GLWA
Great Lakes Water Authority

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Great Lakes Water Authority (GLWA)
Michigan, USA

- Manager for GLWA’s systems control center, leading the operations and maintenance for GLWA’s water distribution and wastewater collection systems.
- A process control engineer at PCI Detroit Co., worked on a multi-year project to modernize DWSD’s water and wastewater systems with control and SCADA solution.
- College of Engineering, Wayne State University, USA, 2000.

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Great Lakes Water Authority (GLWA)
Michigan, USA

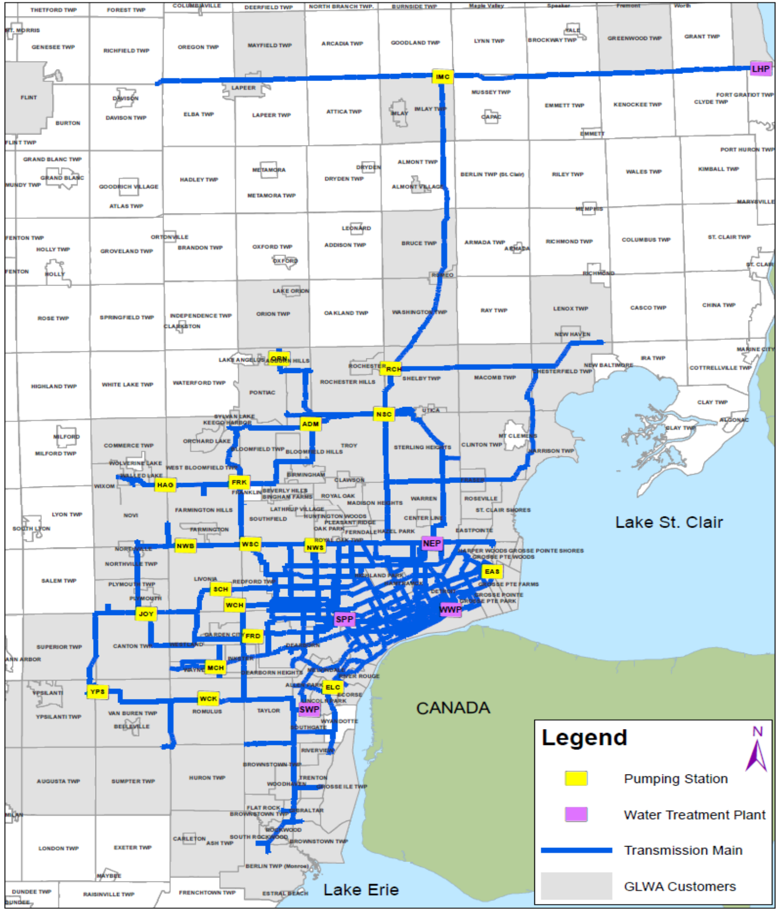
- Operational engineer for GLWA’s systems control center, working on the operations, maintenance and optimization for GLWA’s water system.
- A project engineer at Alfred & Benesch Co., worked on hydraulic modeling, water master plan, pipeline and pumping station design projects.
- College of Engineering, Wayne State University, USA, 1994.

Real-Time Pump Efficiency Evaluation Program for A Large Water System

Biren Saparia & Steven Jin
Great Lakes Water Authority

GLWA's Water System

- Serving 3.8 million people in 112 communities
- 5 treatment plants
- 19 pumping stations
- 816 miles of transmission main



GLWA’s Systems Control Center

Program of Real-Time Efficiency Evaluation for Pumping Stations – REEPS

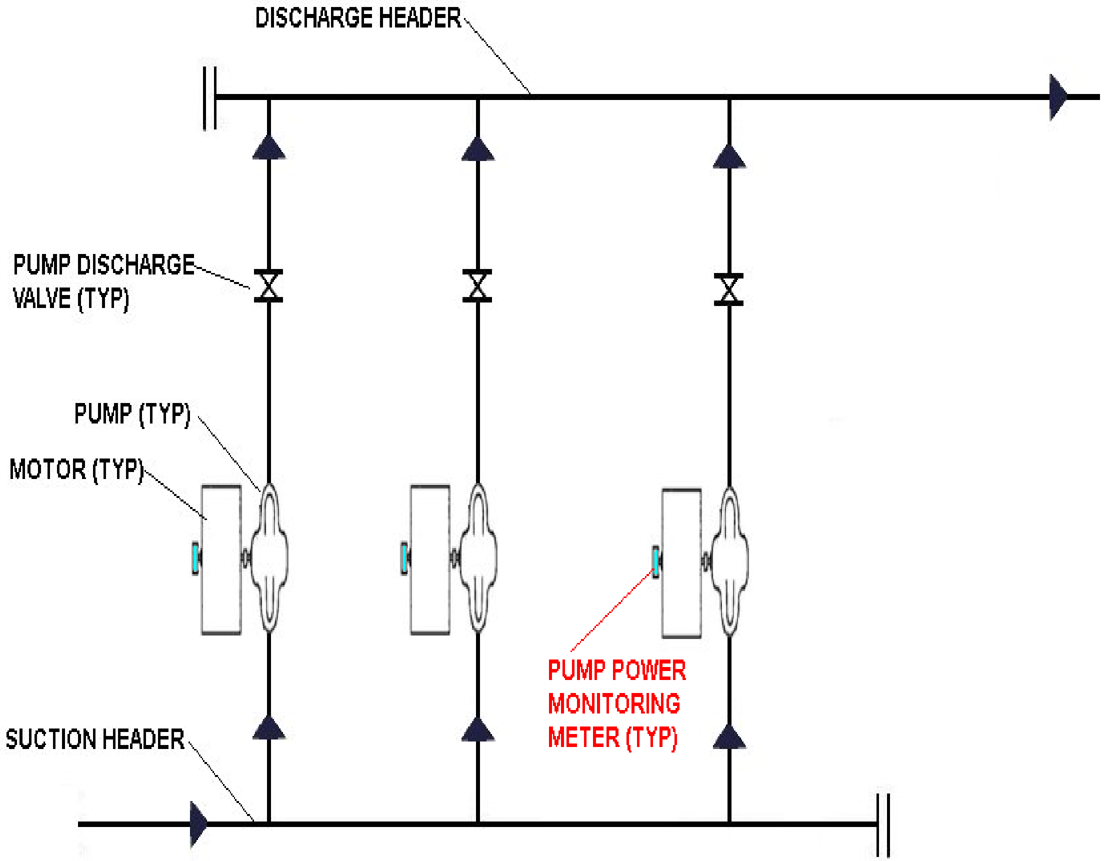
- GLWA pays over $20M annual electricity costs for pumping water to the customers
- To analyze pump efficiency, GLWA developed the REEPS program
- REEPS would evaluate real-time efficiency for each of the 120 booster pumps and 54 high lift pumps
- REEPS would find ways to improve pumping efficiency for individual pumps and systematic operations

REEPS Method

Evaluating Pump Efficiency:

- $\eta_p = P_{hyd} / P_b$
- $P_b = P_m \times \eta_m$
- Install a power monitoring meter for each pump (P_m)

Where:
η_p = the pump efficiency
P_{hyd} = the pump hydraulic power in kilowatts
P_b = the pump input (brake) power in kilowatts
P_m = the motor power in kilowatts
η_m = the motor efficiency (assuming 93%)



REEPS Method

Hydraulic Power*: P = power in hp

P = hQ/360 h = pump head in ft

*source: Quora.com Q = flow-rate in gpm

$$P_{hyd} = 0.131 \times Q \times H_{tdh}$$

A flow meter is not fitting in a pump system due to its lay length.

