Physical Hydraulic Modeling a Tool for Pumping System Design and Optimization

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Why use Physical Hydraulic Modeling?

Troubleshooting problems with existing facilities:

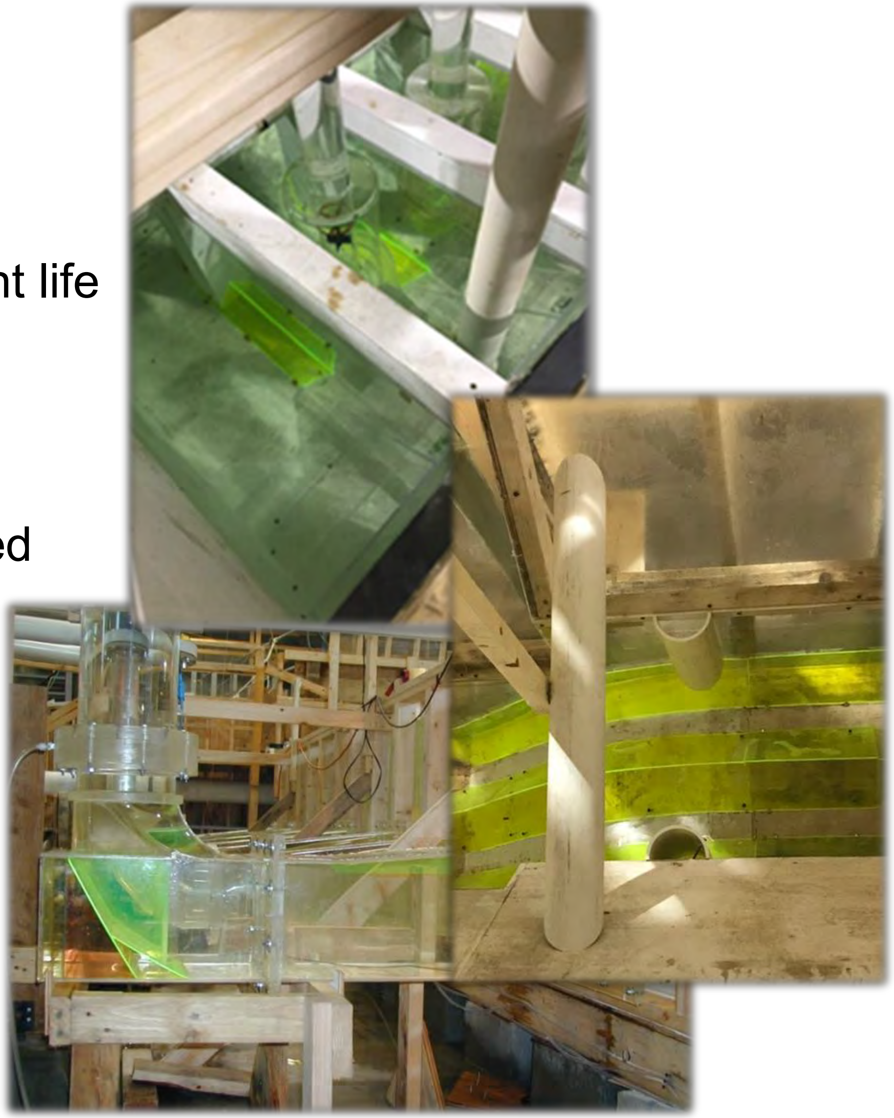
- Develop cost effective solutions
- Improve pump performance, reduce wear and increase equipment life
- Improve solids and debris distribution and capture

Confirm intake designs for pumping stations:

- New designs: Some situations are complex and can’t be designed with confidence based on prior experience
- Existing pumping station upgrades and modifications
- Solids and debris distribution and capture
- Develop design modifications for improved performance

