Applications for Variable Frequency Drives (VFDs) at Water Treatment Plants

March 14, 2023

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SMART ENERGY DESIGN ASSISTANCE CENTER

Providing effective energy strategies for buildings and communities

Smart Energy Design Assistance Center (SEDAC)

We assist buildings and communities in achieving energy efficiency, saving money, and becoming more sustainable.

We are an applied research program at University of Illinois.

Our goal: Reduce the energy footprint of Illinois and beyond.

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ILLINOIS SUSTAINABLE TECHNOLOGY CENTER
PRAIRIE RESEARCH INSTITUTE

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ISTC Mission

To encourage and assist citizens, businesses and government to prevent pollution, to conserve natural resources, and to reduce waste to protect human health and the environment in Illinois and beyond.

IEPA WWTP Energy Assessment Program

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About the Program

The Illinois EPA Public Water Infrastructure Program helps municipalities reduce the cost of water and wastewater treatment.

- NO-COST energy assessment for publicly-owned water and wastewater facilities
  - Similar assessments: $6,000-$12,000

- Comprehensive report listing:
  - Cost of upgrades
  - Estimated payback period
  - Any applicable incentives or available funding opportunities

- 160 total assessments since 2018
- $3,400,000 in total cost savings identified

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Applying for the Program

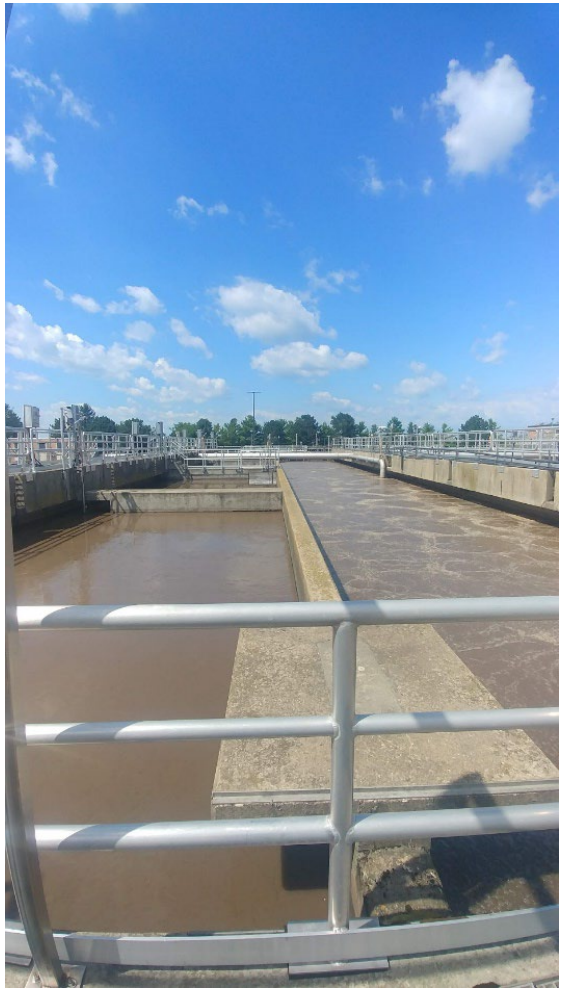
Step 1: Initial Application – Pre-Qualification

- Be located in Illinois & a publicly-owned plant
- Allow SEDAC/ISTC to visit the site
- Be willing to share facility information with SEDAC and ISTC
- Share final assessment report with Illinois EPA Office of Energy

Step 2: Data Collection

- Facility information – energy use, maintenance reports, process flow, etc.
- 2 years of utility bills and DMRs

Step 3: Site Visit Scheduled



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Site Visit Overview and Project Timeline

- Site visit on-site or conducted virtually
- Receive short list of energy efficient opportunities 1 week after site visit
- Receive assessment report
  - ~6-8 weeks after site visit
- Project leader & IEPA Office follows up ~two weeks after report sent
  - Ask about potential to complete projects
  - Assist in locating and applying for grant, incentive, and loan funding opportunities.

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Site Visit Process

Before Assessment Begins:

- Utility Benchmarking
- General process overview
- Review known issues
- Review desired changes

Data Source	Electric Use Intensity (kWh/MG/year)	Energy Use Intensity (kBtu/MG/year)	Energy Cost Intensity ($/MG)
YOUR Water Plant	9,999	99,999	$999
Nat'l Avg (surface water)	1,406[1]	6,223[2]	N/A
IL Mean (surface water)	2,019[3]	6,889[2]	$586[3]
Nat'l Avg (ground water)	1,824[1]	6,223[2]	N/A
IL Mean (ground water)	2,844[3]	9,704[2]	$239[3]

During the Assessment:

- Walk-through
  - Process flow
  - Equipment
  - SCADA

- Detailed process questions and overview during walkthrough
- Usually request equipment run hours, any process tracking to assist with calculations

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Energy Assessment Report

Energy Efficiency Assessment Report

City Facility

Water Treatment Plant
123 Anystreet
Anytown, Illinois 61111

Facility Contact

John Doe, Public Works Director
555.555.5555
john.doe@anytown.il.us

Prepared By

University of Illinois
Smart Energy Design Assistance Center (SEDAC)
1 St. Marys Rd
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University of Illinois Energy Specialist

Shawn Maurer, SEDAC
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Assessment Date

May 5, 2023

Report Publish Date

August 5, 2023

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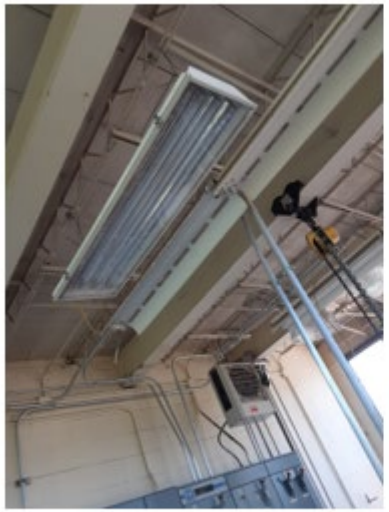
Table 1: Measure Analysis Summary

Measure #	Description	Potential Energy Savings				Estimated Project Cost	Potential Incentive	SPB[1] w/o Incentive (years)	SPB w/ Incentive (years)
		kW	kWh	Therms	$				
1	LED Lighting Upgrades	5	13,000	0	$1,200	$5,600	$400	4.6	4.3
2	Automate Filter Backwash	0	6,100	0	$600	$5,000	$1,900	8.6	5.4
3	Heat Pump HVAC	(8)	(14,600)	1,900	$1,400	$15,600	$7,500	11.5	6.0
4	Well Pump VFDs	4	6,000	0	$600	$43,700	$0	76	76
5	Extreme Efficiency Motors	1	3,100	0	$300	$68,900	$0	234	234
6	Heat Pump Water Heater	(1)	2,600	0	$250	$2,500	$600	10	7.4
PKG 1	**Measures 1 - 3**	**(3)**	**4,500**	**1,900**	**$3,100**	**$26,200**	**$9,700**	**8.3**	**5.2**

6.1 Measure 1 – Upgrade Interior & Exterior Lighting to LEDs



Project Cost	
Investment ($)	**$5,600**
Incentives ($)	**$400**
Total ($)	**$5,200**
Annual Savings	
Electricity (kWh)	**13,000**
Natural Gas (therms)	**0**
Savings ($)	**$1,200**
CO_2e (MT)	**6**
Economic Data w/ Incentives	
Simple Payback (yrs)	**4.3**
Internal Rate of Return[2] (%)	**19%**
Net Present Value[3] ($)	**$4,100**

Current Issues and Observations:

Guest Speakers

VFD Applications at Water Treatment Plants

Shawn Maurer, P.E., C.E.M.
SEDAC
Technical Director

Matt Johnson, P.E.
Xylem
Sr. Applications Engineer

Don Jensen
Highland Park WTP
Superintendent

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Pump Affinity Laws – Simple Right?

$$\frac{RPM_1}{RPM_2} = \frac{GPM_1}{GPM_2}$$

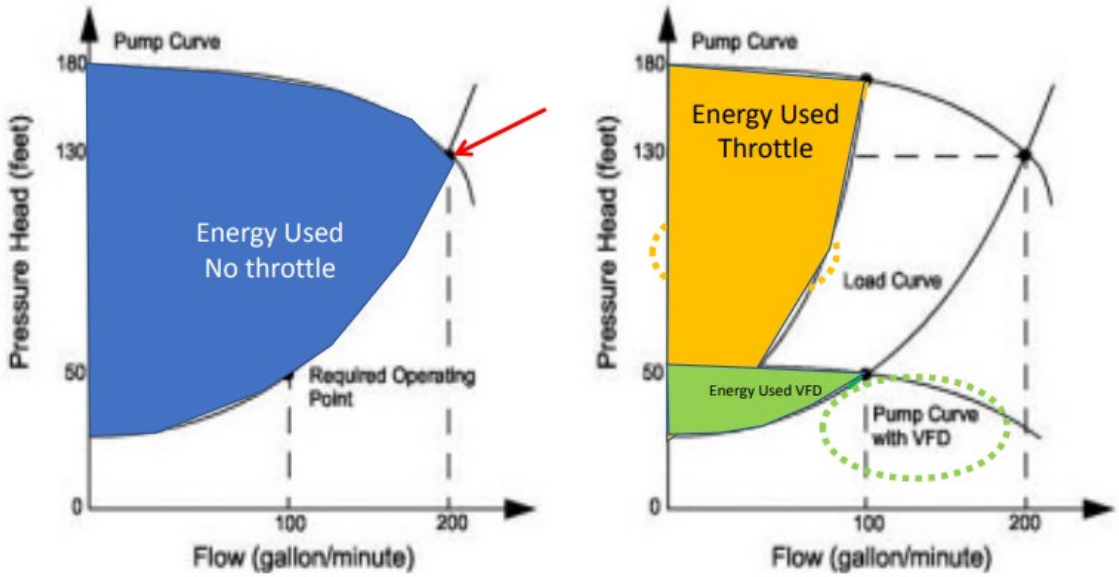
$$\left(\frac{RPM_1}{RPM_2}\right)^2 = \frac{\Delta P_1}{\Delta P_2}$$

$$\left(\frac{RPM_1}{RPM_2}\right)^3 = \frac{\bar{P}_1}{\bar{P}_2}$$

These laws are why VFDs on centrifugal systems are highly promoted!

- 20% reduction in speed is about 51% reduction in power.

So, we can put a VFD on any centrifugal pump, right?



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Understanding VFD Potential

System curve impacts operation, too!

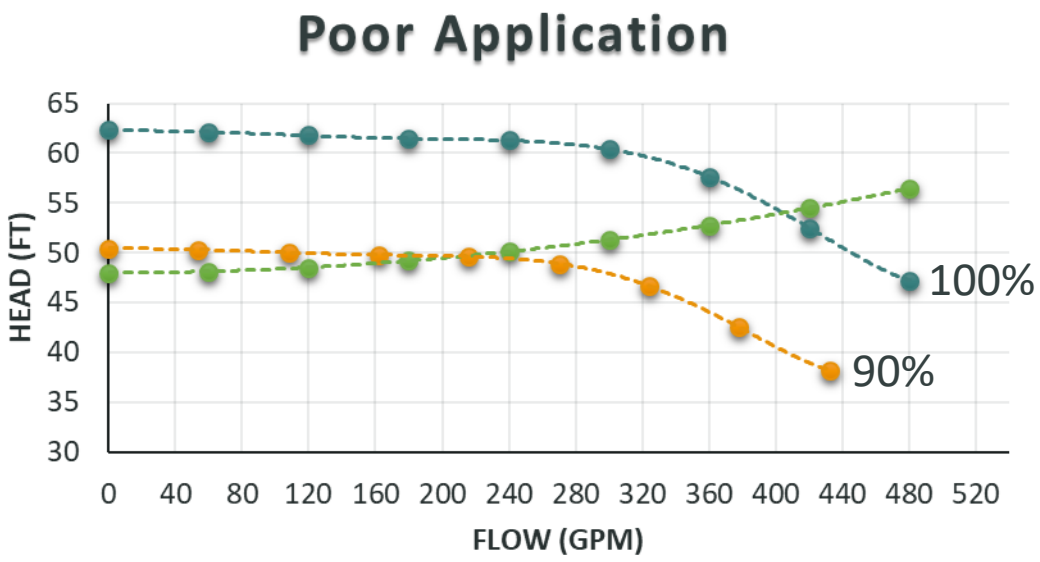
- Flat curves not good for VFDs
- Steeper curves better for VFDs

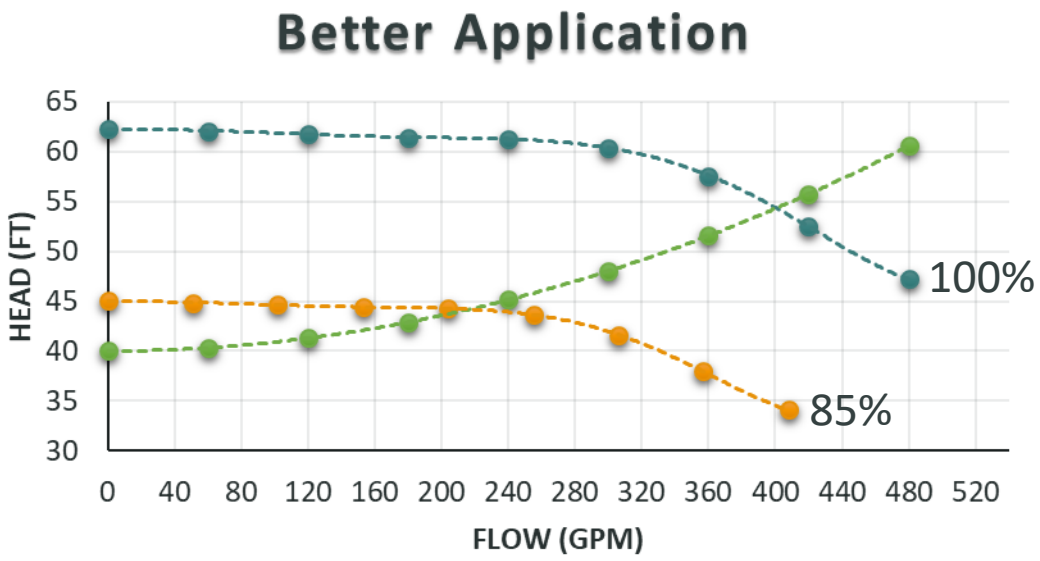
*Generally, above applies.

