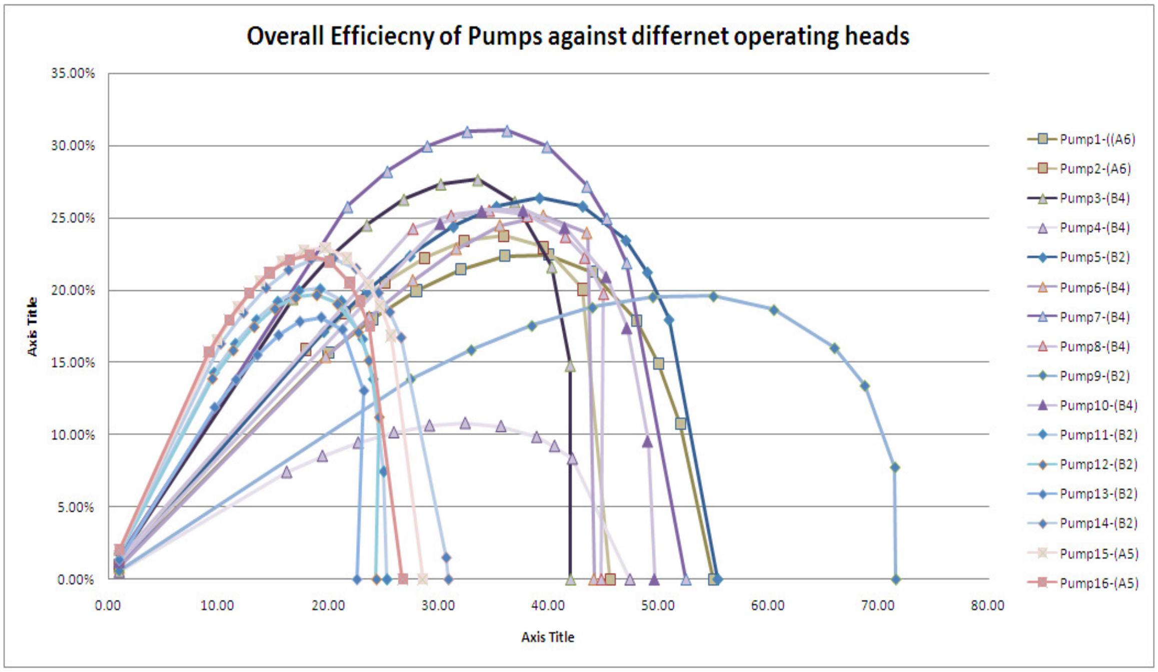

FIGURE 46: EFFICEICNCY OF ALL PUMPS AGAINST OPERATING HEADS

The current practice of selecting the pump in the village is based on the feedback on the pumps used by other farmers in the vicinity. Some of the farmers select a pump based on the initial feel on the water level and head as advised by the local dealer, based on this preliminary information. This approach grossly ignores many factors influencing the performance of the pumps over a period of time leading to huge losses incurred on account of inappropriate selection of pumps

The following figure represents the present losses on account of pump operation away from the BEP resulting in operation at considerably lower BEP of the pump.

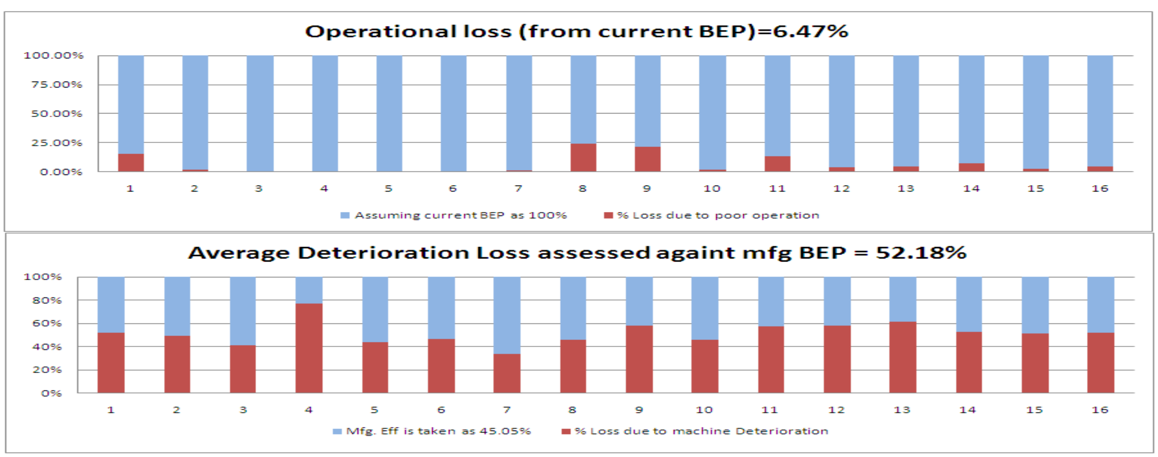

FIGURE 47: SCOPE FOR ASSET MANAGEMENT

Going only by the current situation would be misleading, as all pumps are subjected to continuous deterioration. The challenge here is to accurately select a pump which will operate at the best possible efficiency during its life. In order to do so it is necessary to know at what rate the head producing capacity of a pump is falling and what is the working life of a pump under the scenario, besides knowledge on the decline of water table during its life cycle.