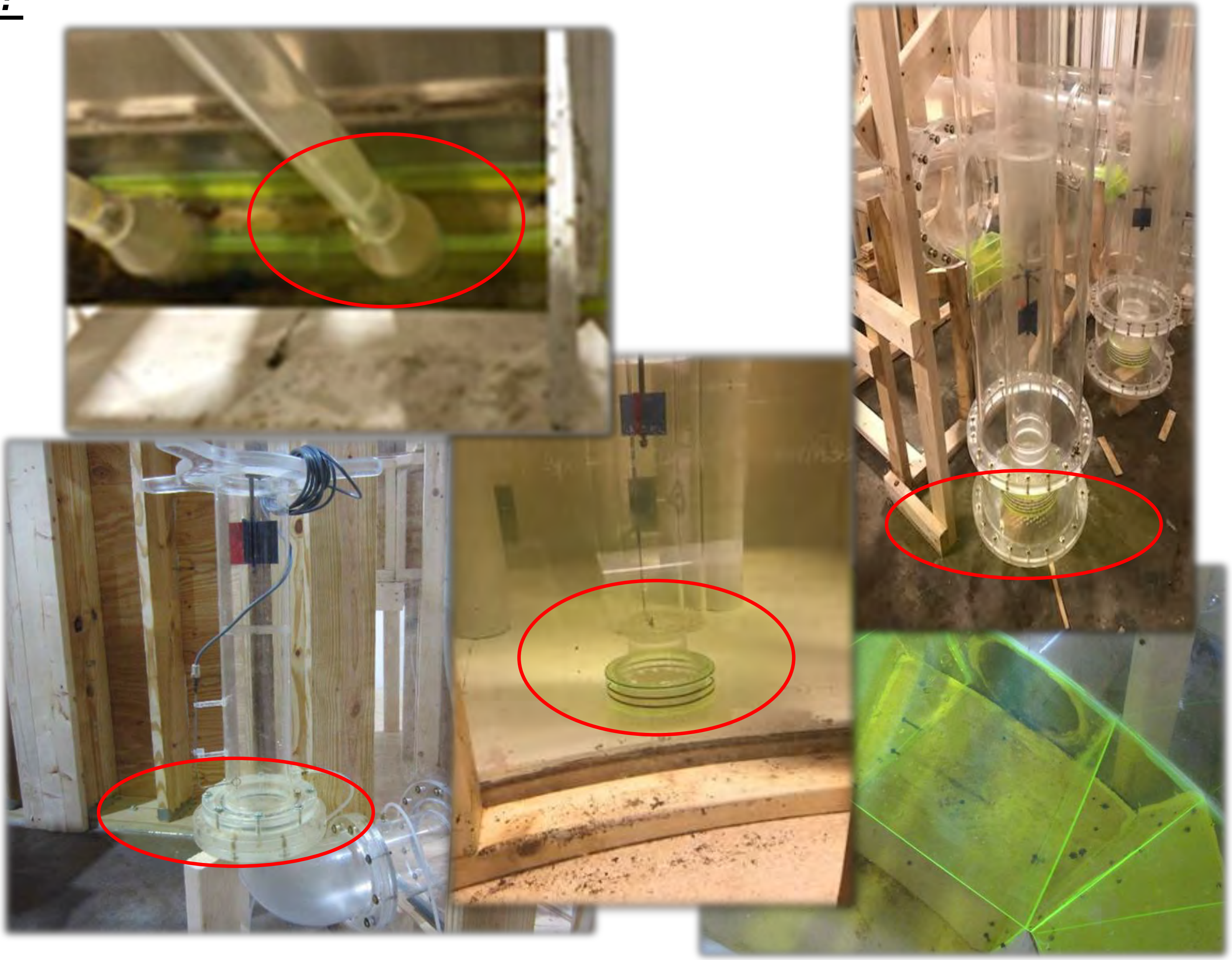
Optimize pumping station designs:

- Reduce physical size and depth with resulting construction cost saving



What does the Model consist of?

- Upstream conditions such as pipe bends, structures, screens, etc that affect the flow patterns
- Wet wells, gate openings and interior geometry
- Suction piping or suction header up to the pump suction nozzle for dry pit pumps
- Intake bell for wet pit pumps
- Pump volute or bowl geometry where critical
- <u>Not the pump and impeller</u>



What are the goals of a physical hydraulic model?

This is a very simple concept…Construct a pump intake in which the pumps will operate in the field as well as the do in the factory performance testing.

- Maximize pump performance
- Minimize maintenance and associated costs
- Maximize life of the pumping equipment
- Provides assurance of performance

Modeling is a fraction of the design and construction cost, but fixing problems after construction is completed can be 10 x the cost of a physical model or more

ANSI/HI 9.8.7.1: Evaluate the Need for Physical Hydraulic Modeling

9.8.7 Physical model studies of intake structures and pump suction piping

9.8.7.1 Need for a physical model study

A properly conducted physical model study is a reliable method to identify unacceptable flow patterns at the pump suction for given sump or suction piping design and to derive acceptable intake sump or piping designs. Considering the cost for a physical model study, an evaluation is needed to determine if one is required. A physical hydraulic model study shall be conducted for pump intakes with one or more of the following features:

A suction intake arrangement with elevation relative to water level that does not provide the minimum submergence requirement of this standard, irrespective of pump manufacturer's stated submergence values.