Pump head curve formulation*:

$$H_{tdh} = H_{st} - a\,Q^b$$

*source: EPANET Users Manual

Where:

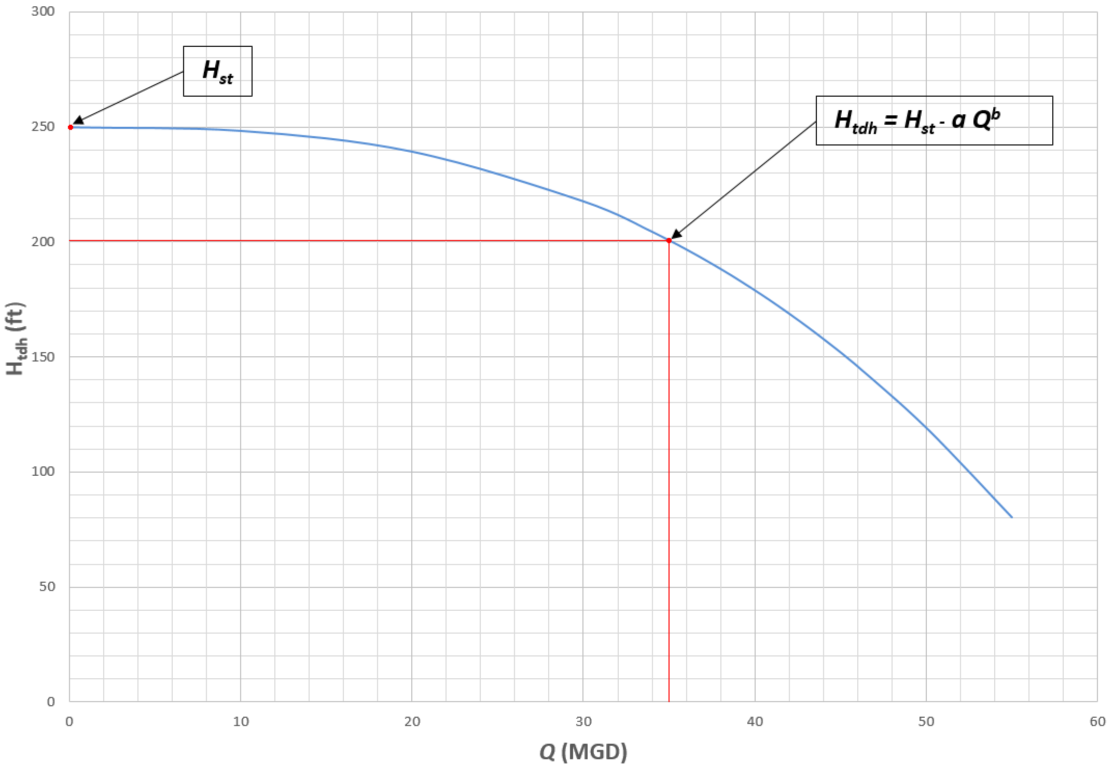
Q = the pump flow rate in MGD

H_{tdh} = pump total head in feet

H_{st} = pump shut-off head in feet

a = pump resistance coefficient

b = pump flow exponent



REEPS Method

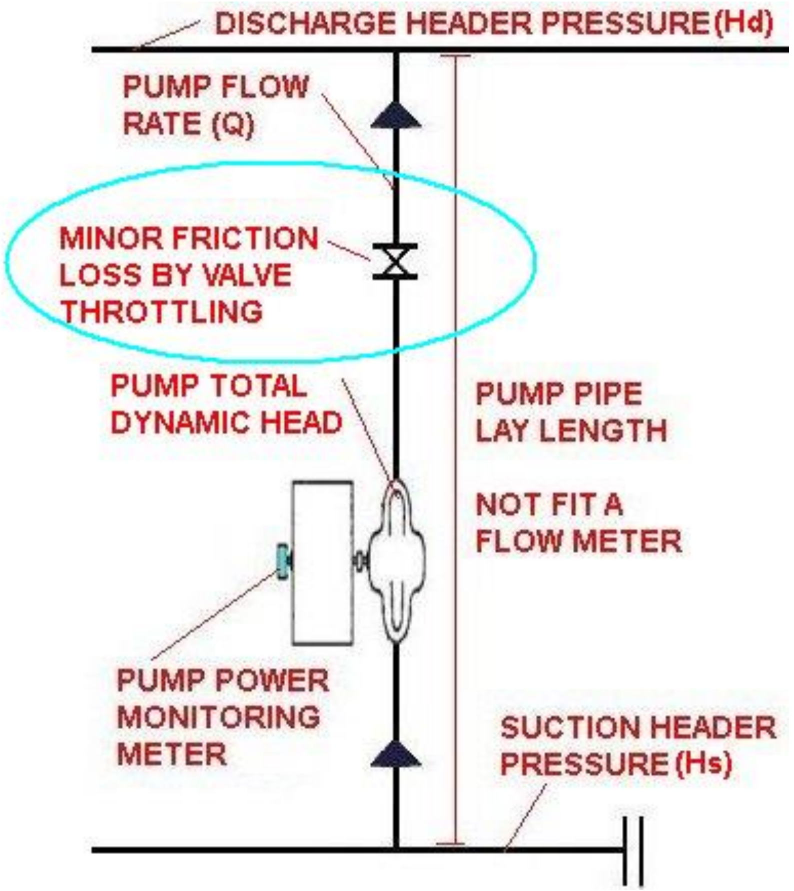
Compute minor friction loss:

$$V = Q / A = Q / (\pi D^2 / 4)$$

$$H_{ml} = K V^2 / 2g$$
$$= 0.011 \times K \times Q^2 / D^4$$

Where:

V = flow velocity in feet per second
A = the section area of pipe downstream valve (ft^2)
D = the diameter of pipe downstream valve in feet
K = minor friction loss coefficient for discharge valve (based on manufacturer’s valve curve data)
g = gravity acceleration (32.2 ft/s^2)



Manufacturer's Valve Curve Sample

$$C_V = 29.8\, D_V^2 \sqrt{\frac{1}{K}}$$

A 36-inch Cone Valve of GLWA

Table for valve flow coefficient values

VALVE SIZE	PLUG ANGLE IN DEGREES FROM CLOSED								
	90	80	70	60	50	40	30	20	10
RESISTANCE FACTOR "K"		.46	1.9	5.2	13	31	74	180	580
6	3596	1566	826	472	300	193	123	78	44
8	7423	2784	1468	839	534	343	219	139	78
10	12165	4350	2294	1311	834	536	342	217	122
12	18466	6265	3304	1888	1201	772	493	313	176
14	25613	8527	4497	2567	1635	1051	671	426	239
16	34820	11138	5874	3356	2136	1373	877	556	312
18	45515	14096	7434	4248	2703	1738	1110	704	395
20	56191	17403	9178	5244	3337	2145	1370	870	488
24	80915	25060	13216	7552	4806	3089	1974	1253	703
30	134100	39157	20651	11880	7509	4827	3084	1957	1100
36	200780	56386	29738	16993	10813	6951	4441	2819	1583
42	277053	76748	40476	23129	14718	9462	6045	3837	2155
48	372356	100242	52867	30210	19224	12358	7895	5012	2815

