Energy Efficiency Improvements to a Water Distribution System, Galati, Romania

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ABSTRACT

Apaterm, a municipal provider of water and district heating, operates two drinking water plants that serve roughly 400,000 persons in Galati, Romania, supplying an average of 300,000 cubic meters or over 75 million gallons per day (MGD). The system draws roughly two-thirds of its water from the Danube River and the remainder from a series of wells 70 kilometers outside of Galati. A major concern of system operators is the electricity consumption of the various pump stations. Currently, the pumping systems consume approximately 34 million kWh per year at a cost of roughly $1.4 million. Energy prices are similar to those in the U.S. ($0.06/kWh) and are strongly tied to the U.S. dollar, while water prices are low at roughly $0.60 per 1,000 gallons and the system's receipts are tied to the rapidly devaluing Romanian lei. The resulting cost per gallon pumped is on the order of 16 times that in the United States. The ratio is increasing as the price of water deflates in relation to energy prices.

This project examined the operational and mechanical efficiency of Apaterm's pumping systems. Initial findings included:

- Many of the motors in the system are old and are suspected of being relatively inefficient. Rewinding similar motors has increased efficiency approximately 10 percent.

- Tests conducted during the project determined that the actual pump performance characteristic curves differ from the theoretical ones used in the initial design. This causes the pumps to operate far below their peak efficiency.

- Several motors powering pumps are undersized, causing the pumps to operate in a flow regime outside of their peak operational efficiency.

- When lower than peak flows are required, for example at night, throttling valves are used to increase system pressure and decrease pump capacity. This method of pump control wastes energy.

A series of energy conservation measures were identified during the project that will save roughly $250,000 per year in electricity costs. Low-cost measures included trimming impellers to better match pumps, and motors with required flows and pressures. Moderate-cost measures included leak detection and reduction and limited pump replacement. Additional measures included pump and motor replacement. Funding is now being sought for the additional higher cost measures.

Acknowledgements

The Cadmus Group, Inc. would like to express its sincere thanks to the staff of Apaterm without whose assistance this study would not have been possible.

Introduction

Apaterm, the operator of the Galati water system, faces the problem of escalating energy prices which cause energy to be a large and growing portion of the cost of providing potable water. The purpose of the project was to work in partnership with Apaterm to:

- Find cost-effective energy conservation measures. The hope at project initiation was that some of these measures could be relatively low cost.
- Produce methods and results that could be transferred to other water systems.

Methods

The energy consumption of a pump is proportional to the flow rate, static pressure, and efficiency. By measuring flow, pressure, and electricity consumption, the efficiency of the combined motor and pump, or "wire-to-water" efficiency, can be determined. Methods for collecting these data are described below. Flows were measured by Apaterm using permanent ultrasonic meters.

Pressure Metering

Measurements were taken at pipe stubs installed by Apaterm staff for this project. Each stub was installed with a gate valve for ease of sensor installation. Measurements were collected:

- In the suction header upstream of the pumps.
- Downstream of each pump (discharge) prior to the throttling butterfly valve.
- At the discharge header, downstream of all throttling valves.

Electrical Metering

For the low-voltage equipment, current transformers were attached to each of the three phases and measurements collected every 5 minutes. Current readings for medium-voltage equipment were collected using two of the metering phases powered by permanently installed current transformers. During the first visit, voltage, power factor, and power use (in watts) were measured as point-in-time measurements using a Fluke Model 43 power analyzer.

System Description

Galati is a city of roughly 350,000 persons located in the far north of the eastern part of Romania. Historically a small port town, Galati grew rapidly in the early 1960s when the Sidex steel plant, one of the largest in Europe, was completed. Galati's water system is supplied with raw water from a pump station operated by Sidex, the steel plant located northwest of the city, and a series of wells 30 km west of the city. Most of the system's water comes from the first source. Apaterm reported during the October trip that the monthly fee paid to Sidex was 3,000,000,000 lei, or roughly $125,000.

Water flows from the Sidex pump station to the system's two treatment plants, Uzina 1 and Uzina 2. Both plants employ primary screening, coagulation and clarification, rapid sand filtration, and post chlorination. Uzina 2 was completed in 1995. Treated water from each plant is pumped to the city by 6,000-volt pump stations.

