Measuring Steam Consumption with an Alarm Clock

https://tinyurl.com/MeasureSteamWithAlarmClock

Presented By:
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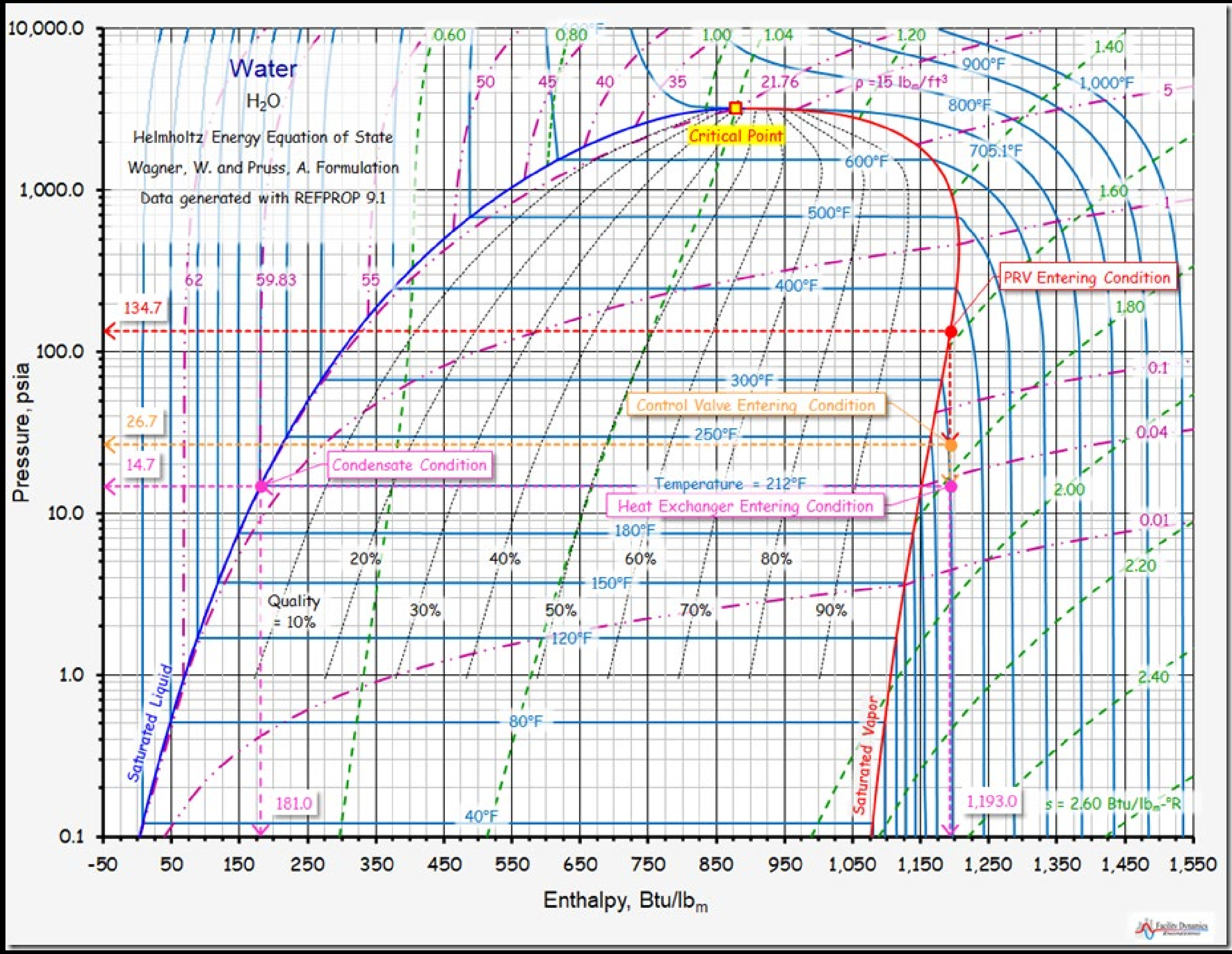
A Related Topic

The Energy Content of a Pound of Steam

https://tinyurl.com/SteamNRGContent



Measuring Steam Flow can be Challenging

Very Hot

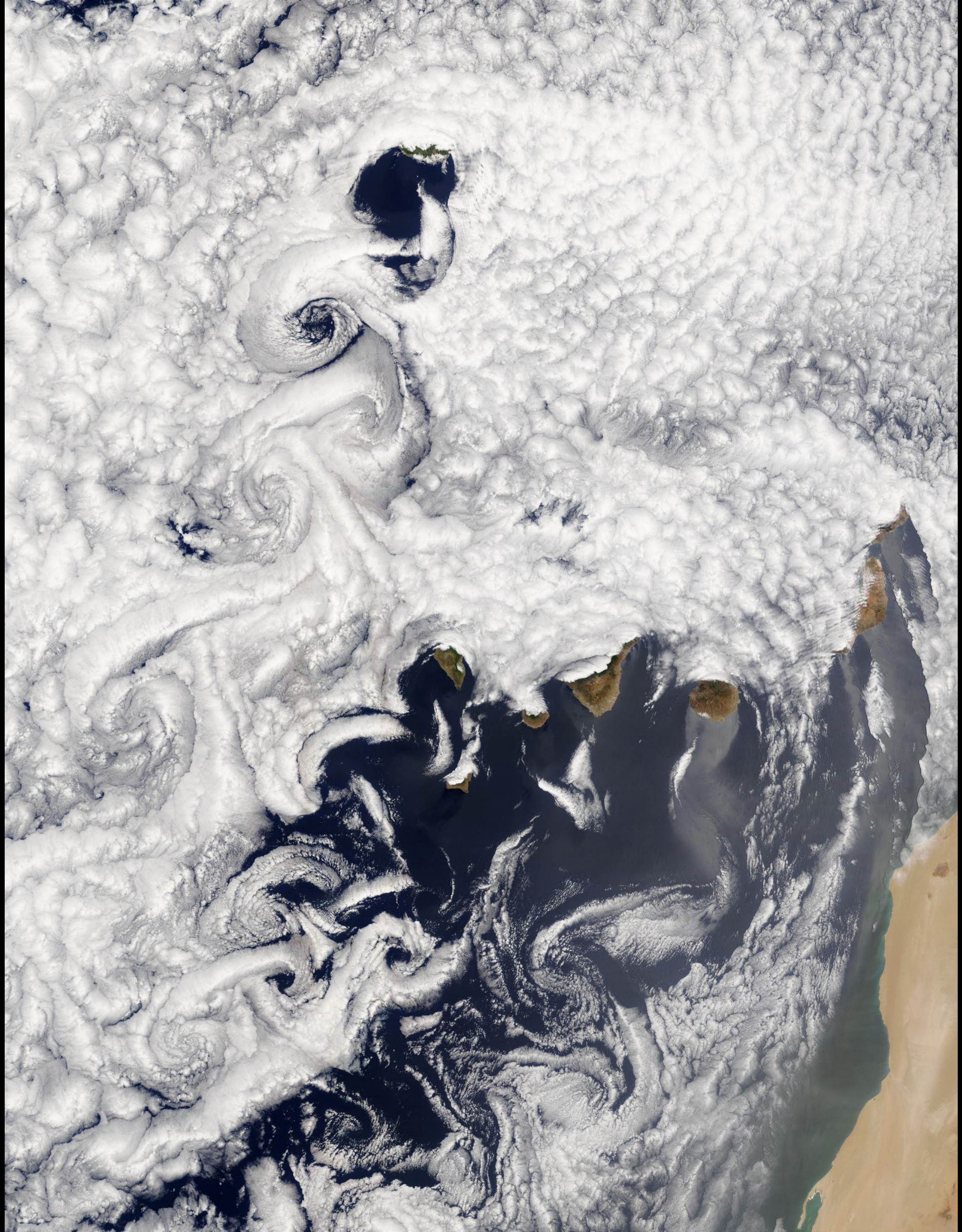
- 15 psig saturated steam is at approximately 250°F
- 50 psig saturated steam is at approximately 298°F
- 150 psig saturated steam is at approximately 366°F

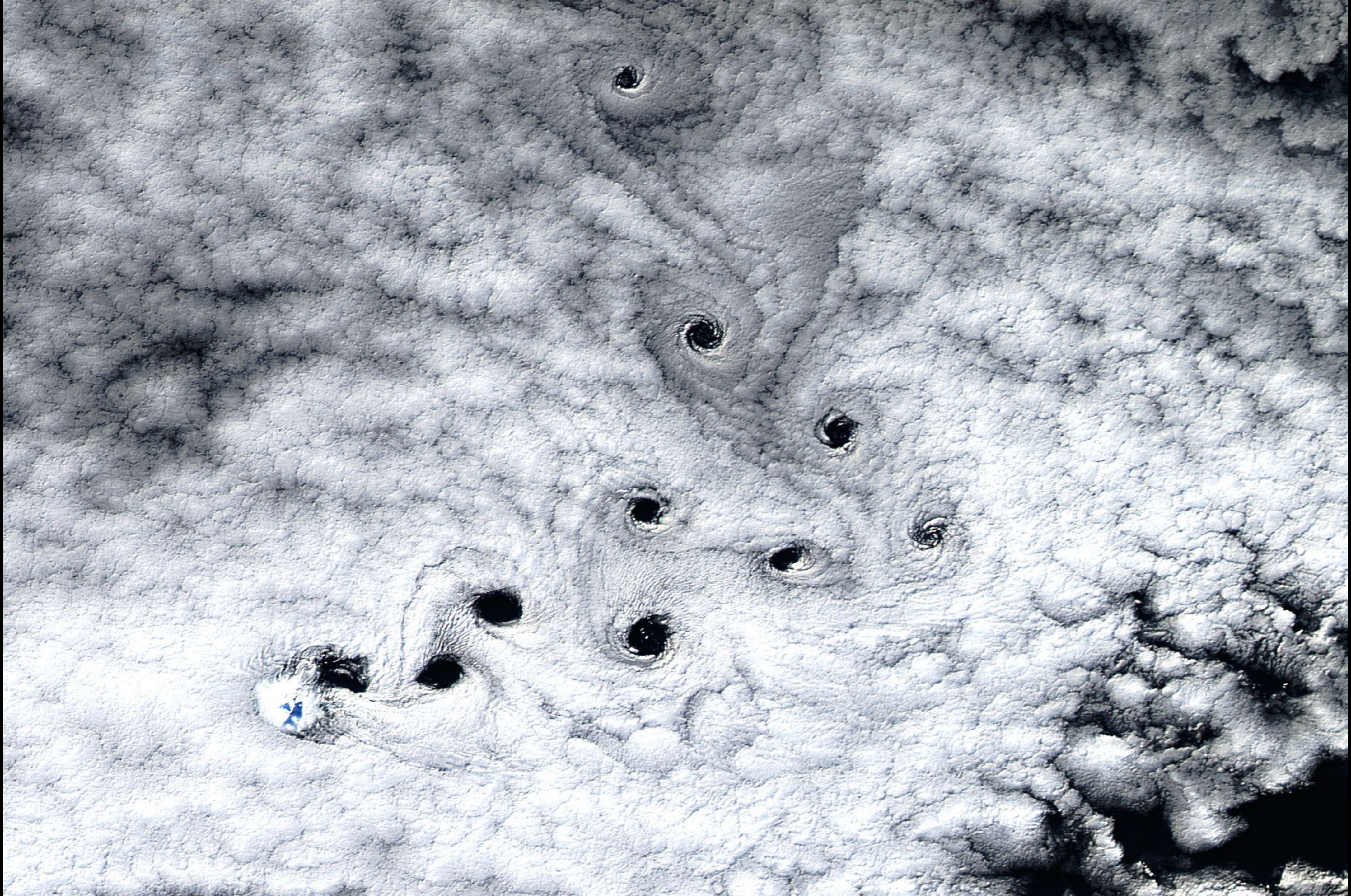
High Velocities

- Noise
- Erosion, especially if not dry
- Damage due to water hammer

Energy Content Varies with Pressure and Temperature


MED PRESS CONDENSATE





https://tinyurl.com/VonKarmanVortices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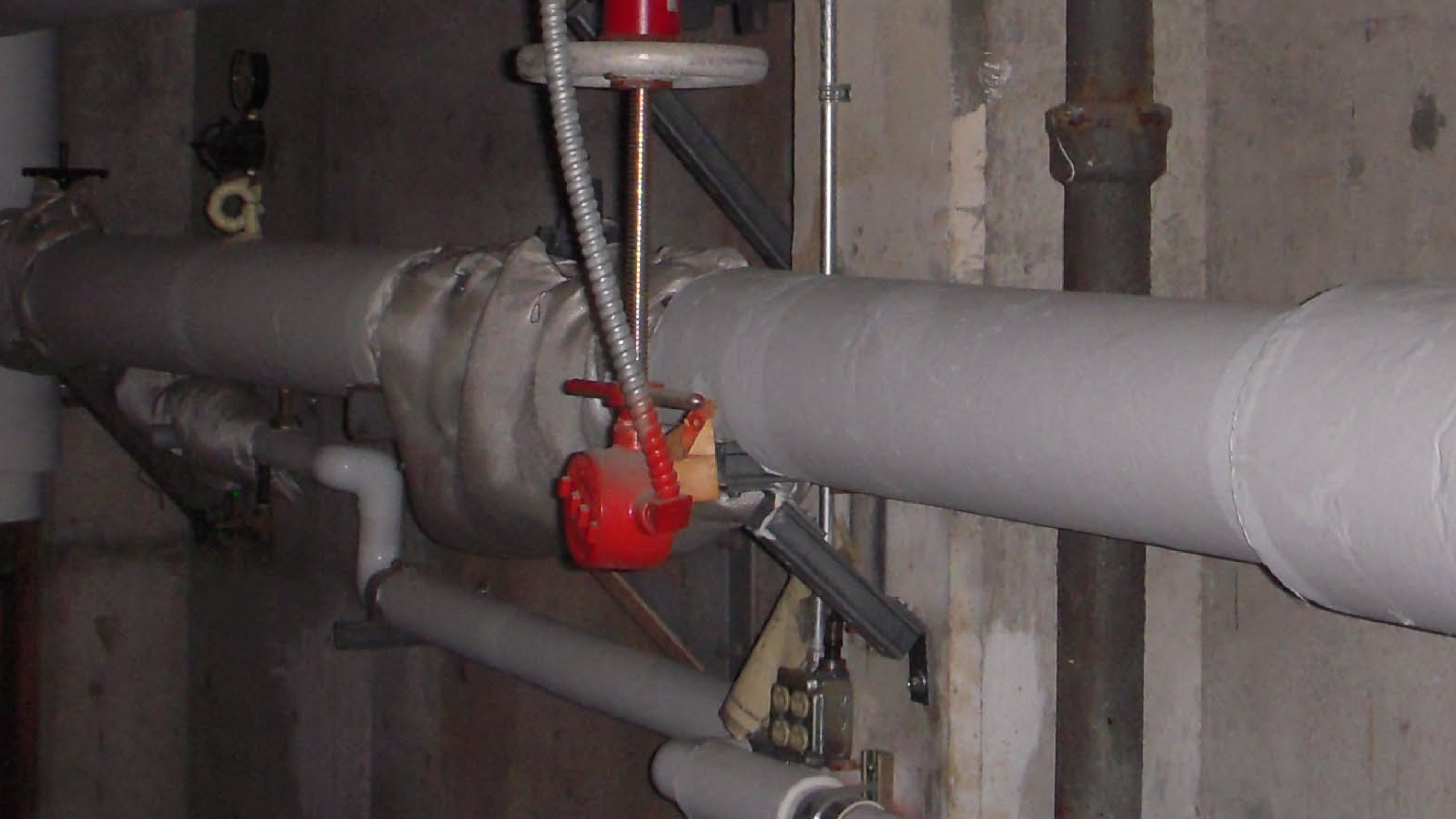