Example to right

Same Design Condition:

- 400 GPM, 54 ft TDH
- Different system designs

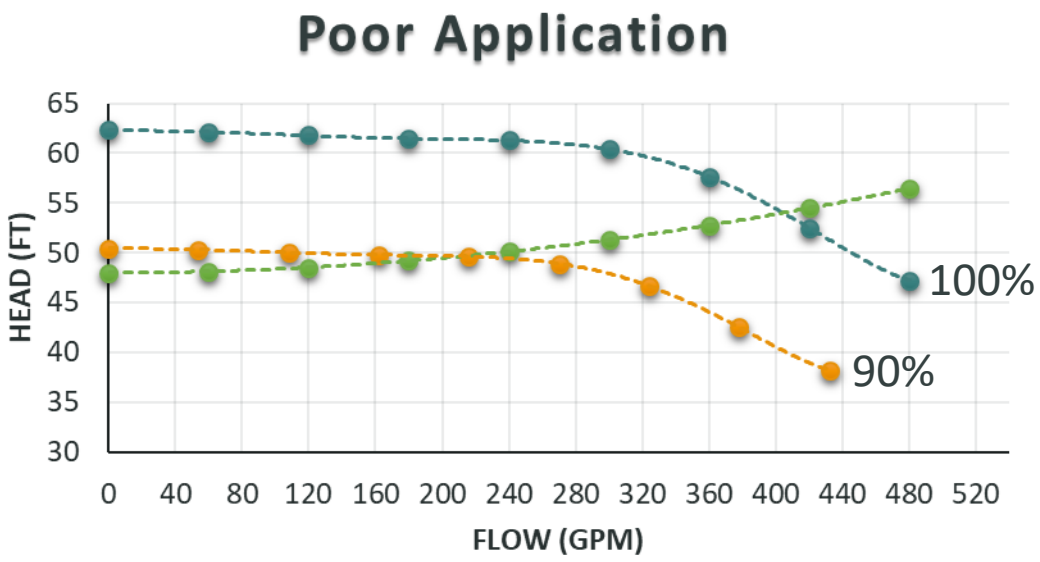




Understanding VFD Potential

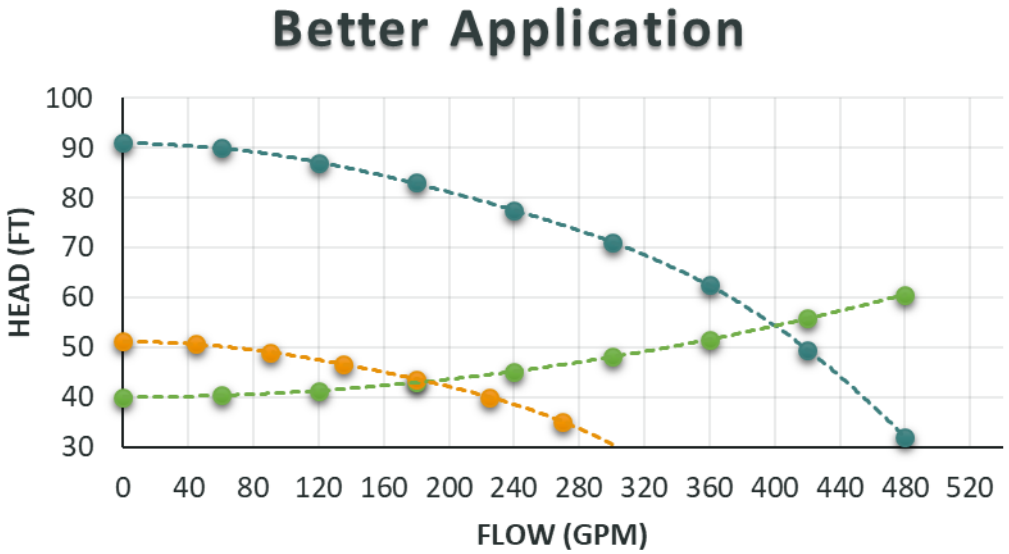
Match steep pump curves to flat system curves

- VFD may be applicable



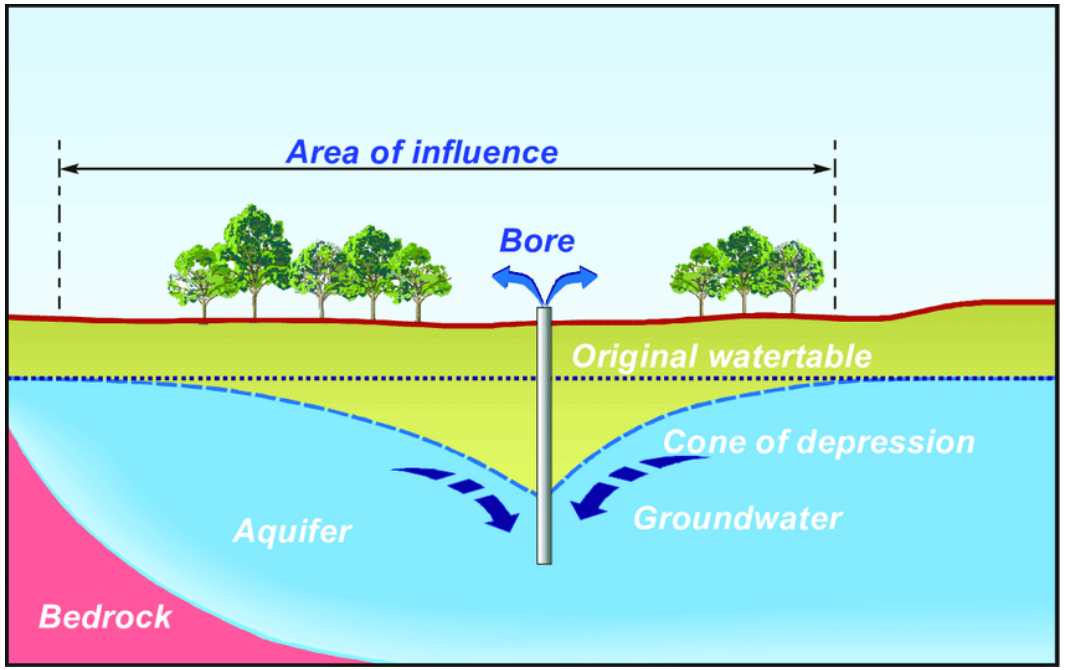
Same Design Condition:

- 400 GPM, 54 ft TDH
- Different pump curves, same system design



Benefits for Raw Water Well Pumps

- Reduce well draw-down
  - Decreases static head
  - Extend well life between cleanings
- Vary flow to match process demand
- Reduce wear and tear on pumps and motors
- Match oversized pump/motor to demand



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Benefits for High Service Pumps

- **Closed Loop**
  - Pressure modulation
  - Demand matching
  - Water hammer reduction

- **Water Tower/Gravity Pressure**
  - Tower Draw-down matching
  - Pressure transient reduction

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Thank you!

Questions?

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Variable Speed Pumping

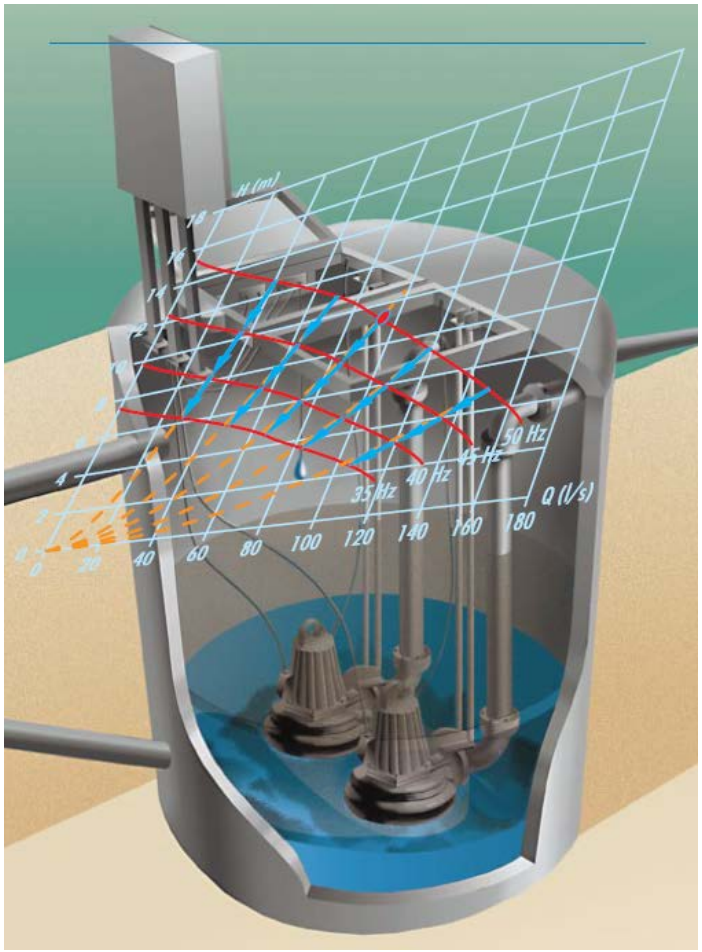
MATT JOHNSON, PE IN, IL
SR. APPLICATIONS ENGINEER
MATT.JOHNSON@XYLEM.COM

March 14, 2023

Why are VFD used

There are several reasons why a VFD might be used, including:

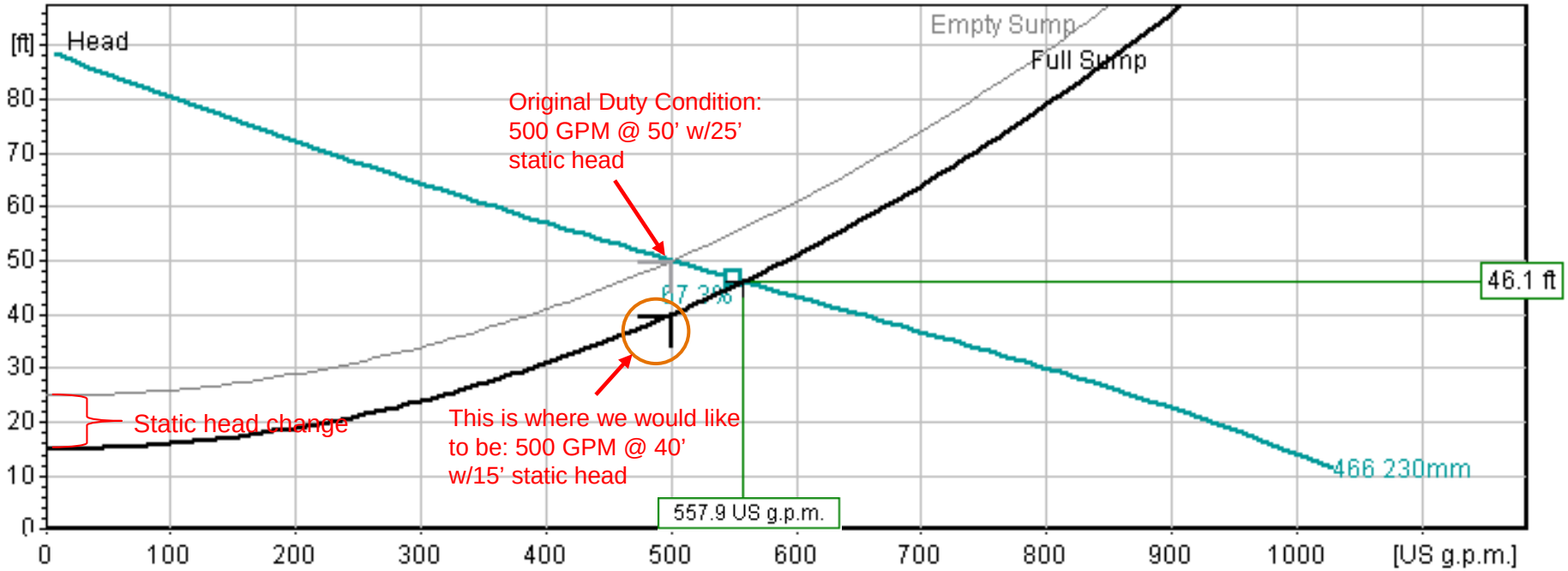
- Correcting flow to meet current and/or future demands.
- Flow matching (maintain sump level)
- Soft start to limit in-rush currents
- Soft stop to limit transients like water hammer
- Phase inversion (1-phase to 3-phase)
- Voltage correction
- Power Factor Correction
- Maximizing system efficiency
- Lowering operational costs
- Maintaining sump and pipe cleanliness



Let's look at one of the main reasons VFD's are used.

Use VFD's to Correct Flow – Example

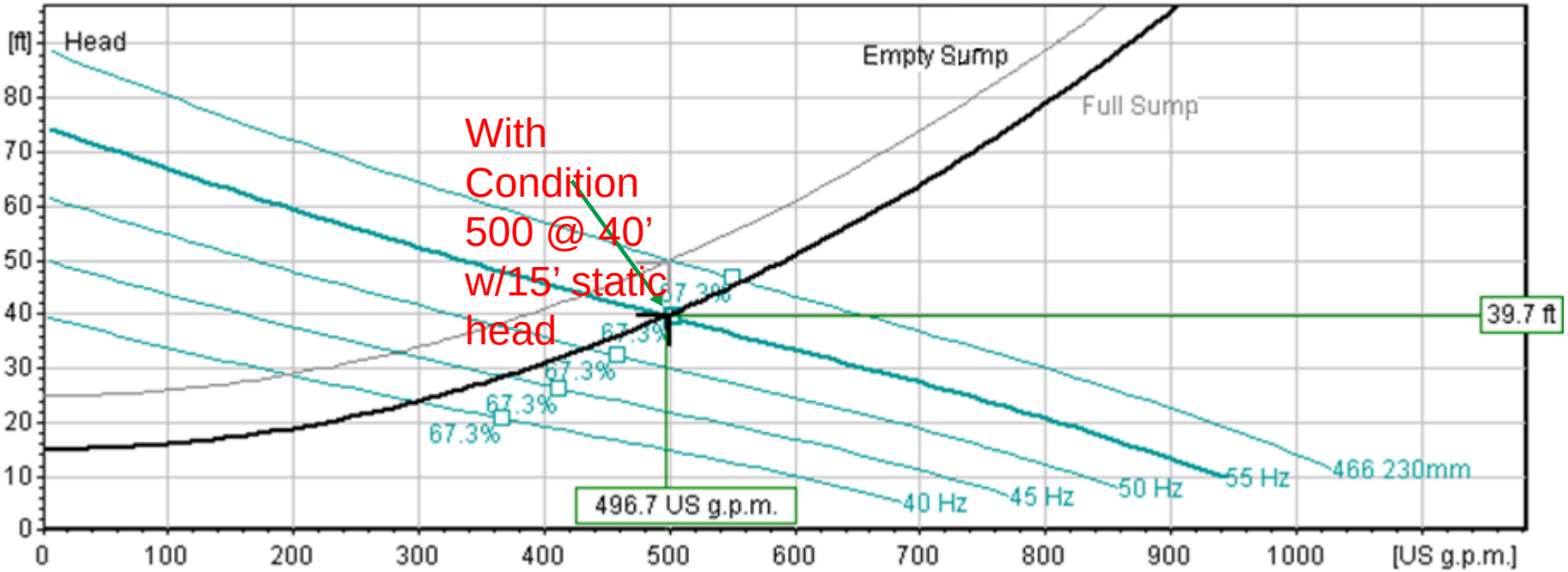
As levels in the sump change so does the system curve because static head will also change with level



However, with a higher level in the sump, the static head will drop causing the pump to operate at a different point

Use VFD's to Correct Flow – Example

With a VFD added to the system the flow can be held constant regardless of the sump level (aka flow matching)