The following Figure indicates the BEP of installed pumps at Mohali and Patiala with its corresponding efficiency (operating efficiency in blue). The graph also indicates the BEP against the proposed head of (excess 30% head above BEP suggested) indicated in Red. The current BEP efficiency levels are indicated in green.

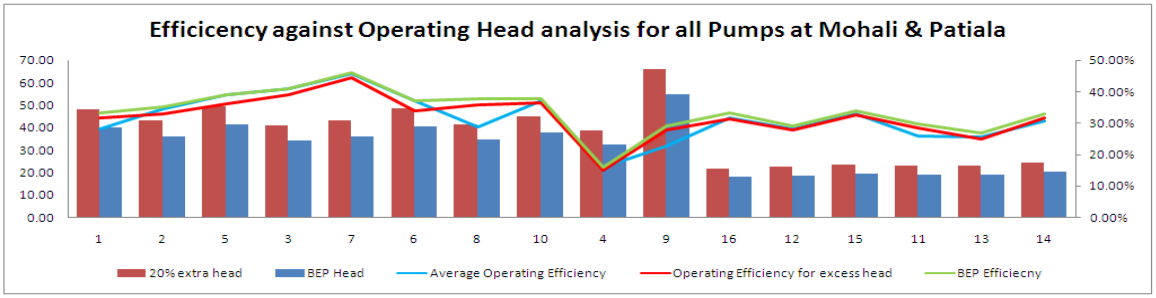

FIGURE 48: AGE-WISE DETERIORATION OF CURRENT BEP AND PROPOSED BEP PUMPS

The existing scenario has an average 2.12% operational loss (due to operations away from BEP). Incase if the pumps are selected with 30% higher head from the BEP, it will have will have an operational loss of 1.74% (due to operations away from BEP), effectively for the entire operating life.

Observations

- It is observed that the head producing ability of a pump drops as its age increases causing the operating point to shift away from its BEP.
- Now if we select a pump having 20% more head producing capacity then what is required we realize that this pumps average operating efficiency point stays close to the BEP and will run more efficiently over the operating years as shown in the above figure.
- From the above figure, the current operating efficiency (indicated in Blue) is operating at an average of 2.12% away from the BEP (indicated in Green) while the proposed 20% excess head (indicated in Red) will be is only 1.74% away from BEP.
- It is estimated that the operating point of oversized pumps will be only 1.74% below BEP as compared to 2.12% below BEP on the current situation.
- The improvement in efficiency on account of selecting pumps 20% additional head from BEP is estimated as (2.12% - 1.74%) = 0.38%.

7.2.2 Replacement of pumps after 10 years

Pump replacement is the easiest way to achieve better efficiencies. However the gains from replacement is influenced by many factors such as the pump deterioration, the variation in the water tables, shift in the operating point due to these factors and the analysis can be quite complex. To strike a golden mean between the ad hoc pump selections as practiced today and a complex analysis as carried out here, a simplistic approach can be derived. This may be tackled in the next stage of this research program.

The deterioration factors and the increasing maintenance cost over the time, studied under this report emphasis the need for a periodical replacement of the pumps. Ideally the periodical replacements shall be according to the deterioration rate in each location. However an upper limit shall be determined to limit the age of a pump. The government policies and programs shall be aligned to address this aspect as well.

Observations:

- It can be observed from the figure 46 that the pump performance drops drastically as the operating point of the pump shifts from BEP towards the shut off. As the pump deteriorates, the ability of the pump to lift water is affected, resulting in substantial reduction in flow rate and efficiency.
- The suggested age of replacement of inefficient pumps by locally available best performing pumps is 10 years i.e. those pumps older than 10 years are to be replaced best by the best performing brand (A5) of new pumps.

TABLE 40: SAVINGS ON ACCOUNT OF MACHINE REPLACEMENT AFTER 10 YEARS

Average age of pumps in years	Number of Pumps older than 10 years	Average age of these pumps older than 10 years	Average overall efficiency of these pumps (A)	Manufacturers overall BEP Efficiency (Extrapolated) (B)	Savings on account of replacement of machines after 10 years (B-A)
13.75	11	16.63	23.41%	36.08%	12.67%

- The effective gain on entire Punjab site by replacing 11 low efficiency pumps older than 10 years is (12.67 x 11/16) = 8.71%

7.3 Use of multi speed motors

Considering the fact that the use of step down synchronous speed (i.e. from 2900 rpm to 1480 rpm) using a multi speed motor will substantially reduce the head and flow generation capacity of pump.

The feasibility for using multi speed motors for Mohali and Patiala is nil, as these pumps would not be able to generate the required head

Observation:

- It is not feasible to use multi speed motors for high head bore well pumps.

7.4 Use of level based controls

The ground water level at Mohali and Patiala village is found to be plentiful. The test was carried out in mid-summer and the results showed good water levels at all bore wells. The result clearly indicates a negligible scope for savings on account of level control.

7.5 Other Opportunities

The frictional loss in the pipe line is estimated to of a trivial value of the total energy usage and do not have any appreciable scope for improvement.

Integrated Water Energy Resource Management is a new approach to towards managing water-energy-infrastructure, understanding their inter dependencies. Smart technologies are bringing down the cost of monitoring water-energy-infrastructure. Integrated approach is necessary for a sustainable solution in agriculture Water-Energy resource management, as the issues are intrinsically interlinked.