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Energy Management Consultation and Training Project (EMCAT): Demand-Side Management/Project Management

MUNICIPAL WATER PUMPING

PUNE, INDIA

Trip Report

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LIST OF ABBREVIATIONS AND ACRONYMS

EMCAT	Energy Management Consultation and Training Project
GPM	gallons per minute
HP or hp	horsepower
HWW	Holkar Water Works
KD	Khadakwasla Dam
kl	kiloliter
km	kilometer
kW	kilowatt
kWh	kilowatt hour
lpcd	liters per capita per day
LPS	liters per second
MLD	million liters per day
MRBC	Mutha Right Bank Canal
MSEB	Maharashtra State Electricity Board
mm	millimeters
NMRBC	New Mutha Right Bank Canal
PMC	Pune Municipal Corporation
PWW	Pashan Water Works
RMA	Resource Management Associates of Madison, Inc.
Rs.	rupees
USAID	United States Agency for International Development
WTP	water treatment plant
WW	water works

1. INTRODUCTION

This trip report covers the activities of Messrs. Charles Fafard and Doug Presny under the Energy Management Consultation and Training (EMCAT) Project. EMCAT is funded by the US Agency for International Development (USAID) for which Resource Management Associates of Madison, Inc. (RMA) serves as the prime contractor in implementing the project. Under this contract, RMA provides energy efficiency consulting services to India. During this trip, Messrs. Fafard and Presny were in the Indian cities of Calcutta, New Delhi, and Pune, from August 2 through 15, 1997, to conduct preliminary energy audits of the municipal water supply systems for Calcutta and Pune.

This report covers the energy audit work conducted at Pune. Portions of the report were taken from documents made available during the trip. The authors acknowledge and appreciate these documents as well as the time and effort given to this project by the staff of the Pune Municipal Corporation. The authors would expressly like to thank the following Pune Municipal Corporation (PMC) staff members for their assistance.

Mr. S.N. Jawdekar	Deputy City Engineer
Mr. R.T. Shelkande	Deputy City Engineer
Mr. R.A. Ghodke	Additional City Engineer
Mr. Ramanath Jha	Municipal Commissioner

2. BACKGROUND

Pune is a city of approximately one and a half million inhabitants, located in western India in the state of Maharashtra. Pune has a thriving metropolitan business climate, with many industries located in the metropolitan area. Over the past years, Pune has had buoyant sources of revenue and a significant revenue surplus. This has enabled Pune Municipal Corporation (PMC) to undertake a majority of the capital investments in urban infrastructure from its own revenue surpluses. As a result, PMC has a relatively low level of outstanding debt. This represents a considerable future debt servicing capability. PMC is one of the three municipal authorities in India that has been rated for a potential municipal bond issue. Its rating for a Rs. 200 crores (US$ 57 million) General Obligation bond is AA. PMC has also initiated the process of appointing merchant bankers to address this issue.

Growth and expansion are significant issues for Pune. The municipality's jurisdiction is expanding to include thirty-one neighboring villages. This will cause an increase in its service territory from approximately 140 square kilometers to 480 square kilometers, over a two hundred percent increase. PMC has, therefore, developed a plan to provide expanded water and sewage services to the region. The project will be completed in three phases, with phase one scheduled for completion in 2001.

Phase one is to be implemented through private sector participation, so that it becomes possible to incorporate the latest technology, ensure availability of finance and timely completion of construction work, improve efficiency of service delivery by reduction in losses, and enhance recovery though better consumer services and billing and collection systems. PMC has invited private sector firms to submit proposals for the first phase of the project, which includes construction and operation of selected new facilities. Improved management of billing and collection systems in selected localities is also under active consideration.

3. EXISTING SYSTEMS

One of the first water supply schemes in Pune City was through a small dam constructed on the river Amba near Katraj in 750. From this, water was supplied to the city through a pipeline. Later a small bund was constructed on the Mutha River in the year 1848 to supply water to Pune Cantonment. Over time, with the growth in population, these two reservoirs proved inadequate, and a large reservoir was created on the Mutha River by constructing a dam at Khadakwasala about 12 km from the city. From this dam, a Right Bank Canal was constructed for the city water supply with a discharge capacity of 412 cubic meters per second. Raw water is currently tapped from the canal at Parwati, Cantonment, and Holkar water works. To ensure a good quality of water supply to the city, water was sedimented, chlorinated, and supplied to house connections through pipelines.

Transmission and Distribution

Currently, the PMC supplies water to the population within the corporation's limits, as well as to fifteen surrounding villages. Even though the supply levels are fairly adequate compared to other major cities in India, there are certain pockets in the peripheral and newly developed areas that do not receive adequate supply and pressure. In addition, the PMC's limits are expected to be increased during the current year, with the merger of thirty-six surrounding villages, which will have to be provided with basic services, such as water and sewerage. The corporation is also required to provide water supply to the surrounding villages within 5 km of municipal limits as per the recent State Government directive. The thirty-six villages that are likely to be merged will impose a severe burden. It is in this context of likely growth in water demand that PMC proposes to augment the water supply services.

By 1950, the population of Pune City had increased to 0.45 million. Thus, the available capacity of 45 million liters per day (MLD) began to prove inadequate. In 1949, the Pune Municipality was upgraded to the status of a Municipal Corporation. A new scheme of 110 MLD of filtered water was proposed by the newly formed PMC. However, this scheme took a long time to materialized and was commissioned only in 1968. A modern 100-MLD filtration plant, with flash mixers, clarifloculators, filter house, sump well and pumping station, was constructed at Parwati. The population of Pune City had reached 0.9 million by 1968, and the new plant ensured a rate of 110 liters per capita per day (lpcd). To meet the burgeoning water demand of a growing population, another filter plant of 160 MLD capacity was constructed at Parwati in 1975. This increased the supply of treated water to a total of 270 MLD serving a population of 1.5 million. Subsequently, in the years 1980 and 1990, the capacities of these two filter houses were further augmented. Currently, the total filtration capacity at Parwati Water Works is 540 MLD.

The level of supply is now in the range of 198 lpcd after considering transmission and distribution losses of 20 percent (assumption). The actual leakage situation needs careful study. This supply level is favorable when compared to the average supply in million-plus cities and with the norm of 150 to 200 lpcd for domestic and non-domestic use for cities with a population of more than one lakh (100,000 people) as recommended by the Central Public Health and Environmental Engineering Organization in its *Manual on Water Supply* (1987). PMC is undertaking an augmentation of capacity of Pune Cantonment water works from 120 to 270 MLD, which is

expected to be commissioned during 1997. This augmentation will increase the total available capacity to 843 MLD, which translates to 245 lpcd after assumed losses of 20 percent. Without any further additions to the capacity, the supply level is likely to decline to 138 lpcd by 2011 and 84 lpcd by 2025, which would be nearly half of the prescribed standard. It is in this context that PMC proposes to augment the capacities in a phased manner

Table 1 gives the details of total water supply available for Pune and its utilization. The present combined capacity of all water works is 680 MLD. In comparison, utilization is to the extent of 530 MLD in different seasons. The main reason for under-utilization is the availability of 90 MLD excess capacity at Parwati.