FLOW of FLUIDS

CRANE TECHNICAL PAPER NO. 410
Flow of Fluids Through Valves, Fittings, and Pipe

CRANE

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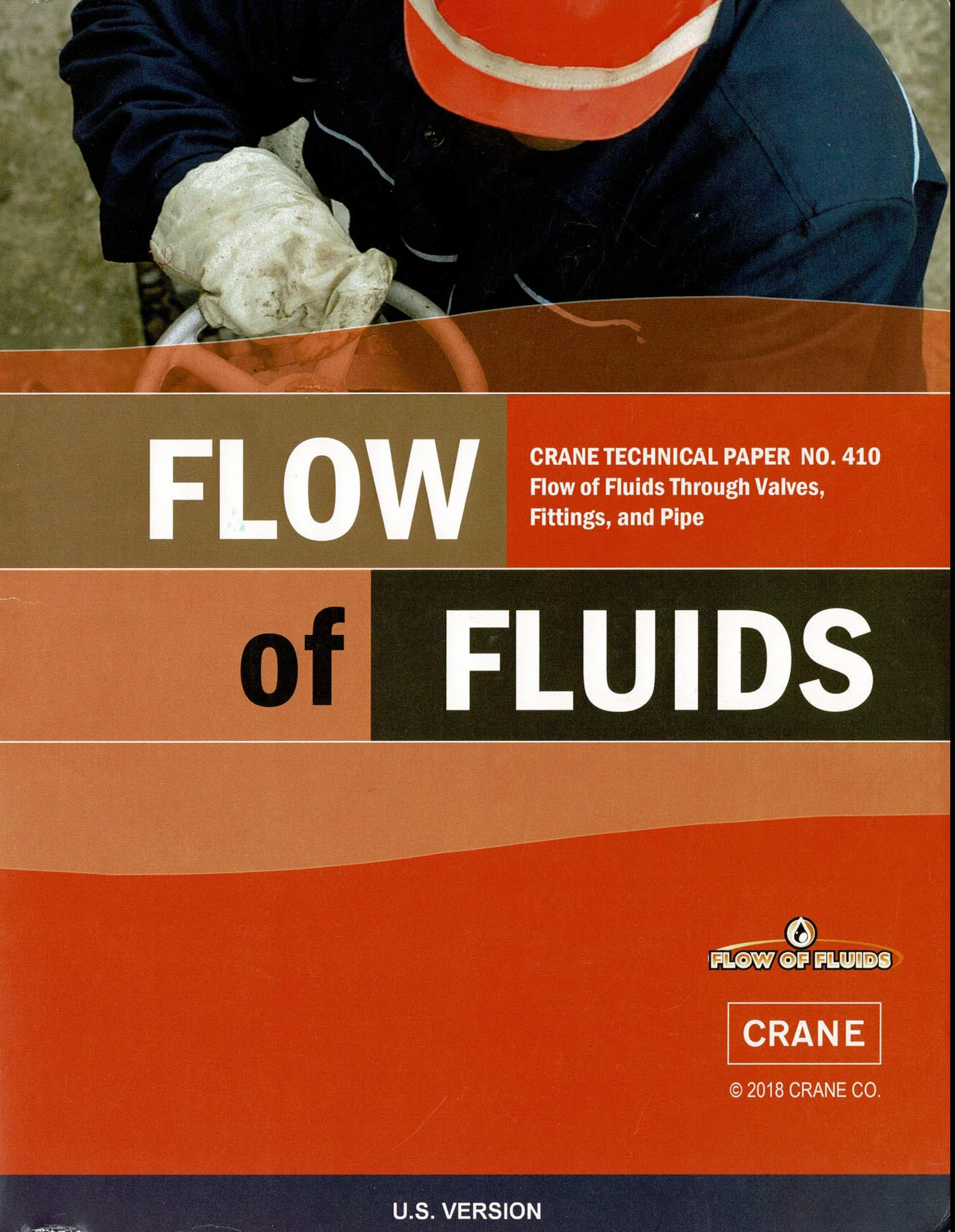


of the pipe.

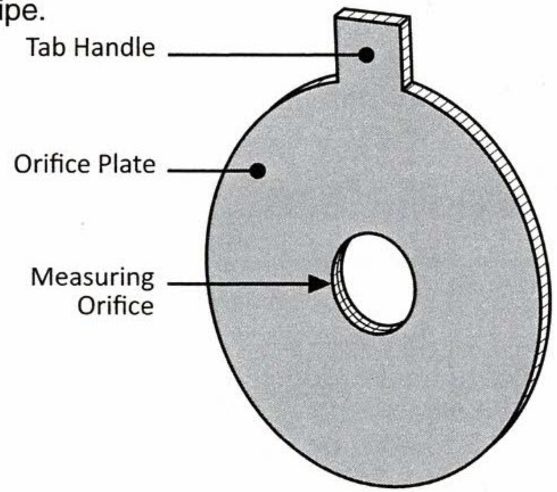


Figure 4-1: Concentric orifice plate

The general shape of the plate is such that the upstream and downstream faces of the plate are flat and parallel (Figure 4-2).

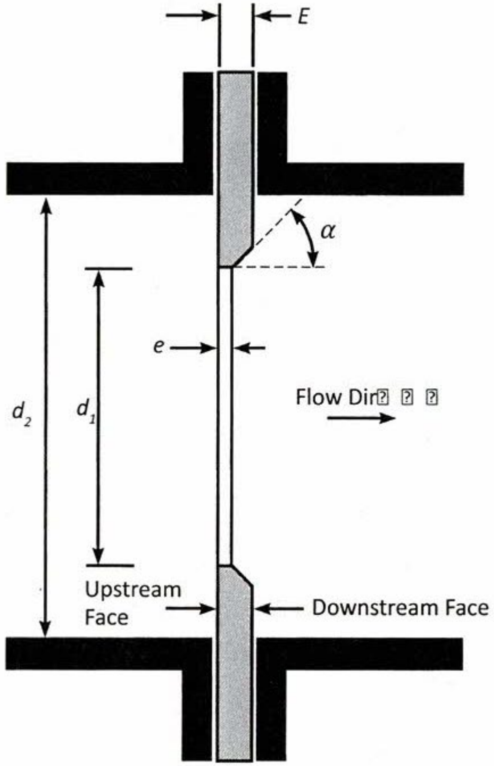
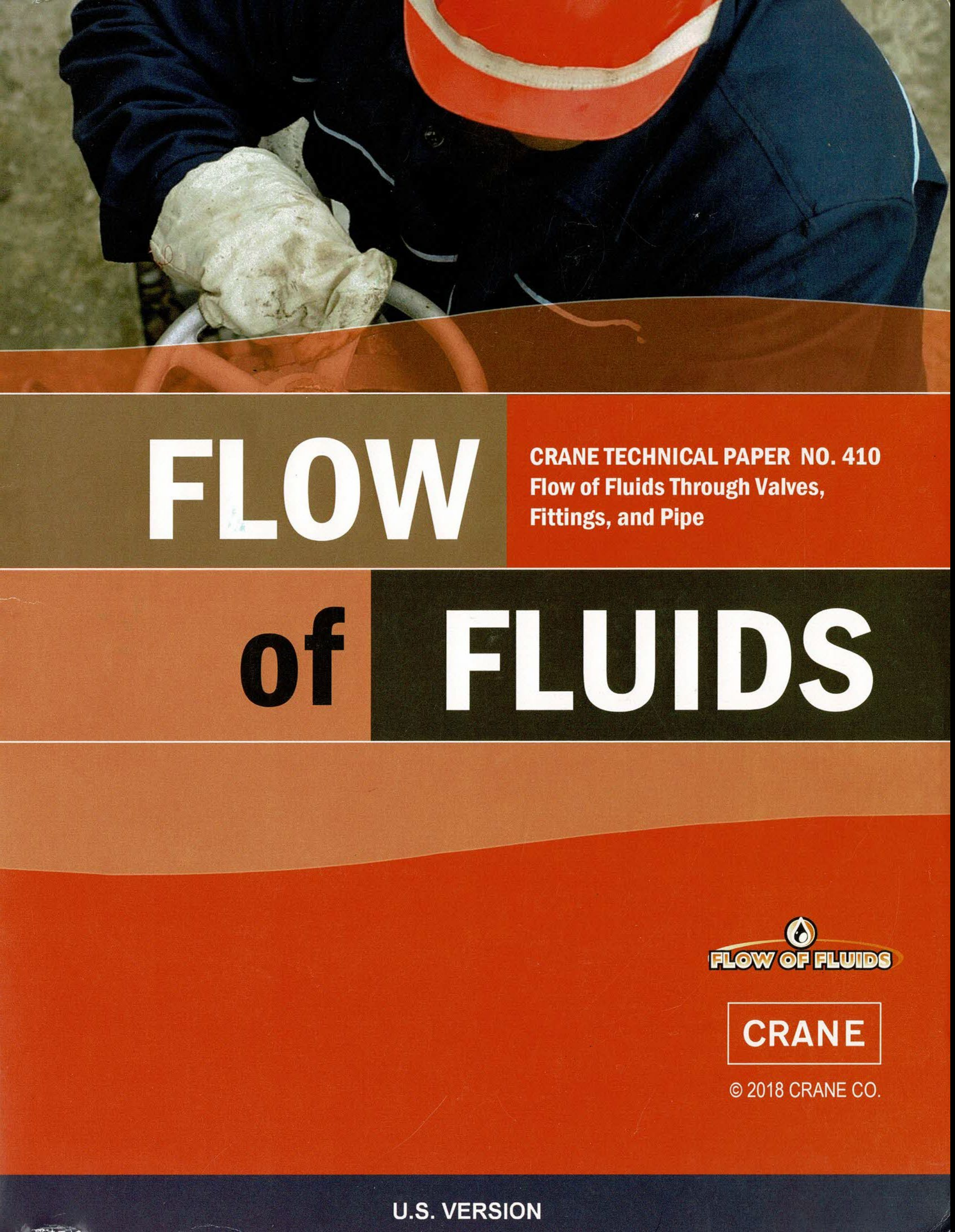


Figure 4-2: Orifice plate geometry



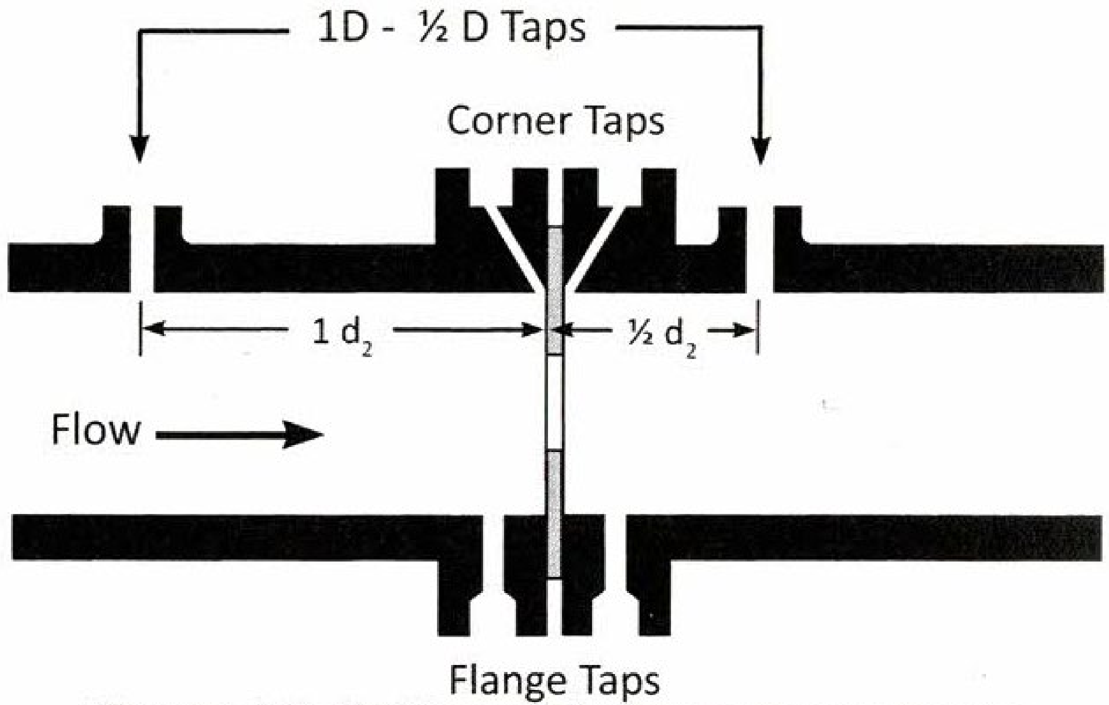
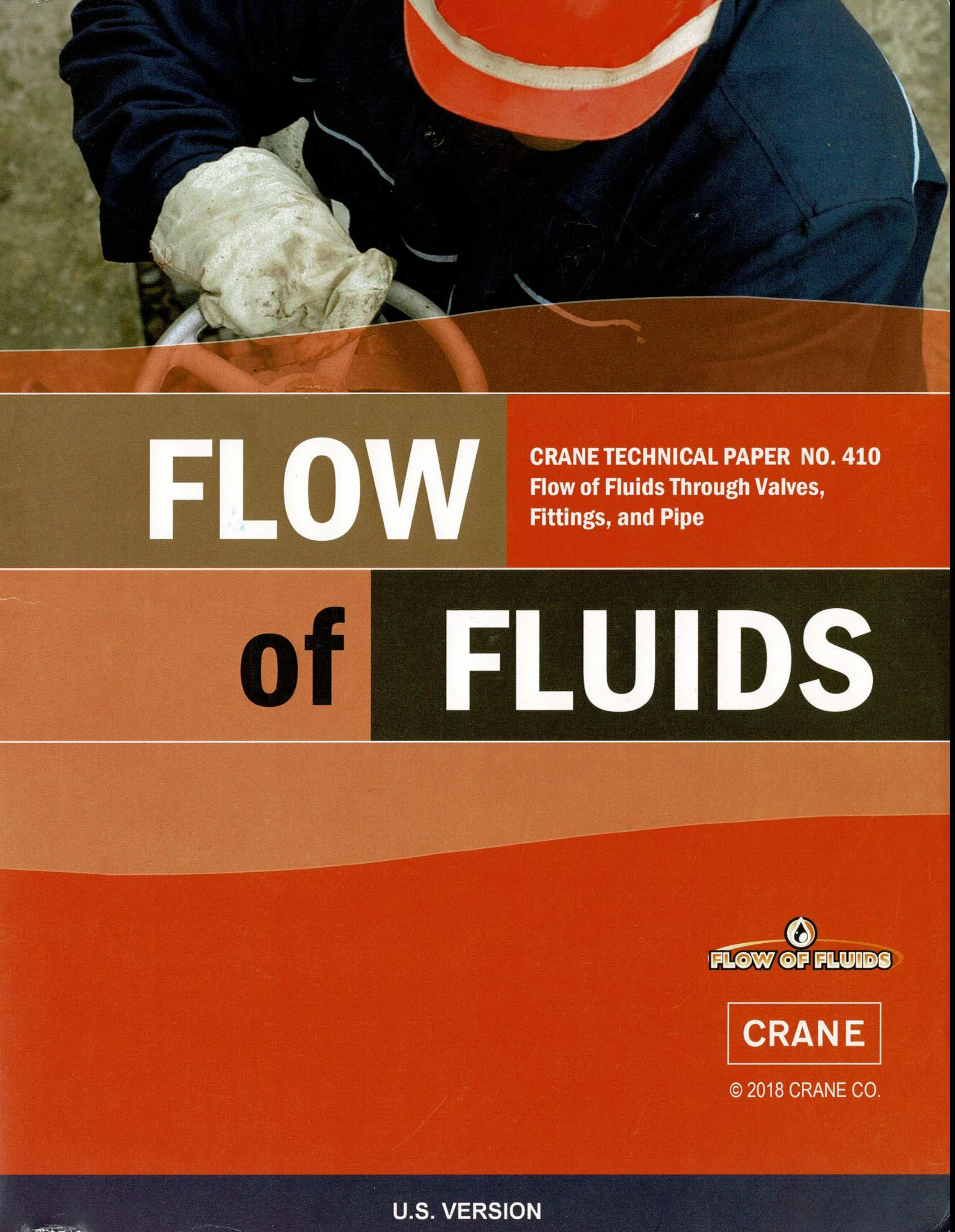