Figure 1 shows the volume of treated water delivered on a typical day. Station (Uzina) 1 delivers a base load of roughly 3,000 m^3/hr. Station (Uzina) 2 delivers most of the system's water, but pumps much less water from 23:00 to 5:00. The Filesti station pumps a mixture of unfiltered well and filtered surface water. It is higher than the other two pumping stations, so it is used to serve several parts of the city located at a higher elevation. Filesti delivers the smallest portion of the three stations and like Uzina 2 has two pumping schedules; it pumps a relatively small volume of water at low pressure from 12:00 to 4:00 and higher volumes at other times. The periods of low pressure and low flow in Uzina 2 and Filesti are generally set by time and not typically adjusted for system conditions. The rationale behind this is that periods of low flow save energy and are set to occur when complaints about low pressure are least likely. This type of operation can, however, become inefficient depending on the seasonal or daily system characteristics.

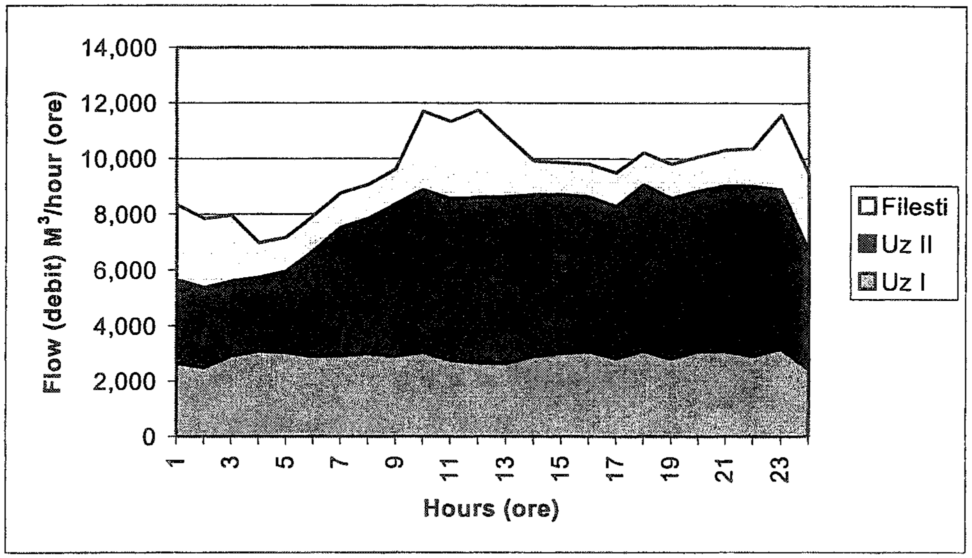

Figure 1. Typical Hourly System Pumping Rates

Findings: Water Use

Although the focus of this project was pumping efficiency, the energy consumed by pumping systems is directly proportional to the amount of water pumped and was therefore briefly examined. Using historical data supplied by Apaterm, we estimated that the average daily water use of Galati is 210,000 m^3. Based on our understanding that most of this water is used for non-industrial purposes, consumption averages 600 liters/person/day. Per capita U.S. consumption including leakage is roughly 378 liters/day. One would expect water consumption in Galati to be much lower than in the U.S. because there is:

- ✓ Less ownership of clothes washers.
- ✓ Relatively low use of hot water. (Hot water is frequently unavailable in Galati.)
- ✓ Low water use for lawn watering, automobile washing, etc.

There are several probable causes of this high apparent water consumption:

- ✓ Leakage in the distribution system.
- ✓ Leakage in water fixtures including showers and tubs, toilets, urinals, and sinks.
- ✓ The use of generic water bills (assumed use of 11m^3/month/person), which do not encourage water conservation.

We therefore recommend that:

- ✓ A leak detection and elimination program be initiated.
- ✓ Metering in the distribution system be increased.
- ✓ Metering of apartment blocks and individual flats be initiated.
- ✓ Water conservation devices be made available at reduced prices or free of charge to commercial facilities and residences.

Savings from Leak Elimination

Based on an average pressure of 5.0 atm, a combined motor and pump efficiency of 50 percent,[1] and an electricity cost of $0.05/kWh, pumping 10,000 liters costs $0.13. Even a small leak can easily waste a large amount of electricity. A toilet constantly running can waste as much as 1 liter/minute or 1,500 liters/day. Over a year this is roughly 500,000 liters or $7.00. If the leak can be fixed for $7.00, the repair pays for itself in a year and generates an additional $35 in savings over the next 5 years. A comprehensive program that fixed 1,000 leaking fixtures thus could save $7,000 per year. Because labor in Galati and the parts to fix leaks (washers, seals, etc.) are inexpensive, a leak detection and elimination program would rapidly pay for itself.

A program that metered usage by apartment would pass on to the end user the incentive to save. Apaterm could encourage meter use by offering slight discounts to residences willing to install meters. If the program also made parts available at a deep discount, conservation could occur with minimal repair labor by Apaterm.