The intake design is not a standard intake design presented in this standard or the geometry (such as bay width, bell clearances, sidewall angles, bottom slopes, distance from obstructions, the bell diameter, submergence, or piping changes, etc) deviates from this standard.

There is no prior physical model study for the intake design considered in terms of physical features and flow rates.

ANSI/HI 9.8.7.1: Evaluate the Need for Physical Hydraulic Modeling

Non-uniform or non-symmetric approach flow to the pump sump exists (e.g., intake from significant cross-flow, use of dual flow or drum screens; use of elbows, bends, or multiple screens just upstream of a trench-type wet well; or a short-radius pipe bend near the pump suction, etc.).

Proper pump operation of a critical service or application as defined by the customer (such as a safety related system).

Pump repair, remediation of a poor design, and the impacts of inadequate performance or pump failure all to-gether would cost more than 10 times the cost of a physical model study.

Circular stations with four or more pumps.

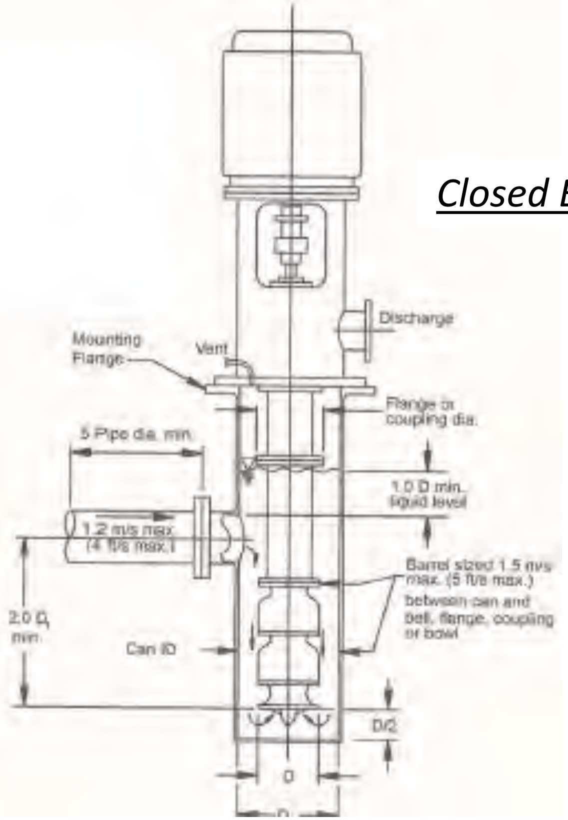
For trench type wet wells (clear or solids-bearing liquids) the pumps have flows greater than 1260 L/s (20,000 gpm) per pump or the total station flow with all pumps running would be greater than 3155 L/s (50,000 gpm).

Circular pump sumps (clear or solids-bearing liquids) with flows exceeding 315 L/s (5000 gpm) per pump require a physical model study (see Sections 9.8.3.3 and 9.8.4 .3) . Circular pump sumps (clear liquids) per Figures 9.8 .3.3.1c and 9.8.3.3.1 f with station flows exceeding 315 L/s (5000 gpm) require a physical model study.

ANSI/HI 9.8.7.1: Evaluate the Need for Physical Hydraulic Modeling

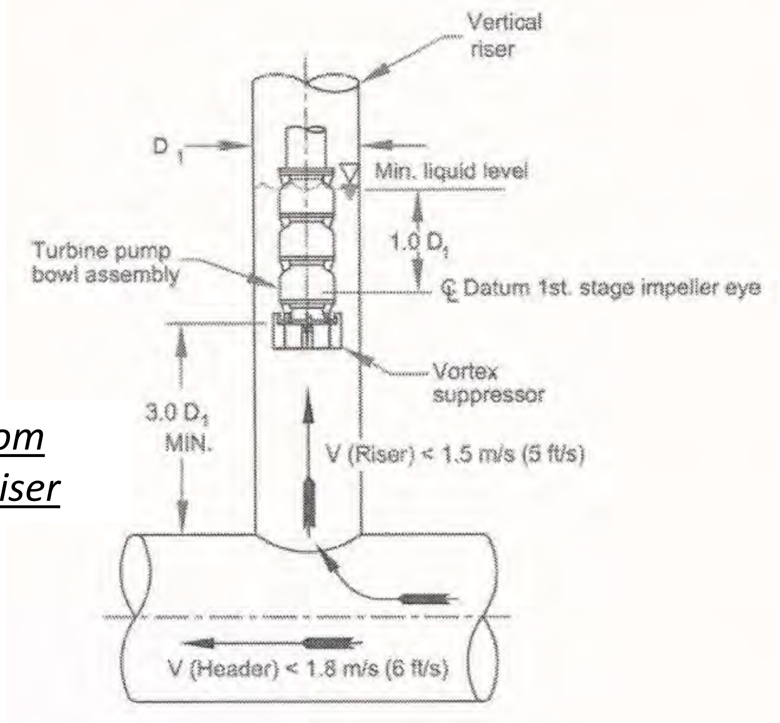
The pumps of an open bottom barrel or riser arrangement with flows greater than 315 L/s (5000 gpm) per pump (see Section 9.8.3.6).