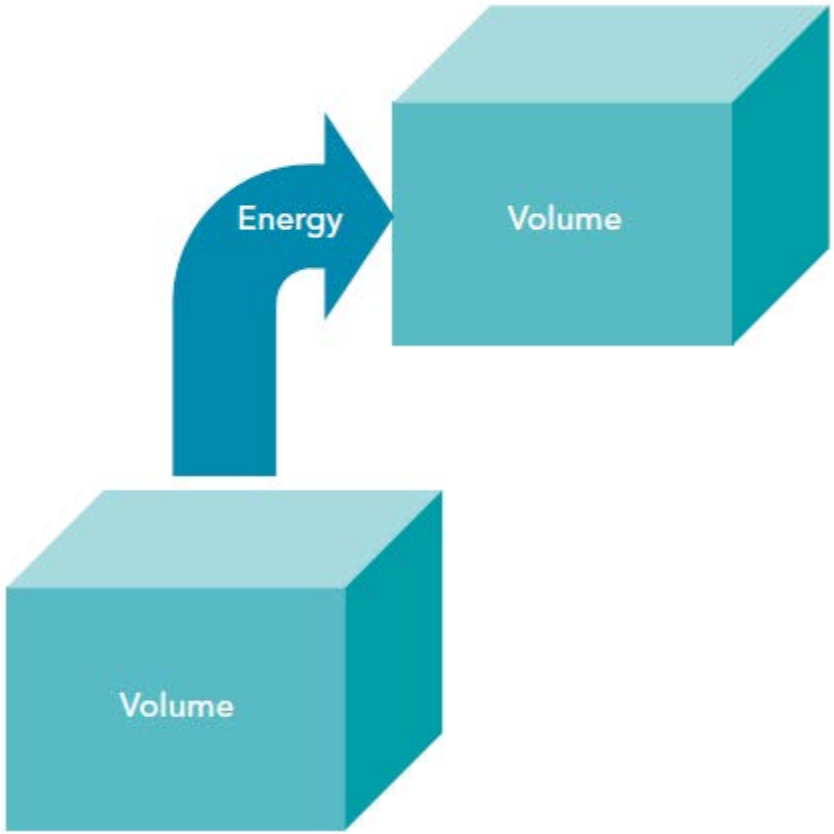
With the proper control system, the pump can be automatically adjusted to maintain a fixed flow rate

Specific energy

$$E_s = \frac{energy}{volume}\left[\frac{kWh}{m^3}\right]\left[\frac{kWh}{Mgal}\right]$$

$$E_s = \frac{h}{\eta}\rho g * \frac{1}{3600000}\left[\frac{kWh}{m^3}\right]$$

$$E_s = \frac{h}{\eta}\rho g * \frac{1}{639}\left[\frac{kWh}{Mgal}\right]$$

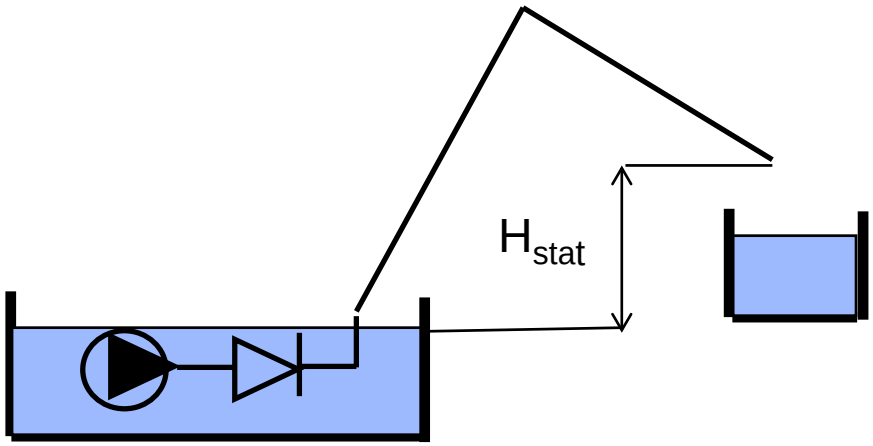


Process control aspects
-Variable speed pump systems

Reducing the total pumping head

$$E_s = \frac{h}{\eta}\rho g * \frac{1}{3600000}\left[\frac{kWh}{m^3}\right]$$

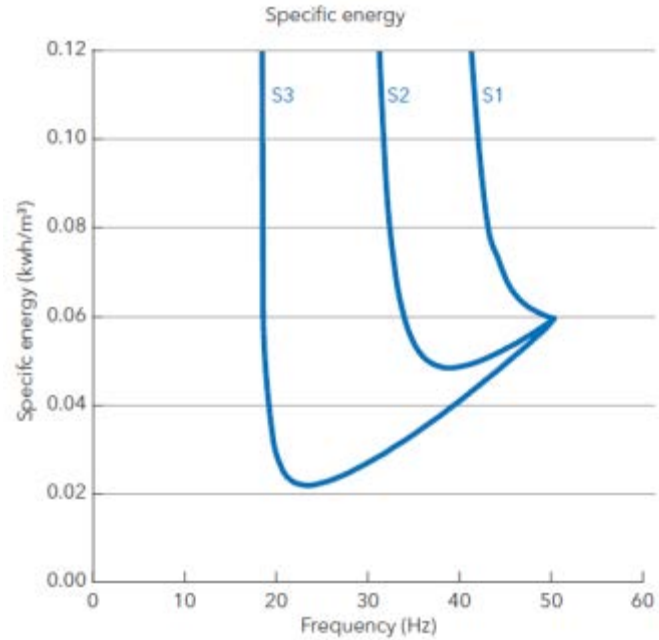
Maximizing pump efficiency

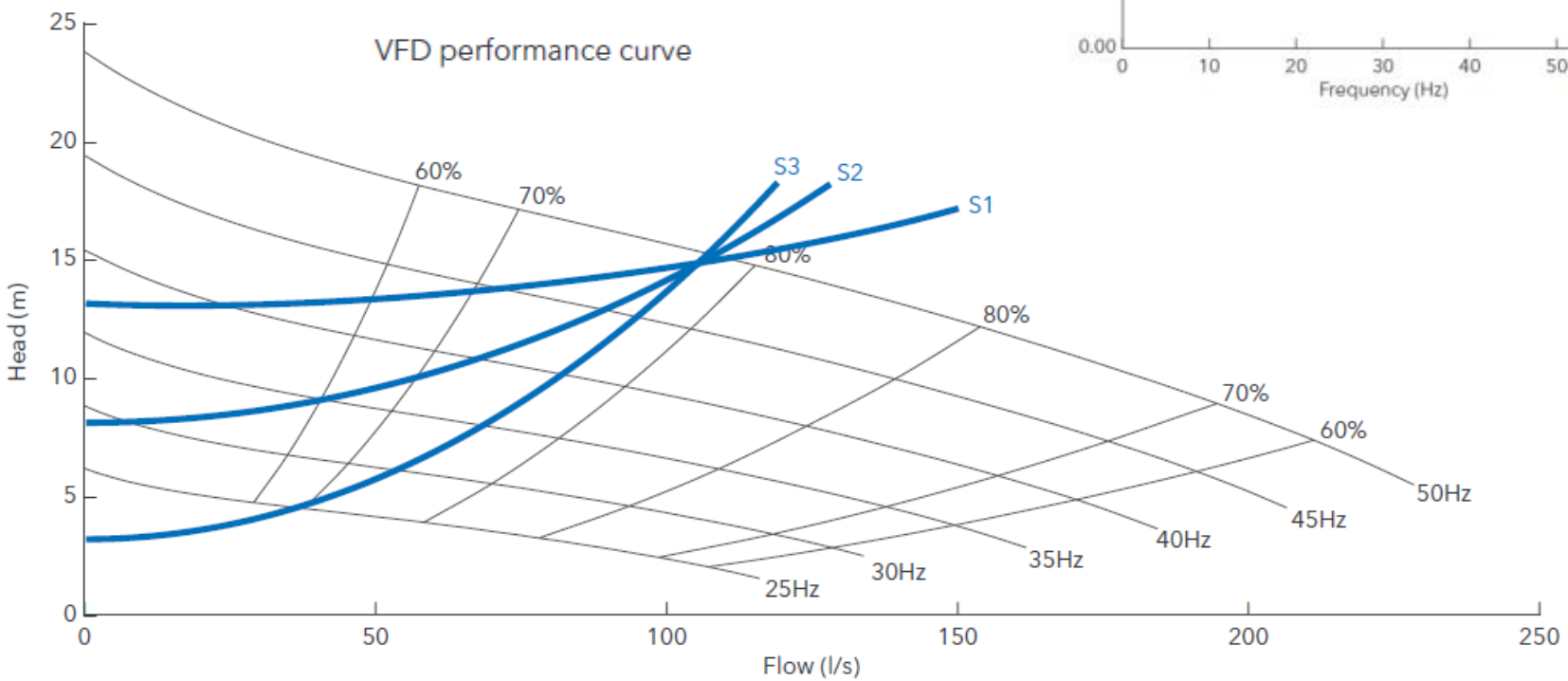


Pump sump level control

-Minimizing energy usage

$$Specific\ \ Energy = \frac{Energy}{Volume} \propto \frac{H}{\eta}$$

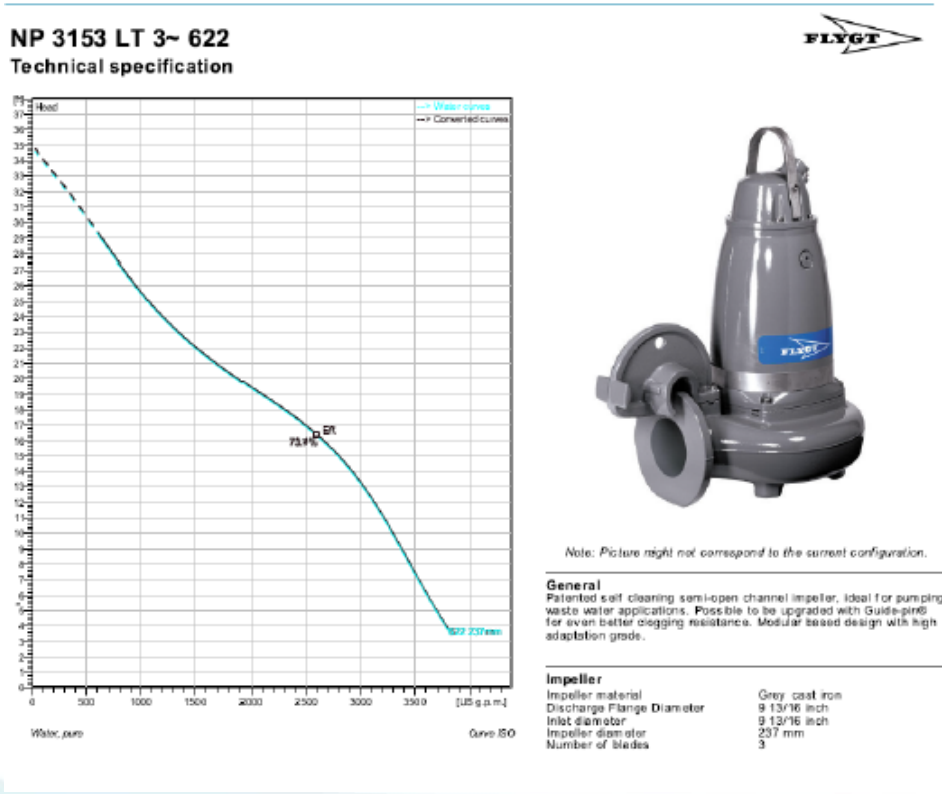




xylem
Let's Solve Water

Internal Recirculation Pumps

- Design flow: 8.4 MGD (5,830 gpm) – 2 Pump operation 1 standby
- Flow range 2.3-8.4 MGD (1,550 – 5,830 gpm)
- Average flow 3,400 gpm
- Pump selection NT 3153 LT
- 10” inlet and outlet



NP 3153 LT 3~ 622

Technical specification

Note: Picture might not correspond to the current configuration.

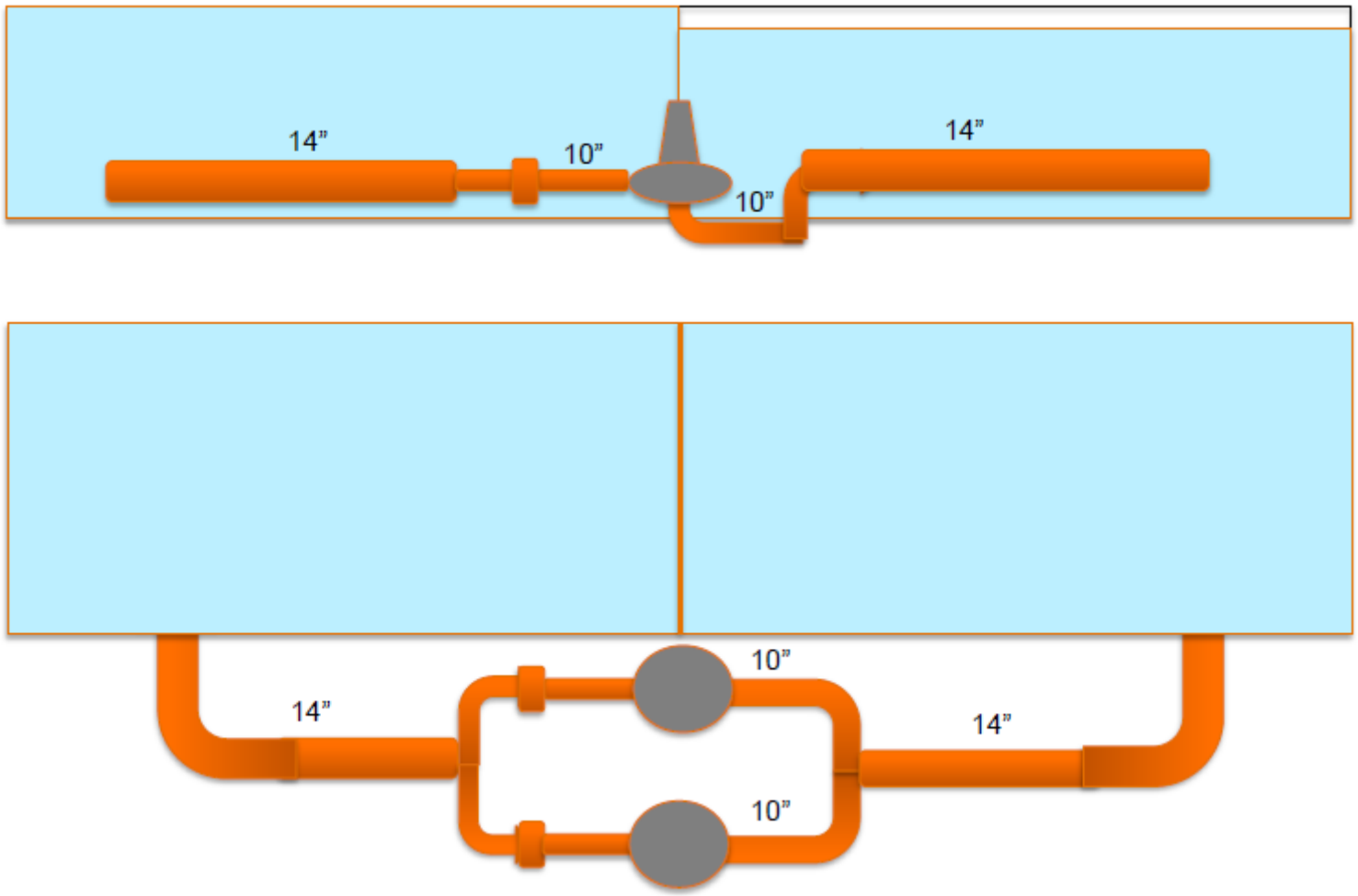
General

Patented self cleaning semi-open channel impeller, ideal for pumping in waste water applications. Possible to be upgraded with Guide-pin® for even better clogging resistance. Modular based design with high adaptation grade.