A viable initial goal would be to reduce water use 1 percent, or 2,640 m^3/day, through leak elimination and conservation measures. An ongoing program could achieve this level of reduction for 5 years, resulting in a total reduction of 5 percent at the end of the program. This would save roughly $13,000 the first year and $65,000 by the end of the program. Including the monthly fee reported to be paid to Sidex for water pumping, water conservation could yield twice the savings calculated above.

Findings: Pump Efficiency

The following section outlines pressure and electrical measurements collected at each of the pump stations, shows derived pump curves and calculated efficiencies, and describes energy conservation measures. Detailed analyses are shown for selected pumps only, but all measures are summarized at the end of the report.

Uzina 1 Pump Low-Voltage Pump Station

This station transfers treated water from Uzina 1 to the reservoir in Uzina 2. It is served by four, MV402 vertical-shaft, 380-volt pumps. The system pressure consists almost entirely of static head—the pump station transfers water in the wet well below the station, with a surface elevation of 7.3 to 11.0 meters, to the reservoirs at Uzina 2, which have a surface elevation of 13 to 22.95 meters depending on the volume held in the reservoirs. The outlet for this pump station is reported to be near the top of the reservoirs, so even when the levels in the tanks are lower, the static pressure does not drop.

[1] Efficiencies in the system were measured directly and varied from 42 to 64 percent. Higher apparent pump efficiencies in some cases were diminished by the use of throttling valves.

Based on observation and conversation with Apaterm, it appears that this station operates without throttling. Pumps are operated to keep a desired level in the Uzina 2 reservoir. As the reservoir level falls, pumps are added to increase delivered flow. Because of the system's large pipe size (600 mm) and the relatively short run (several hundred meters), the system's pressure appears to consist primarily of static head. During the site visit Pumps 1and 2 were running continuously. Pumping records provided by Apaterm show that on average 2.2 pumps operate.

Field tests. On June 5, Cadmus and Apaterm completed a test of Pump 1 in the low-voltage (380 volt) pumping station. It was tested with the throttling valve at 25-, 50-, 75-, and 100-percent open. The pressure observed that night was 0.9 atmospheres (atm), equivalent to a head of 9 meters.

Table 1 presents the wire-to-water efficiencies that were measured. These efficiencies (which combine losses in the pump and the motor) are very low compared to those commonly achieved in water pumping stations. In Figure 2, pressure and flow for the pump test are graphed against theoretical curves provided by the factory. The actual curve differs greatly from the factory curves.

Table 1. Efficiency vs. Valve Opening, Low Voltage MV 402 Pump (#1)

Valve Opening (0-100%)	Wire-to-water Pump Efficiency
100	42%
75	42%
50	42%
25	37%

Energy efficiency measure: reduce the height of the reservoir discharges, increase Net Positive Suction Head (NPSH) of pump. Reducing the height of the discharge would decrease the static head between the wet well in the low-voltage pump station and the actual discharge. If the height of the reservoir were an average of 1 meter below the discharge and the discharge were lowered, roughly 10 percent of the pumping costs could be eliminated. The cost of the measure would include labor and minimal parts (pipe extensions). This measure would save roughly 100,000 kWh/yr or $5,000/yr.

One obstacle to this measure is the perception that pumping the water to the top of the reservoir and allowing it to fall to the water surface keeps the treated water circulating, reducing settling of material and eliminating anoxic conditions. These benefits were reported to us, but were not directly investigated. Water circulation may be able to be accomplished in other ways. For example, the pipe could be shorten but directed upwards or across the tank. Flow could be increased for short periods, increasing circulation without the head penalty of the top of reservoir release. Other methods include a small, dedicated circulation pump or air sparging system. The sparging system would need to use air already in the reservoir because introducing outside air could contaminate the treated water.

The net head supplied by the pump is determined in part by the NPSH. The higher the level in the wet well containing the pumps, the less energy required to pump to the height of the reservoir. Based on a review of plant drawings, it appears that the height in the well can be raised without flooding the end of the treatment system. Because flow through the treatment system is by gravity, there is no cost to raising the height. An average increase of 0.5 meters could decrease pumping head and pumping energy by 5 percent. This would save roughly 50,000 kWh/yr, or $2,500/yr.