Source: http://literature.puertoricosupplier.com/003/QG2286.pdf

REEPS Method

Bernoulli equation for a pump system:

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+z_2+h_{friction}-h_{pump}$$

When $V_1 = V_2$, then

$$\mathbf{H_{tdh} = (H_d - H_s) + H_{ml} \text{ ....Eq-A}}$$

Eq-A can be changed as follows and is used to solve for Q:

$$\mathbf{(H_{st} - a\,Q^b) = (H_d - H_s) + (0.011\ K\ Q^2\ D^{-4})}$$

Eq-A becomes

$$\mathbf{f(Q) = (H_d - H_s) + (0.011\ K\ Q^2\ D^{-4}) - (H_{st} - a\,Q^b) = 0}$$

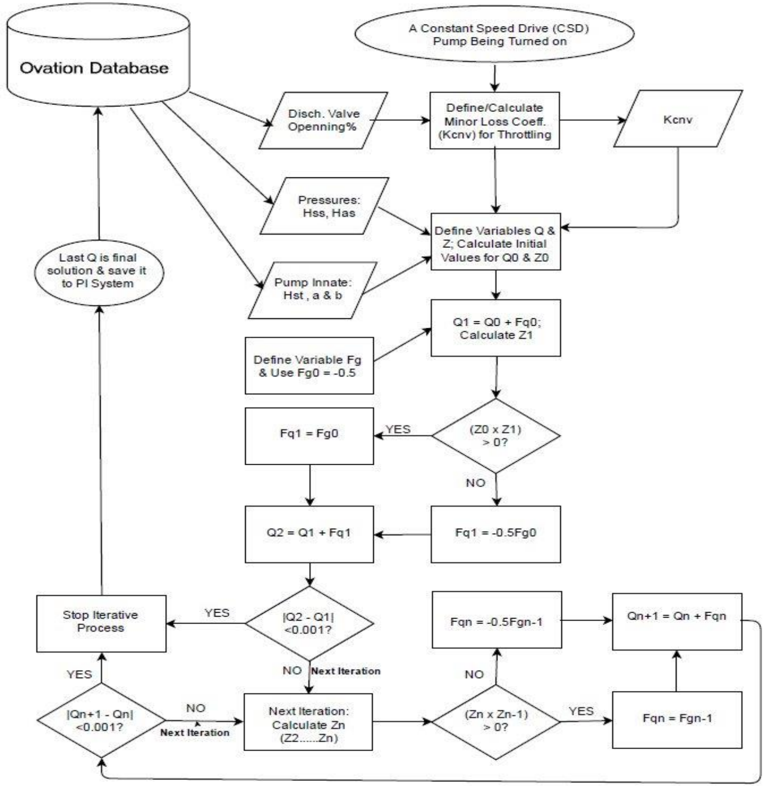
Where:

H_{ml} = minor friction loss of a pump system in feet

H_d = the elevation of station discharge head (ft)

H_s = the elevation of station suction head (ft)

An iterative algorithm to solve Eq-A



REEPS Method

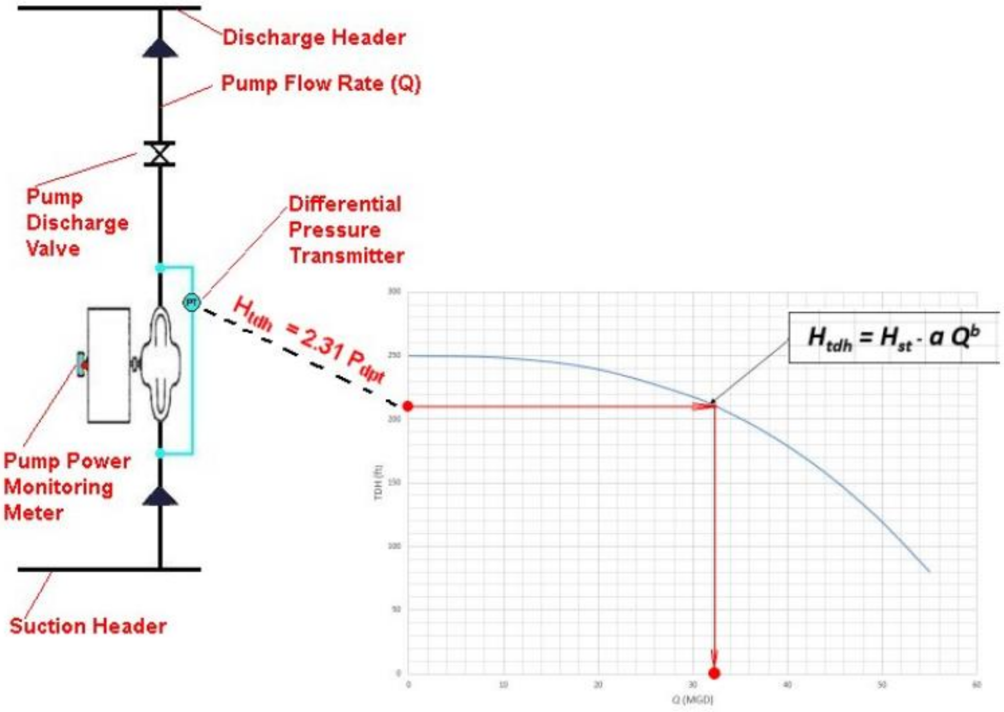
When the valve curve data is unavailable:

A differential pressure transmitter (DPT) is installed for each pump.

$$H_{tdh} = 2.31P_{dpt}$$

$$Q = ((H_{st} - H_{tdh}) / a)^{(1/b)}$$

$$= ((H_{st} - 2.31P_{dpt}) / a)^{(1/b)}$$



Where:

P_{dpt} = the pressure differential (psi) measured by a DPT

REEPS Method

Affinity Laws for VFD Pumps

Flow is proportional to speed

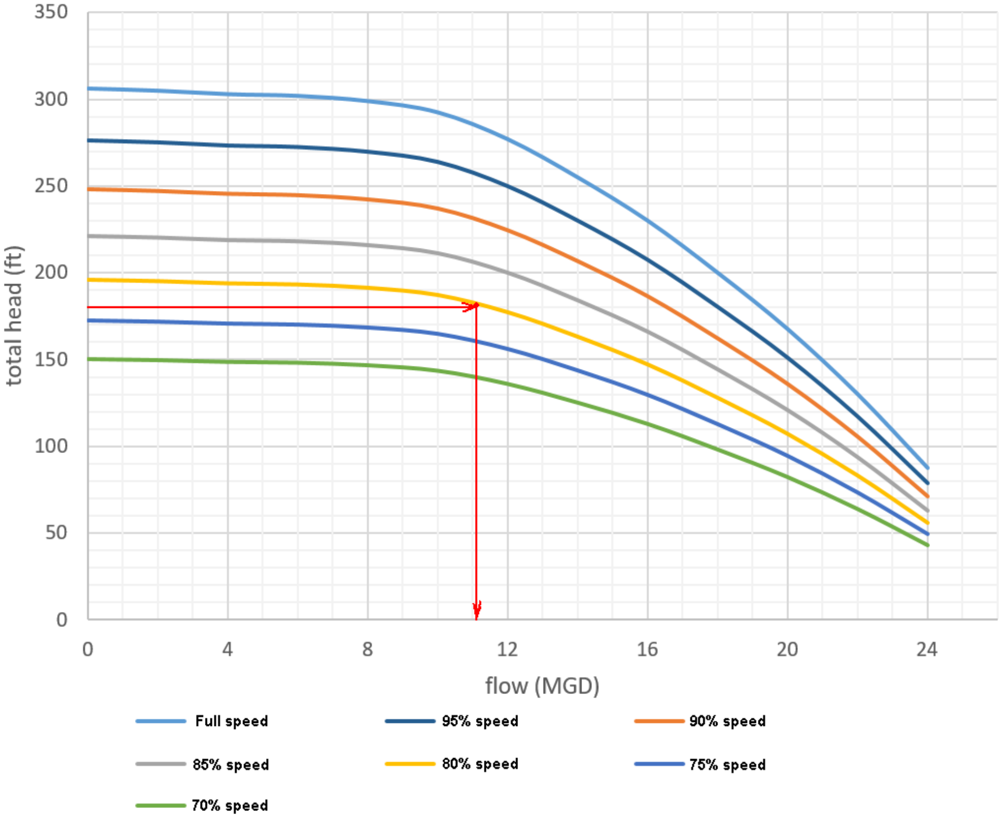
$$Q_p / Q_f = N_p / N_f = F_s$$

Pressure is proportional the square of speed

$$H_{thp} / H_{thf} = (N_p / N_f)^2 = F_s^2$$

Where:

Q_p = the partial speed flow rate for a VFD pump in MGD
Q_f = full speed flow rate for a VFD pump in MGD
N_p = partial pump speed in RPM
N_f = full speed for a VFD pump in RPM
F_s = factor of speed (N_p / N_f)
H_{thp} = pump head under a partial speed in feet
H_{thf} = pump head under full speed in feet



REEPS Method

VFD Pump: the discharge valve is open.

Pump head curve formula:

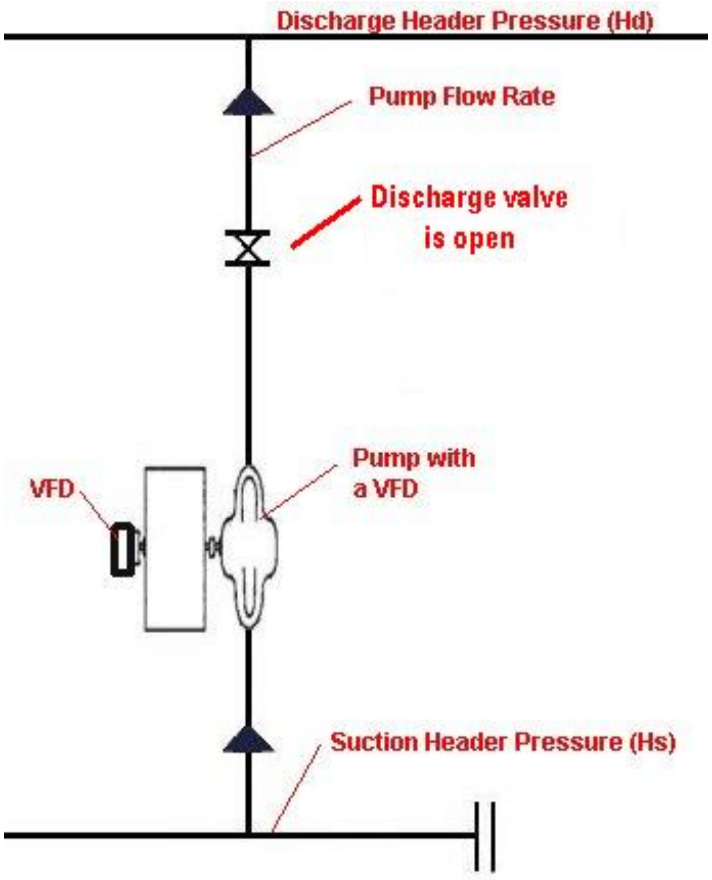
$$H_{tdh} = H_{st} - a\,Q^{b}$$

$$Q = ((H_{st} - H_{tdh}) / a)^{(1/b)}$$

Combined with Affinity Laws:

$$Q_{p} = F_{S}\,((H_{stf} - (H_{d} - H_{s}) / F_{S}^{\,2})/a)^{(1/b)}$$

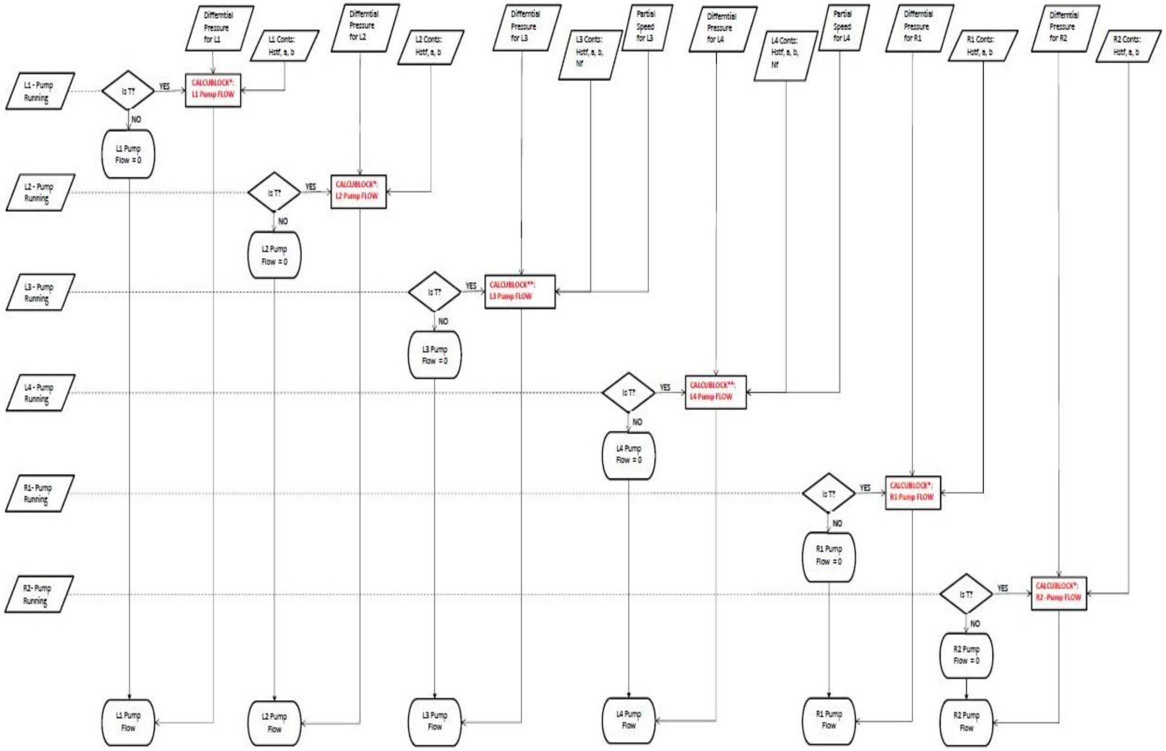
Where:
H_{stf} = pump shut-off head under full speed in feet