The pump of a closed bottom can intake has flows greater than 440 L/s (7000 gpm) (see Section 9.8.3.6).



Closed Bottom Can

Open Bottom Barrel or Riser

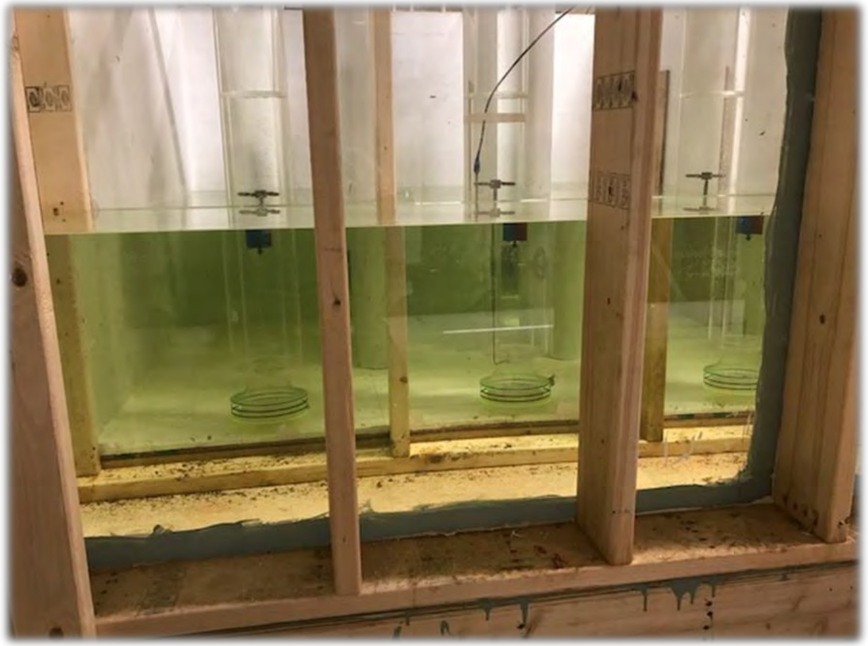


AECOM

ANSI/HI 9.8.7.1: Evaluate the Need for Physical Hydraulic Modeling

The pumps have flows greater than 2520 L/s (40,000 gpm) per pump or the total station flow with all pumps running would be greater than 6310 L/s (100,000 gpm) .

When evaluating the impacts of inadequate performance or pump failures, the probability of failure may be considered, such as by comparing the proposed intake design to other intakes of essentially identical design and approach flow that operate successfully. The physical model study shall be conducted by a hydraulic laboratory using personnel that have experience in modeling pump intakes.



Its all about risk and cost of potential field modifications

Evaluate the Need for Physical Hydraulic Modeling – Troubleshooting

Vortices

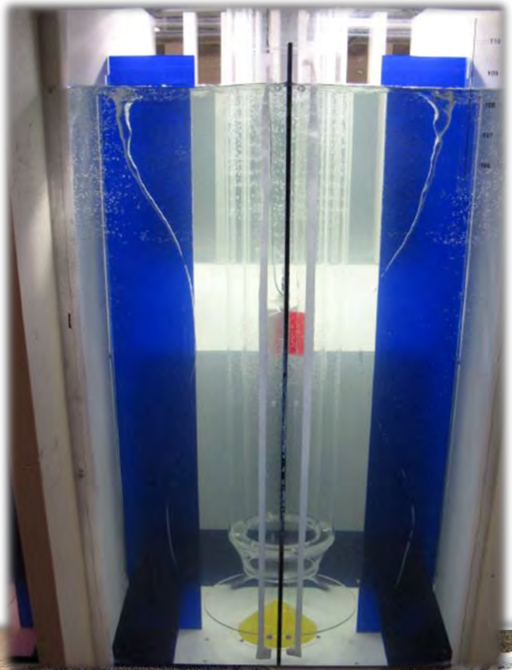
- Accelerated Bearing Wear
- Component Fatigue Failure
- Cavitation
- Air Entrainment

Pre-Swirl

- Cavitation
- Reduced Performance
- Vibration

Air Entrainment

- Cavitation
- Excessive Noise
- Reduced Performance
- Prime Loss
- Air Binding



Excessive Turbulence

- Cavitation
- Accelerated Bearing Wear
- Component Fatigue Failure
- Reduced Performance

Non-Uniform Velocity Distribution

- Accelerated Bearing Wear
- Component Fatigue Failure
- Reduced Performance

At What Stage of a Project should Physical Hydraulic Modeling Occur?