Figure 4-3: Orifice plate tap arrangements



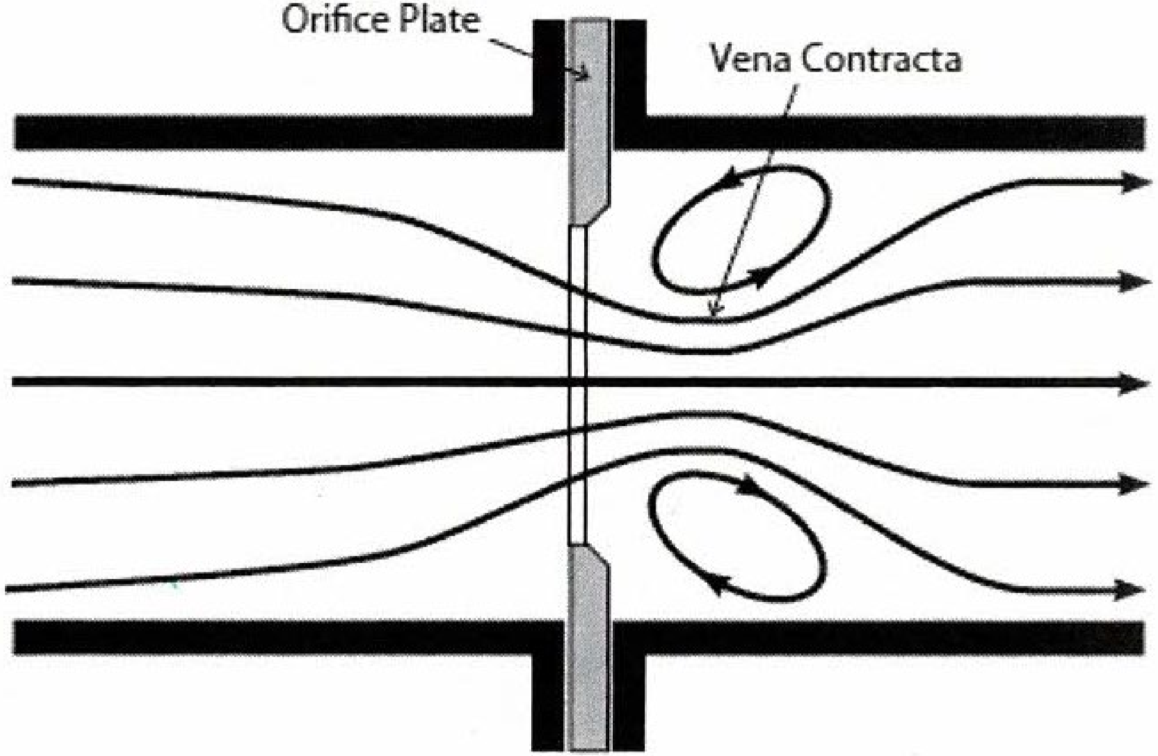


Figure 4-8: Flow through an orifice

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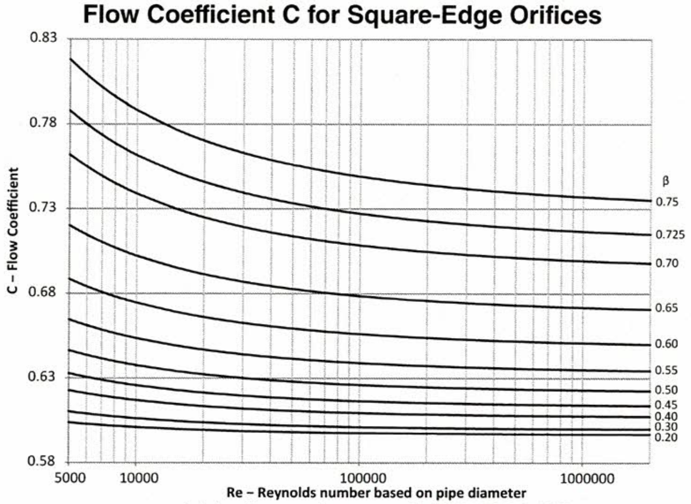
Flow Coefficient C for Square Edge Orifices and Nozzles[27]

$$C = \frac{C_d}{\sqrt{1-\beta^4}}$$

$$K_{orifice} = \left[\frac{\sqrt{1-\beta^4\left(1-C_d{}^2\right)}}{C_d\beta^2} - 1\right]^2$$

$$\beta = \frac{d_1}{d_2}$$



Calculated from equations presented in ASME MFC-3Ma-2007

Note: *Most accurate when pipe diameter is greater than 2.8 inches.*

FLOW of FLUIDS

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Differential Pressure Flow Meters

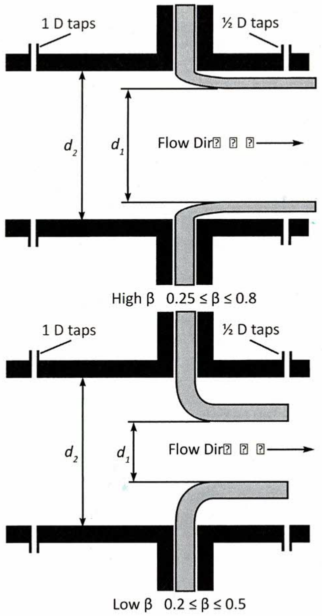


Figure 4-4: Long radius flow nozzles

ellipse with a large major axis diameter. The low β nozzle follows the shape of a quarter ellipse with a smaller major axis diameter.

The standard tap locations for long radius nozzles place the upstream tap at one pipe diameter from the plane of the inlet face of the nozzle, and the downstream tap at one half pipe diameter from the plane of the inlet face of the nozzle.

<u>ISA 1932 nozzles:</u> The ISA 1932 nozzle is similar in shape to the long radius nozzle with the exception of the convergent section, which has a rounded profile as opposed to elliptical (Figure 4-5).

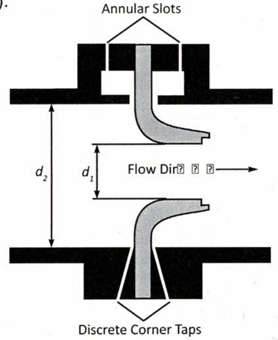


Figure 4-5: ISA 1932 flow nozzle

There is also an optional recess around the inside circumference of the nozzle outlet which is designed to prevent damage to the edge.

Corner taps are used with the ISA 1932 flow nozzle. These corner taps can either be single discrete taps, or annular slots as shown in Figure 4-5.

<u>Venturi nozzles:</u> The venturi nozzle consists of a convergent section with a rounded profile (exactly like the ISA 1932 nozzle), a cylindrical throat, and a divergent section (Figure 4-6).

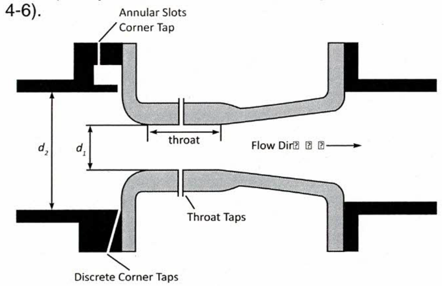


Figure 4-6: Venturi nozzle

The venturi nozzle design delivers a lower permanent pressure loss than either the long radius nozzle or ISA 1932 nozzle. The upstream pressure taps for a venturi nozzle are corner taps. They can be either single discrete taps, or annular slots. The downstream pressure taps are located in the throat section, and are referred to as the throat pressure taps.

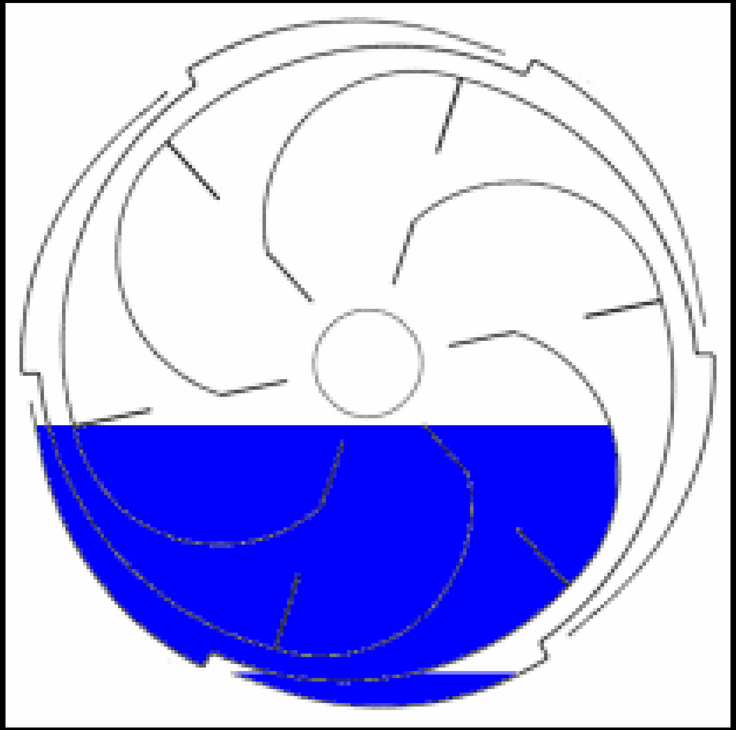
Limits of Use: The formulas for standard flow nozzles in this chapter can be applied under the following geometry and flow conditions:

1. For long radius nozzles:
   a. 2 inch ≤ d_2 ≤ 25 inch
   b. $0.20 \le \beta \le 0.80$
   c. $1 \times 10^4 \le R_e \le 1 \times 10^7$
   d. $\varepsilon/d_2 \le 3.2 \times 10^{-4}$
2. For ISA 1932 nozzles:
   a. 2 inch ≤ d_2 ≤ 20 inch
   b. $0.30 \le \beta \le 0.80$
   c. $7 \times 10^4 \le R_e \le 1 \times 10^7$ for $0.30 \le \beta \le 0.44$
   d. $2 \times 10^4 \le R_e \le 1 \times 10^7$ for $0.44 \le \beta \le 0.80$
3. For venturi nozzles:
   a. 2.5 inch ≤ d_2 ≤ 20 inch
   b. d_1 ≥ 2 inch
   c. $0.316 \le \beta \le 0.775$
   d. $1.5 \times 10^5 \le R_e \le 2 \times 10^6$

Flow nozzles are dimensionally more stable than orifice plates, and as such can handle high temperature and high velocity service applications. Flow nozzles can also handle higher flow capacities; however, like orifice plates, they are sensitive to flow conditions. Therefore it is recommended that they be installed in a straight length of pipe which is free of obstructions, valves, and fittings. A table of straight lengths between nozzles and fittings can be found in the ASME MFC-3M standard.[27]

Steam Becomes Condensate

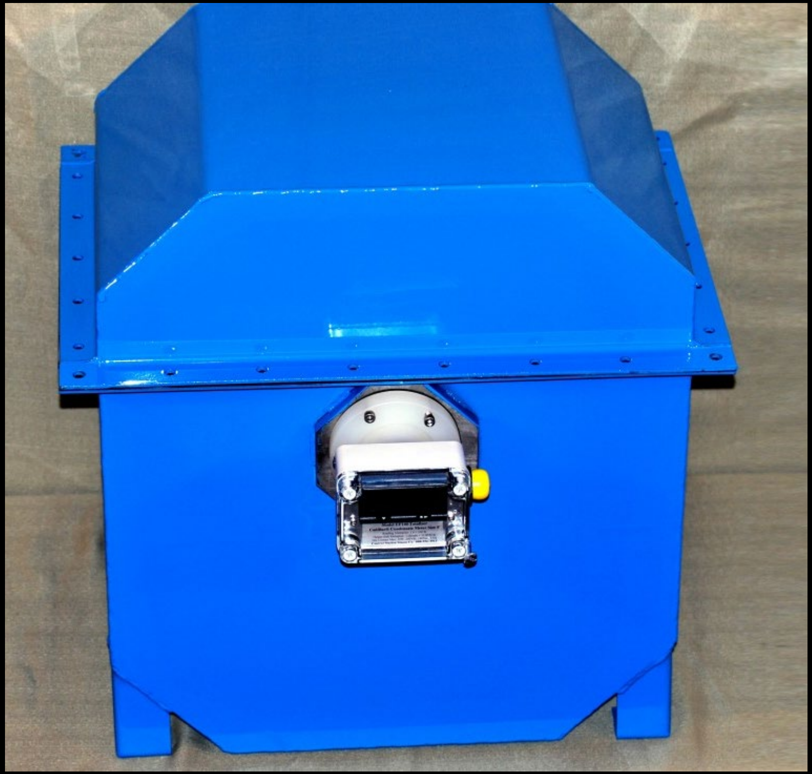
Metering condensate can be an option

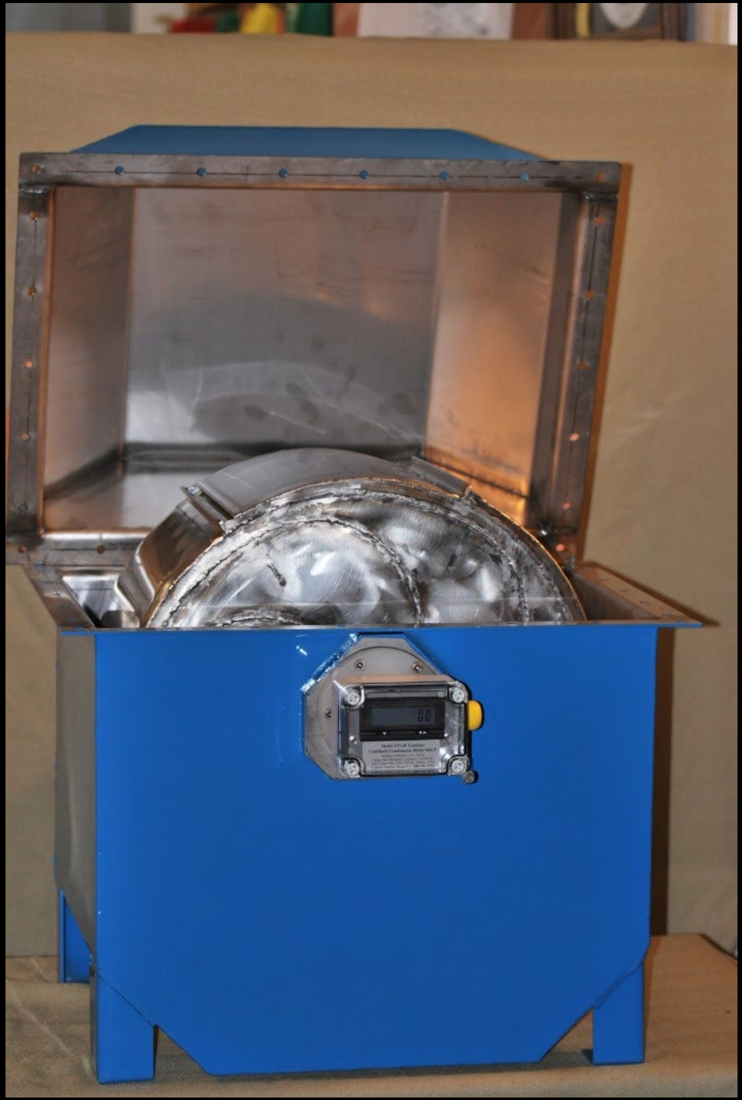


Video and .giff courtesy Lincoln Meters; [*http://www.lincolnmeter.com/*](http://www.lincolnmeter.com/)