REEPS in Ovation

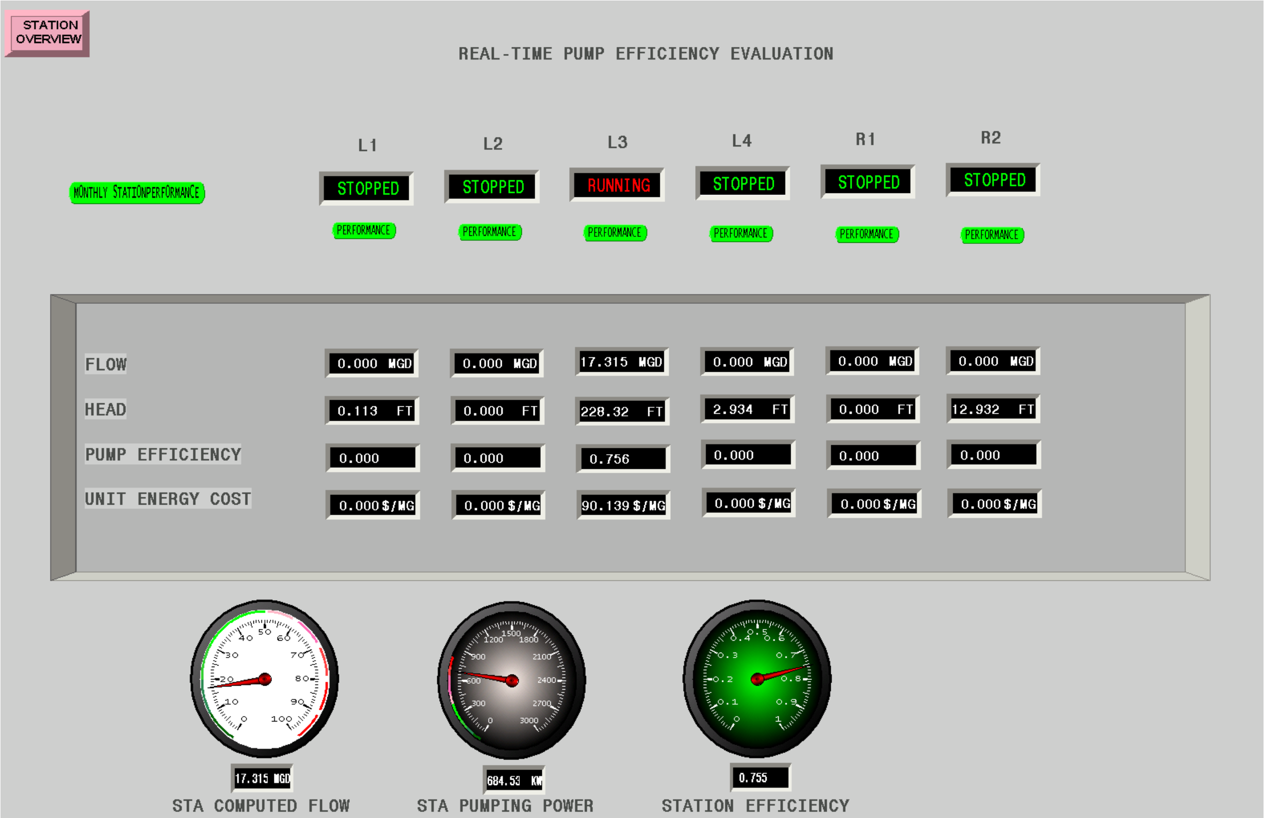
Flowchart for

Calculating flow rates for each of the six pumps in Franklin Pump Station



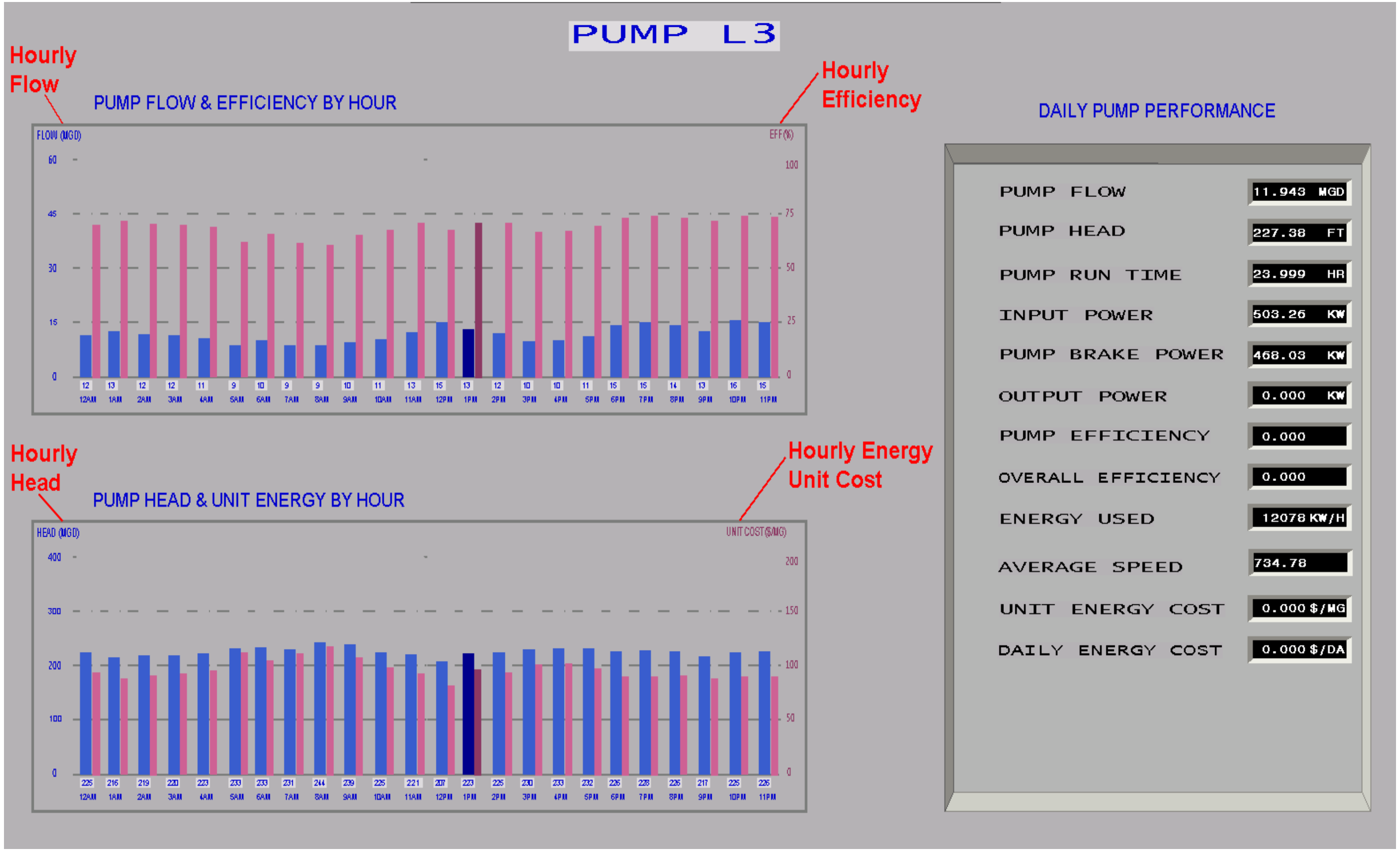
REEPS in Ovation

Real-time pump efficiency & energy cost evaluation



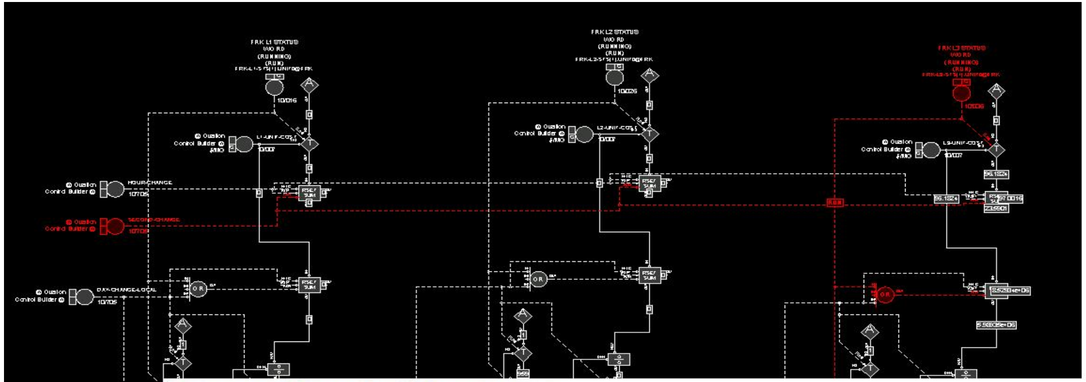
REEPS in Ovation

Hourly and daily pump performance



REEPS in Ovation

Electricity costs are calculated based on the rate schedule of DTE Energy



Power Supply Charges:

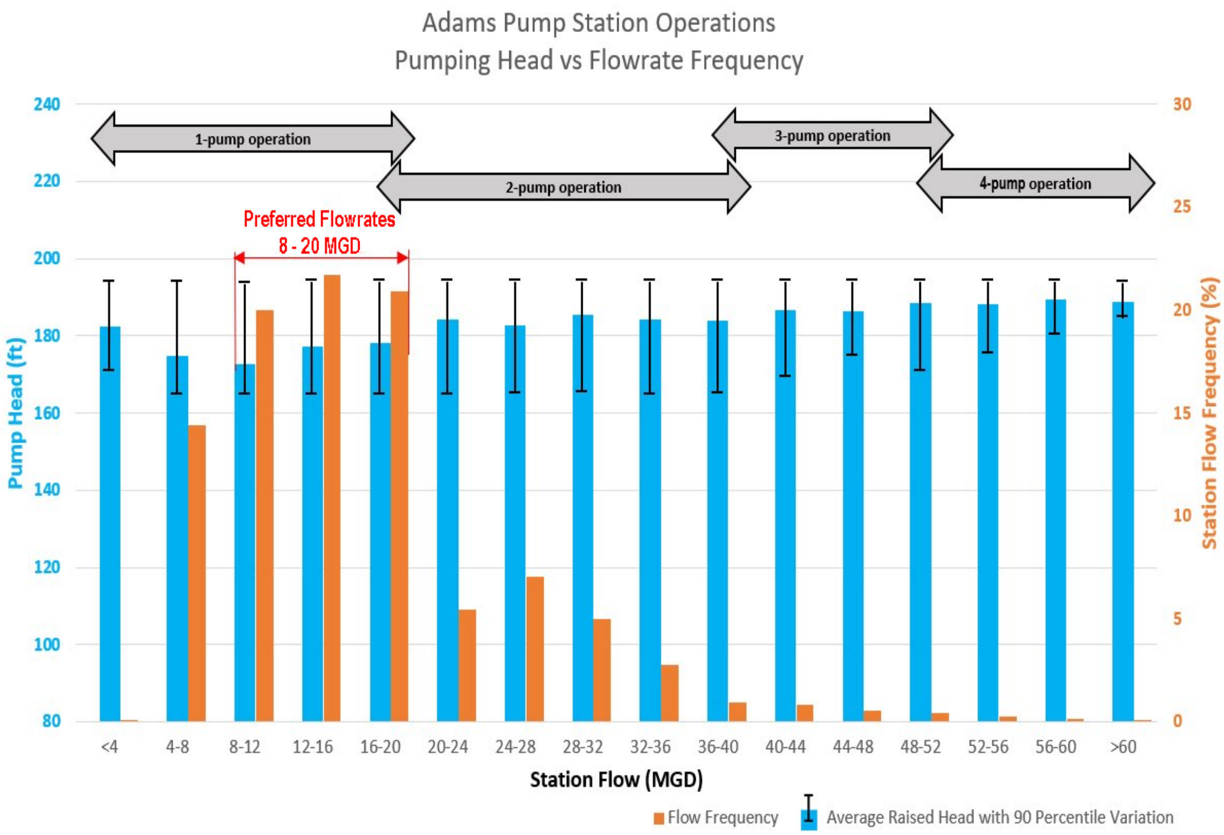
Demand Charge:	$16.24 per kW of on-peak billing demand
Energy Charges:	3.719¢ per kWh for all on-peak kWh
	3.419¢ per kWh for all off-peak kWh