The present population of the city and the fringe areas where the PMC supplies water is approximately 2.2 million. The projected population of this entire area, including thirty-six villages that are to be merged, has been estimated to be 3.0, 4.3, and 6.5 million by 2001, 2011, and 2025, respectively.

Table 1
Details of Pune Water Works

Water Works	Year of First Commissioning	Capacity (MLD)	Actual Average Daily Pumping 1995-96 (MLD)		
			Winter Sept-Jan	Summer Feb-May	Monsoon June-Aug
Parwati	1969	540	400	480	440
Pune Cantonment	1893	120	100	120	110
Holkar Bridge	1930	25	25	25	25
Pashan	1850	5	5	5	5
Total		**680**	**530**	**630**	**580**

Currently, PMC fulfills its responsibility to supply the city of Pune and sixteen adjacent villages with water. The supply network now covers 139 square kilometers and serves 1.73 million people. This is in addition to serving industrial and commercial needs. A breakdown of PMC's distribution is presented in *Table 2*.

All water used for Pune's potable purposes originates at the Khadakwasla Dam (KD). The dam is located 12 km away from Pune. The dam controls water from the Mutha River. Its elevation is well above that of the city; thus, the raw water is delivered for treatment via gravity flow.

An open channel known as the Mutha Right Bank Canal (MRBC) serves to supply raw water from KD to three of Pune's four water treatment plants (WTP). The MRBC continues beyond the Parwati WTP to supply the Pune Cantonment WTP with raw water. This section of the canal is known as the New Mutha Right Bank Canal (NMRBC). After reaching the Pune Cantonment WTP, the water is emptied into a sump. A series of sump pumps lifts the water from the sump so

that it can then run, via gravity, through the treatment process. It is then pumped to begin distribution.

Table 2 PMC Distribution System

Sr. No.	Name of Zone	Connected to Water Works
1	Parwati HLR	
2	Parwati MLR	
3	Parwati LLE	
4	Bibavewadi	
5	Dhanakawadi (Taljai)	
6	Katraj	PARWATI WW
7	SNDT MLR #1	
8	SNDT MLR #2	
9	SNDT HLR #1	
10	NDT HLR #2	
11	Chatushringi	
12	Pune Cantonment Low Level	
13	Pune Cantonment Middle Level	PUNE CANTONMENT WW
14	Yerawada Middle Level (Thakarsi Hill)	
15	Pune Cantonment HLR (Bakari Hill)	
16	Pune Cantonment HLR (Wanorie)	
17	Holkar Bridge	HOLKAR BRIDGE WW
18	Khadaki Cantonment	KHADAKI WW
19	High Explosives Factory	HIGH EXPLOSIVES FAC. WW
20	Pashan Village	PASHAN WW

The third treatment plan is the Holkar Water Works (HWW). It is comprised of three small water treatment plants. They are the High Explosive Factory WW, the 1940 Khadki WW, and the Holkar Bridge WW. Raw water is delivered from the NMRBC by gravity to each water works. The HWW is located 21 km from the KD. In all three plants, the water filtration process is accomplished using gravity.

The fourth water treatment plant is the Pashan Water Works (PWW). This is the only plant which receives its raw water from a source other than the KD; PWW's water comes from the Ram River. This raw water is pumped into a tank and then gravity-fed through the entire treatment process.

In Pune, water is supplied 24 hours a day. The exception to this rule occurs in some impoverished areas where water is available 16 hours per day from public "standposts." Water is distributed to the city via a system of pump stations, elevated reservoirs, and booster pump stations.

For practicality, water distribution is divided among twenty zones. The responsibility for water distribution is divided according the schedule below. The distribution system is illustrated in *Figure 1.*

water pressure is developed by pumping the treated water from the treatment plants to reservoirs at higher elevations. In some cases, the water is pumped from one reservoir up to a higher reservoir. This is the method employed to provide water to the higher elevations of Pune. After reaching a reservoir of sufficient height, the water is gravity fed to the piping distribution system.