Design Phase:

- Best time in the project schedule
- After 30% and when the design conditions and layout are firmed up
- Modifications are very inexpensive to incorporate
- Intake design is confirmed
- Final report becomes part of specifications

During Construction Phase:

- Not the most opportune time in the project schedule
- Need to clearly specify the modeling requirements
- Engineer losses some control
- Potential risk for change orders and time delays
- Need for a line item/provisional sum in specs for modification costs

What are we looking to test for and measure in a model?

ANSI/HI 9.8.7.7

The ***acceptance criteria*** for the model test of the final design shall be the following: Free surface and subsurface vortices entering the pump must be less severe than vortices with coherent (dye) cores (free surface vortices of Type 3 and subsurface vortices of Type 2 in Figure 9.8.7 .5a). Dye core vortices may be acceptable only if they occur for less than 10% of the time or only for infrequent pump operating conditions.

Swirl angles, both the short-term (30-second model) maximum and the long-term (10-minute model) average indicated by the swirl meter rotation, must be less than 5 degrees. Maximum short-term (30-second model) swirl angles up to 7 degrees may be acceptable, only if they occur no more than 10% of the time or for infrequent pump operating conditions. The swirl meter rotation should be reasonably steady with no abrupt changes in direction when rotating near the maximum allowable rate (angle).

Time-averaged velocities at points in the throat of the bell or at the pump suction in a piping system shall be within 10% of the cross-sectional area average velocity. Time-varying fluctuations at a point shall produce a standard deviation of less than 10% of the time averaged signal.

For the special case of pumps with double suction impellers, the distribution of flow at the pump suction flange shall provide equal flows to each side of the pump within 3% of the total pump flow.

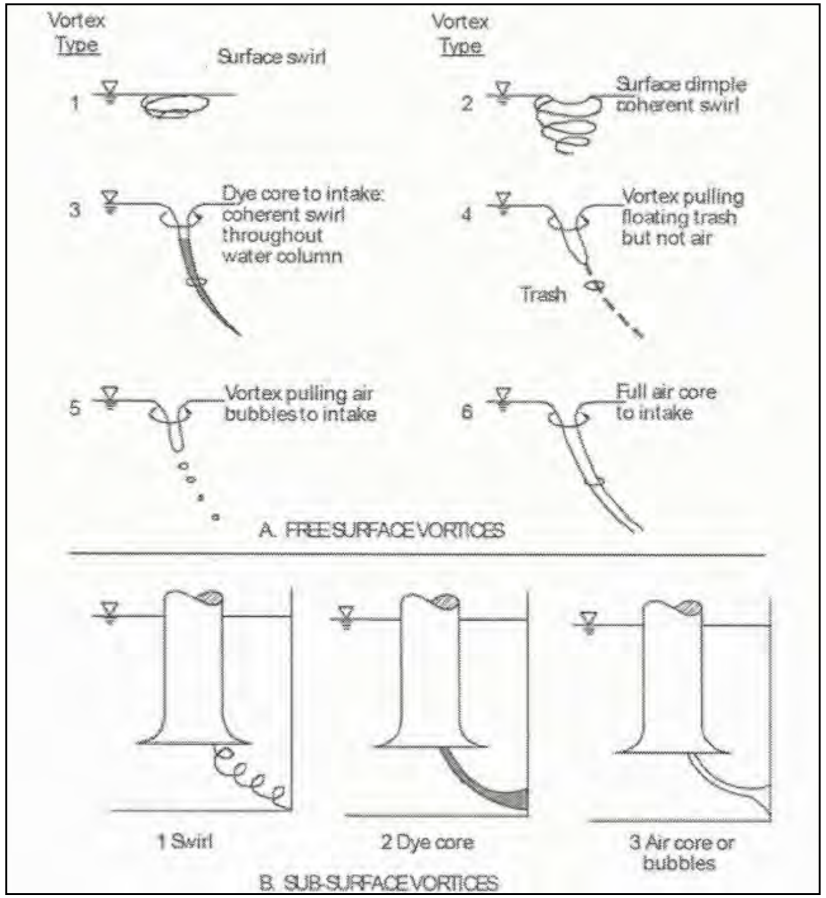
Make sure the overall flow is uniform and stable…dye study.