MONTHLY ON-PEAK BILLING DEMAND: The monthly on-peak billing demand shall be the single highest 30-minute integrated reading of the demand meter during the on-peak hours of the billing period.

On-peak hours are those hours between 1100 hours and 1900 hours each day, Monday through Friday, legal holidays excluded.

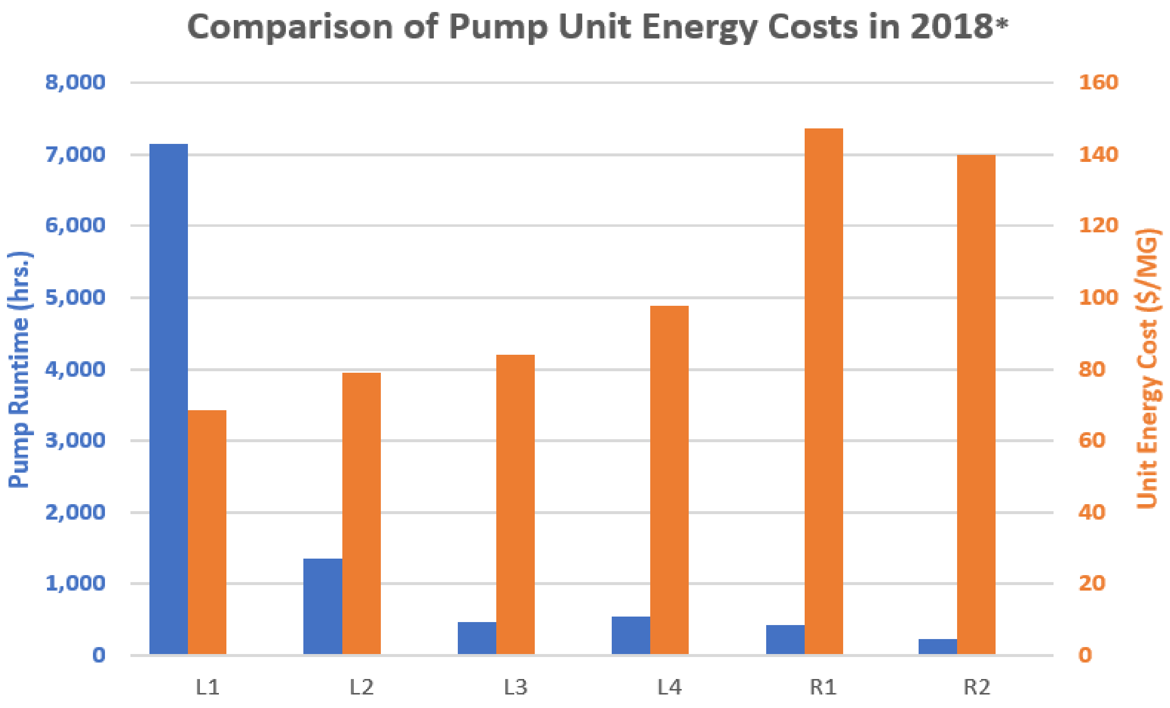
REEPS Sample Application

Pump flow, head & efficiency analysis for Adams Station



REEPS Sample Application

Pump flow, head & efficiency analysis for Adams Station



*average costs for 12 months of 2018 weighted by the monthly pump run hours; the energy costs are estimated at $0.095 / kWh.