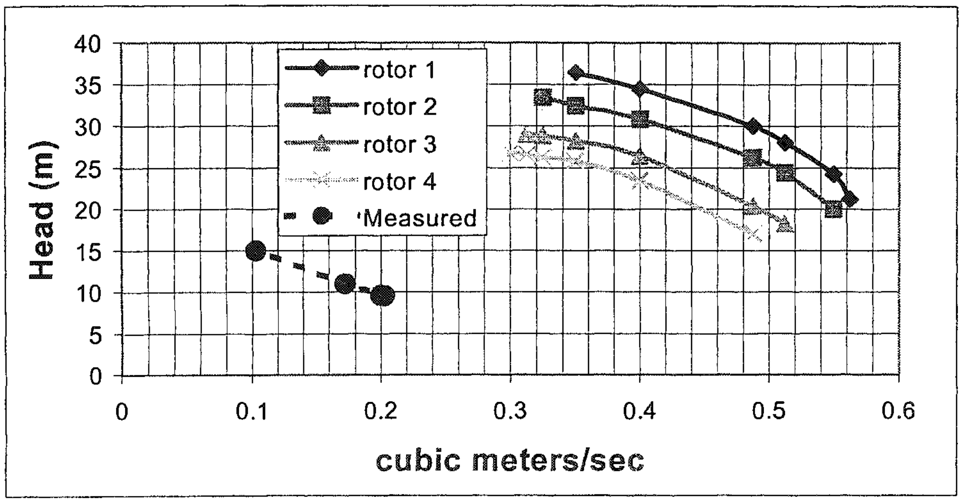

Figure 2. Measured MV 402 Pump Curve vs. Factory Data

Energy efficiency measure: replace Pump 1 and Pump 2 with one high-efficiency single-speed-drive pump. Based on initial observations, it appears that for most periods two of the existing pumps operate continuously without throttling. For several hours on most days a third pump is run. Rarely is only a single pump run. Because this station simply fills a reservoir, the pump schedule is relatively unconstrained. This measure replaces two of the pumps with a larger pump. The revised system could deliver low flow using a remaining MV402 pump, could deliver a base flow of roughly 1,800 m^3/hr with the new pump, and could deliver high flow equivalent to the three existing pumps using the larger new pump and an existing MV402.

As shown in Table 2, the pumps use roughly 670,000 kWh per year at the measured flow and pressure. Actual consumption may vary slightly because of variations in flow and pressure. At a wire-to-water efficiency of 75 percent, a replacement pump and motor set could save roughly $19,000 per year.

To match the required flow of 1,600 m^3/hr and a static pressure of 1.0 atm, a model series 9100 pump manufactured by ITT was chosen. The pump has a rated peak efficiency of 87 percent. Assuming that a motor with an efficiency of 90 percent could be coupled with the pump, a system of 79 percent efficiency would result. The analysis was based on 75 percent efficiency to account for additional losses. Based on a budget quote of $50,000, this measure would pay back in 2.5 years.

Table 2. Projected Energy Savings, Replace MV 402 Pumps #1 and #2

	Flow	Pressure	Duration	Energy Use at Listed Efficiency		
	Debit	Presione	Duration	Consumption - kWh		
	(m^3/hr)	atm	hrs/yr	42%	70%	75%
Pump 1	800	0.92	8,760	434,102	260,461	243,097
Pump 2	800	0.92	8,760	434,102	260,461	243,097
Pump 3	800	0.92	2,000	99,110	99,110	99,110
				967,315	620,033	585,305
					Savings	
	Energy Price			kWh	347,281	382,010
	$ 0.05	USD/kWh		USD	$ 17,364	$ 19,100

Shaded cells show no assumed efficiency improvement.

Uzina 1 Pump Medium-Voltage Pump Station

System operation. This station transfers treated water from Uzina 1 to a series of distribution mains. A portion of the water is piped directly to the Turnu, or tower station. This water is then distributed to higher portions of Galati. The remainder of the water pressurizes the distribution system in the lower portions of the city. The system consists of six pumps in parallel, of which two run most of the time and, rarely, three run in conjunction. The characteristics of the pumps are shown in Table 3.

Table 3. Uzina 1 Pumps

Location	Pump No.	Pump type	Size	Motor Type	Notes (June)
Uzina 1	1	14 NDS	630 kW	AS	Repair
Uzina 1	2	14 NDS	630 kW	AS	Repair
Uzina 1	3	12 NDS	250 kW	AS	
Uzina 1	4	12 NDS	250 kW	AS	Repair
Uzina 1	5	14 NDS	500 kW	S	
Uzina 1	6	14 NDS	630 kW	AS	Backwash

In early June during the first field measurement trip, Pumps 3 and 5 were run most of the time, with Pumps 5 and 6 operated near noon and midnight presumably in a backwash function. While the pump sequence varied, typically one 12 NDS pump and one 14 NDS pump are run together. Either a 12 NDS or a 14 NDS pump is often added during the backwash sequence.