Free surface and subsurface vortices *entering the pump must be less severe than vortices with coherent (dye) cores (free surface vortices of Type 3 and subsurface vortices of Type 2 in Figure 9.8.7 5a). Dye core vortices may be acceptable only if they occur for less than 10% of the time or only for infrequent pump operating conditions.*

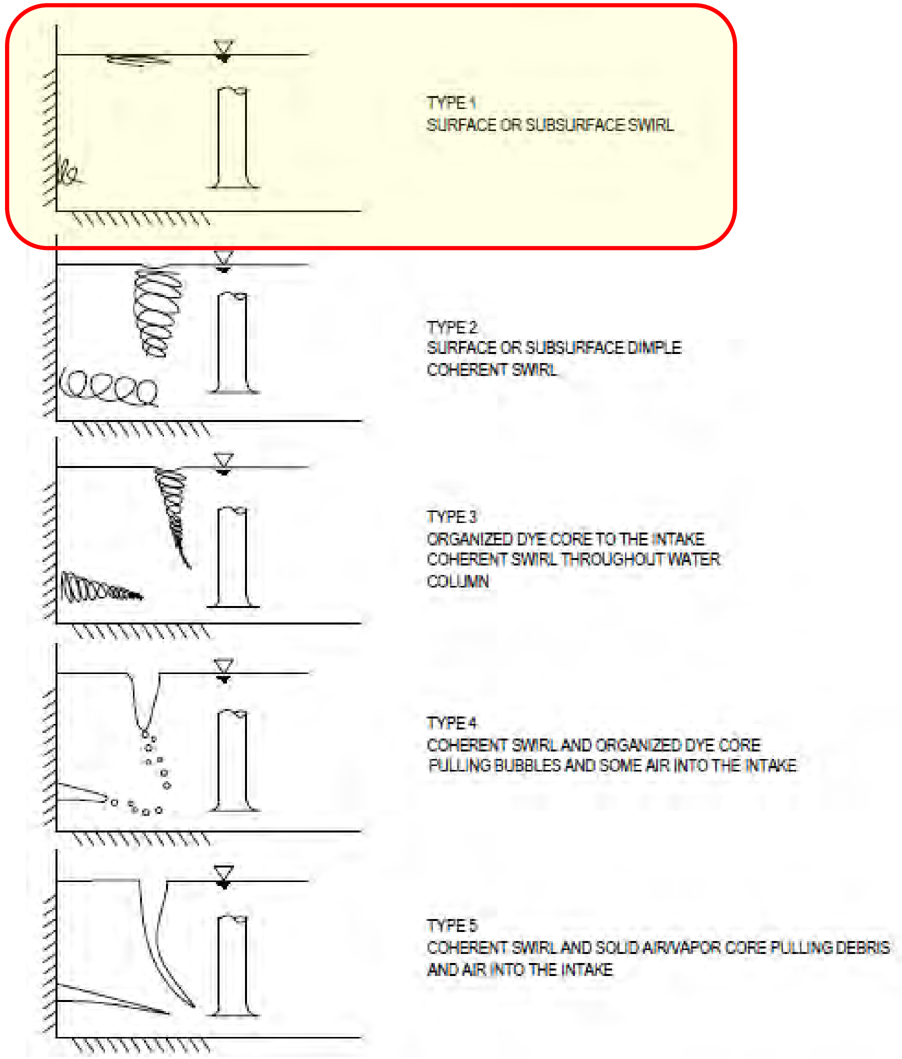
Recommendation: Although HI allows a wider range of vortex activity the target is to have no organized free surface or submerged vortices greater than Type 1,