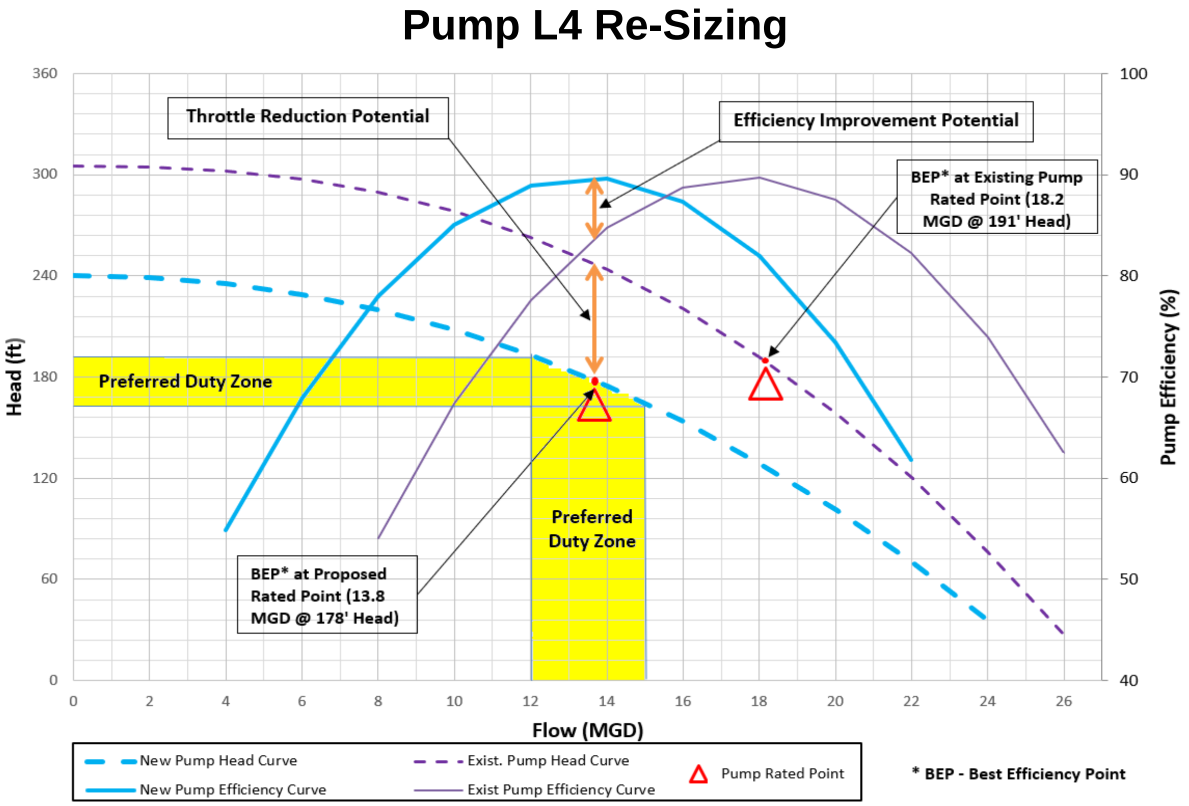
REEPS Sample Application

Pump flow, head & efficiency analysis for Adams Station

Pump ID	L1 (VFD*)	L2	L3	L4	R1	R2
Average Pump Efficiency (%)	66.7%	77.4%	77.7%	65.7%	81.5%	80.6%
Average Discharge Valve Position (%)	~100%	80.4%	54.0%	77.4%	23.3%	41.8%
Energy Loss Due to Throttling (kWh)	No Throttle	41,635	27,985	17,273	83,956	41,242
Throttling Energy Loss (%)	No Throttle	5.9%	11.8%	5.6%	25.3%	21.0%
Overall Efficiency with Throttling (%)	64.7%	67.6%	62.0%	56.8%	52.1%	55.5%
*VFD has a efficiency of 97% on average.						

REEPS Sample Application

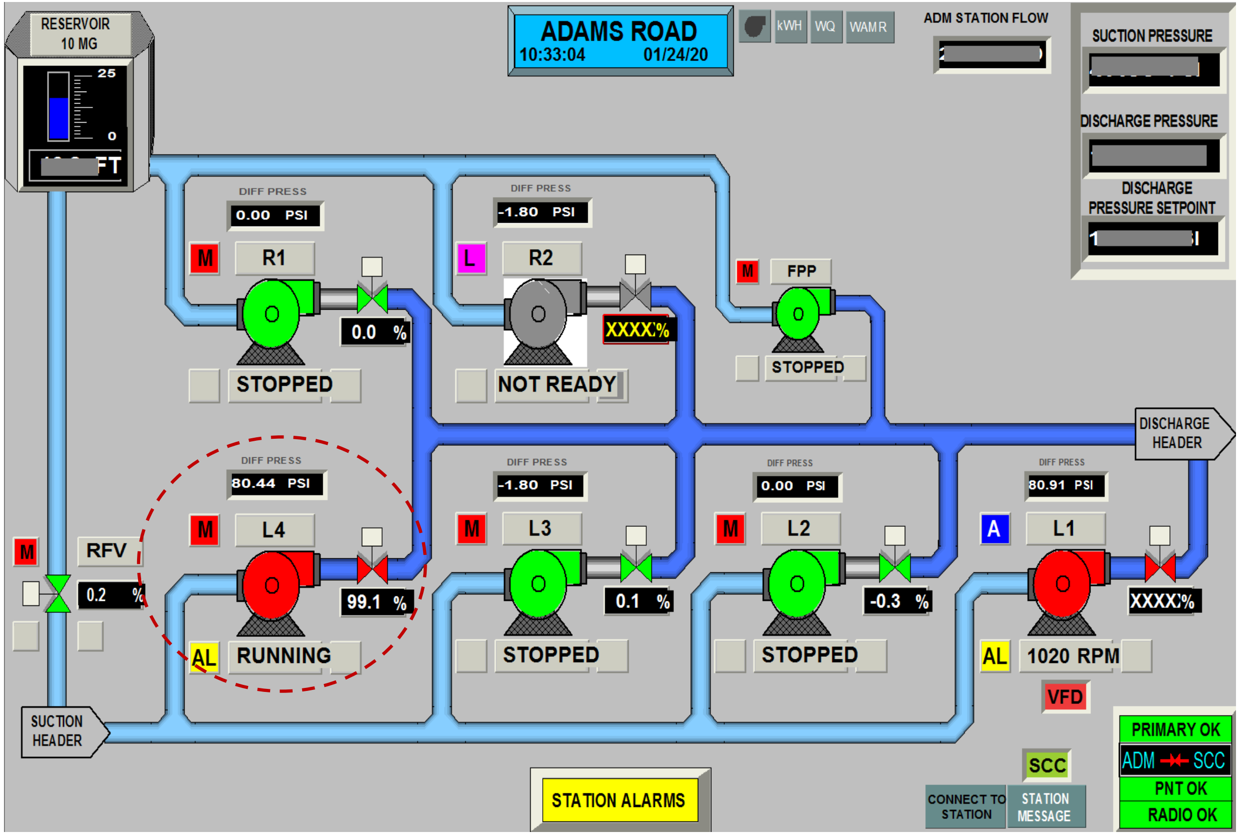
Pump flow, head & efficiency analysis for Adams Station