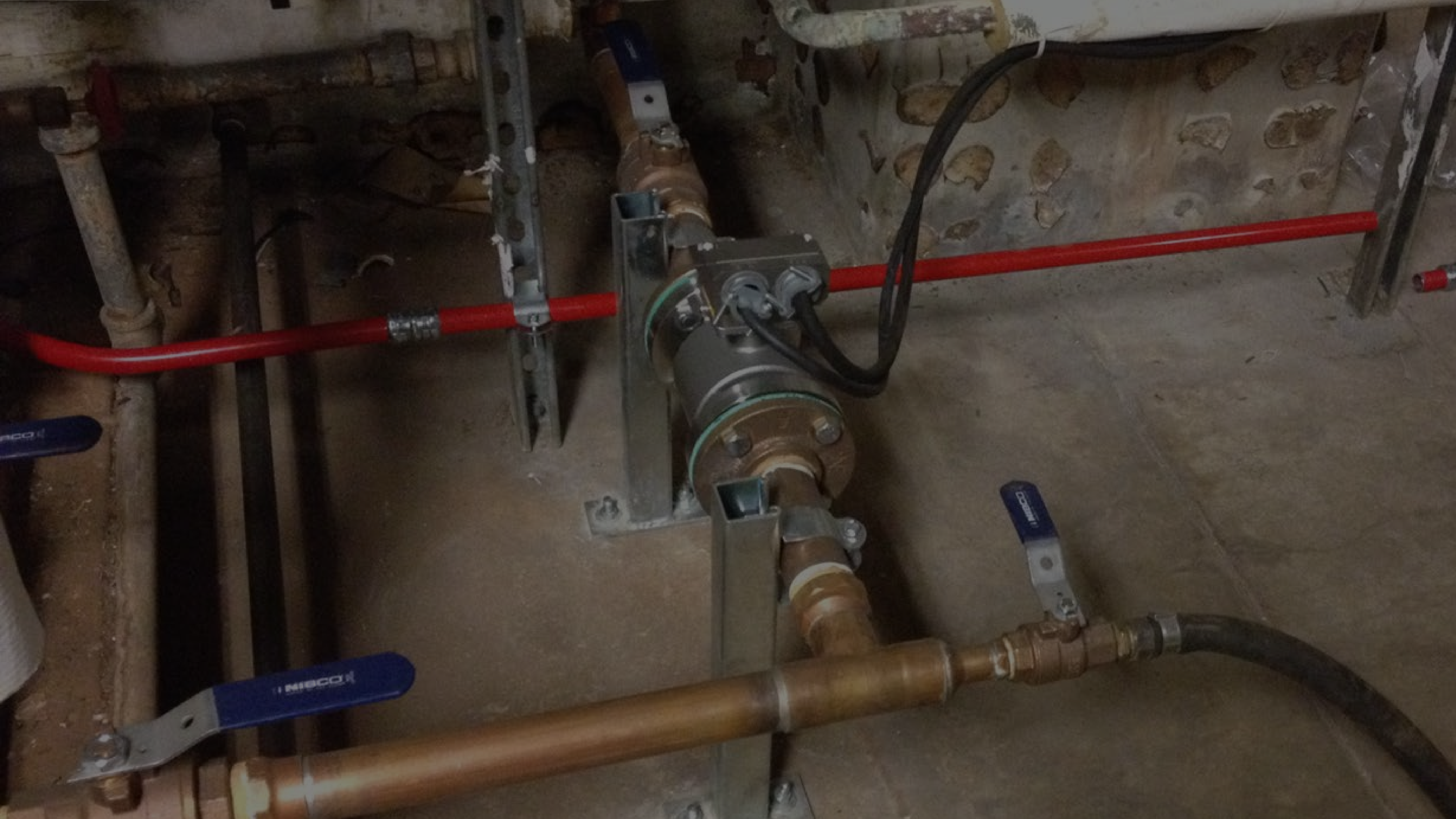
Steam Becomes Condensate

Metering condensate can be an option



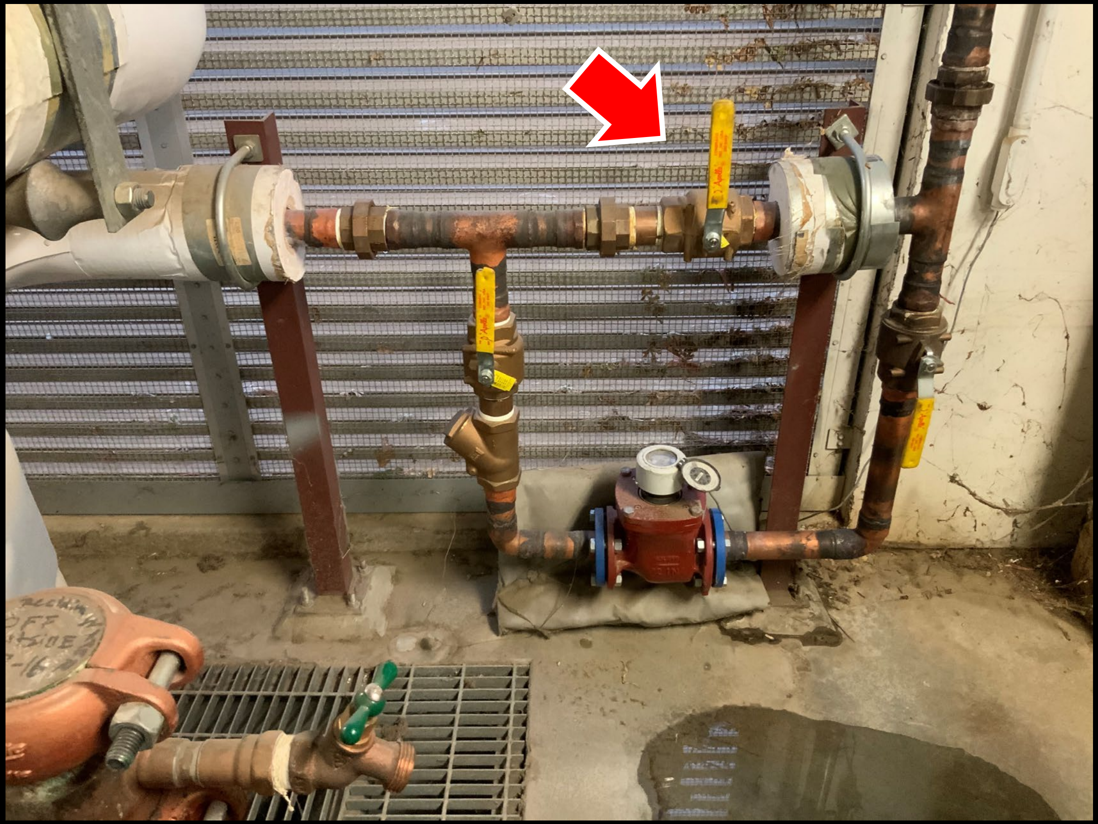


Images courtesy Cadillac Meters; https://cadillacmeter.com/


NIBCO

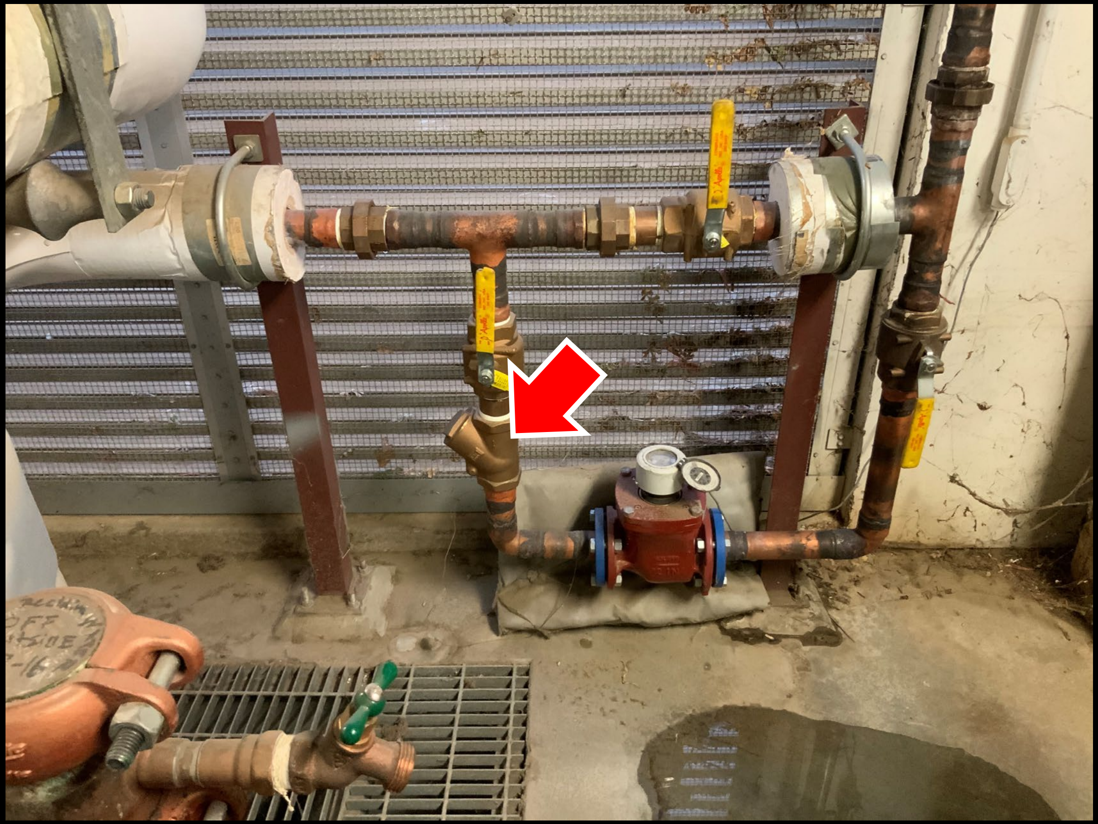
Potential Condensate Metering Issues

- Meter bypass open



Potential Condensate Metering Issues

- Meter bypass open
- Check valve doesn’t hold



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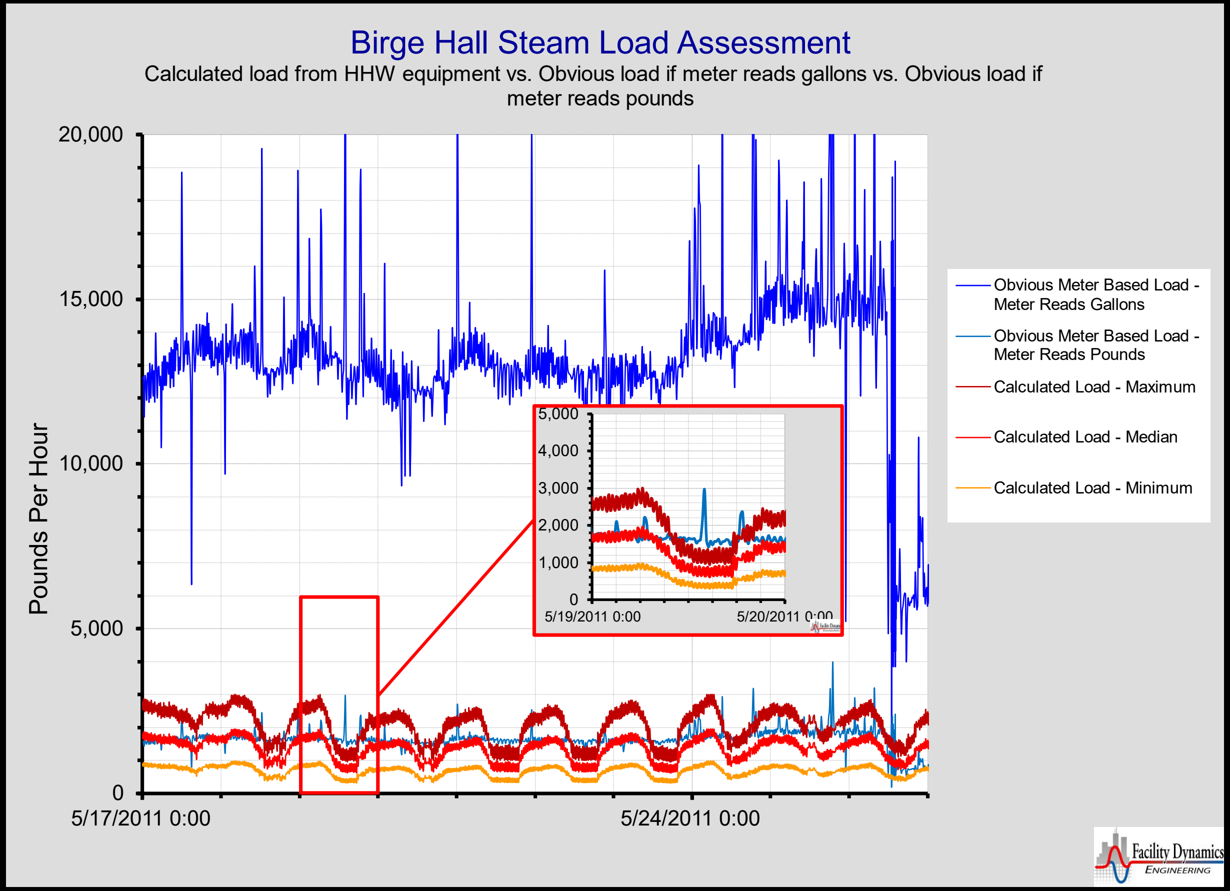
- Meter bypass open
- Check valve doesn't hold
- Condensate leaks
- Condensate return system failures

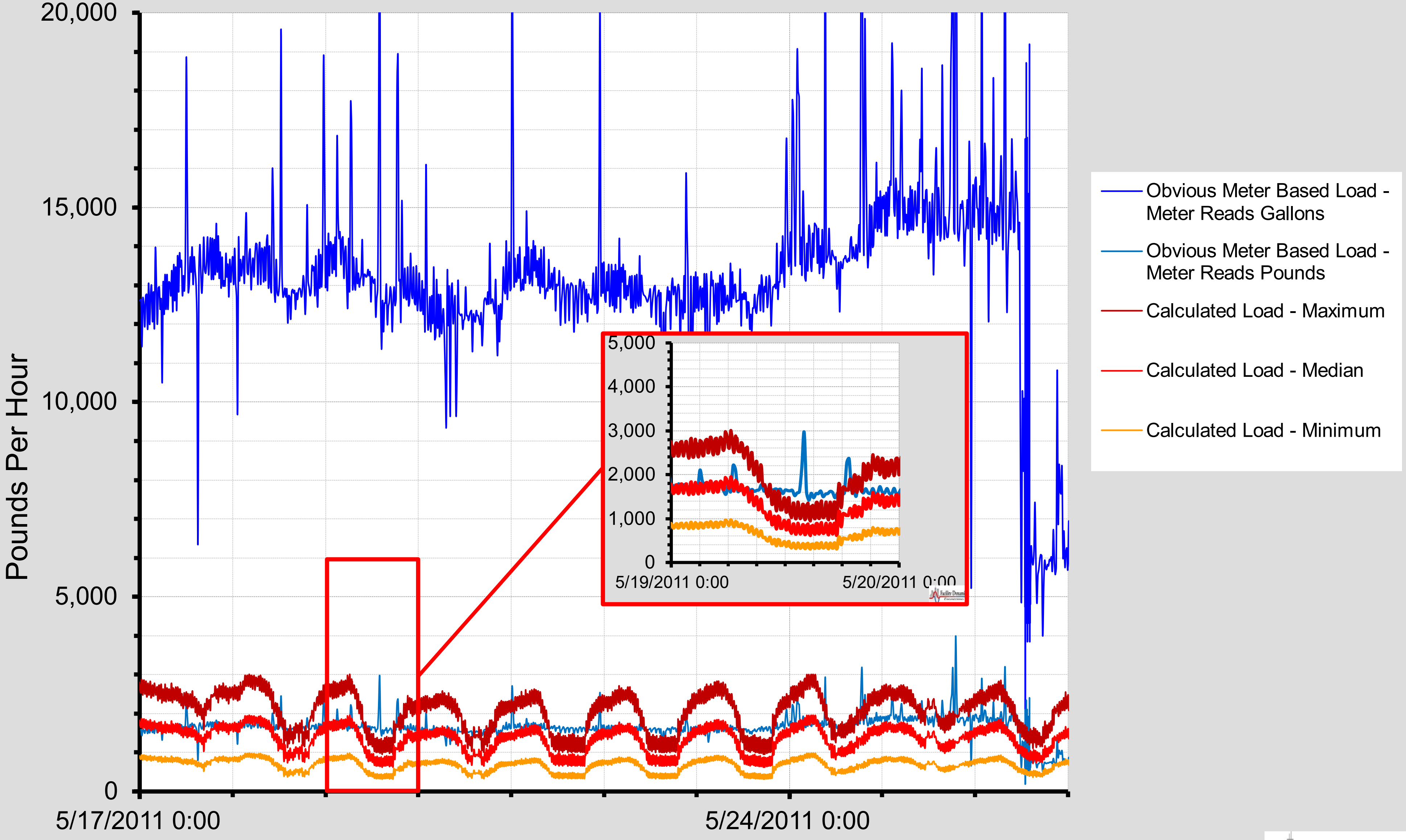
Potential Condensate Metering Issues

- Meter bypass open
- Check valve doesn't hold
- Condensate leaks
- Condensate return system failures
- Engineering units are wrong



Birge Hall Steam Load Assessment

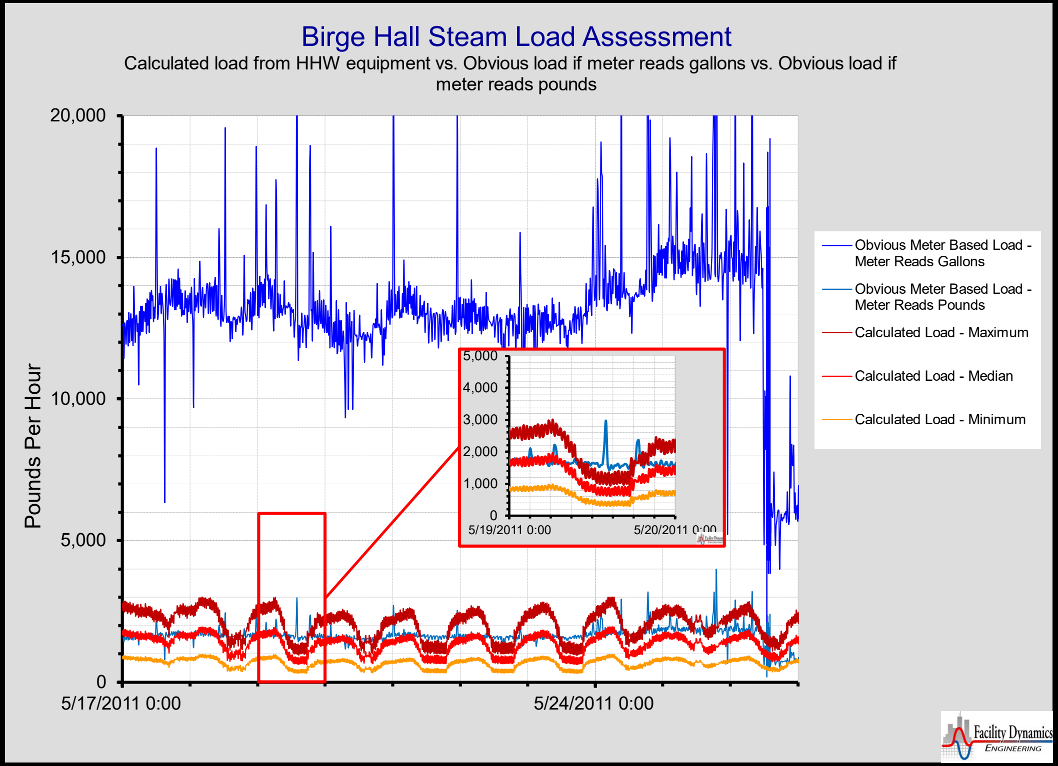
Calculated load from HHW equipment vs. Obvious load if meter reads gallons vs. Obvious load if meter reads pounds