Pump 3 field testing. On June 5 and early June 6, Cadmus and Apaterm completed a test of Pump 3 in the medium-voltage (6,000-volt) pumping station. It was tested with the throttling valve at 25-, 50-, 75-, and 100-percent open. The valve position was changed and flow and electricity consumption measurements were collected for 5 minutes. The valve position was then changed again and a new set of measurements collected. The accuracy of the measurements was affected because the flow meter was not precise over this short duration, but the short testing period allowed us to modify the system without affecting service.

Table 4 presents the wire-to-water efficiencies that were measured. These efficiencies (which combine losses in the pump and the motor) are very low compared to those commonly achieved in water pumping stations. Pressure and flow for the pump test are graphed in Figure 4. The low measured efficiencies indicate that substantial savings are available.

The pressures in the Pump 3 discharge and downstream of the butterfly throttling valve were metered for 16 hours (Figure 3). During operation, the vertical distance between the discharge pressure and the value downstream of the valve is the pressure drop in the immediate vicinity of the pump. Roughly 0.4 atm (5.2 meters) of pressure, about 8 percent of the pump's energy, is lost in the elbow and open valve immediately downstream of the pump.

Pump 3 efficiency measures. As shown in Table 5, during its 5,854 hours of annual operation, based on records for 1999, the pump uses roughly 2,500,000 kWh at the flow and pressure measured during the pump test. Actual consumption may vary slightly because of variations in flow and pressure. At a wire-to-water efficiency of 75 percent, a replacement pump and motor set could save roughly $55,000 per year.

Table 4. Medium Voltage 12 NDS Pump #3

Valve Opening (0-100%)	Wire-to-water Efficiency
100	42%
75	39%
50	39%
25	40%

Table 5. Projected Energy Savings Based on Pump Test, Replace Pump #3 12 NDS (Uzina 1)

Flow	Pressure	Duration	Energy Use at Listed Efficiency		
Debit	Presione	Duration	Consumption - kWh		
m^3/hr	atm	hrs/yr	42%	70%	75%
1,360	4.67	5,854	2,503,332	1,501,999	1,401,866
				Savings	
Energy Price			kWh	1,001,333	1,101,466
$0.05	USD/kWh		USD	$50,067	$55,073

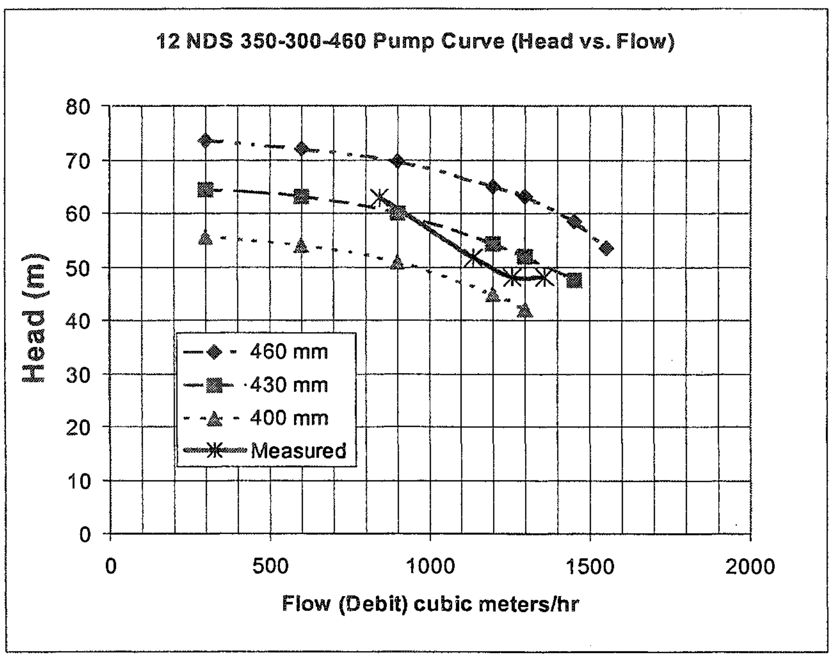

Figure 4. Measured vs. Factory Pump Curve, Pump #3 12 NDS (Uzina 1)

This same analysis was run using the pump pressure measured during actual operation (5.6 atm; there is a 0.4 atm pressure loss in the first fitting) and a flow of 1,150 m^3/hr derived from the pump test and from the measured and factory pump curves (Table 6). The resulting savings are nearly identical, roughly $55,000. Savings could be even greater if the pump were used for more hours as a base load and supplemented by existing pumps. The duration of operation is limited by the need for maintenance.