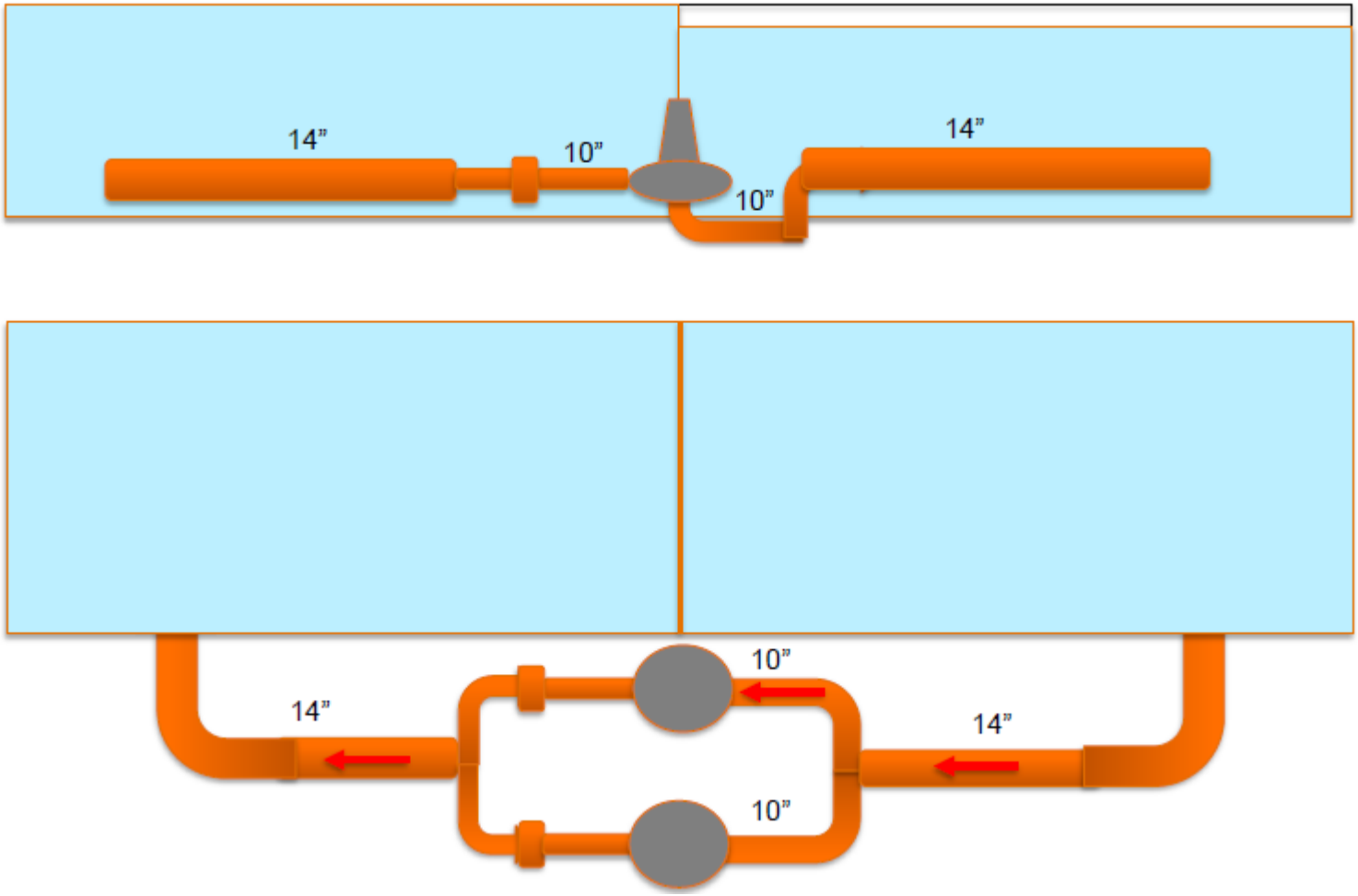
Impeller

Impeller material	Grey cast iron
Discharge Flange Diameter	9 13/16 inch
Inlet diameter	9 13/16 inch
Impeller diameter	237 mm
Number of blades	3

WWTP Recirculation System



WWTP Recirculation System
One pump operation



WWTP Recirculation System
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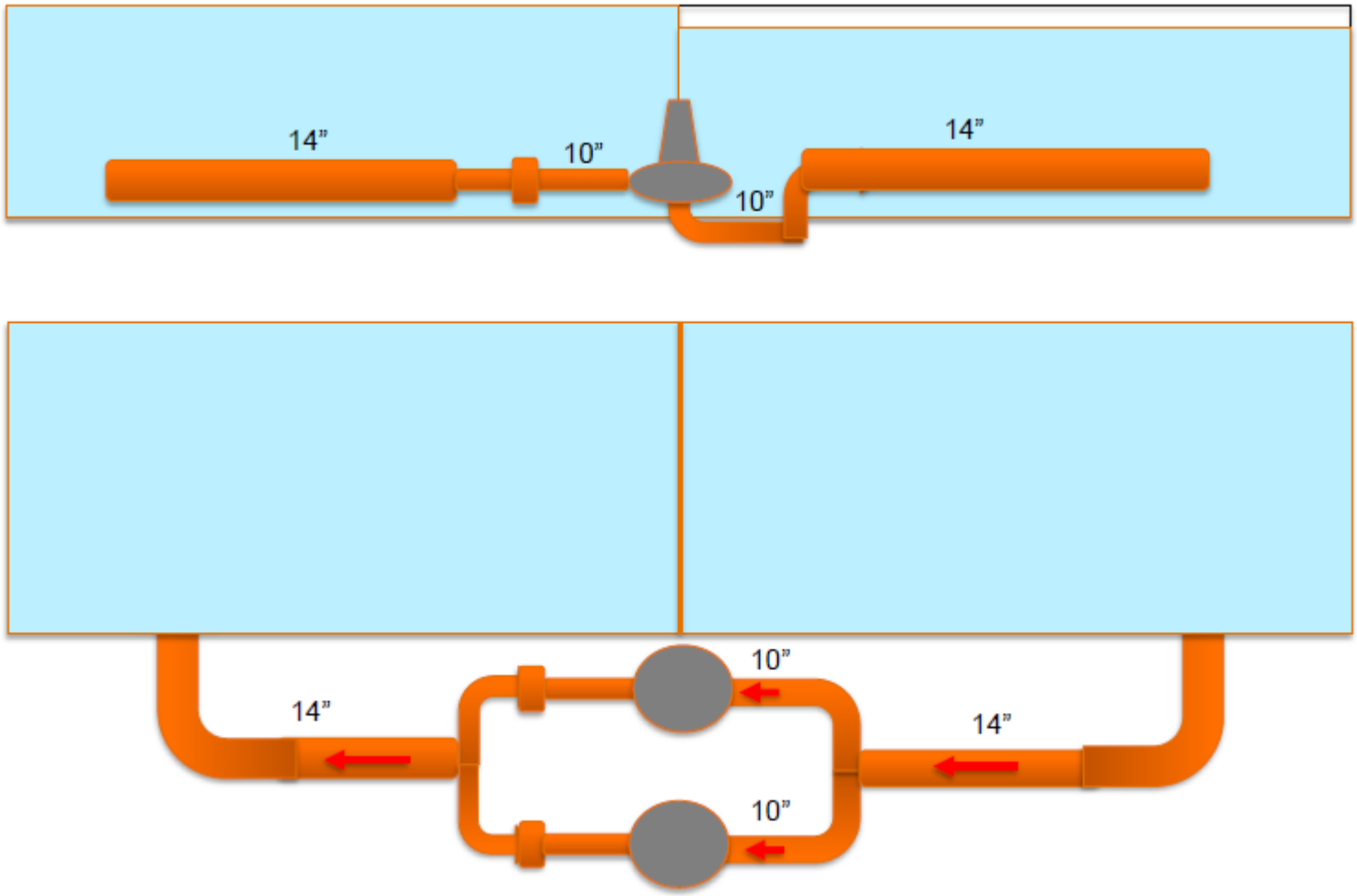
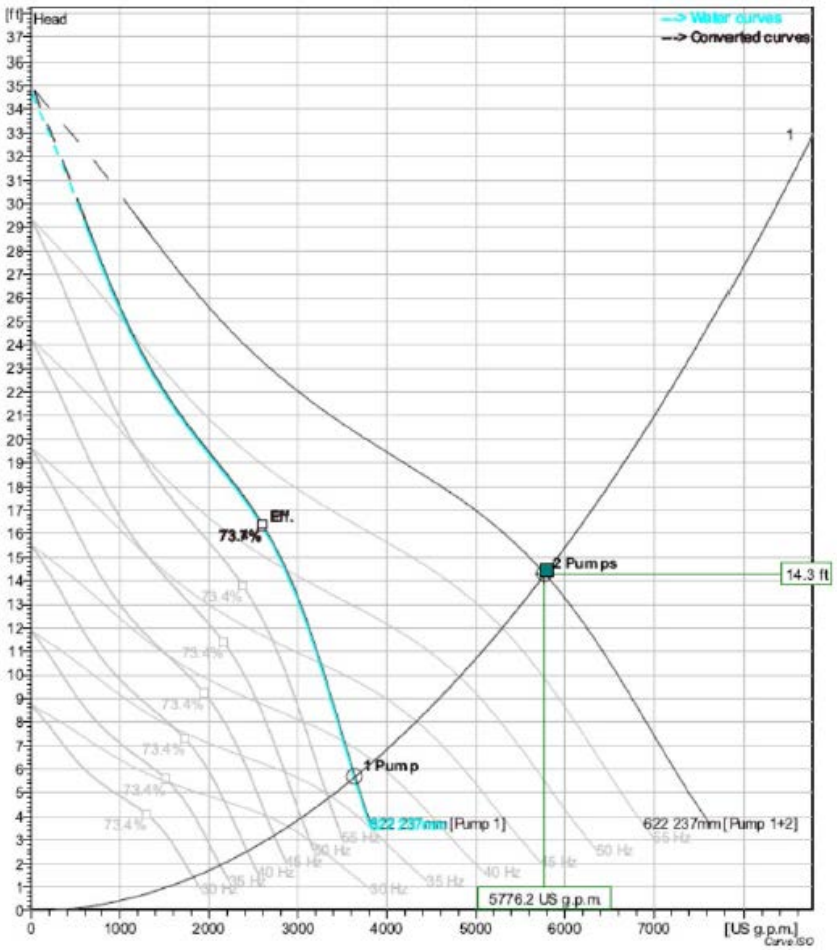
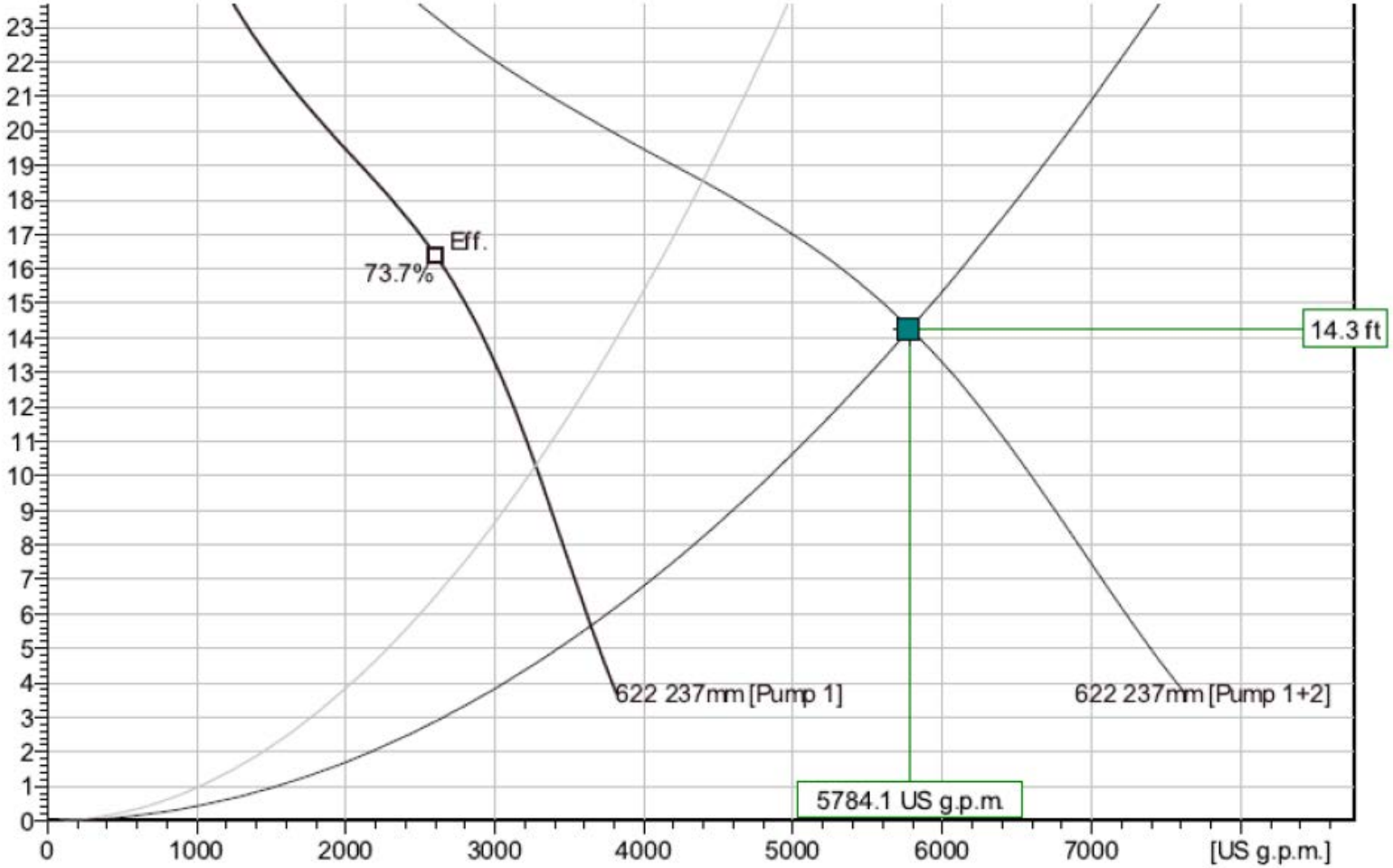