Proposed Project

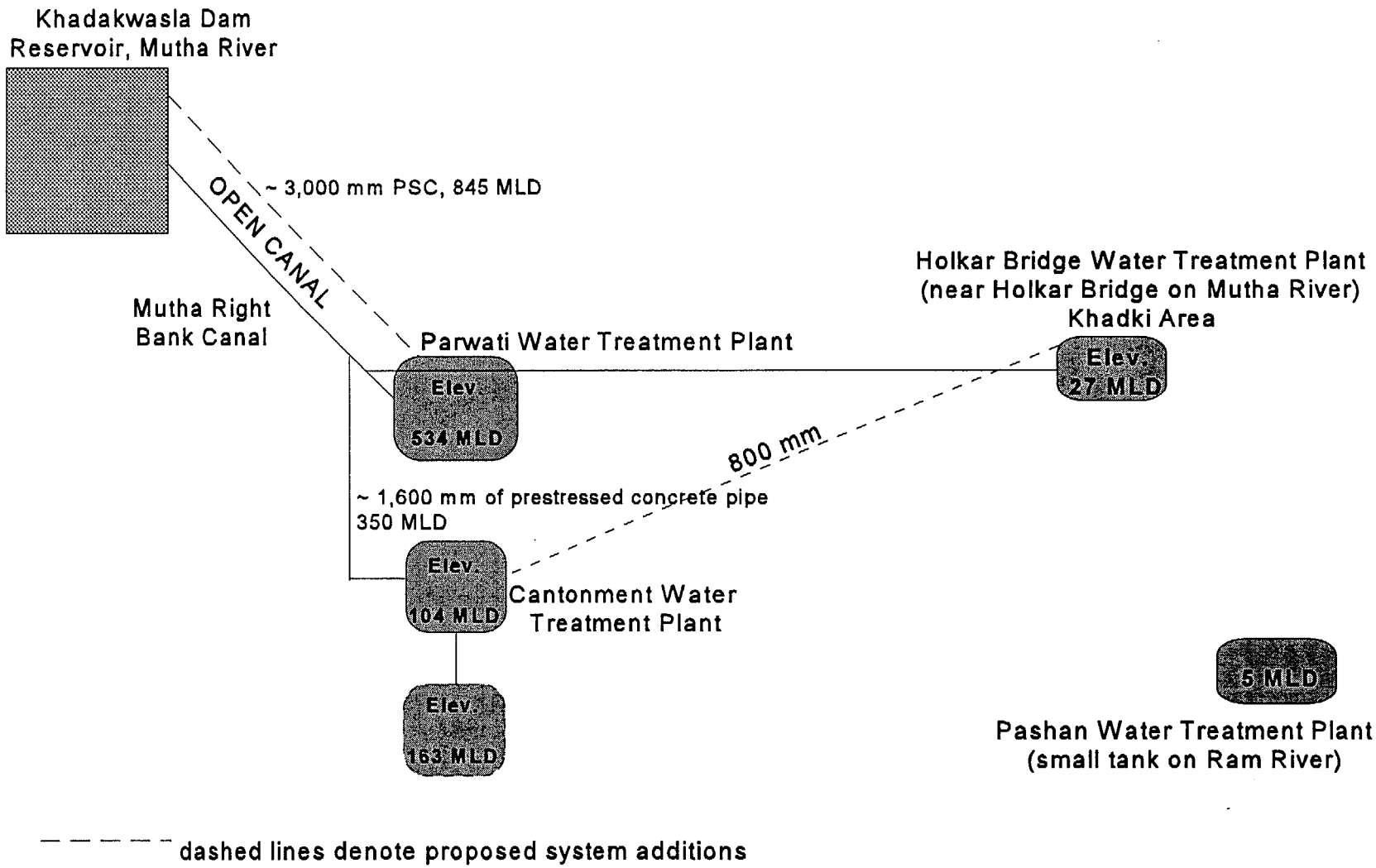
PMC intends to undertake and implement a water supply and sewerage project (augmentation of existing systems and new units) to cater to the present and future requirements of Pune City up to the year 2025. The project is to be implemented through private sector participation, so that it becomes possible to incorporate the latest technology, ensure availability of financing and timely completion of construction work, improve efficiency of service delivery by reductions in losses, and enhance recovery through better consumer services and billing and collection systems. At this stage, PMC plans to invite private sector firms to submit proposals for the first phase of the project, which includes construction and operation of selected new facilities. Improved management of billing and collection systems in selected localities is also under active consideration.

Based on long-term planning, PMC identified investments in the water and sewerage sector in three phases. The construction of first-phase components is expected to be completed by 2001. The second-phase and third-phase components will be commissioned during 2001-2011 and 2011-2021, respectively. The components under these three phases include augmentation and construction of water treatment plants, transmission lines, improvement of existing water distribution system, extension of the water distribution system to new areas, augmentation and creation of new sewage treatment plants and pumping stations, and laying of a sewage collection network. The base costs (at 1996 prices) for proposed investments in the water and sewerage sector during these three phases are estimated to be as follows:

First Phase	Rs. 4,960 million (US$ 141.7 million)
Second Phase	Rs. 2,670 million (US$ 76.3 million)
Third Phase	Rs. 3,060 million (US$ 87.4 million)

The first phase includes improvement of the water supply system within the city (Parwati), Pune Cantonment, Khadki Cantonment, and Pashan Water Works Zones; laying of a transmission line from the Khadakwasla dam to the Parwati Water Works; construction of a water treatment plant of 200 MLD capacity at Kothrud; laying of the main sewer lines, rising mains, and sewage pumping stations at Tophkana, Tanajiwadi, and Bahiroba Nala; and construction of sewage treatment plants at Dr. Naidu Hospital, Bahiroba Nala, and Kalyaninagar, with a provision for recycling the effluents into the irrigation canal. Out of these components, PMC invited tenders for laying of the 13 km, 3,000-mm-dia., mild-steel raw water main from KD to Parwati Water Works during October 1996 at an estimated cost of Rs. 550 million (US$ 15.7 million). The work on this component began in May 1997. The base cost of first-phase components that are proposed to be undertaken on the "Build-Finance-Transfer" basis was estimated to be Rs. 4,410 million (US$ 15.7 million).

Figure 1 Existing Water Distribution System with Proposed Modifications



4. ENERGY CONSUMPTION & RATES

Water charges are levied on a consumption basis for metered connections. The present rates are in the range of Rs. 2 to 10 per kiloliter (kl) for different user groups, with a specification of minimum rates that have to be paid. There are two types of minimum charges that are levied on a household basis. First, the minimum rates of metered connections correspond to the situation where the meters are in working condition. This is to ensure a minimum revenue from metered connections in case the consumption is low. The second type of minimum charge is levied in cases where the meters are not in working condition. These rates are relatively high to ensure a compliance of users to maintain/replace the meters. The metered rates were revised during 1994-95. The corresponding minimum rates for meters in working condition were last revised in 1988. For the domestic sector, the rates in Pune are Rs. 2 per kl; whereas, in the Cantonment area, the corresponding rate is Rs. 2.5 per kl. The details of the minimum rates are presented *Tables 3* and 4. *Table 5* details the water tax rate structure.

Table 3 Rates for Metered Connections in Rs./kl

Year	PMC Area				Cantonment
	Domestic		Non-domestic		Domestic
	Rate	% Increase	Rate	% Increase	Rate
1992-93	1.3	--	6	--	
1193-94	1.5	15.4	8	33.3	
1994-95	2.0	33.3	10	25.0	
1995-96	2.0	0.0	10	0.0	2.5

The water tax is levied only on unmetered connections. These connections are prevalent in older parts of Pune. In certain cases, one unmetered connection serves more than one family, up to a maximum of five families. If one unmetered connection serves more than five families in one premises, PMC has been insisting on taking up additional connections that will be metered. The water tax is 17.5 percent, with a minimum tax of Rs. 525 per connection. Out of 56,000 unmetered connections, approximately 11,000 connections pay the tax based on 17.5 percent (on average, Rs. 2,800 per connection), and the rest pay the minimum rate of Rs. 525 per connection. The rate structure for this tax is shown in the following table. These taxes were revised during 1993-94 and 1994-95, as illustrated in *Table 4*.