Table 6. Projected Energy Savings Based on Measured System Characteristics, Replace Pump #3 12 NDS (Uzina 1)

Flow	Pressure	Duration	Energy Use at Listed Efficiency		
Debit	Presione	Duration	Consumption - kWh		
m^3/hr	atm	hrs/yr	42%	70%	75%
1,150	5.6	5,854	2,538,333	1,523,000	1,421,466
				Savings	
Energy Price			kWh	1,015,333	1,116,866
$0.05	USD/kWh		USD	$50,767	$55,843

Based on daytime pipe pressure of 5.2 atm and a pump curve derived flow of 1,150 m^3/hr

Pump 5 efficiency measures. An analysis similar to that performed for Pump 3 was performed for Pump 5. Estimated savings are summarized in Table 7.

The annual operation of this pump was not examined, but the pump was observed in constant use during our June field work, which was verified in a data review of June records. As shown in Table 7, during an estimated 6,000 hours of annual operation, the pump uses roughly 3,000,000 kWh per year at the measured flow and pressure. The operating characteristics are based on an observed operational pump pressure of 5.6 atm and an estimated flow of 1,828 m^3/hr, based on the pump test flow corresponding to the pressure of 5.6 atm. At a wire-to-water efficiency of 75 percent, a replacement pump and motor set could save roughly $42,000 per year.

Table 7. Projected Energy Savings Based on Pump Test, Replace Pump #5 12 NDS (Uzina 1)

Flow	Pressure	Duration	Energy Use at Listed Efficiency		
Debit	Presione	Duration	Consumption - kWh		
m3/hr	atm	hrs/yr	55%	70%	75%
1,828	5.6	6,000	3,157,999	2,481,285	2,315,866
				Savings	
Energy Price			kWh	676,714	842,133
$0.05	USD/kWh		USD	$33,836	$42,107

Uzina 2 Pump Medium-Voltage Pump Station

System operation. This station transfers treated water from the two reservoirs of Uzina 2 to the distribution system. The system consists of four pumps in parallel. Normal operation is to run a single 24-NDS pump during most of the day and a single 14-NDS pump in the early morning. The characteristics of the pumps are shown in Table 8.

Table 8. Uzina 2 Pumps

Location	Pump No.	Pump type	Size	Pressure	Notes (June)
Uzina 2	1	24 NDS	1250 kW		Repair
Uzina 2	2	24 NDS	1250 kW	7.2	
Uzina 2	3	24 NDS	1250 kW		
Uzina 2	4	14 NDS	630 kW	5.6	

As observed during the second field measurement trip in October, the pumps are operated on a schedule based primarily on time of day. Pump 4, the smallest pump, with a nominal capacity of 1,800 m^3/hr, is operated from 23:30 to 4:00, and Pump 2, with a nominal capacity of 4,000 m3/hr, is operated the remainder of the day. The reason for this schedule is twofold: water consumption decreases at night, and customer tolerance for lower system pressures at night allows the system pressure to be reduced at 23:30.

Because the fixed-drive pumps have different capacities, it is difficult to optimize the pumps' schedule for energy consumption. The conditions the night of the test illustrate this. At 23:00 the system was pumping at roughly 7.2 atm with Pump 2's throttling valve open only 20 percent. Pump 4 with its throttling valve 100-percent open could hold a pressure of only 5.8 atm. While throttling Pump 2 so far wastes energy (static head), the alternative, Pump 4, is incapable of holding sufficient pressure. After 23:30, Pump 4 is used at a lower pressure because experience has shown that customer tolerance of lower pressures is satisfactory at this time of night.

Field metering. On June 6, Cadmus and Apaterm completed tests of Pump 2 (NDS 24) and Pump 4 (NDS 14) at Uzina 2. Pump 2 was tested with the throttling valve in two positions (16- and 20-percent open). The test was limited to these positions because of system constraints. Pump 4 was tested at 25-, 50-, 75-, and 100-percent open.

In October, during the second site visit, Cadmus and Apaterm engineers performed a second test on Pump 2 to check surprisingly high efficiency ratings calculated after the June pump test. Cadmus also metered Pump 4 for a second time.

Energy efficiency measure: replace Pump 4 with a high-efficiency variable-speed-drive pump. This pump runs roughly 5 hours per day. The throttling schedule has not been recorded, but the pump appears to be throttled during its nighttime operation. We observed periods when the header pressure was roughly 5.5 atm, but pump pressure was 7.4 atm. At the throttled condition, efficiency rises to 70 percent based on the pump test.

This efficiency measure is based on replacing this pump with a high-efficiency variable-speed-drive pump. Savings for this measure are calculated based on higher efficiency (75 percent), the elimination of throttling, and the assumption that the pump picked would achieve peak efficiency at the system operating point of 5.6 atm and roughly 2,000 m^3/hr.