HI 9.8

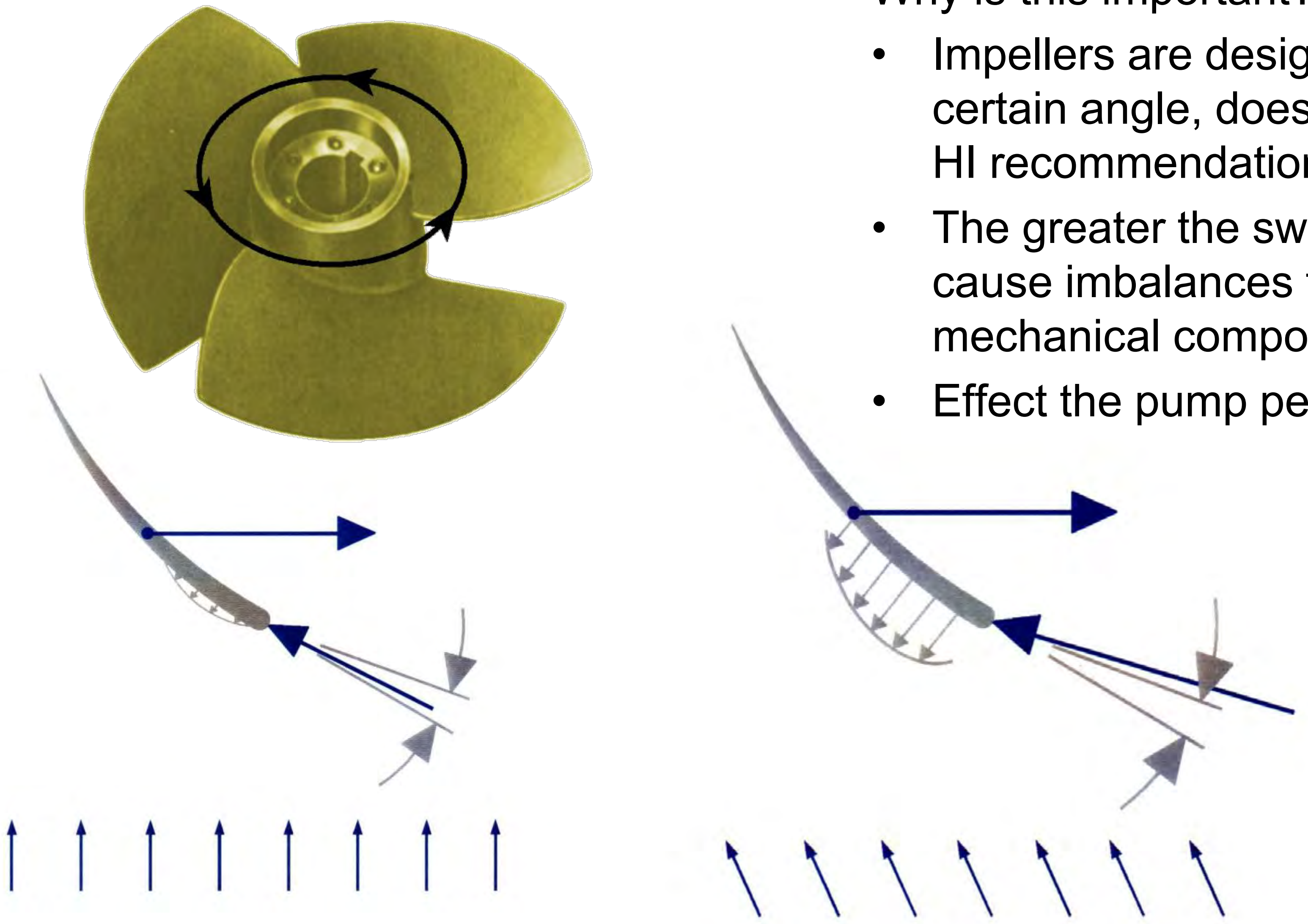
Figure 9.8.7.5.a



SURFACE & SUB-SURFACE VORTEX CLASSIFICATION



Pre-Swirl

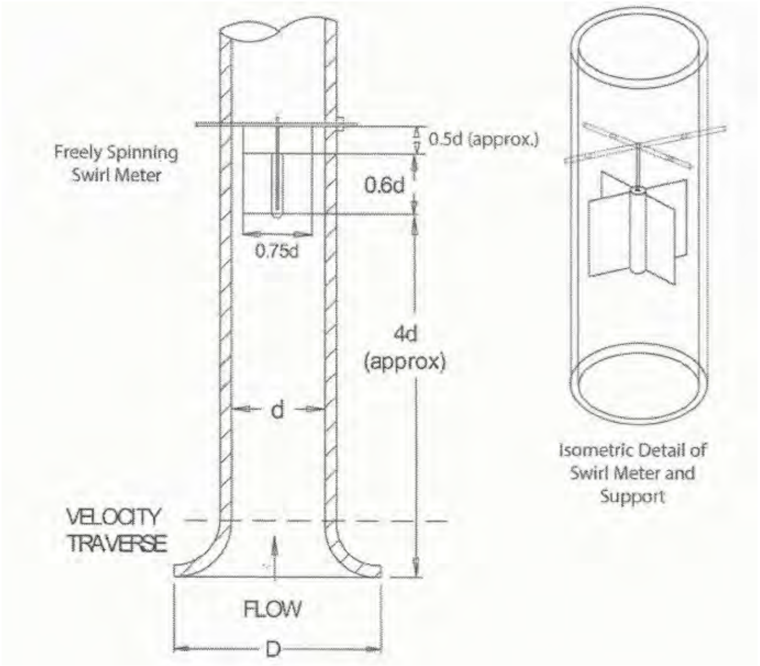


Why is this important?