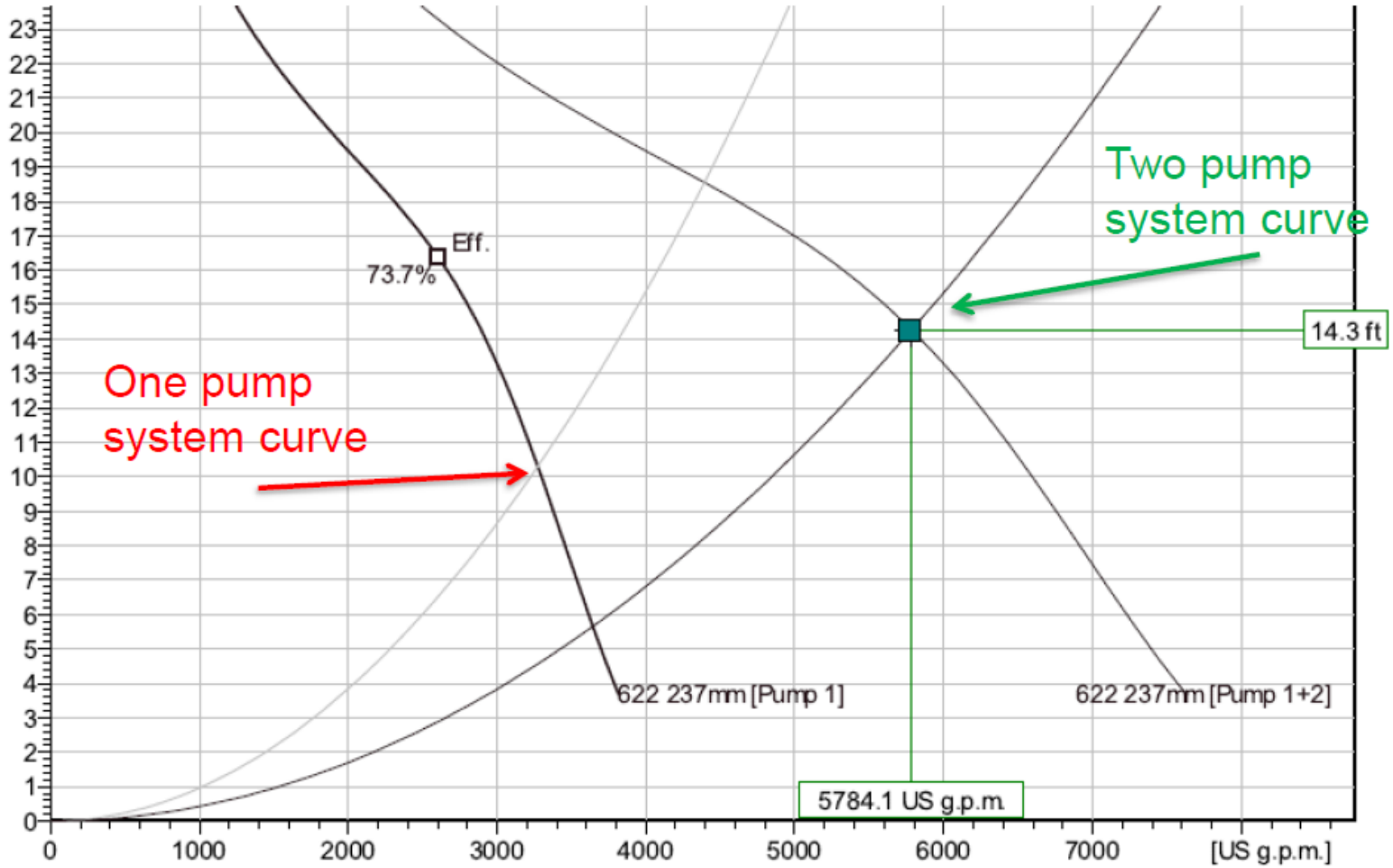
One pump operation evaluation



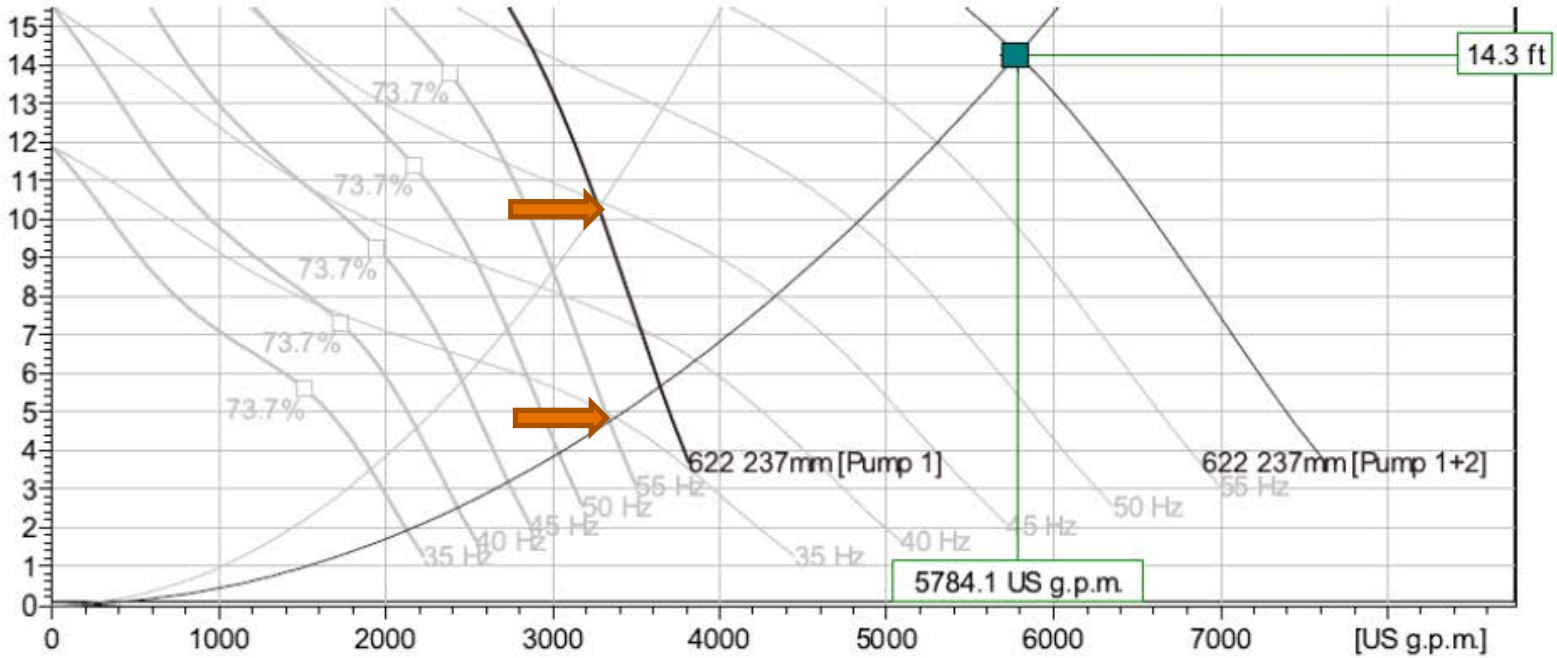
Evaluation of 1 pump vs 2 pump operation requires system curve information



One Pump Operation Evaluation



Variable Speed Curves for 1 vs 2 Pump Duty



Operating Characteristics

Pumps / Systems	Frequency	Flow	Head	Shaft power	Flow	Head	Shaft power	Hydr.eff.	Specific Energy	NPSHre
2 / 1	35 Hz	1680 US g.p.m	4.83 ft	2.86 hp	3370 US g.p.m	4.83 ft	5.73 hp	71.9 %	26.5 kWh/US M	10.8 ft
1 / 1	60 Hz	3270 US g.p.m	10.3 ft	13.9 hp	3270 US g.p.m	10.3 ft	13.9 hp	61.2 %	60.3 kWh/US M	25.5 ft

Specific Energy Definitions

E_s is needed energy to transport a liquid volume

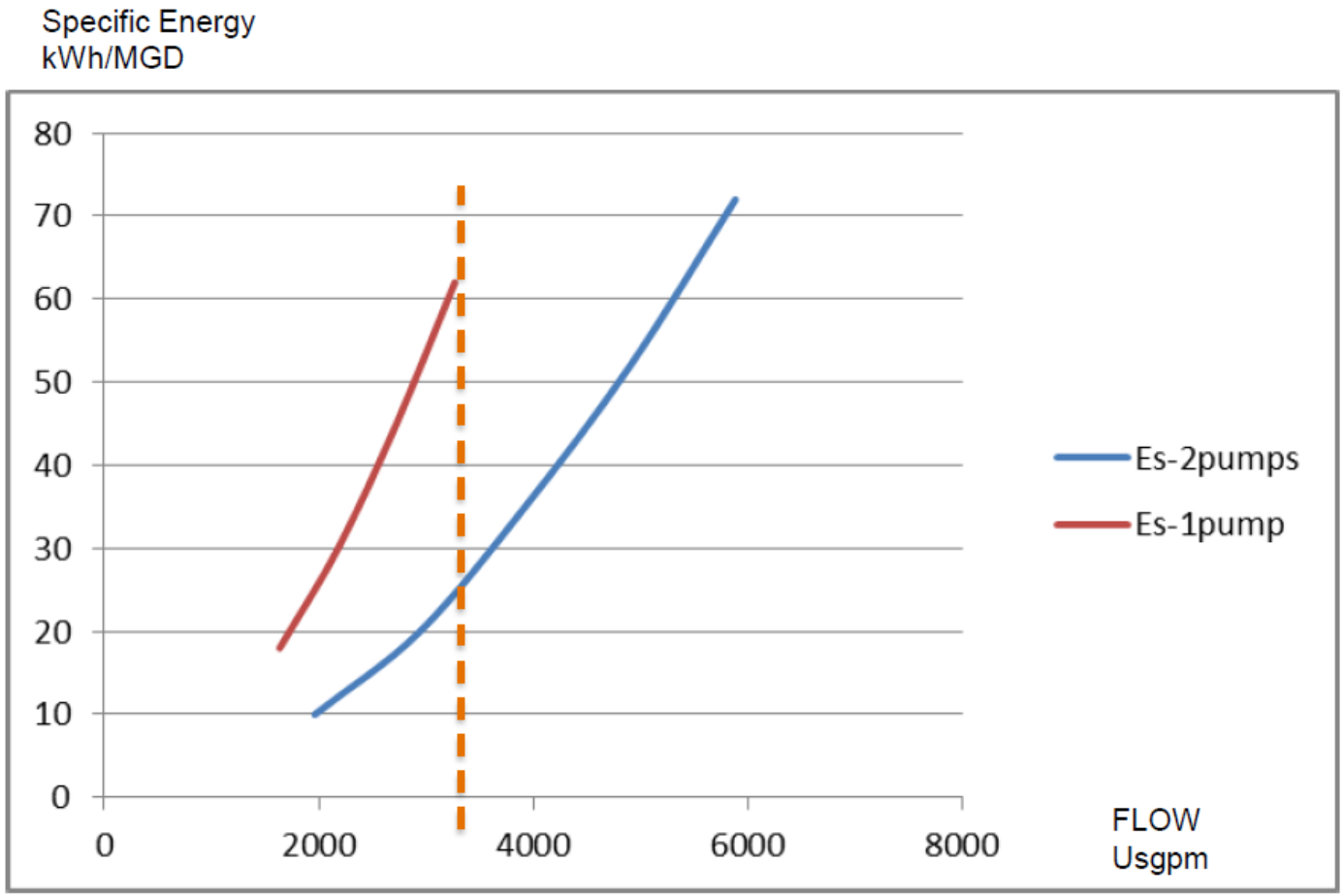
$$E_s = \frac{Energy}{Volume}$$

$$E_S = \frac{Energy}{Volume} = \frac{Pt}{Qt} = \frac{\rho g Q H}{\eta_{tot}} \frac{1}{Q} = \frac{H}{\eta_{tot}} \rho g$$

ρ = density
g = gravity constant

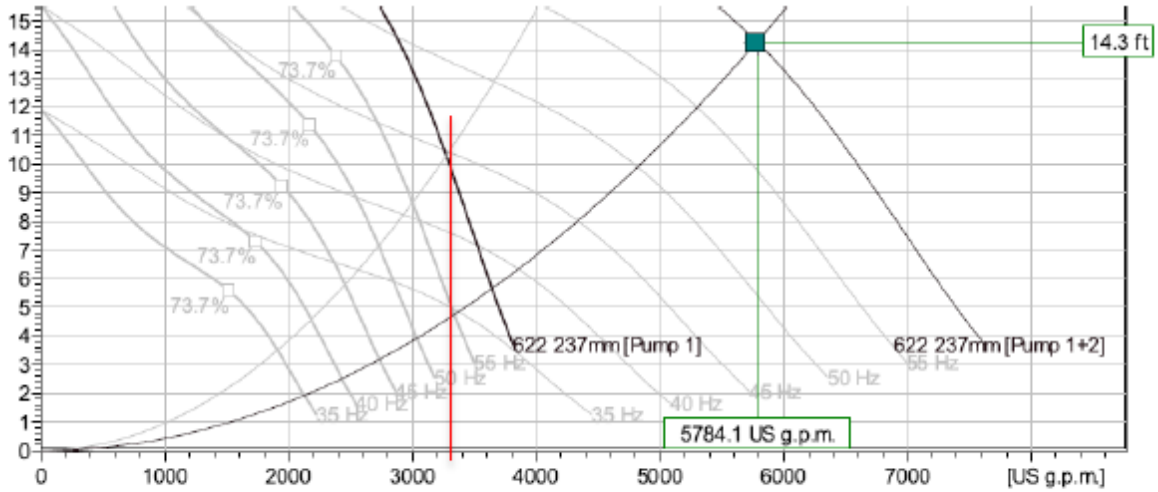
Bring system pressure down and total efficiency up!!

Specific Energy Analysis



Energy Cost

- Example
- Average flow 3,4000 gpm (4.9 MGD)



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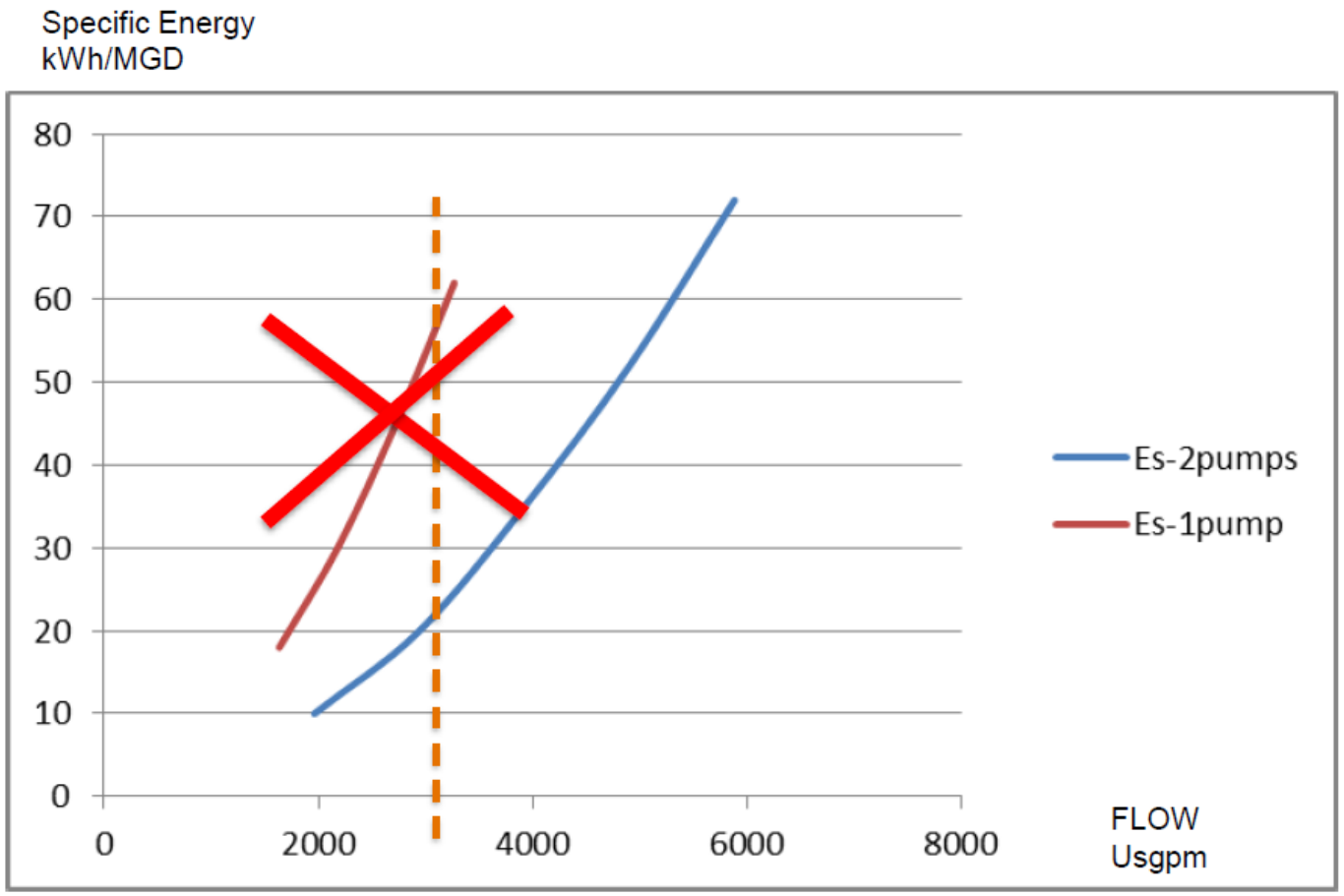
1 pump operation Head=0.3’, Total efficiency=61.2%, ES=60kWh/MGD
2 pump operation: Head=4.8’, Total efficiency=71.9%, ES=26.5kWh/MGD