Table 4 Minimum Rates for Metered Connections in Rs./Month/Family (effective April 1, 1988)

Size of Connection (Inches)	Meters in Working Condition			Faulty Meters **	
	Domestic	Non-domestic	Hotels	Domestic	Non-domestic
0.50	20	50	300	60	90
0.75	40	100	700	120	180
1.00	100	400	1500	240	360
1.50	200	500	3000	540	810
2.00	300	1,000	6,000	960	1,440
3.00	400	1,400	14,000	2,160	3,240
4.00	700	2,400	25,000	3,840	5,760
6.00	1,500	5,000	50,000	8,640	12,960
8.00	3,000	9,000		15,360	23,040
10.00	4,500	10,000		24,000	36,000

Note: 1. The minimum rates are charged on the basis of number of families served by one connection.
2. ** In situations where the meters are not in working condition, the minimum rates per family are calculated based on 200 lpcd, 5 persons per family, and Rs. 2 per kl.

Table 5 Water Tax

	1992-93	1993-94	1994-95	1995-96
Water Tax	15%	15%	17.5%	17.5%
Minimum Rate (Rs./connection/year)	365	450	525	525
Revenue (in Rs. million)				
Arrears	--	24.92	28.08	29.82
Current demand	--	31.45	35.06	40.50
Total demand	--	56.38	63.13	70.32
Collections	--	28.30	33.72	34.86
Collection Performance (in %)	--	50.2	53.4	49.6
Revenue per Connection (in Rs./year)	--	580	630	628
Growth in Revenue per Connection	--	--	8.6	-0.3

5. COST OF ELECTRICITY

Electricity is provided by the Maharashtra State Electricity Board (MSEB). The standard rates paid by PMC are shown below:

Demand	= Rs. 100/kW per month
Energy	= Rs. 3.13/kWh
Tax	= Rs. 0.18/kWh

Average costs per month are shown below for a 1-kW load with a 75% load factor(LF):

Assuming 1 kW for 1 month with 75% LF,

the result is : 1 kW * 730 hr/month (average) * 75% = 547.5 kWh per month

Average demand cost per kWh $= \frac{\text{Rs. } 100}{547.5 \text{ kWh}} = \frac{\text{Rs. } 0.1826}{\text{kWh}}$

Total cost per kWh = Rs. 3.13 + Rs. 0.18 + Rs. 0.18
= Rs. 3.5 ($0.0993) / kWh

6. SITE VISITS & OBSERVATIONS

Several important characteristics were observed at the Parwati Water Works site. Probably the foremost observation was that a significant number of pumps and valves were leaking. In fact, one reservoir was also leaking, and two or three cracks in the concrete were visible. While this situation is fairly typical for India, it is not typical for western countries. Questions in regard to the condition of the piping and the leaks prompted general responses such as "They're being repaired." While this is undoubtedly true, there appears to be a long period of time between identifying leaks and making the necessary repairs. This is unfortunate because it promotes a mentality where leaks are considered normal and are tolerated for extended periods of time. Leaks in water systems (mainly underground piping) can be extremely difficult to detect and repair because the piping is not visible. The fact that even visible leaks are tolerated makes it even less likely that staff will be motivated to look for other leaks and repair them in a timely fashion.

Another situation that was observed included the filling of tanker trucks. This happened on an almost continuous basis on the day of the site visit, and spillage was substantial. Observers estimated that at least 10% to 20% of the water being loaded was spilled in the process. It was not determined if the water involved was raw or filtered or even if it was pumped or gravity-fed. However, it would take very little to modify the process of filling trucks to minimize losses attributable to leaks or spills. Again, the existing mentality tolerates leaks and spillage and does not encourage immediate repairs. The excessive amount of time now being taken to repair a leak points out the need to revise operating procedures.

7. ENERGY ANALYSIS

In analyzing the pumping systems, the two major pieces of equipment that need to be evaluated are the pump(s) and the motor(s). However, another major area of interest is the general integrity of the system. For water systems, this typically refers to leakage. Each of these items will be discussed in greater detail below.

Pumps

Pumps are simple mechanical devices designed to move a fluid, often water. The pump typically consists of a set of blades (impeller), a housing, and a motor. Pumps are designed to move a given quantity of fluid against a resistance, or pressure. These two factors, flow rate and pressure, determine the size of the pump required to meet the specified conditions. Normally pumps can have different sizes of impellers and motors, so that one housing can be matched up for different conditions. This flexibility also provides opportunities for energy improvements in the operation of the pumps.

In designing systems, the designer calculates the expected pressure and fluid flow rate that the pump will encounter. It is normal for the designer to then add a factor of safety to one or both of these values, ensuring that the pump will meet the minimum required performance. This "over-sizing" results in potentially inefficient operation. Therefore, once a system is installed, actual flow and pressure readings should be conducted to determine the exact requirements that exist in the system. The manufacturers data and pump curves should then be consulted to determine if a different size of impeller or motor could meet the system requirements.

Pump optimization must take place in the field, and cannot be accomplished in the design phase. Measurements are required to determine where the pump is actually operating on the pump curve. Appendix A shows a typical set of pump curves for one pump. The curve illustrates that several sizes of pumps and impellers can be utilized for the pump. Measurements of pump performance were not taken during this trip, and PMC staff only had name plate data. However, that data was sufficient to calculate the overall system performance (see Energy Calculation section). Since the systems and equipment are old, it is possible that the efficiency of each pump could be increased by several percentage points.

Motors

As mentioned in the previous section, the first consideration regarding motors is to determine if the motor is properly sized. Motors operating at less than 50% tend to be less efficient than properly sized motors. However, this is also a condition of the motor size, as shown in *Figure 2*. The smaller the motor, the more impact part load operation has on the motor's efficiency. In addition, the efficiency of the motor should be examined. Many of the motors are quite old. These motors were probably not very efficient when they were new, and would now be considered quite inefficient compared to modern motors (especially U.S. models). *Table 6* illustrates the resultant savings from using motors of higher efficiency than those listed. The second column of the table presents a very conservative 1% improvement for each size motor. The third column illustrates a 5% improvement and savings for each size motor.