REEPS Sample Application

Pump flow, head & efficiency analysis for Adams Station

Using Re-Sized Pump L4



REEPS Sample Application

Pump flow, head & efficiency analysis for Adams Station

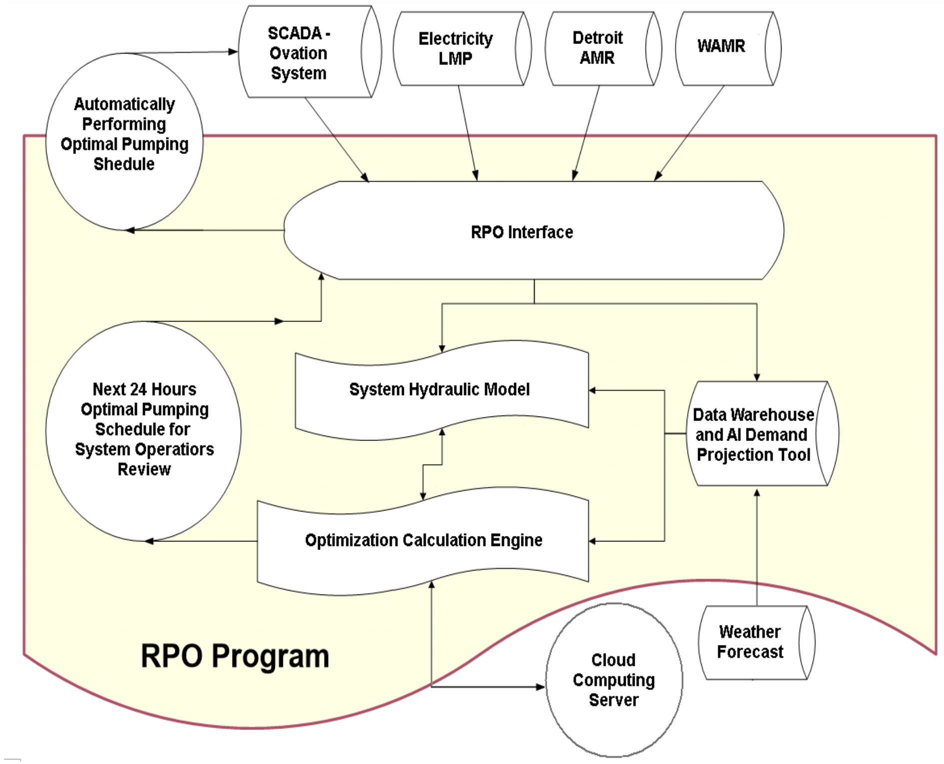
Energy Savings by Using Re-Sized Pump L4

- Pump efficiency increased from <70% to 82%
- Pump discharge throttling reduced from >50% to approximately 10%
- Annual energy savings is estimated about 180,000 kWh (approx. 6%)
- The overall unit energy cost reduced from $81.1 per MG to $75.7 per MG (annual cost savings of about $16,500)

REEPS Sample Application

Real-time Pumping Optimization Project

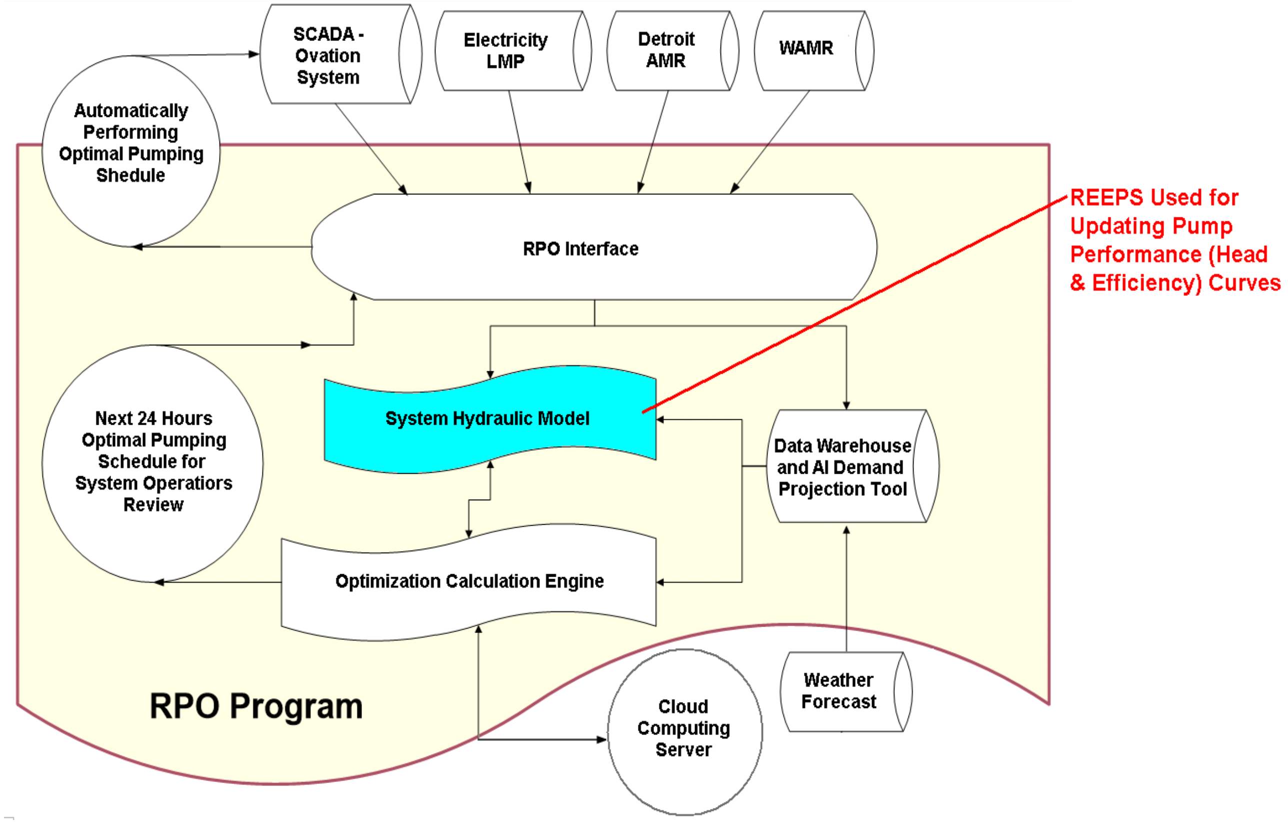
- Generate optimal pumping schedule for next 24-hour
- Reduce on-peak billing demand of electricity
- Reduce energy costs against DTE Energy's tariff
- Optimize water transmission paths to reduce pumping requirements
- Use cloud computing technology to speed up the calculation in optimization algorithm engine



REEPS Sample Application

REEPS helps real-time pumping optimization program

Real-time Pumping Optimization Project



Questions?

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THANK YOU