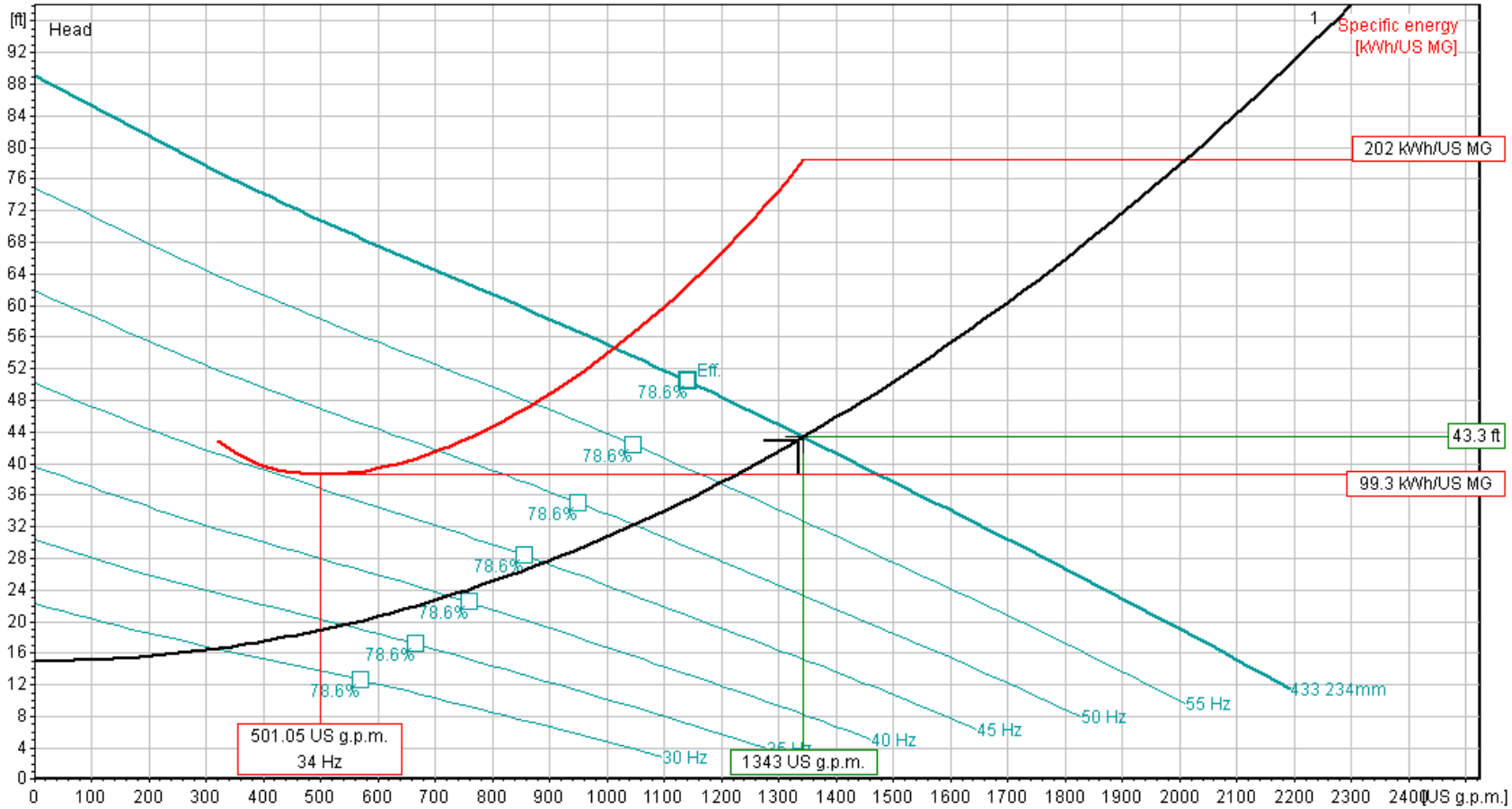
Energy Analysis

- To operate 1 pump at ~60Hz and 3,400 GPM (4.9 MGD) for 1 year (24/7) would require 107.3 MWh
- 2 pumps at ~35 Hz and the flow would require 47.4 MWh,
- A difference of ~ 60 MWh.

Skip the one pump alternative Always try to operate as close to BEP!



Select Pump to the Right of BEP for VFDs



- From 202 kWh/MG to 99.3 kWh/MG

Questions?

VFD Application in Highland Park

Implementing VFDs for Drinking Water Plants - March 14, 2023

Don Jensen, Water Plant Superintendent

Highland Park

On Lake Michigan 25 miles North of Chicago

Incorporated in 1869

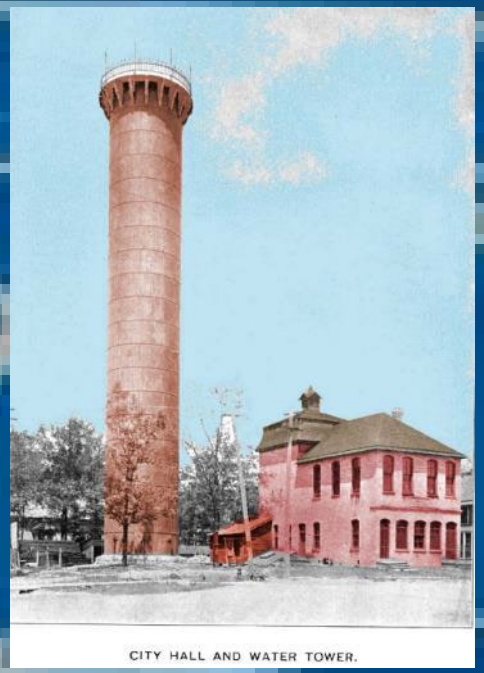
A ‘bedroom’ suburb – primarily residential and commercial

Population 30,176.

Serving another 30,000 in neighboring communities

Early water supply
Artesian Well

Artesian Well 1889



1893 Water Tower & City Hall

Early water supply

Steam Powered Pump Station 1893

In 1893-94 a steam powered lakefront pump station-settling basin with a 2,230 foot 16 inch Lake Michigan intake

In time, the citizens of Highland Park became dissatisfied with the quality of this water (referred to in the local paper as "liquid mud").

HIGHLAND PARK WATER WORKS.

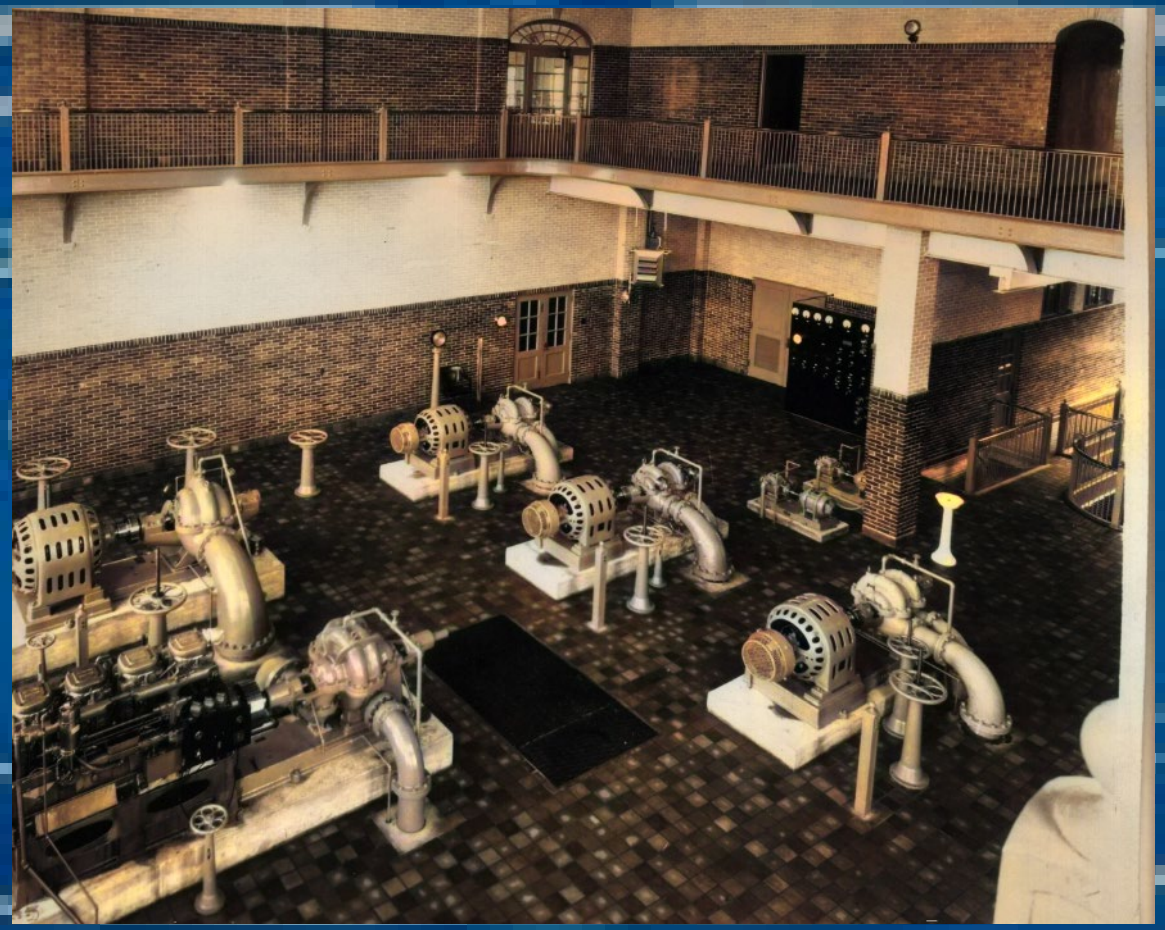
NEW Filter Plant & Tower 1929

At that time, the population numbered 12,000 and required 840 million gallons of water per year.

The plant was designed to supply seven million gallons per day.

The tower is 125 feet high and features a unique ornamental brick enclosure.

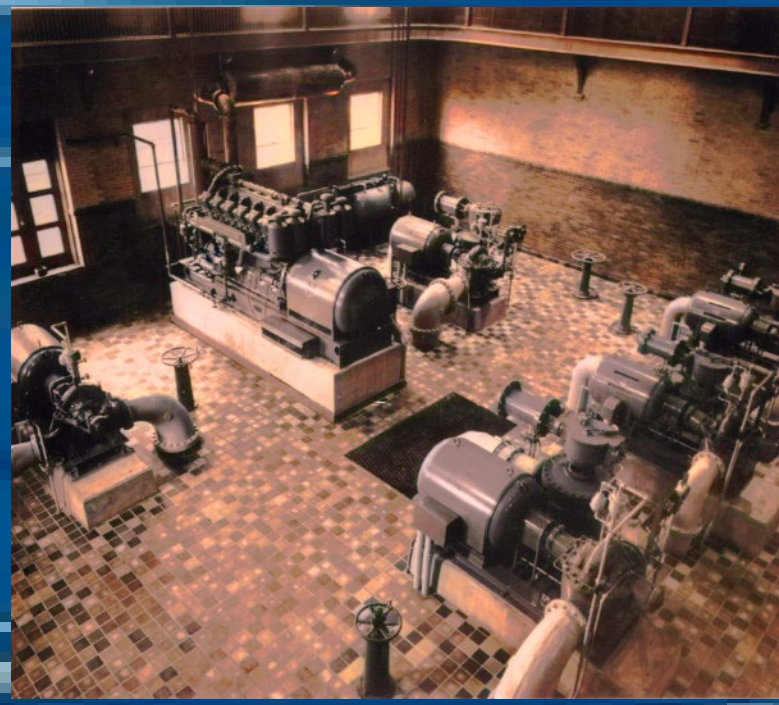
Our New 4,160 Volt Pumps - 1929



Treatment Plant Expansion **1960**

This expansion project doubled the plant's settling basin and filter capacity and converted all of the pumps to 440 volt operation

‘State of the Art’ Controls



New Pumps & Generator

Plant Upgrade 1986

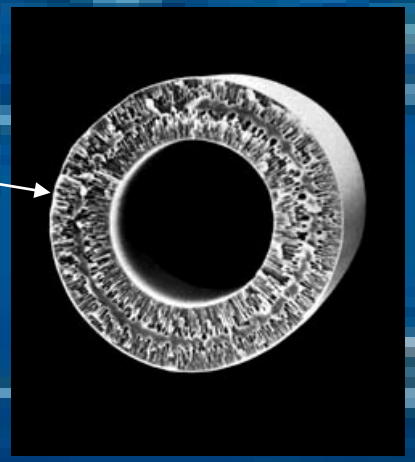
Multi-media filter media increased the plant's capacity to 21 million gallons per day.

This also included

- Replacement of several pumps,
- New (liquid) chemical feed building addition,
- Up-dating of the plant’s laboratory,
- Early SCADA control system (upgraded in 2002)

Ultrafiltration 2013-14

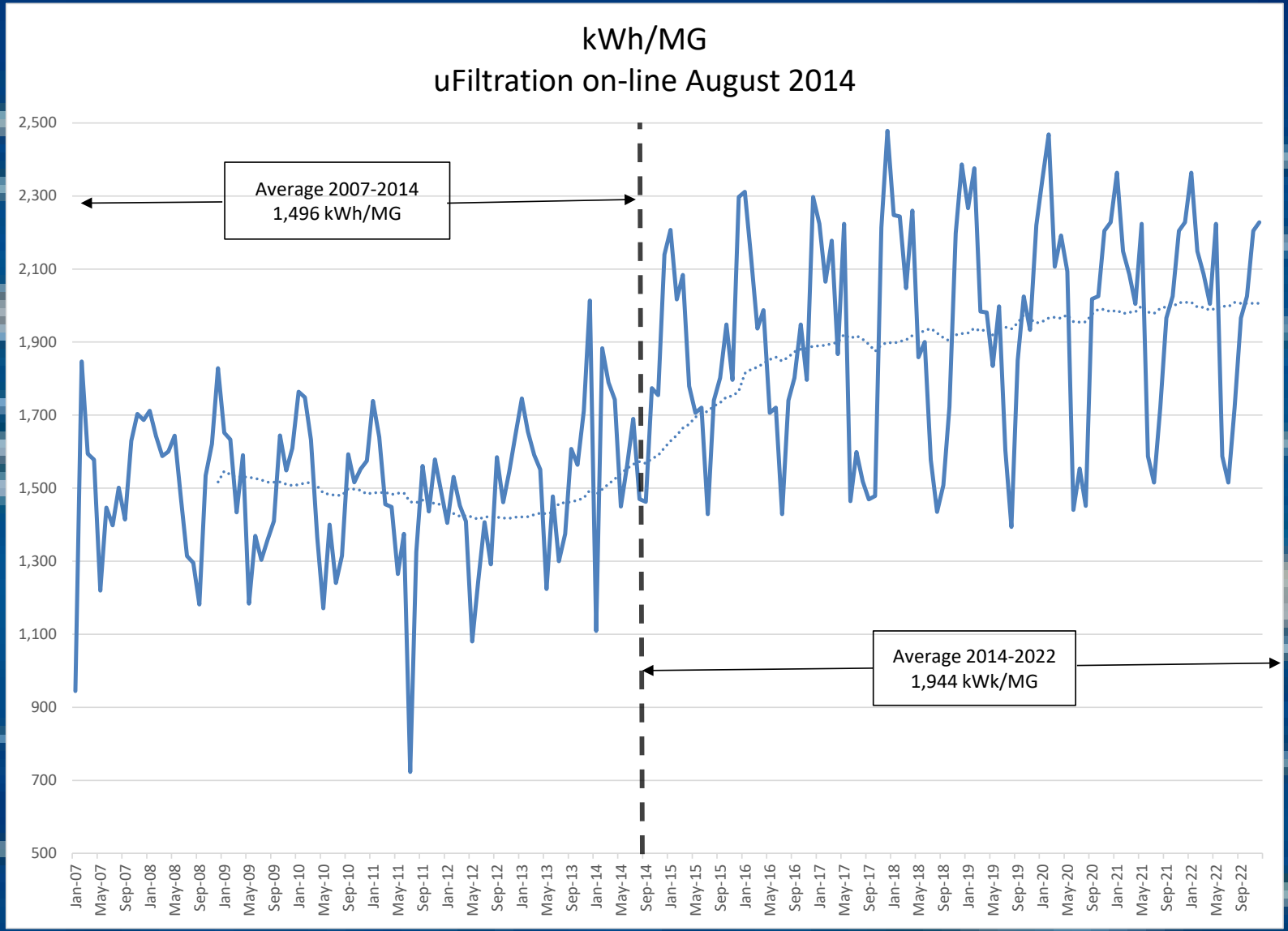
This major upgrade replaced the conventional surface water treatment with 0.2 micron ultrafiltration fiber technology providing superior pathogen protection and increasing the Plant capacity to 30 MGD