As shown in Table 9, the pump uses roughly 1,135,000 kWh per year at the measured flow and pressure during 1,825 hours of operation. Actual consumption may vary slightly because of variations in flow and pressure. At a wire-to-water efficiency of 75 percent, a replacement pump and motor set could save roughly $19,000 per year.

Pump 2. The apparent wire-to-water efficiencies presented in Table 10 were measured for Pump 2 in June. The test was limited to two readings because opening the valve wider would have over-pressurized the system. The efficiency values were originally thought to be high based on the low efficiencies measured in the other pumps. Other reasons to suspect the results were that the Pump Curve had an unusual shape and the Danfoss flow meter was giving unreliable readings.

The values measured in October were higher, as shown in Table 11. An important finding in October, however, was that the pump is always throttled because it is larger than needed, the motor is too small to drive the pump with no throttling, and the circuit protection won't allow full open operation. The measured pump test is shown superimposed on factory data in Figure 5. Examining the pump curve, the flow provided at 20-percent open is sufficient to meet most periods, and the pump pressure is well in excess of that needed for system requirements. The third column in the table shows that after throttling, the net efficiency varies from 63 to 71 percent. Based on a reported throttling of 25 percent, the net efficiency is 64 percent, low for a pump this large.

Table 9. Projected Energy Savings, Replace Pump #4 14 NDS (Uzina 2)

	Flow	Pressure	Duration	Energy Use at Listed Efficiency		
	Debit	Presione	Duration	Consumption - kWh		
	m^3/hr	atm	hrs/yr	51%	70%	75%
Existing	2,208	5.6	912	625,275		
Existing	1,900	7.5	912		525,014	
Future	2,000	5.6	1,825			770,689
					Savings	
	Energy Price			kWh		379,600
	$0.05	USD/kWh		USD		$18,980

Table 10. Efficiency vs. Valve Opening, Medium Voltage 24 NDS Pump (#2), June 2000

Valve Opening (0-100%)	Wire-to-water Efficiency
20	70%
16	59%

Table 11. Efficiency vs. Valve Opening, Medium Voltage 24 NDS Pump (#2), October 2000

Valve Opening (0-100%)	Pump Wire-to-water Efficiency	Pump/Valve Wire-to-water Efficiency
40	80%	71%
30	79%	63%
20	78%	64%

Efficiency measure: trim Pump 2's impeller. As noted above, Pump 2 is too large for its motor, although it can provide sufficient flow and pressure while heavily throttled. This was verified by reviewing the pump's power requirement curve and the nominal motor capacity. Additional verification came from the fact that, when we opened the valve to 40 percent, we were on the verge of tripping the motor circuit's breaker. We recommend that Apaterm trim the pump's impeller to better match it to system requirements and to its motor. In discussing this recommendation, Apaterm indicated that there are several short peak periods, roughly several hours per day for a day or two per year, when higher capacity is needed. Because of the limitations of the breaker and motor, we think that any additional flow needs are best met with a parallel pump assisting Pump 2. Assuming that the impeller can be trimmed to deliver 5,000 m^3/hr at a system pressure of 6.46 atm without throttling, savings on the order of $100,000 could be achieved (Table 12). The cost of the measure would be low, but the measure could require some additional engineering study.

Table 12. Savings from Impeller Trimming, Medium Voltage 24 NDS Pump (#2)

	Flow	Pressure	Duration	Energy Use at Listed Efficiency	
	Debit	Presione	Duration	Consumption - kWh	
	m3/hr	atm	hrs/yr	79%	80%
Existing	5,000	8.15	6,200	9,043,811	
Future	5,000	6.46	6,200		7,078,863
					Savings
	Energy Price			kWh	1,964,948
	$0.05	USD/kWh		USD	$98,247