Facility Dynamics ENGINEERING

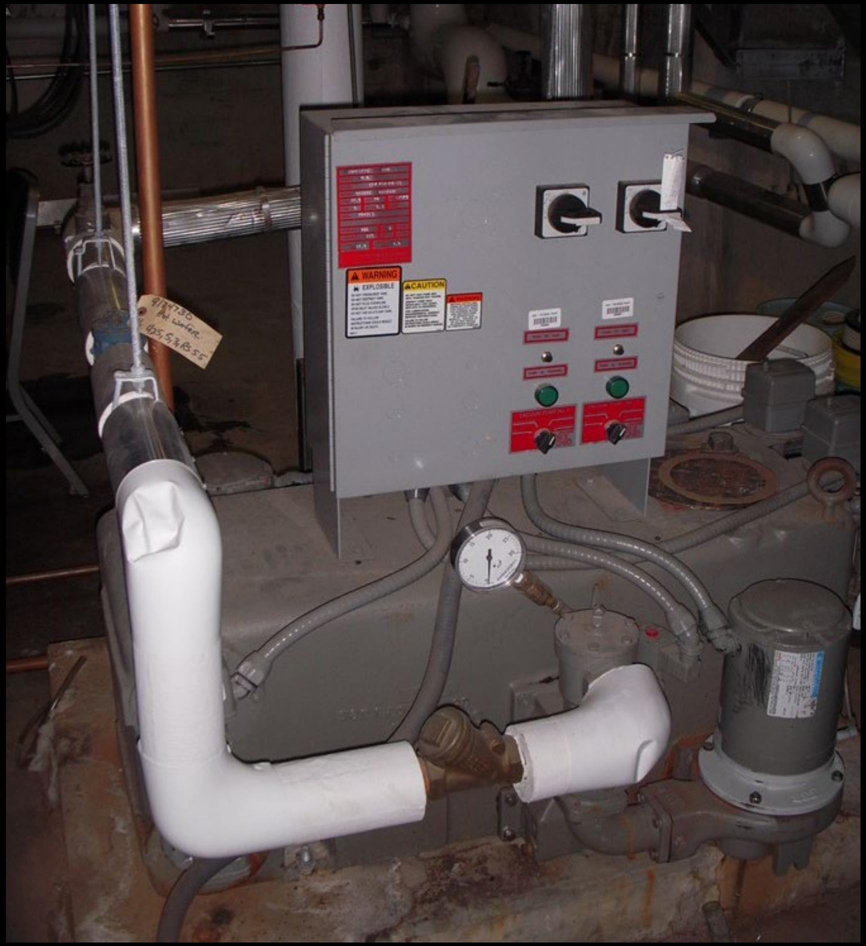
Load Projections Based on Equipment and SEP Metrics

Steam loads from original drawing capacities			
Item	Rating, lb/hr	Assumed load	Comment
DHW Heaters	4,000	2,000	Rating based on trap rating from original drawings, Suspect real consumption is minimal and very intermittent
HHW Hx	6,500	3,250	Assumed load based on pump rated flow at design temperature rise
Still	90	45	3/4" line, assumed very intermittent
Future loads	Unknown	0	1" capped connection on each floor is available
TOTAL	10,590	5,295	
Steam loads from original equipment metrics			
Original steam meter size -		12,000	lb/hr (from original drawings)
Steam PRV station rating for HHW Hx -		7,500	lb/hr (from original drawings)
Original Hx Rating -		6,500	lb/hr (from original drawings)
HW system rating - 500 x pump gpm x Δt -		3,250	lb/hr (from original drawings)
Steam loads from SEP metrics			
SEP Annual Consumption Metric -		113,750	therms/year at the central plant
SEP steam system efficiency -		12.5	th/MMBtu
-		80%	
SEP metric at the building -		91,000	therms/year at the building
-		10	therms/hour average
-		1,039	lb/hr
Building squarefootage -		97,768	sq.ft.
Index -		1.16	therms per sq.ft per year



Condensate Pump + Alarm Clock = Meter

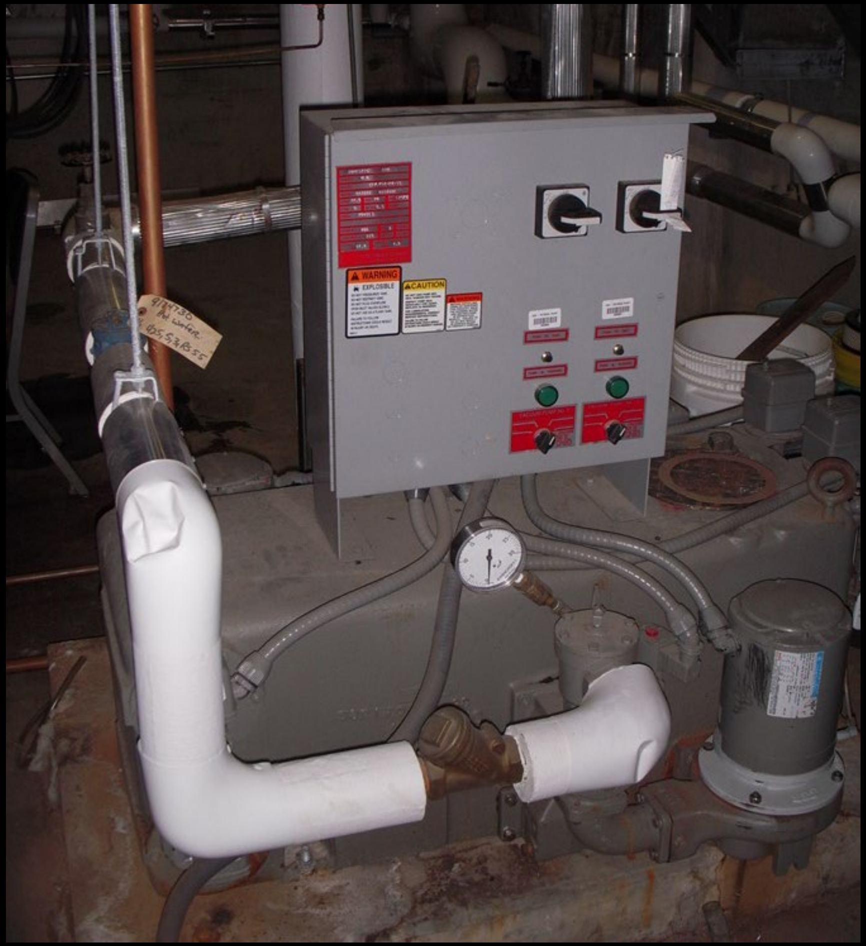
Chuck McClure



Condensate Pump + Alarm Clock = Meter

Chuck McClure

- Each pump cycle = Known Volume/Mass of Condensate
- Cycles per Hour x Mass = Pounds per Hour



Meet Our Condensate Pump

Field Notes:

- Condensate receiver dimensions
  - 38” high
  - 38” wide
- Level change per cycle – 3-5/8”
- Typical cycle time – 13 seconds

Deploying the Logger

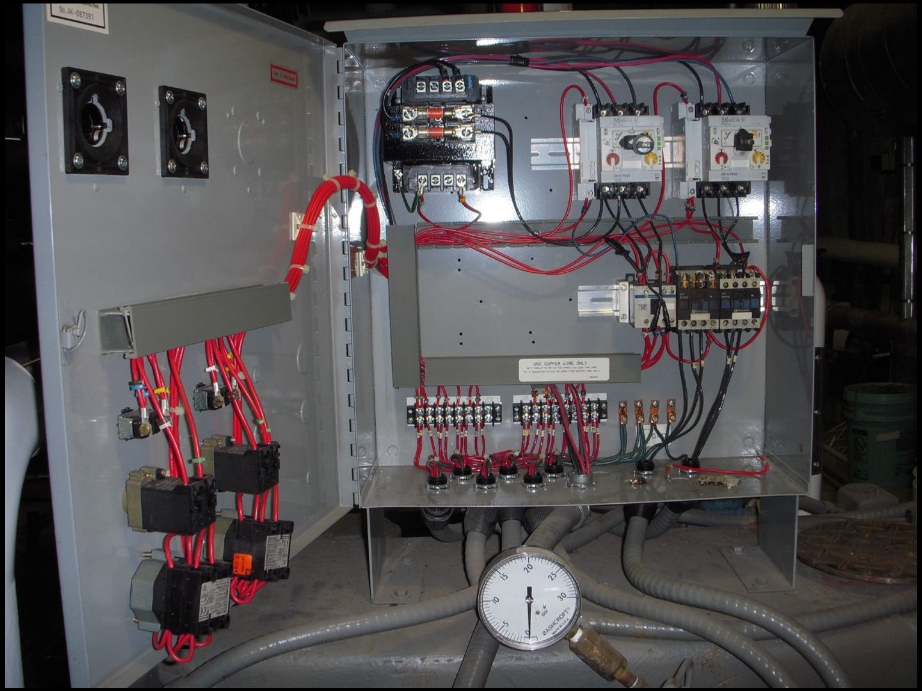
Considerations

- Type of Logger?

Deploying the Logger

Considerations

- Type of Logger?
- Safety?

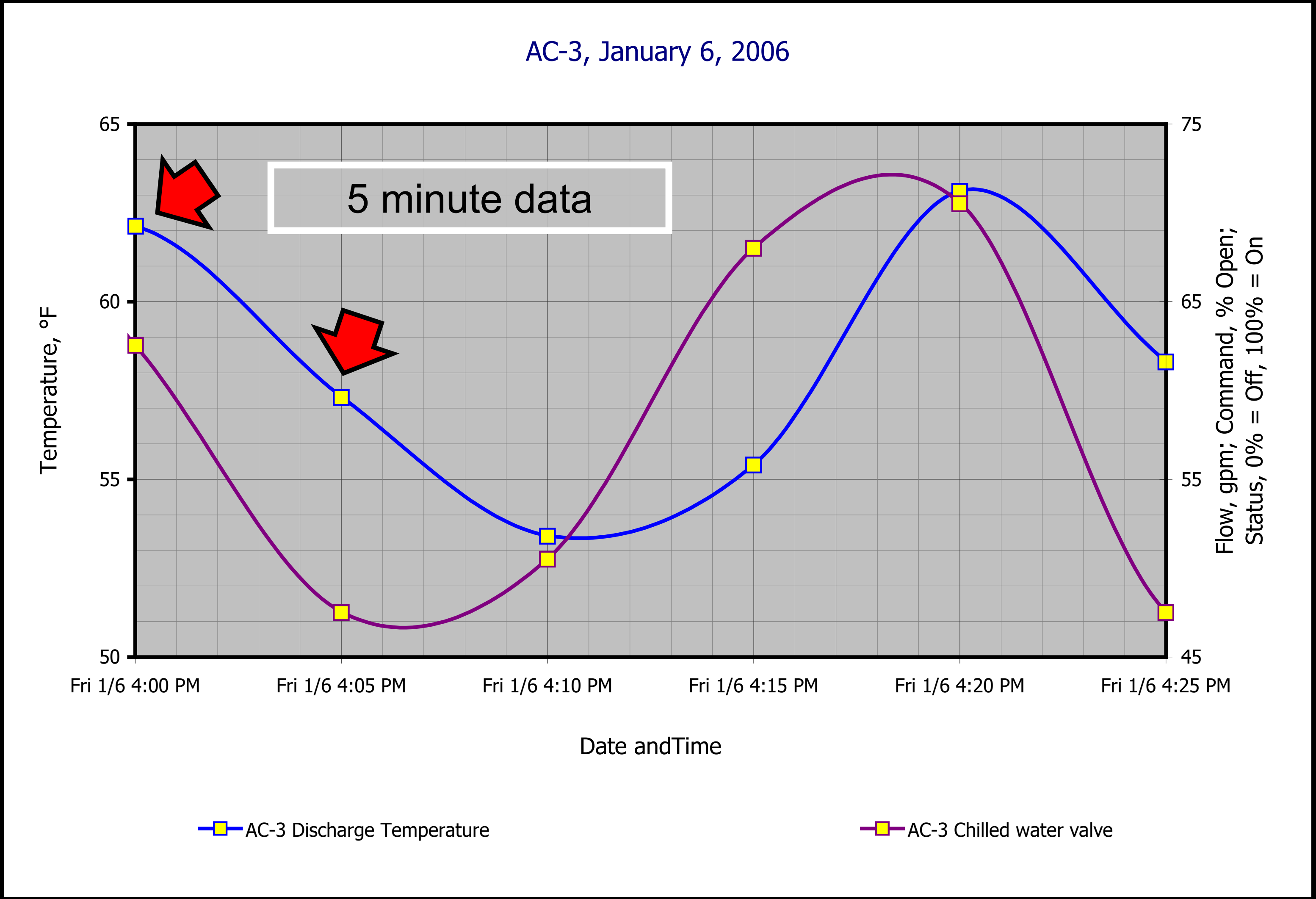


Deploying the Logger

Considerations

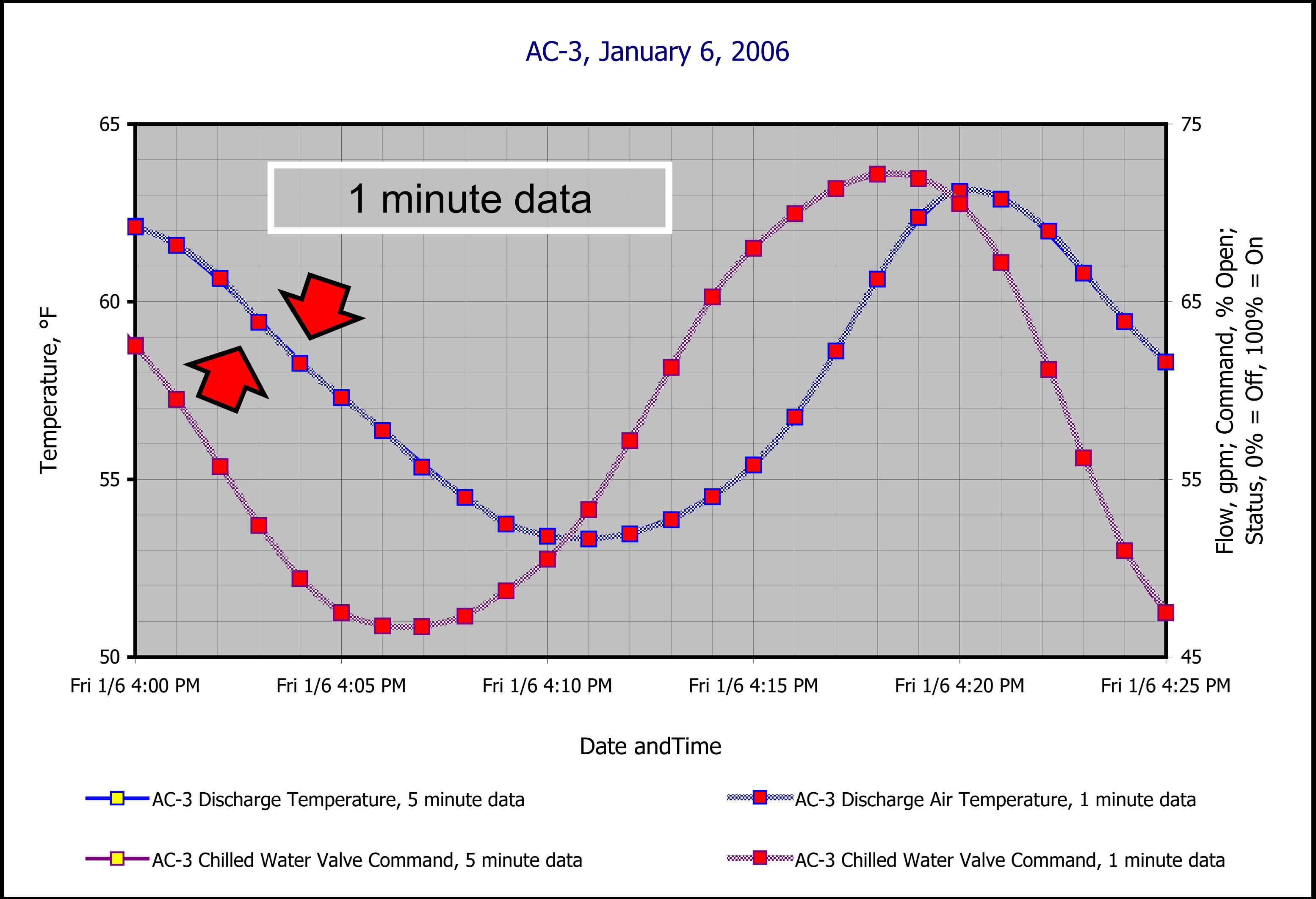
- Type of Logger?
- Safety?
- Sampling Frequency?