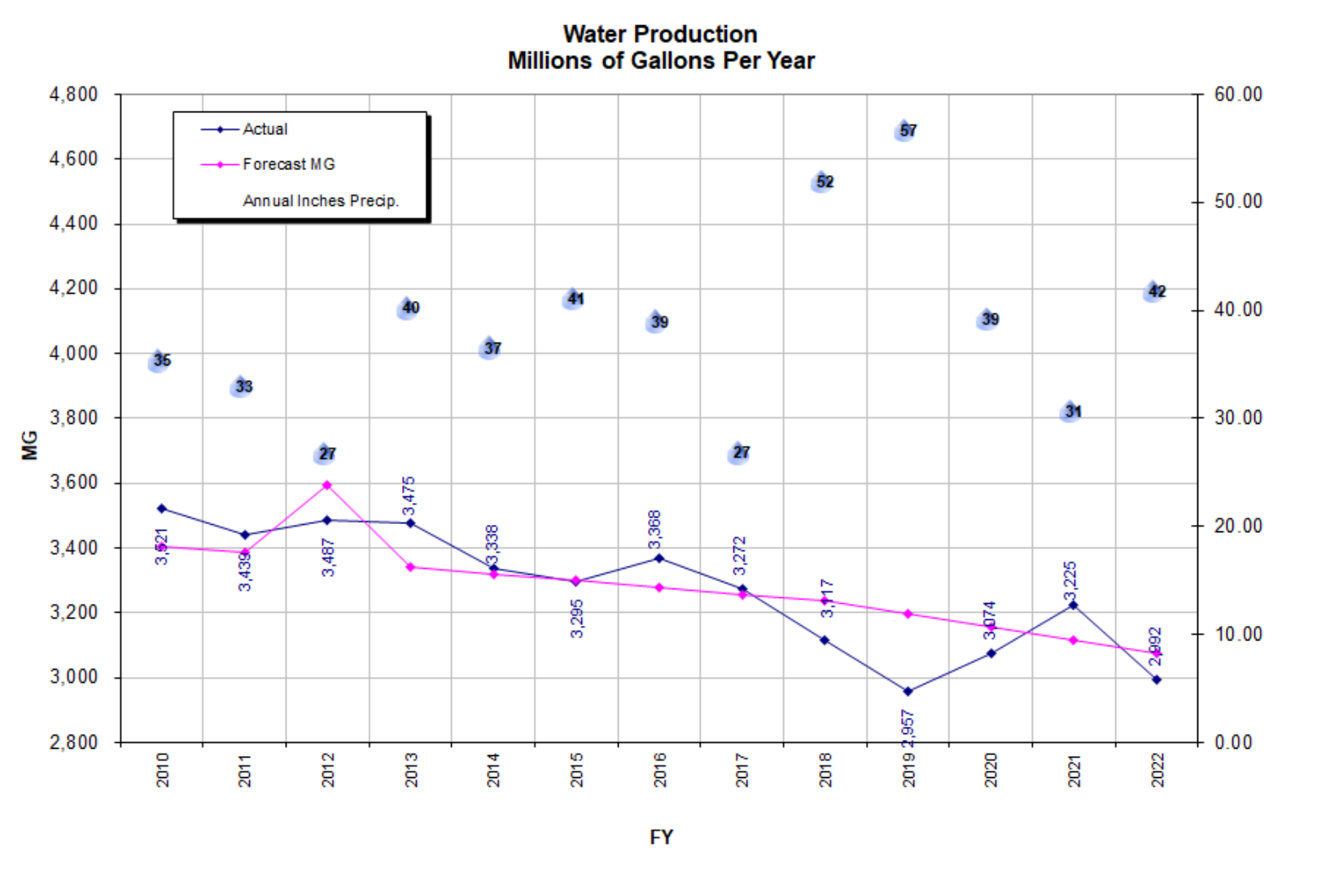
Historical kWh/MG

Ultrafiltration conversion increased the kWh/MG approximately 30%

Not surprising as this required a 3rd pumping stage, blowers and large air compressors.



Historical Water Production



Declining about 1% per year

Plant Stats

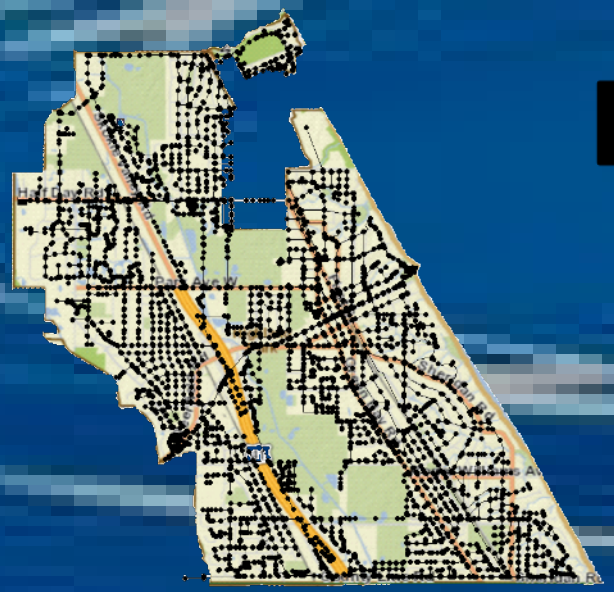
Electricity Budget **$450,000** annually
Average Pressure **100 PSI** at Plant

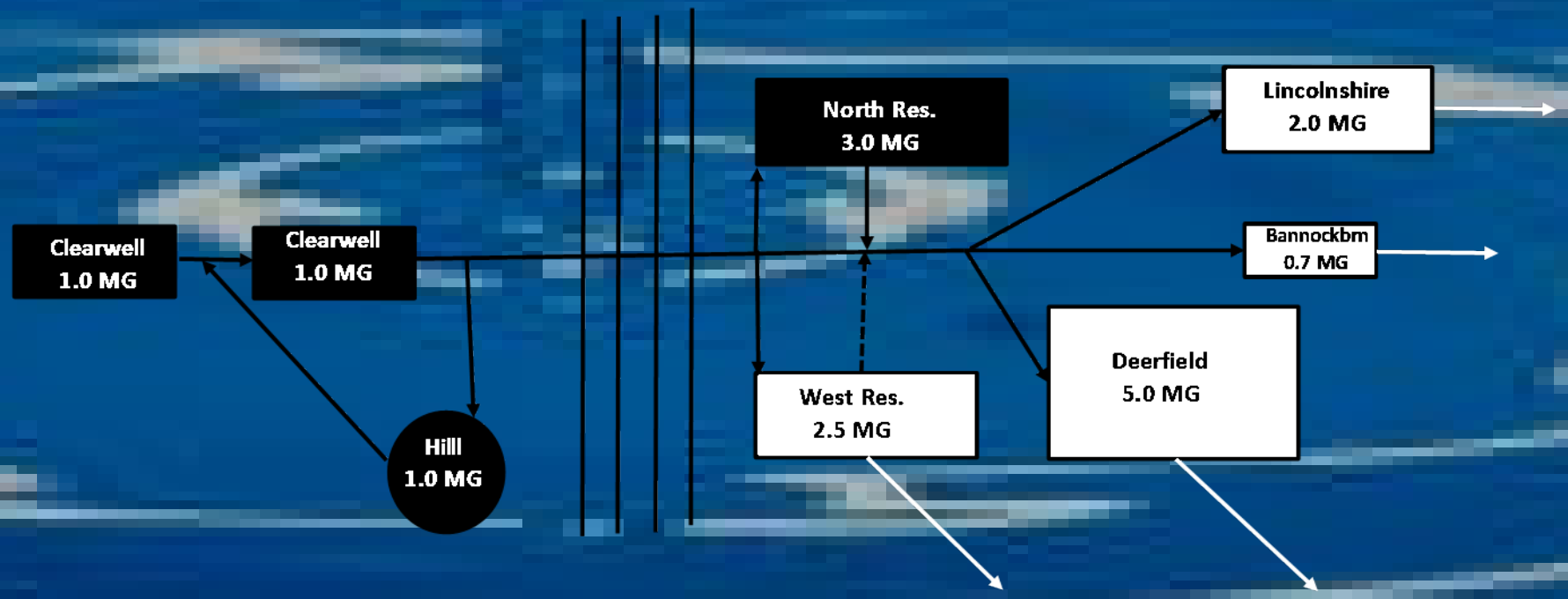
2022	RAW MGD	FIN MGD
Min	5.74	5.41
Max	16.39	15.46
Avg	8.81	8.20

Complex Distribution System

PUMP PRESSURIZED SYSTEM (No 'floating' elevated storage)

50% of water production wholesaled to neighbors





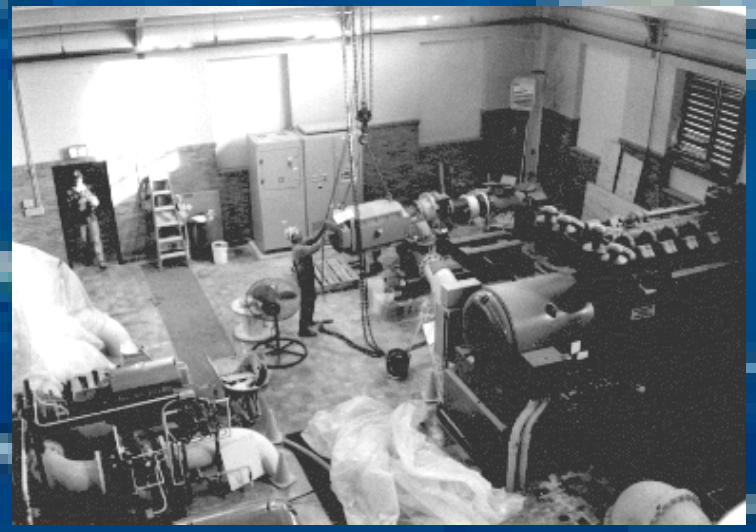
Original Operation: Multiple pumps CLOSED SYSTEM

Plant Operators matched delivery to demand by selecting combinations of various sized HLPs and ‘trimmed’ pressure by bleeding off water into reservoirs.

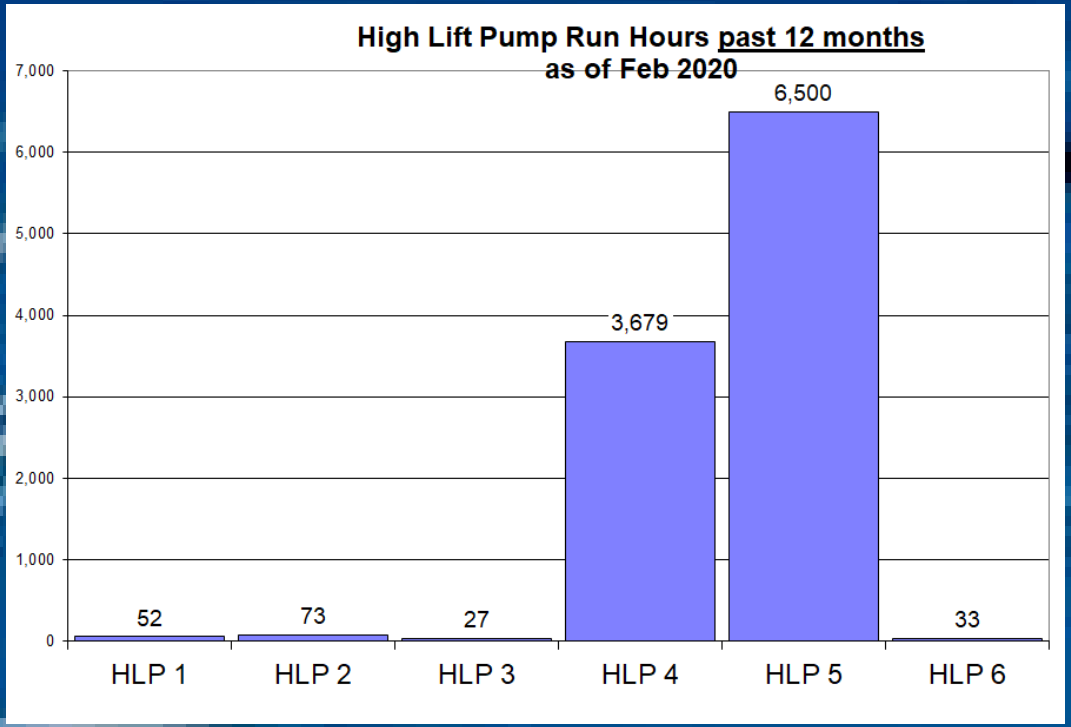
This required constant Operator attention (pre SCADA!) and frequent pump changes producing pressure spikes in the distribution system, especially in winter months when water use is lowest.