Figure 2 Motor Part Load Efficiency as a Function of % Full Load Efficiency

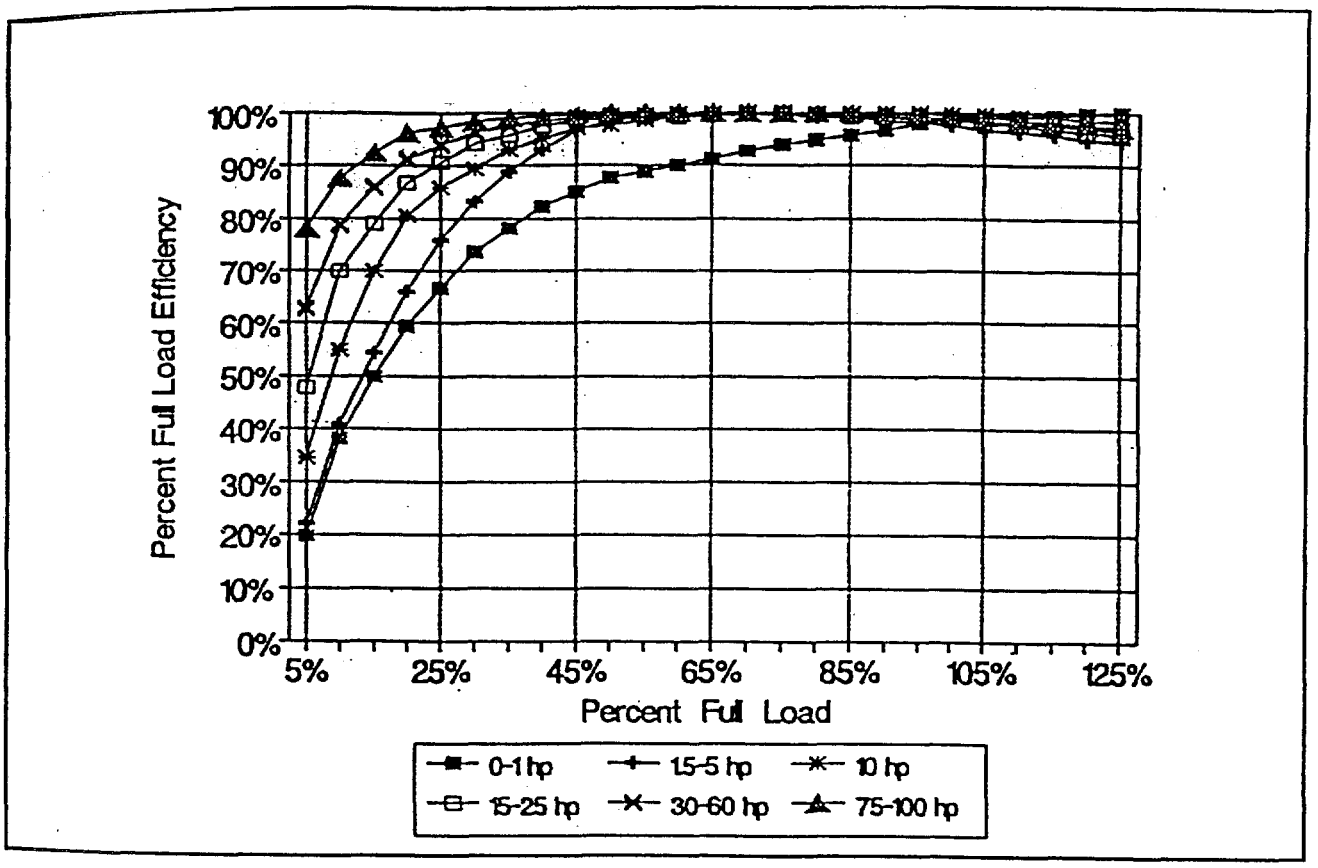


Table 6 Cost Savings Resulting from Motor Efficiency Improvements

HP	1% Savings Rs. Per Year	5% Savings Rs. Per Year
250	80,080	420,448
270	86,486	454,084
350	112,112	588,627
425	136,136	714,762

Table 6 savings are per motor for a full year (8,760 hours) at an electricity rate of Rs. 3.5/kWh (including tax and demand charges). Column two is based on an assumed one percent efficiency gain (from 84% to 85%). These savings are very conservative, as the existing motors are probably nowhere near 84% efficient. Column three represents a five percent savings (from 80% to 85%). New motors manufactured in the U.S. are typically more than 85% efficient, although this varies with size. Indian motors are not as efficient as the standard U.S. motor and are much less efficient than U.S. high-efficiency motors.

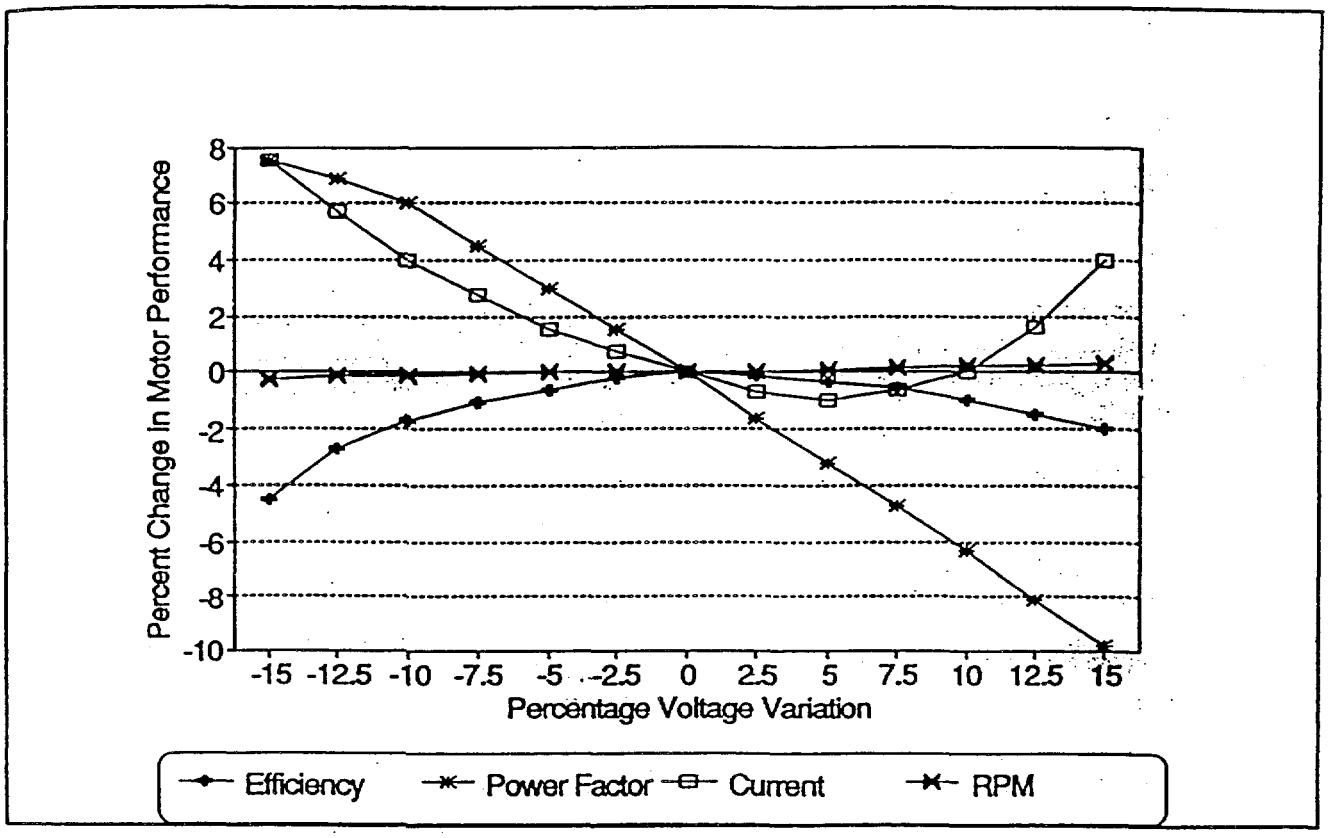
The equation used to calculate energy savings is:

ES = 0.746 x HP x cost x hours x [100/EM - 100/NM]

where ES = annual energy savings
HP = motor horsepower
Cost = energy cost/kWh
hours = number of hours of operation per year
EM = existing motor efficiency
NM = new motor efficiency

Another concern regarding motor performance is the effect of low-voltage supply. *Figure 3* shows the impact low voltage has on motor efficiency. As can be seen, a voltage drop of 15 percent can reduce efficiency by almost 5 percent. In addition, the motor will run hotter, slip more, produce less torque, and have a shorter life expectancy. While this situation was not specifically identified in Pune, it is fairly common throughout India. Therefore, PMC staff should be aware of the impact that low voltage supply has on motor efficiency.

Figure 3 Voltage Variation Effect on Motor Performance



Leaks

Numerous leaks were observed throughout the distribution system. Many of these leaks were substantial, amounting to a large loss in water. In addition, every drop of water lost in the distribution system is very expensive, since it has already been pumped from the river. Costly electricity is wasted moving water which is allowed to leak from the system.

A water leakage rate of one drop per second will ultimately amount to 192 gallons per month, or 727 liters per month. Currently PMC distributes about 198 liters per capita per day. Therefore, over a month's time, a drop per second would provide enough water for 3.7 person-days. A drop per second is quite a slow leak, and the leaks within the distribution system are numerous and much heavier in volume. It is easy to see that the water leakage rate is not a trivial matter, and all possible steps should be taken to improve the maintenance and eliminate all system leaks.

Leakage is estimated at anywhere from 20 to 35 percent of the total volume. Although it is doubtful that any system can be "leak-free," the leakage in the PMC system is excessive and should be addressed. In fact, the existing leaks may well exceed the 20 percent figure that is estimated in some of PMC's reports. As shown in *Table 7*, annual electricity charges for pumping water in 1996-97 were approximately Rs. 15.8 crore (US$ 4.5 million). Since the leakages represent losses, Rs. 3.16 crore (US$ 0.9 million), were wasted in pumping water that was never delivered to the end-user. Again, this amount may be much higher depending on the actual leakage rate.

Table 7 Expenditure on Water Supply (Rs. Million)

	Actual					Estimated		% Growth Rate of Actual
	1990-91	1991-92	1992-93	1994-94	1994-95	1995-96	1996-97	
Establishment	27.80	38.52	59.16	75.03	99.49	115.45	115.85	37.7
Electricity Charges	51.98	82.43	105.10	102.35	125.69	147.10	158.00	26.6
Debt Servicing	9.47	11.04	9.87	9.82	11.18	19.53	22.47	4.8
Contribution to Projects	24.90	64.50	39.30	28.24	57.69	52.75	111.35	49.0
Others	25.86	29.85	33.76	39.06	46.10	54.68	77.05	15.6
Total/Average	**140.01**	**226.34**	**247.19**	**254.5**	**340.15**	**389.51**	**484.72**	**26.9**

8. ENERGY CALCULATIONS

Pumping water is very energy intensive and costly. In Pune, supplying domestic water costs Rs. 485 million annually, with energy comprising one-third of the cost. Any effort should be considered to improve the efficiency of this process in an effort to reduce costs. The most obvious place to look for improvement is in the pumps and motors themselves. *Table 8* is a summary of the major equipment employed by Pune in providing filtered water. The data included under the "nameplate data" columns include specified design values for the pump head, horsepower, and flow rate. Using the pump head and the horsepower, the theoretical flow rate can be calculated, as shown in the table. Comparing the theoretical flow rate with the specified flow rate yields the system efficiency. This efficiency is a combination of the motor efficiency and the pump efficiency. Most of the systems have efficiencies below 70%, indicating that neither the pump nor the motor is very efficient. These are also design values, and because most of the equipment is over twenty-five years old, the actual performance may be less.

The system efficiency is a combination of the pump efficiency and the motor efficiency. As can be seen in *Table 8*, many of the motors are oversized for the application. For instance, all of the motors for Pump House #2 are slightly oversized. The calculations indicate that a 400-HP motor is adequate, but 425-HP motors were installed. However, while larger motors typically cost more to purchase, the larger motors usually do not cost more to operate than the smaller motors. Since the efficiency of large motors does not vary much with load fluctuations (see Figure 2), their operating costs are stable over a wide range of loads.

In *Table 9*, potential savings were estimated on the basis of the system efficiency being 75%. Since the motor efficiency for this size of motor does not vary significantly, pump efficiency would have to be improved. From monitoring data provided, pumps #1-#6 in Pump House #2 have a system efficiency of 69%. If the motor were 90% efficient, replacing it with another standard efficiency motor, but one that was better sized for the load, would not improve the system efficiency. (If, however, it could be replaced with a higher-efficiency motor, there would be some improvement.) So, at 90% motor efficiency and a 69% system efficiency, the pump efficiency is 77% (69% ÷ 90%). If the overall system efficiency could be improved to 75%, the pump would have to have an efficiency of 83% (75% ÷ 90%). This degree of pump efficiency is not uncommon, and it is likely that the pumps could be upgraded to this performance level or they could be replaced with pumps that do operate at the higher performance level. The same estimates based on a system efficiency level of 82% are provided in *Table 10.*

Tables 9 & 10 indicate the annual savings attributable to increased system efficiency (at 75% and 82%). Seventy-five percent system efficiency is an intermediate value, while eight-two percent is equivalent to the most efficient of the existing systems.