What You Sense is What You Get;

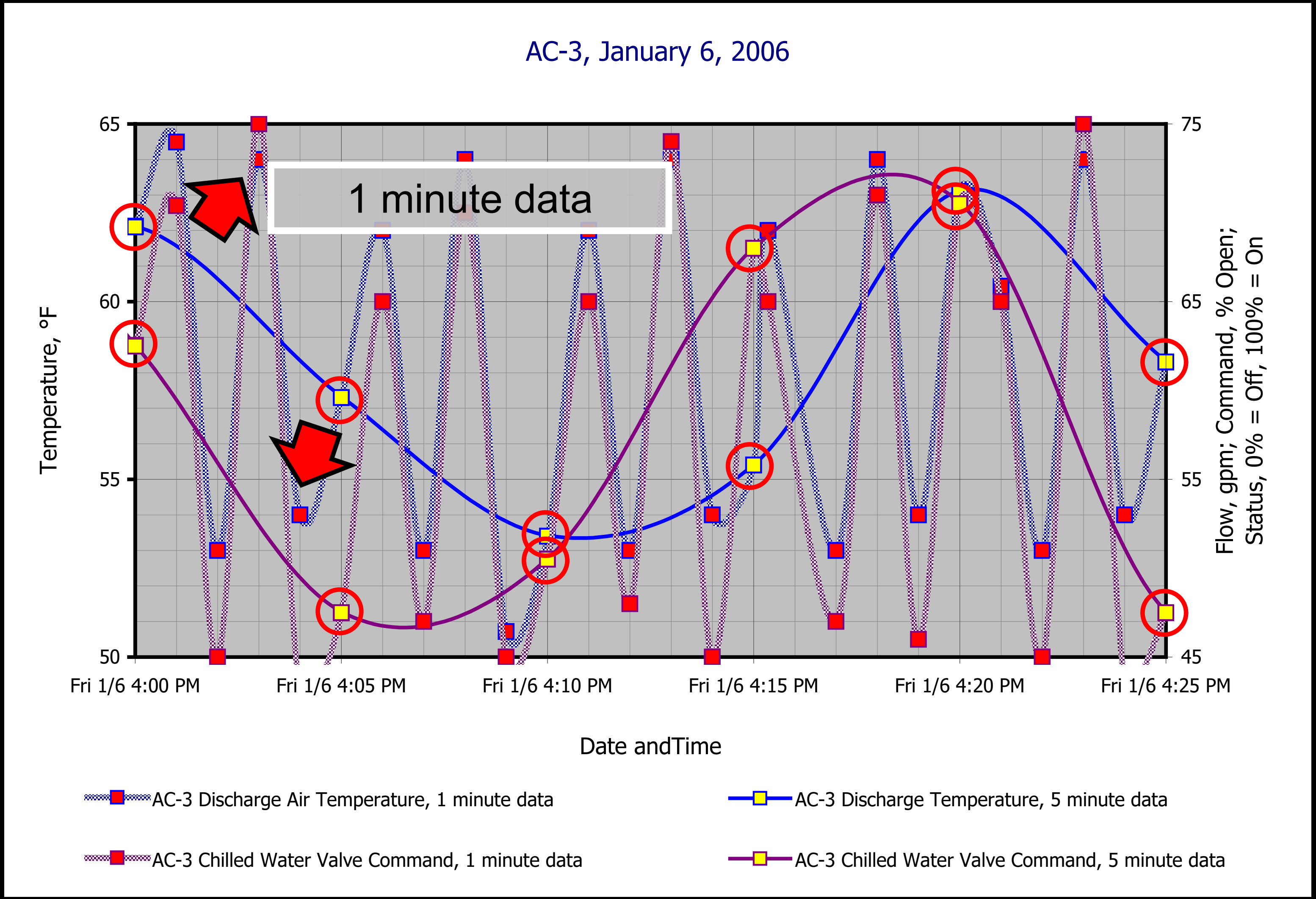


What You Sense is What You Get;

Maybe …



What You Sense is What You Get;
Or Maybe Not!



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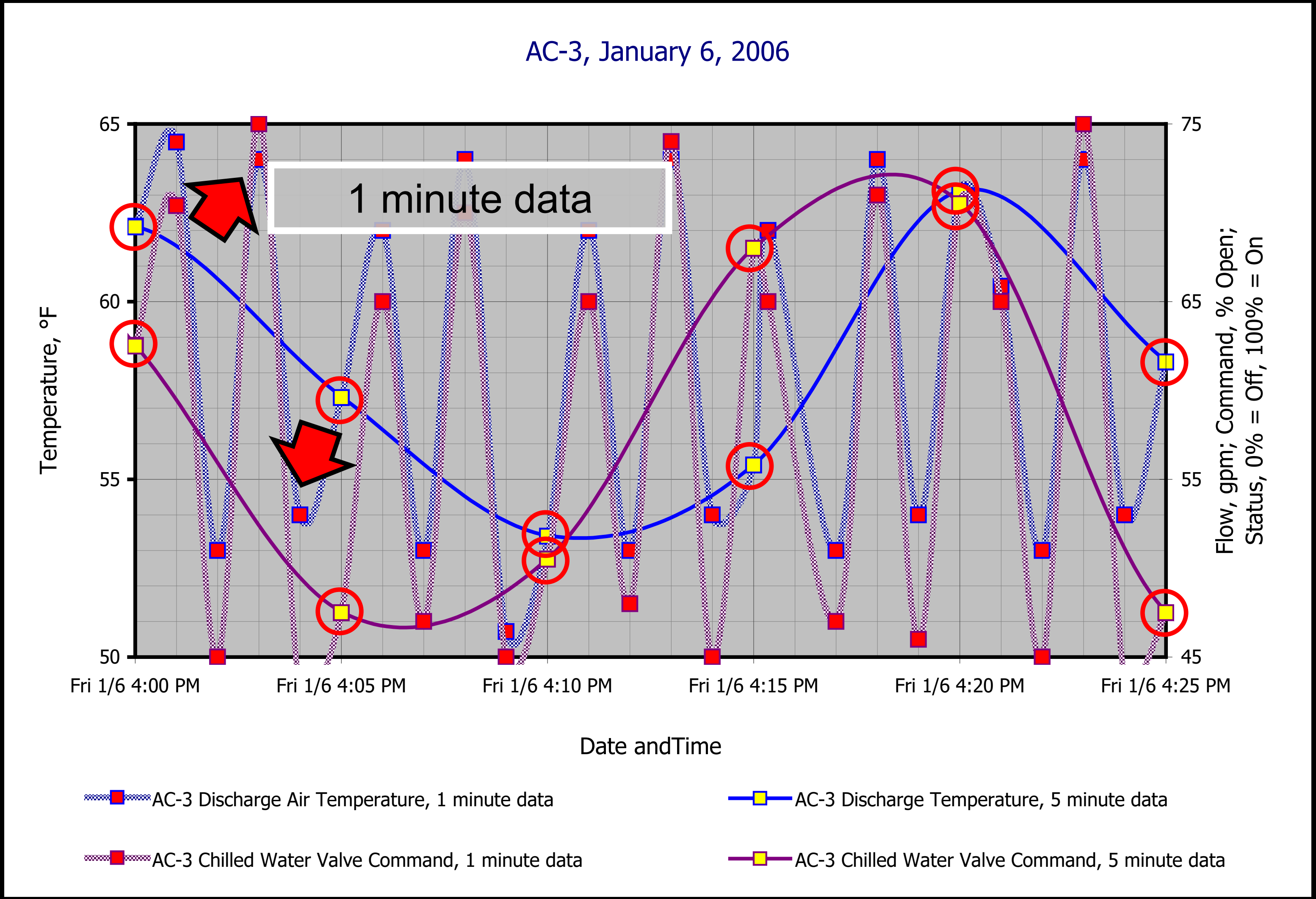


Bottom Lines

To avoid aliasing, you need to sample a process at twice the frequency of the fastest disturbance

At this sampling rate, the wave form:

1. Will be about the right shape
2. May be shifted in time from the actual wave form depending on where the samples were taken in the cycle

The Nyquist Theorem a.k.a the Sampling Theorem
The Theory Behind the Generalization

$$f_s \geq 2 \times f_c$$

Where:

$f_s =$ The sampling frequency

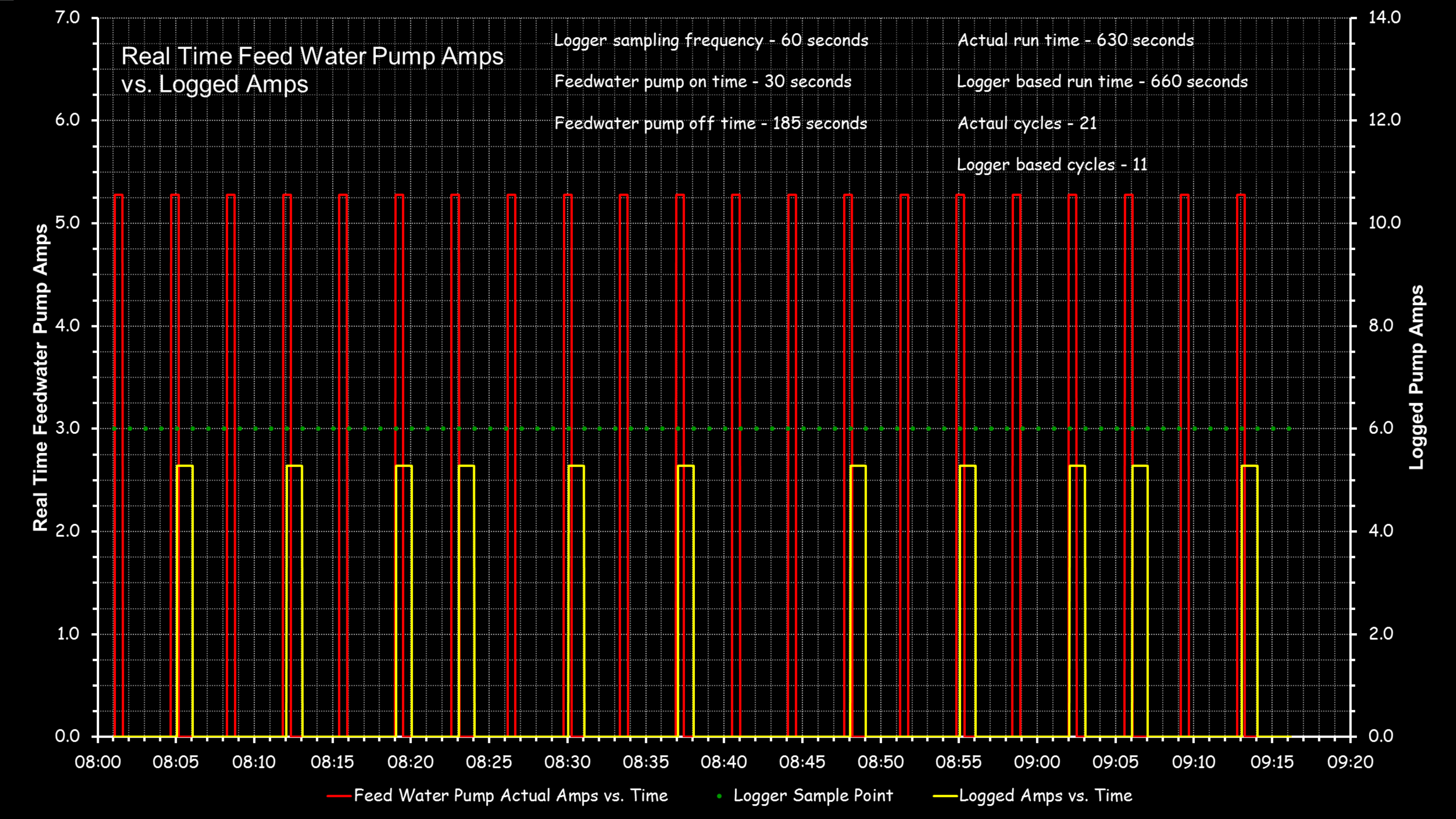
$f_c =$ The highest frequency contained in the signal

In words:

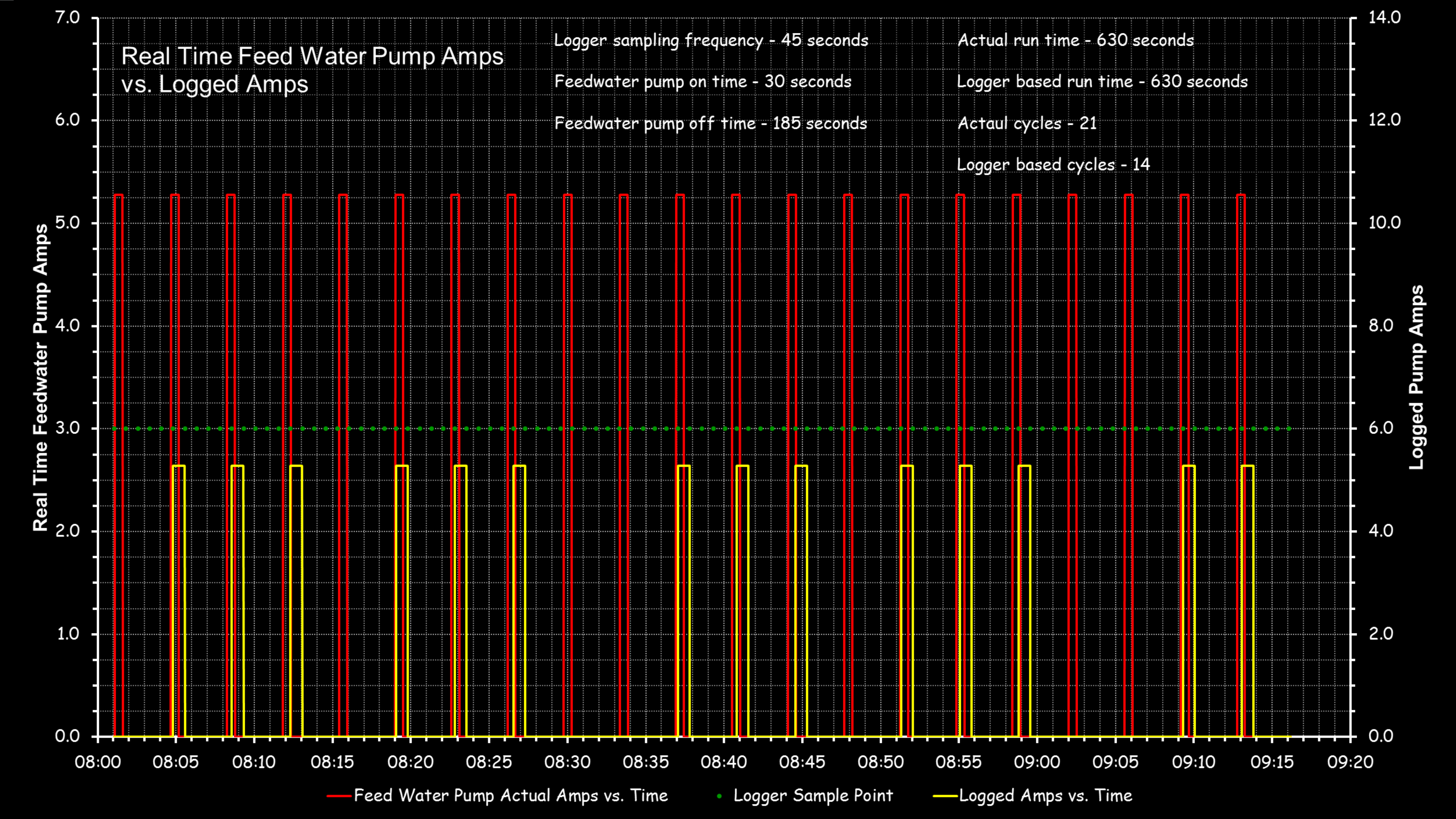
> *The sampling frequency should be at least twice the highest frequency contained in the signal.*