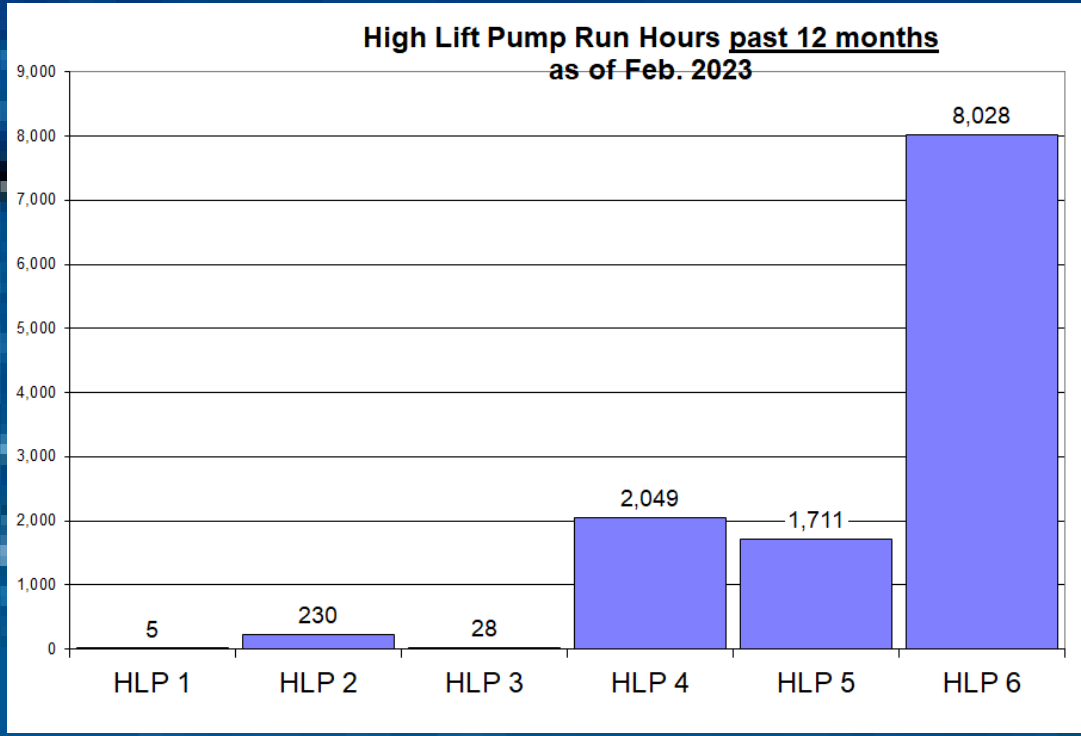
High Service Pump Upgrades Over the Years

						PRESENT		
DATE	1960	1986	1994	2006	2022	PUMP	MOTOR	VFD
HLP #1	4.5 MGD	8 MGD	-	-	-	8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM	US Motors Titan 500 HP	
HLP #2	4.5 MGD	6 MGD	-	-	-	6 MGD Peerless. TDH 250, 1770 RPM	Ideal Electric 350 HP	
HLP #3	6 MGD	8 MGD	-	-	-	8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM	US Motors Titan 500 HP	
HLP #4	6 MGD	-	8 MGD+VFD	NEW VFD	-	8 MGD Aurora Mod. 41, TDH 280 FT, 1750 RPM	US Motors Titan 500 HP	ASI Robicon GT 3000 460 VAC, 18 PULSE
HLP #5	6 MGD		9 MGD+VFD	NEW VFD	-	8 MGD Aurora Mod. 41, TDH 280 FT, 1750 RPM	US Motors Titan 500 HP	ASI Robicon GT 3000 460 VAC, 18 PULSE
HLP #6	-	8 MGD	-	-	VFD	8 MGD Fairbanks Morse, TDH 275 FT, 1775 RPM	US Motors Titan 500 HP	ABB Model ACS880-37-0780A-5



VFDs Get ALL of the Hours!





HLPs 4 &5 have had VFDs since 1994.

HLP #6 received a VFD in 2022

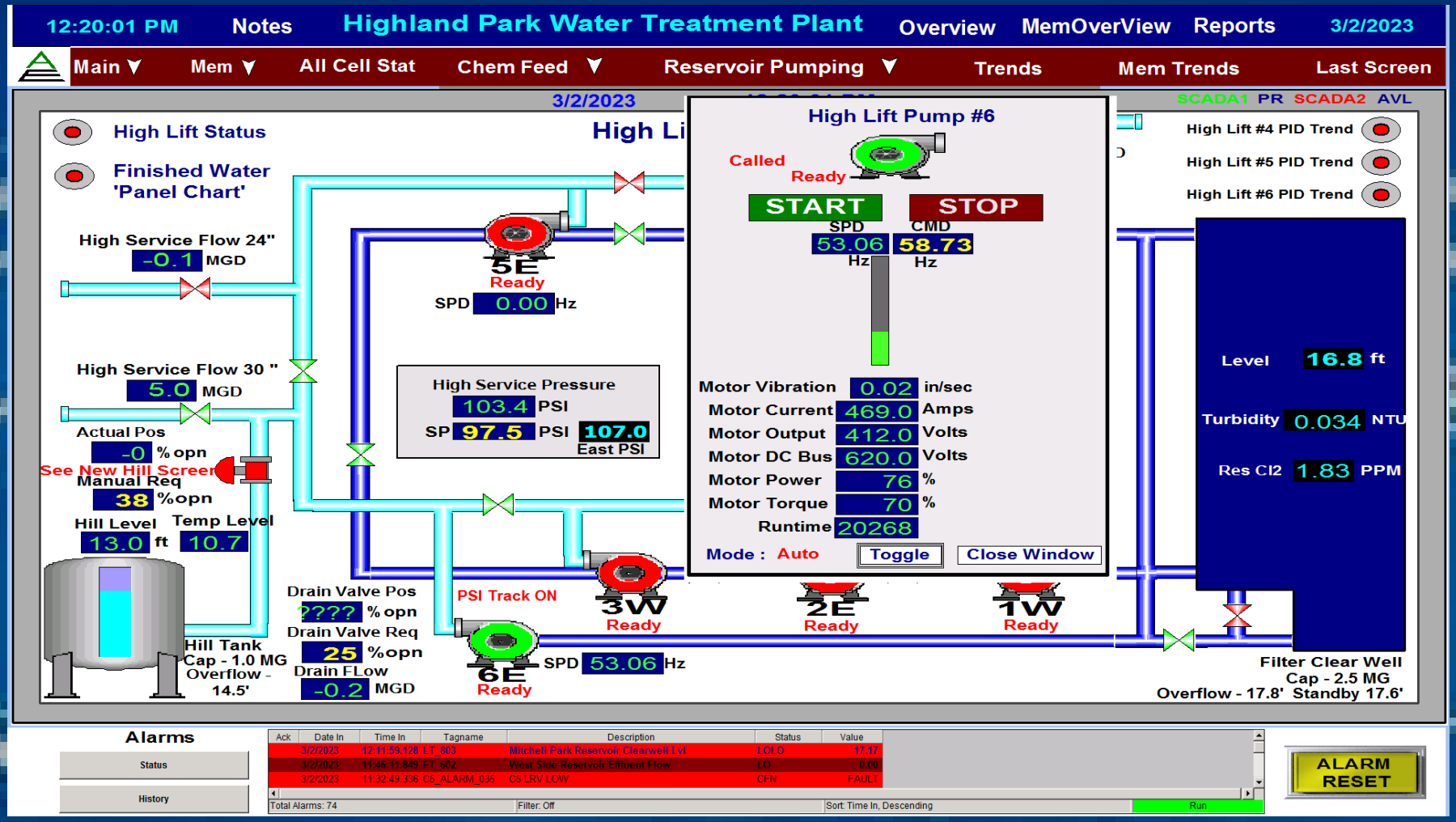
How VFDs are used for control

Since our system is ‘closed’ VFDs are ideal for matching delivery to demand and controlling system pressure.

They also provide for smooth operation over a wide range of conditions. When demand exceeds capacity of a single VFD pump, a second one (both at lower Hz) can be added for fine incremental flow changes.

This also facilitates delivery to connected supplies’ reservoirs.

“Pressure Track” Mode

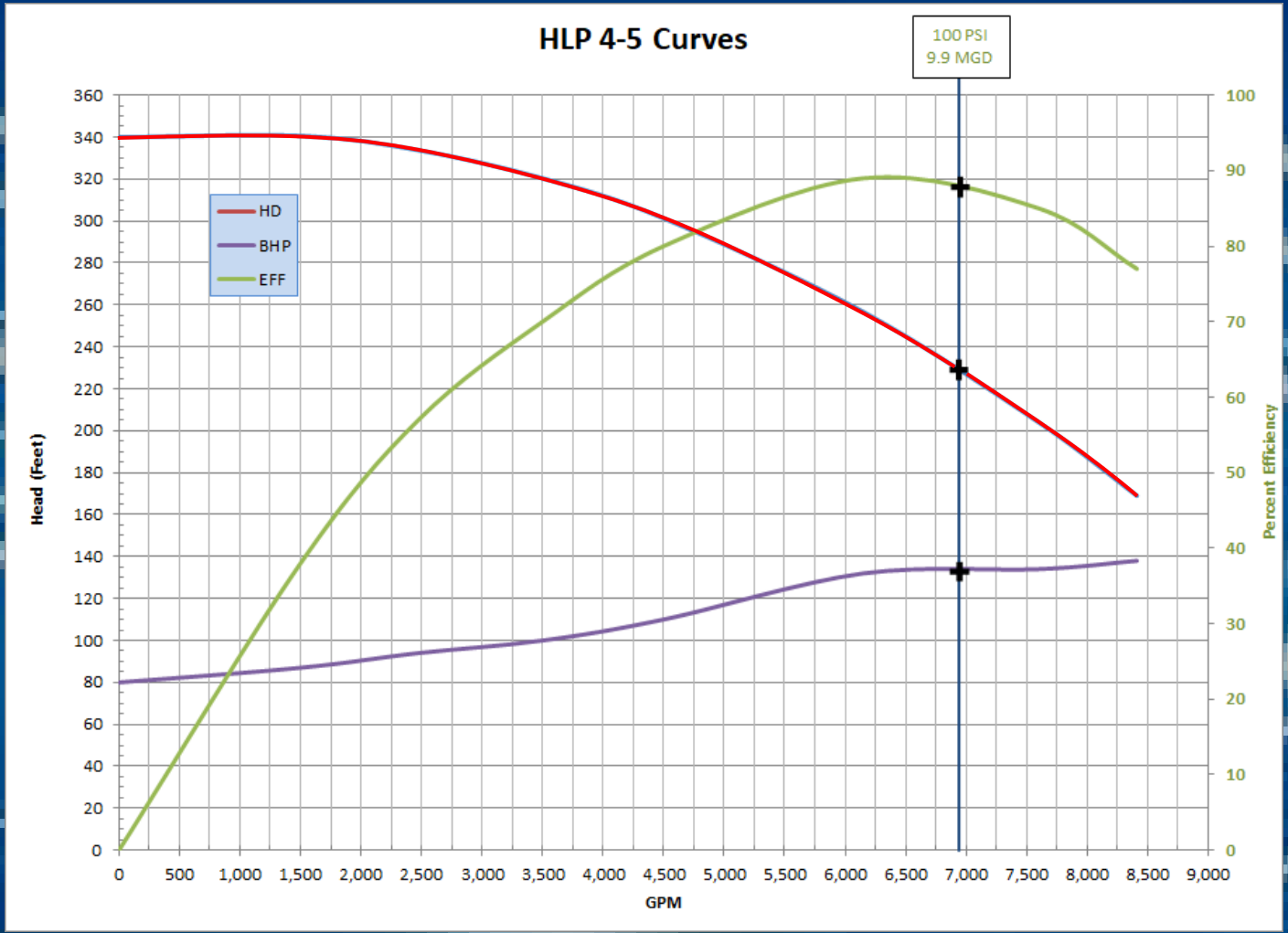


When engaged, adjusts Hz to maintain constant Plant discharge pressure

VFD Pump Curves

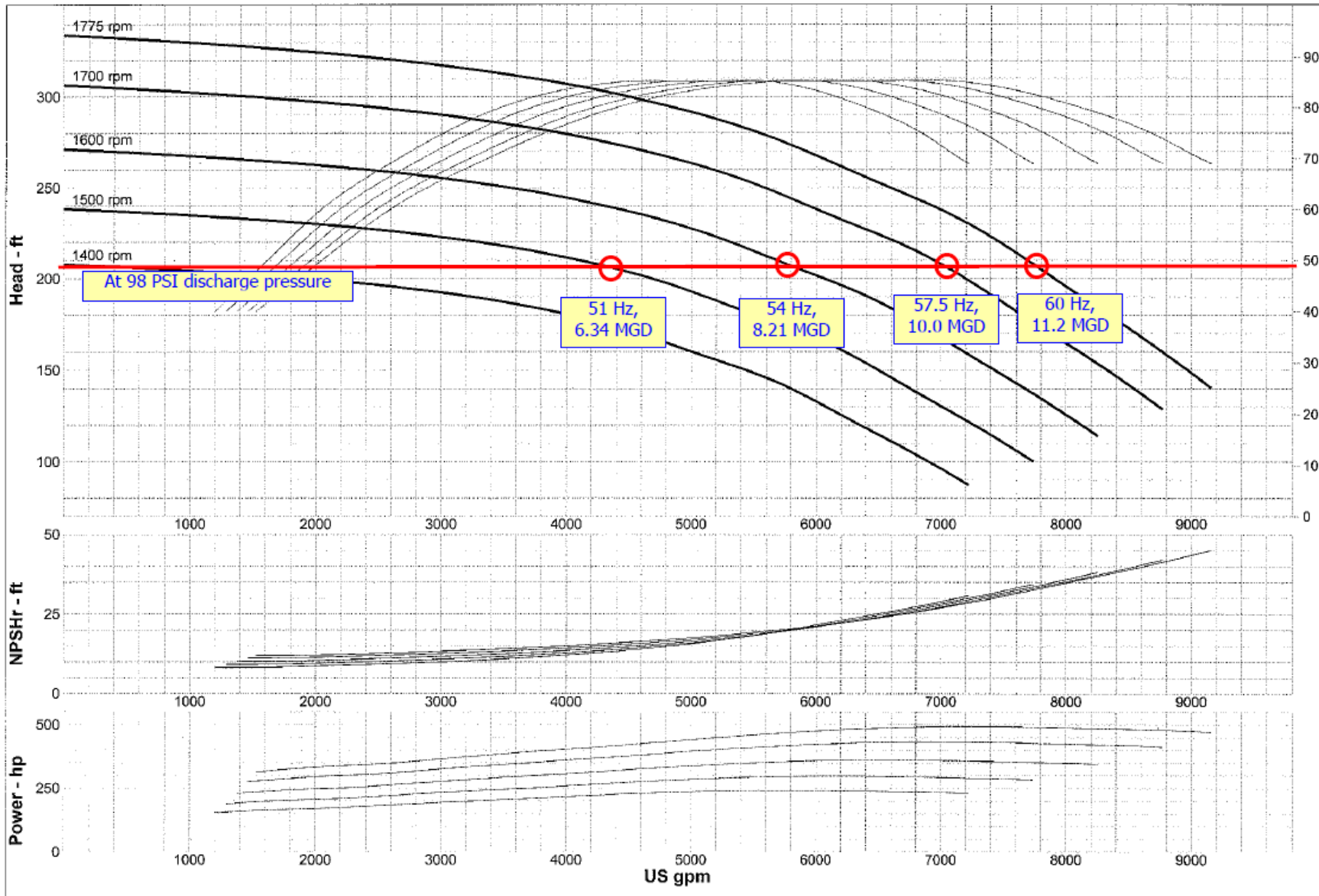
Operation Set Point is 98 PSI Plant discharge pressure.

Plant sits at foot of a 60 foot bluff along Lake Michigan requiring 25 PSI to overcome.



Affinity Curves

We learned about this the hard way!



Company: Metropolitan Industries, Inc.
Name: Highland Park, IL - High Service Pumps
2/18/2010

AURORA PUMPS
Catalog: Aurora Pumps 60 Hz, Vers 2
410-HSC - 1800

Size: 10x12x18
Speed: 1400 - 1775 rpm
Dia: 17.75 in
Curve: PC117403

AURORA
Pentair Pump Group

Energy Conservation Efforts

ComEd
Energy Efficiency Program

INDUSTRIAL SYSTEMS STUDY
APPLICATION FORM

January 1, 2019 – December 31, 2019

ComEd
Energy Efficiency Program

COMPREHENSIVE WASTEWATER TREATMENT/ WATER SUPPLY PLANT STUDY WORKSHEET

January 1, 2018 – December 31, 2018

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Questions?

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Water Production

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