Table 8 Parwati Pumps

PUMP HOUSE	PUMP #	NAMEPLATE DATA							CALCULATED FLOW RATE			PUMP & MOTOR SYSTEM EFFICIENCY
		HEAD		POWER		SPECIFIED FLOW RATE						
		FEET	METERS	HP	kW	gpm	lps	m^3/hr	gpm	lps	m^3/hr	PERCENT
#1	1	130	40	350	261	7,620	480	1,730	10,662	662	2,417	71
	2	130	40	350	261	7,620	480	1,730	10,662	672	2,417	71
	3	130	40	350	261	7,620	480	1,730	10,662	672	2,417	71
	4	130	40	350	261	7,620	480	1,730	10,662	672	2,417	71
	5	60	18	250	187	13,560	854	3,078	16,500	1,040	3,741	130
	6	60	18	250	187	13,560	854	3,078	16,500	1,040	3,741	130
	7	60	18	250	187	13,560	854	3,078	16,500	1,040	3,741	130
	8	60	18	250	187	13,560	854	3,078	16,500	1,040	3,741	130
	9	215	66	270	201	3,000	189	681	4,973	313	1,128	60
	10	215	66	270	201	3,000	189	681	4,973	313	1,128	60
#2	1	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	2	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	3	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	4	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	5	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	6	135	41	425	317	8,640	544	1,961	12,467	785	2,827	69
	7	230	70	425	317	5,007	315	1,138	7,330	462	1,662	68
	8	230	70	425	317	5,007	315	1,138	7,330	462	1,662	68
#3	1	230	70	425	317	5,007	315	1,138	7,330	462	1,662	68
	2	230	70	425	317	5,007	315	1,138	7,330	462	1,662	68

Table 9 Parwati Pumps at 75% Efficiency

PUMP HOUSE	PUMP #	EXISTING			THEORETICAL		REQUIRED		ANNUAL ENERGY COST SAVINGS	
		HP	kW	Efficiency (%)	HP	kW	HP	kW	Rs.	US$
#1	1	350	261	71	334	249	350	261	282,439	282,439
	2	350	261	71	334	249	350	261	282,439	282,439
	3	350	261	71	334	249	350	261	282,439	8,070
	4	350	261	71	334	249	350	261	282,439	8,070
	5	250	187	82	274	204	250	187	-410,663	-11,733
	6	250	187	82	274	204	250	187	-410,663	-11,733
	7	250	187	82	274	204	250	187	-410,663	-11,733
	8	250	187	82	274	204	250	187	-410,663	-11,733
	9	270	201	60	217	162	250	187	15,818	25,892
	10	270	201	60	217	162	250	187	15,818	25,892
#2	1	425	317	69	393	393	400	298	553,615	15,818
	2	425	317	69	393	293	400	298	553,615	15,818
	3	425	317	69	393	393	400	298	553,615	15,818
	4	425	317	69	393	293	400	298	553,615	15,818
	5	425	317	69	393	293	400	298	553,615	15,818
	6	425	317	69	393	293	400	298	553,615	15,818
	7	425	317	68	387	289	400	298	650,343	18,581
	8	425	317	68	387	289	400	298	650,343	18,581
#3	1	425	317	68	387	289	400	298	650,343	18,581
	2	425	317	68	387	289	400	298	650,343	18,581
								TOTAL	7,222,626	206,361

Table 10 Parwati Pumps at 82% Efficiency

PUMP HOUSE	PUMP #	EXISTING			THEORETICAL		REQUIRED		ANNUAL ENERGY COST SAVINGS	
		HP	kW	Efficiency (%)	HP	kW	HP	kW	Rs.	US$
#1	1	350	261	71	313	233	350	261	842,812	24,080
	2	350	261	71	313	233	350	261	842,812	24,080
	3	350	261	71	313	233	350	261	842,812	24,080
	4	350	261	71	313	233	350	261	842,812	24,080
	5	250	187	82	257	192	250	187	0	0
	6	250	187	82	257	192	250	187	0	0
	7	250	187	82	257	192	250	187	0	0
	8	250	187	82	257	192	250	187	0	0
	9	270	201	60	204	152	250	187	1,338,518	38,243
	10	270	201	60	204	152	250	187	1,338,518	38,243
#2	1	425	317	69	368	275	400	298	1,234,068	35,259
	2	425	317	69	368	275	400	298	1,234,068	35,259
	3	425	317	69	368	275	400	298	1,234,068	35,259
	4	425	317	69	368	275	400	298	1,234,068	35,259
	5	425	317	69	368	275	400	298	1,234,068	35,259
	6	425	317	69	368	275	400	298	1,234,068	35,259
	7	425	317	68	363	271	400	298	1,330.795	38,023
	8	425	317	68	363	271	400	298	1,330.795	38,023
#3	1	425	317	68	363	271	400	298	1,330.795	38,023
	2	425	317	68	363	271	400	298	1,330.795	38,023
								TOTAL	18,775,871	536,453

Sample Calculation

Using the standard formula for water pumping shown below, the theoretical flow rate can be determined.

$$HP = \frac{(Q)(H)}{3{,}960}$$

where,

HP = horsepower
Q = flow rate, U.S. gpm
H = pressure head

therefore,

$$Q = \frac{(HP)(3{,}960)}{(H)}$$

Using pump #1 from Pump House #1 yields the following:

$$Q = \frac{(350\ HP)(3{,}960)}{(130\ feet)} = 10{,}662\ gpm$$

However, this pump and motor are rated at 7,620 gpm. Therefore, this system is 71% efficient.

$$\frac{(7{,}620\ gpm)}{(10{,}662\ gpm)} = 71\%$$

Note: This sample assumes the motor is fully loaded at 100% of pump output. Electrical metering can determine exact HP of electrical input.

9. ENERGY RECOMMENDATIONS

The following comments relate to both the existing system and the proposed system for providing filtered water to the Pune area.

1. The Pune Municipal Corporation staff (or their consultants) should survey other cities in India to determine pump histories. Much of the information regarding the reliability, longevity, and durability of pumps (both Indian-made and foreign) is anecdotal. Information gathered should include details on the manufacturer of the pumps, the cost of the pumps and motors, the efficiency of the pumps, the rate of repair of the pumps, and the availability of parts. Since PMC is about to proceed with a major addition to their water pumping system, they should try to get a better understanding of the performance of the pumps that are available.

2. Based on the information obtained in item #1 above, PMC should modify the specifications for the new project to include the best pumps and motors. They should list several alternates for both pumps and motors and procure separate bids on each unit so that the overall value can be determined. For instance, with separate pricing on the pumps and motors, it will be easy to make comparisons between units. If a particular pump and motor is 5% more efficient than the others, but it costs 25% more, a life-cycle cost comparison can be made to determine if the pump is more cost-effective over its life span.

3. PMC should consider adding an energy manager or energy engineer to its staff. This person would be responsible for evaluating all departments for improving energy efficiency. In addition, an incentive program would be a good idea to help in establishing an attitude of energy conservation. Currently there are a lot of opportunities that are ignored, simply because people are used to the *status quo*.