Aliasing; Also a Concern with Binary Data; An Example

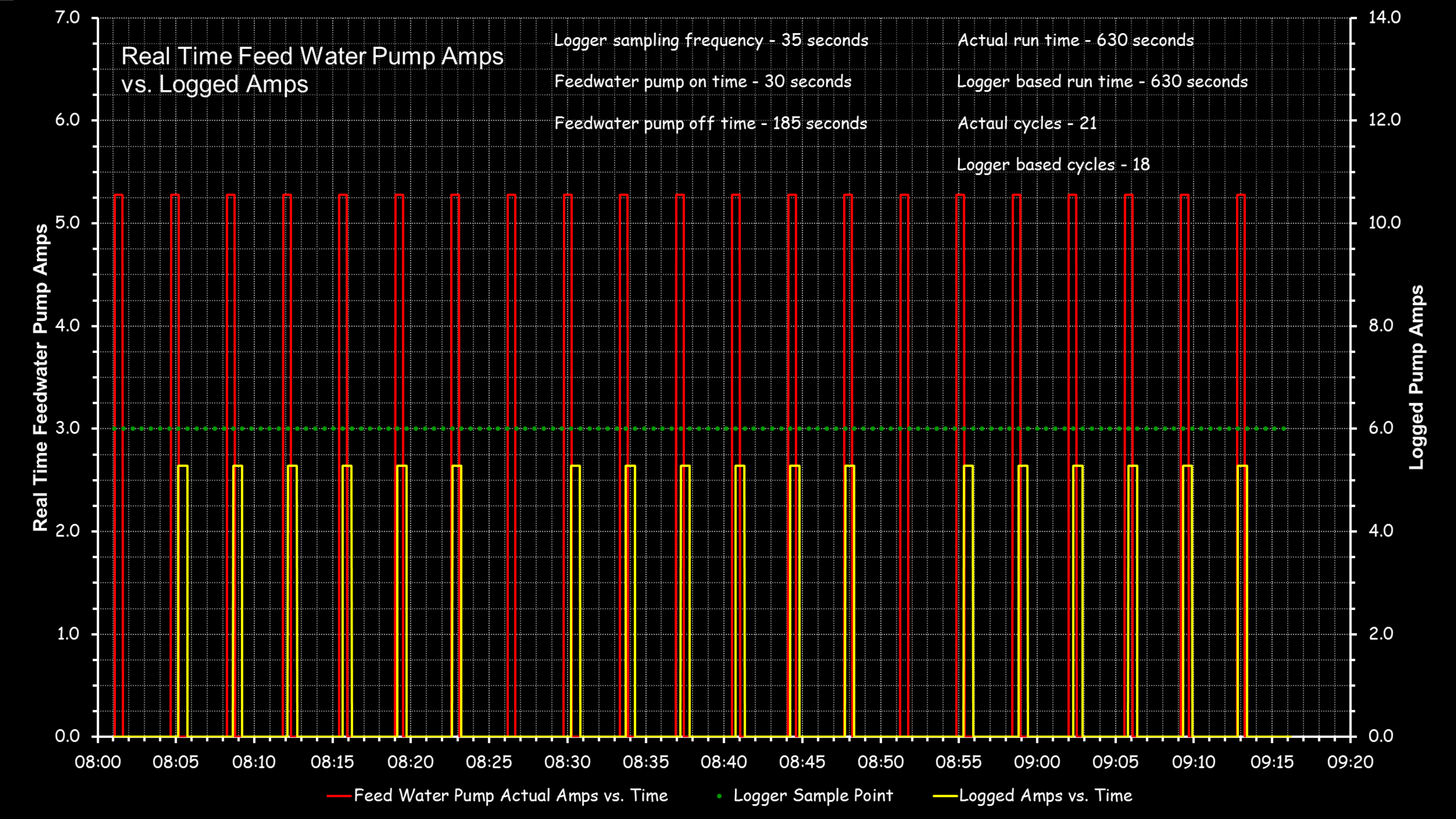
- A data logger has been installed to log feed water pump operation to develop a boiler load profile
- The slides that follow use a spreadsheet model to compare the number of pump cycles and total operating time predicted by data from a logger with the real time data stream
  - The logger only knows what it sees at the time it takes its sample
  - The logger is not averaging data between samples
  - The logger sampling time starts out at twice the feed water pump run cycle time and is reduced to one third of the feed water pump run cycle time



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 60 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 660 seconds
Actaul cycles - 21
Logger based cycles - 11
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 45 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 14
Real Time Feedwater Pump Amps
Logged Pump Amps
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time


Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 35 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 18
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time

Bottom Lines

If the sampling rate is to slow:

1. The operating pattern predicted by the logger data will not match the actual operating pattern.

   That means the shape of the load profile you predicted with the logger data would not match the actual load profile shape

Bottom Lines

If the sampling rate is to slow:

2. The number of cycles predicted by the logger data will not match the number of cycles that actually happened

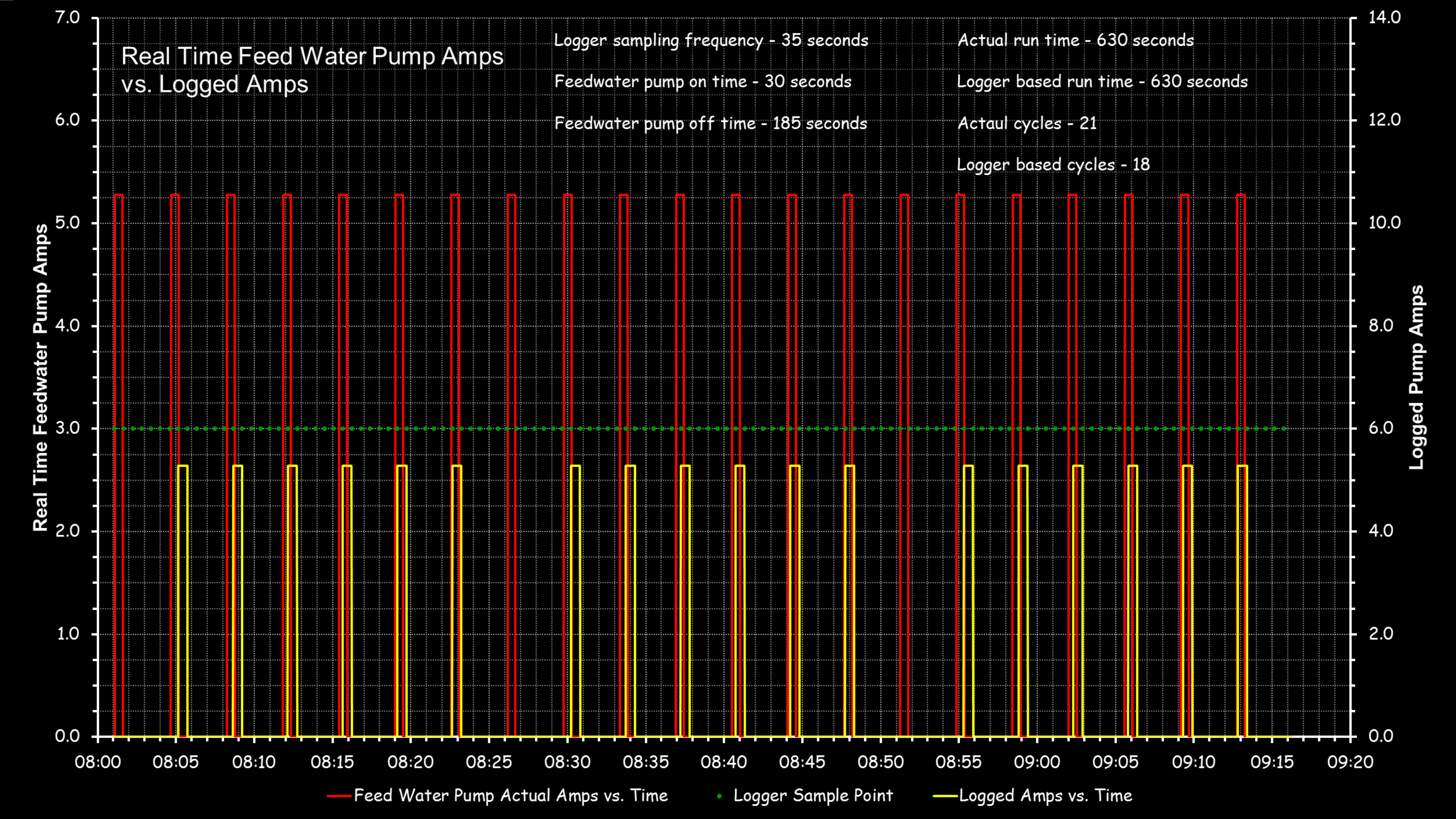
   So, if you were assuming "X" gpm went into the boiler for each cycle based on a field test of the actual pump, then you would under-estimate the actual steam consumption

Bottom Lines

If the sampling rate is to slow:

3. The total run time for the pump predicted by the logger data will tend to be more than the actual run time

   So, if you were assuming a pump flow rate based on a pump test and then multiplying that flow rate by the run time to get the total gallons of water that were converted to steam over a given time period, the logger data would cause you to over-estimate the actual steam consumption



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 35 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 18
Real Time Feedwater Pump Amps
Logged Pump Amps
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
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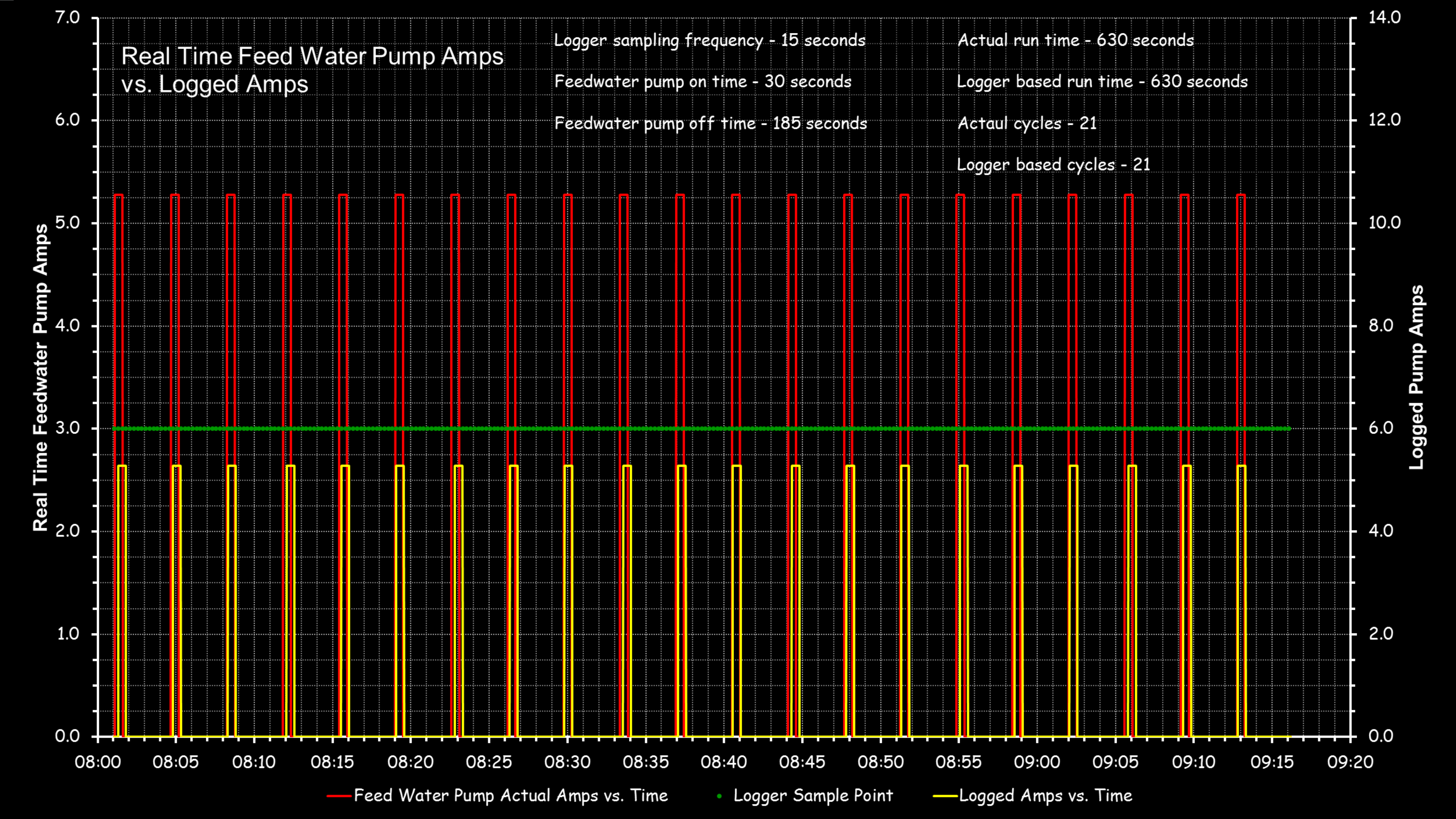
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 15 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time

Bottom Lines

With the sampling rate set to the value suggested by the Nyquist Theorem:

1. The number of cycles and the total run time predicted by the logger now are in agreement with reality

   That means that you would accurately predict the steam consumption using either of those pieces of information along with data from a field test of the pump

   Gallons per Minute x Minutes = Gallons

   This assumes the flow rate is constant for a feedwater pump any times the pump runs, which is reasonable if the boiler pressure is steady and the head above the pump in the feed water tank does not vary much

Bottom Lines

With the sampling rate set to the value suggested by the Nyquist Theorem:

1. The number of cycles and the total run time predicted by the logger now are in agreement with reality

   That means that you would accurately predict the steam consumption using either of those pieces of information along with data from a field test of the pump

   Gallons per Cycle x Cycles = Gallons

   This assumes the on cycle for a condensate pump cycle is the same all the time, which is reasonable if the pump is controlled by a consistent level change and pumps at a relatively steady rate

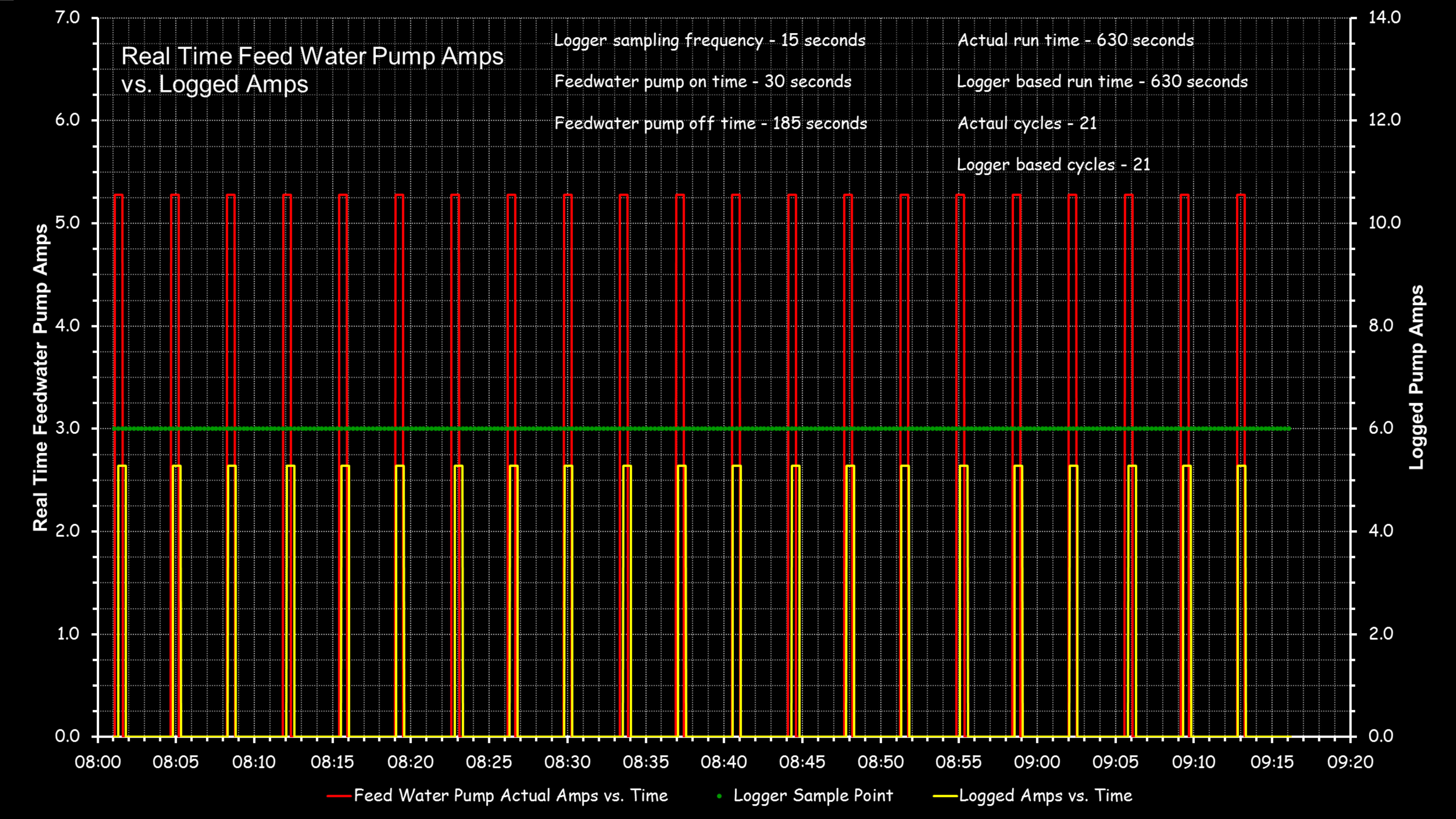
Bottom Lines

With the sampling rate set to the value suggested by the Nyquist Theorem:

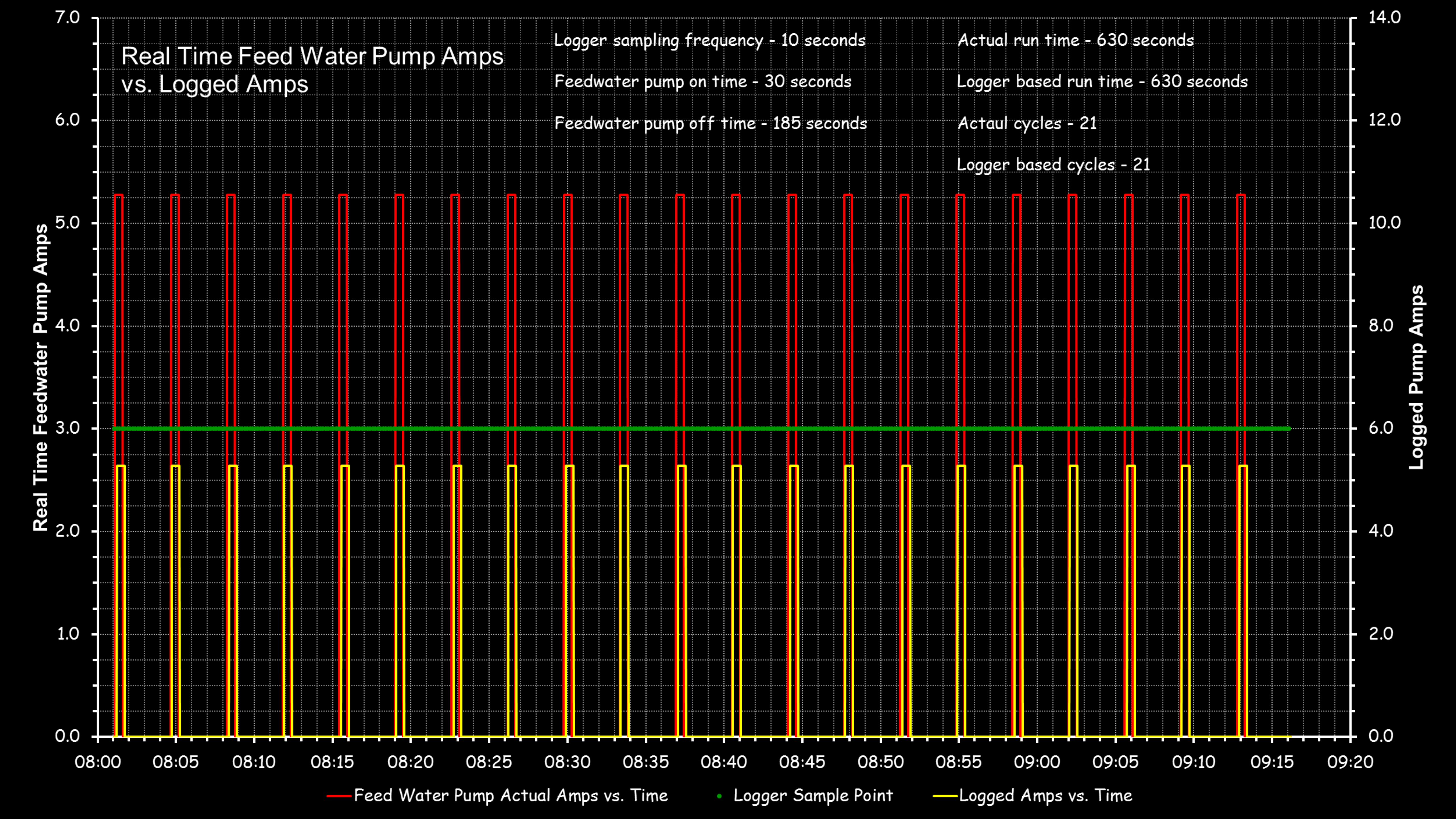
2. The operating pattern predicted by the logger data still does not match the actual operating pattern although it is closer.

   That means the shape of the load profile you predicted with the logger data would not exactly match the actual load profile shape.

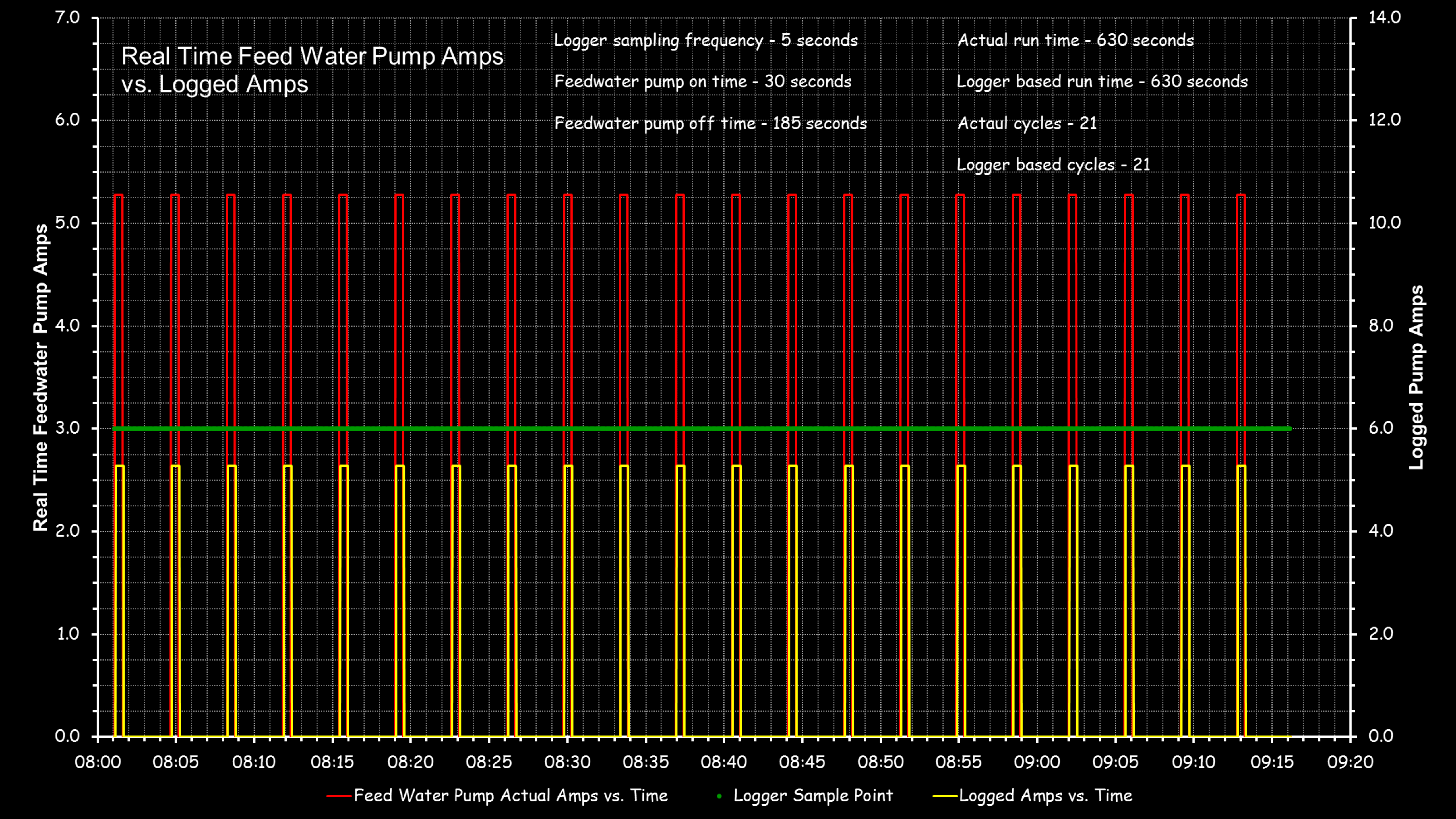
   – How close the patterns match with the sampling rate set to the Nyquist suggested value is generally related to when the logger samples relative to the start of a pump operating cycle



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 15 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time



Real Time Feed Water Pump Amps
vs. Logged Amps
Logger sampling frequency - 10 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time


Real Time Feed Water Pump Amps vs. Logged Amps
Logger sampling frequency - 5 seconds
Feedwater pump on time - 30 seconds
Feedwater pump off time - 185 seconds
Actual run time - 630 seconds
Logger based run time - 630 seconds
Actaul cycles - 21
Logger based cycles - 21
Real Time Feedwater Pump Amps
Logged Pump Amps
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
08:00
08:05
08:10
08:15
08:20
08:25
08:30
08:35
08:40
08:45
08:50
08:55
09:00
09:05
09:10
09:15
09:20
Feed Water Pump Actual Amps vs. Time
Logger Sample Point
Logged Amps vs. Time

Bottom Lines

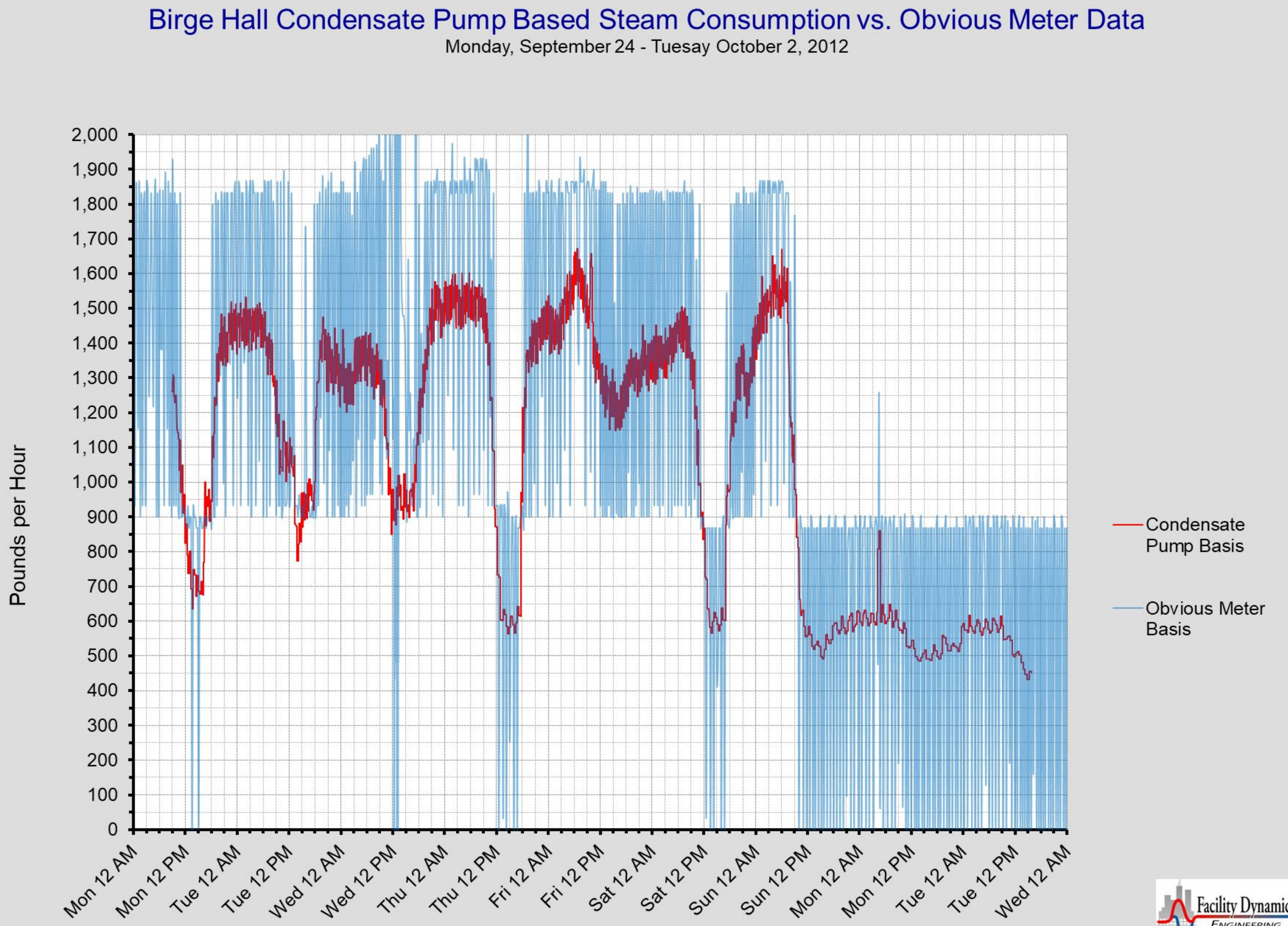
With the sampling rate set to a value that is significantly faster than what is suggested by the Nyquist Theorem:

1. The pattern predicted by the logger is a much closer match to the actual operating pattern

   That means that if you want to not only reflect the steam consumption, but also the shape of the load profile, then you probably want to sample faster than the Nyquist Theorem suggested sampling rate unless you can launch the logger so that it starts logging data exactly when a pump starts

   For more on aliasing, see Aliasing and Other Factors Affecting the Accuracy of Field Data at www.Av8rDAS.Wordpress.com

The Results

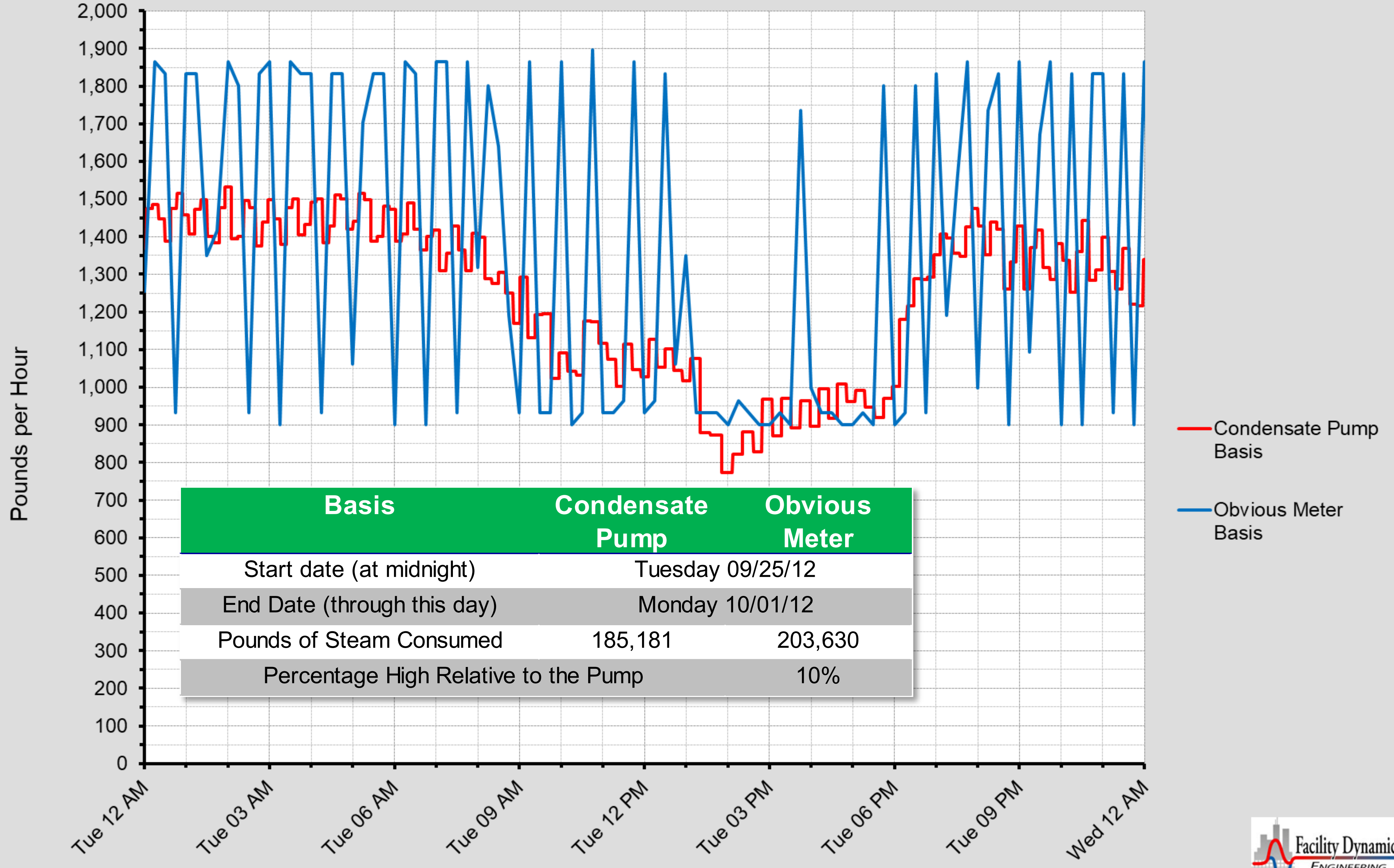


Birge Hall Condensate Pump Based Steam Consumption vs. Obvious Meter Data
Monday, September 24 - Tuesay October 2, 2012
Pounds per Hour
2,000
1,900
1,800
1,700
1,600
1,500
1,400
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
Mon 12 AM
Mon 12 PM
Tue 12 AM
Tue 12 PM
Wed 12 AM
Wed 12 PM
Thu 12 AM
Thu 12 PM
Fri 12 AM
Fri 12 PM
Sat 12 AM
Sat 12 PM
Sun 12 AM
Sun 12 PM
Mon 12 AM
Mon 12 PM
Tue 12 AM
Tue 12 PM
Wed 12 AM
Condensate Pump Basis
Obvious Meter Basis

The Results

Birge Hall Condensate Pump Based Steam Consumption vs. Obvious Meter Data

Tuesday, September 25, 2012



Basis	Condensate Pump	Obvious Meter
Start date (at midnight)	Tuesday 09/25/12	
End Date (through this day)	Monday 10/01/12	
Pounds of Steam Consumed	185,181	203,630
Percentage High Relative to the Pump		10%