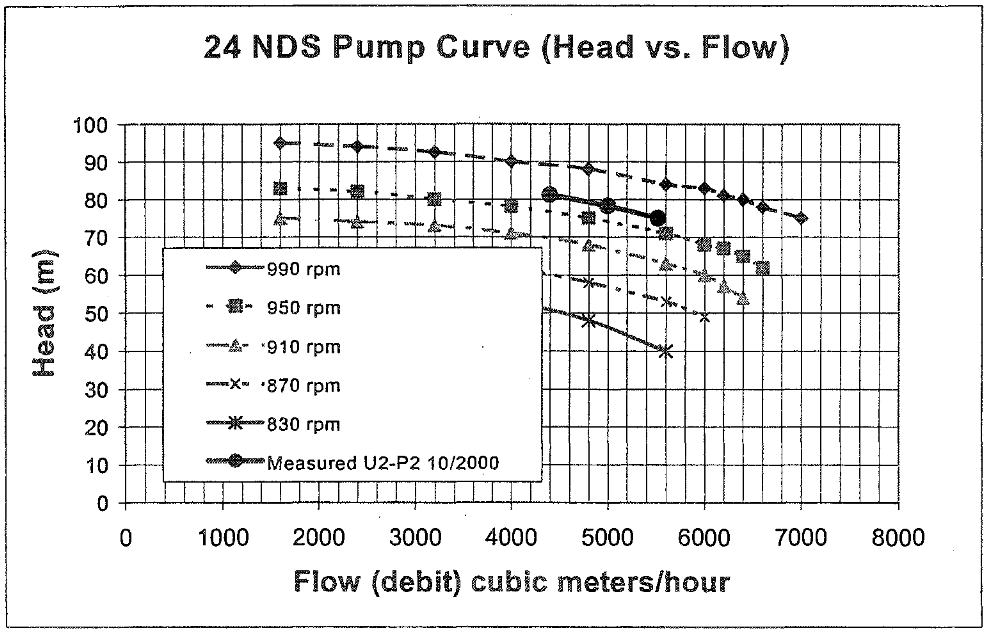

Figure 5. Theoretical and Measured (October 2000), Pressure vs. Flow Characteristic Curve, Pump #2 24 NDS (Uzina 2)

System-Wide Findings

A summary of the measures, with a total savings of roughly $400,000, discussed in this report is shown in Table 13.

Opportunities to increase efficiency through changes in system operation. The primary focus of this project was the operation of the system pump stations. There may be additional energy efficiency opportunities through modification of system operation. Uzina 2 operates at a system pressure of greater than 6 atm primarily to pressure water mains in higher portions of the city. Ultimately, installing several booster stations may allow these higher areas to be served while reducing the pressure supplied by Uzina 2. A review of several months' records for Uzina 2 showed that an average of roughly 32,000 kWh is consumed per day, at an annual cost of roughly $600,000.

A 5-percent reduction in pressure could save $30,000 per year, less the pumping cost of a booster station located in the distribution system.

Table 13. Summary List of Efficiency Measures Identified

Measure #	Measure Description	Annual Savings	Cost	Payback (years)
	System-Wide			
1	Water conservation and leak reduction	$13,000*	$5,000	<<1
2	Reduce the height (head) of the reservoir discharges, increase NPSH of pump in the Uzina 1 low-voltage pump station.	$7,500	$5,000	<1
	Uzina 1			
3	Replace Pump 1 and Pump 2 with a single high-efficiency single-speed-drive pump	$19,100	$50,000	2.5
4	Replace Pump #3 (12NDS) with a high efficiency medium-voltage pump	$50,000	$60,000	1
5	Replace Pump #6 (14NDS) with a high efficiency direct drive pump	$9,000	$100,000	Not Recommended
6	Replace Pump #5 (14NDS) with a high efficiency direct-drive pump	$42,000	$100,000	2.5
	Uzina 2			
7	Replace Uzina 2, Pump #4 (12NDS) with a high-efficiency medium-voltage pump	$18,000	$60,000	3.3
8	Trim the impeller of Pump 2	$98,000	$10,000	<<1
	Filesti (not discussed in this paper)			
9	Reduce pressure drop at the Filesti Station	$50,000	$100,000 est.	2
10	Replace (12NDS) pump	$33,000	$50,000	1.5
11	Replace (18NDS) pump	$69,000	$150,000 est.	2.2
Total	With measure 5 removed	$400,000	$665,000	1.6

Discussion and Conclusion

The measures identified in this report range from low-cost actions such as water conservation and impeller trimming to pump replacement to complex measures involving system pressure planning. There is a substantial opportunity to save energy in this system and to recover investments rather quickly. The result will be a large decrease in the portion of water costs contributed by pump energy expenditures.

The methods used in this project and the findings are broadly applicable to water systems throughout the region. A unique aspect of Romanian systems is that many of them use the same pumps (12 NDS - 24 NDS), so many of the findings are directly applicable to other large Romanian cities.

All but one of the savings measures identified in this project do not include advanced controls and variable speed drives. There are several reasons for this:

- ✓ Most of the pumping schedules are relatively static, with pressure and flow relatively constant.
- ✓ Labor is inexpensive and available, decreasing the non-energy benefits of advanced controls.
- ✓ Apaterm does not have a large capacity for trouble shooting and operating complex controls. We are also concerned that a lack of future funding could leave the systems un-maintained.
- ✓ Most of the available savings can be achieved with single-speed pumps at far lower cost than advanced controls.

The next phase of this project is to solicit funding through loans or grants to implement the findings of the report.