4. The monthly electrical bills should be reviewed and charted. (This would be a good job for the energy manager.) This visual tool would provide an opportunity to determine consumption changes from month to month, and this can help to identify problems such as leaks before too much time has passed. Electrical bills also had apparent discrepancies on the demand portion of the bill. Possibly the energy manager could get some of the pump houses re-classified on different rate schedules, saving money on the electrical demand.

5. Leaks within the filtered water system have been estimated at anywhere from 20% to 35%. However, these are just estimates and, in fact, the leakage could be much higher. All of this leakage is very expensive, especially if it occurs after the water has been treated and pumped. Even if the leakage were only 20%, this still amounts to Rs.31,600,000 annually in electrical costs alone. PMC staff should adopt a "zero tolerance" rule for leaks, and any detected leaks should be repaired as quickly as possible when they do appear. Possibly additional spare parts need to be stored so that the equipment can be fixed in a more timely manner.

6. A program or policy for replacing old and worn out equipment and/or piping should be established. (This may already exist, but we were unable to identify it.) This should be based on an inventory of existing equipment, the year the equipment was installed, and the typical life expectancy of the equipment. For instance, all sections of piping that exceed a certain age should be scheduled for replacement. This may vary from location to location, as well as to type of

piping. But once the number of leaks within any piping become excessive, it is less expensive to replace whole piping sections than to continue to respond by repairing leaks. Therefore, a budget should be established in anticipation of this type of activity. This program or policy should be reviewed every year and re-analyzed based on the previous twelve months of operation.

7. New pump installations should be optimized for energy efficiency. This is done by taking measurements on the flow rate and the head pressure, then consulting the pumps curves or the pump manufacturer. The impeller can then be trimmed to produce the required flow under optimal efficiency conditions. Since the design engineers need to ensure that the systems will work properly, all systems are designed with built-in safety factors. These safety factors can be adjusted once the actual operating values are determined.

8. Another design and operational consideration is for PMC to consider operating their equipment (at least as much as possible) at night, when the other electrical demands are lower. If they could negotiate a special tariff with Maharashtra State Electricity Board, this might allow them to save money and not adversely affect their operation (this might require larger reservoirs than the current units). This is advantageous to MSEB, since the electrical demand from PMC would be lower during peak us hours.

Appendix A

Centrifugal Pump Curves

KIRLOSKAR BROTHERS LIMITED. Kirloskarvadi Dist Sangli

APPROX.

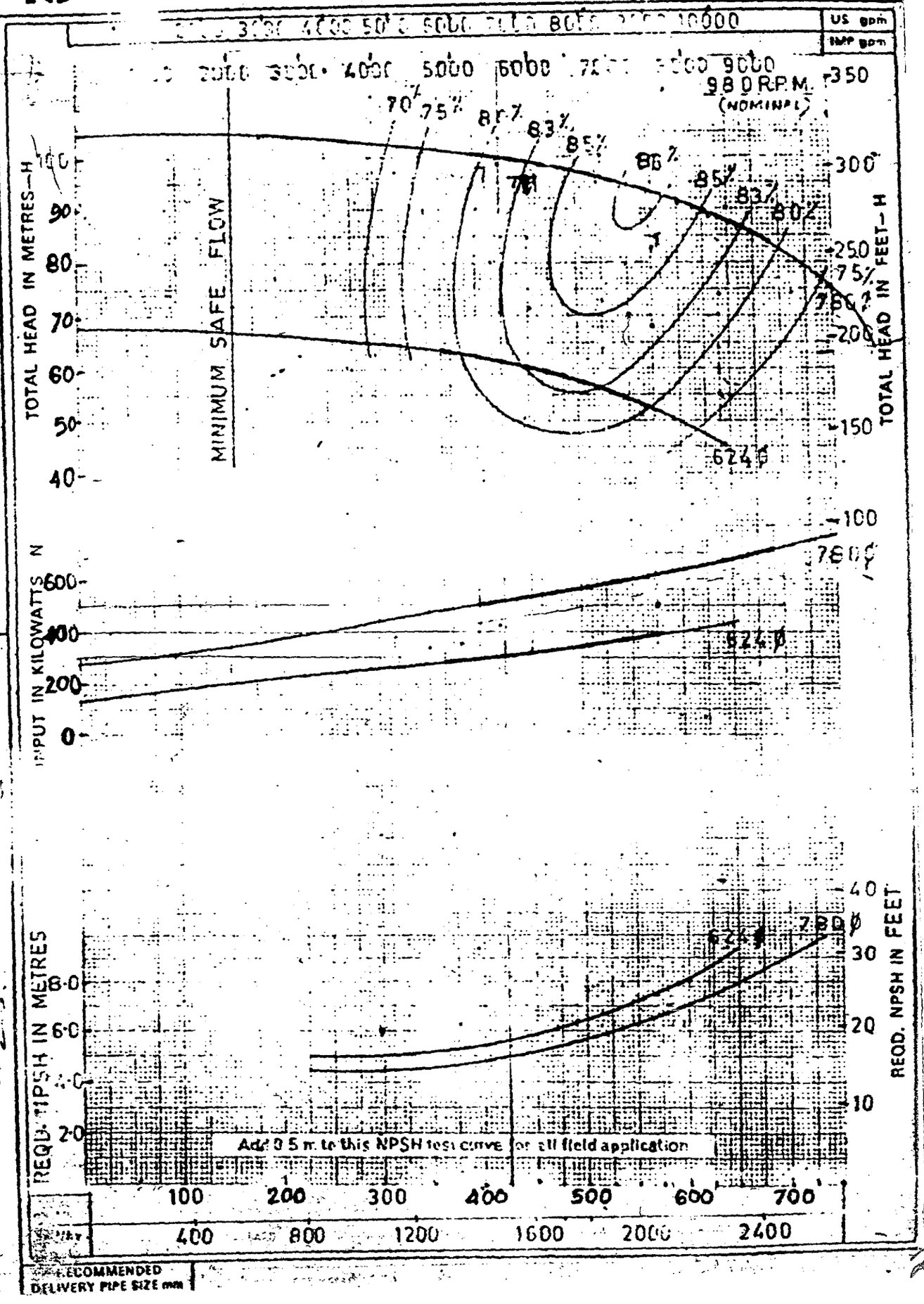
PERFORMANCE CURVE OF PUMP TYPE 14UPH4

Curve relates to the liquid of S G — 1 and viscosity

No. HA 170-031-0

Suc. 400 mm. Del. 350 mm.

IMP. DRG. No. BOTTOM SUCT. DE



CHECKED BY DATE

APPROVED BY DATE

RECOMMENDED DELIVERY PIPE SIZE mm

BEST AVAILABLE COPY

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