- Impellers are designed for the flow to enter at a certain angle, doesn't have to be perfect thus the HI recommendation of a 5 degree allowance
- The greater the swirl angle and pre-swirl can cause imbalances to the impeller and mechanical components of the pump assembly
- Effect the pump performance

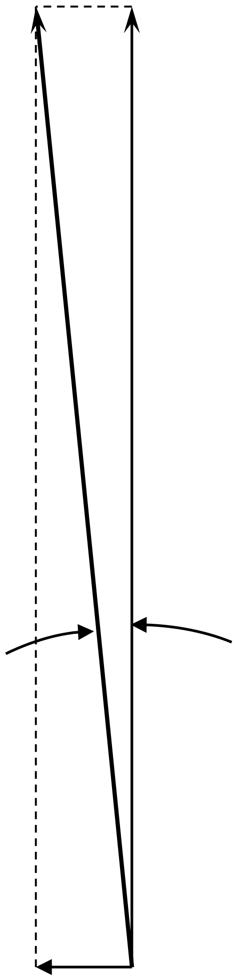
Swirl angles, both the short-term (30-second model) maximum and the long-term (10-minute model) average indicated by the swirl meter rotation, must be less than 5 degrees. Maximum short-term (30-second model) swirl angles up to 7 degrees may be acceptable, only if they occur no more than 10% of the time or for infrequent pump operating conditions. The swirl meter rotation should be reasonably steady. with no abrupt changes in direction when rotating near the maximum allowable rate (angle).

Recommendation: HI Pre-Swirl should be less than 5 degrees, best to try for 2.5 degrees to be conservative



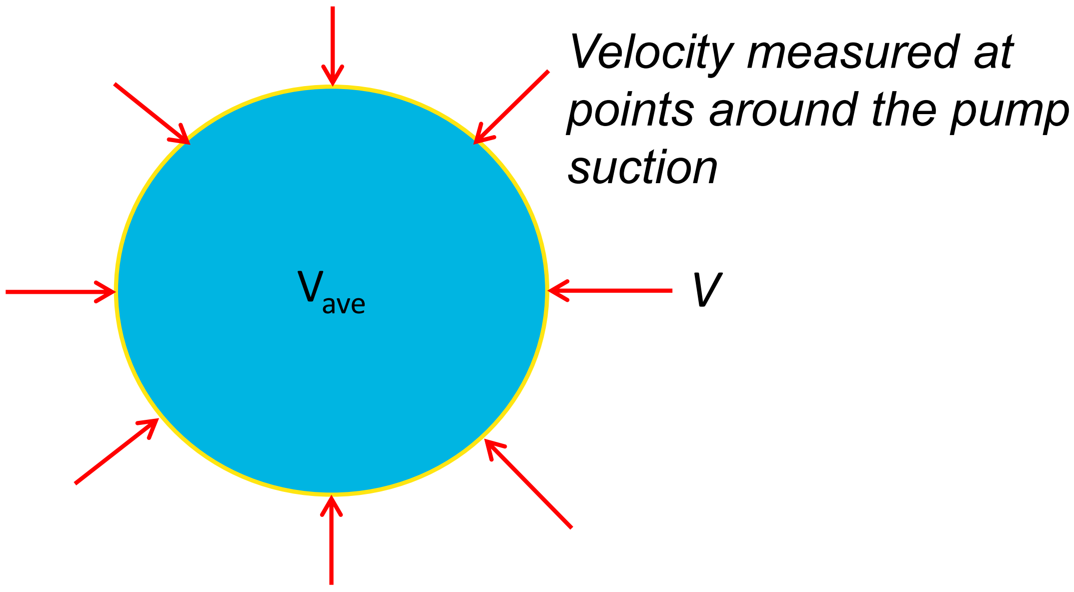
u = average axial velocity
d = Pipe diameter at meter
n = swirl meter rev/sec

$$\theta = \tan^{-1}\left(\frac{\pi dn}{u}\right)$$



Time-averaged velocities at points in the throat of the bell or at the pump suction in a piping system shall be within 10% of the cross-sectional area average velocity. *Time-varying fluctuations* at a point shall produce a standard deviation of less than 10% of the time averaged signal.

Turbulence



$$V \div V_{ave} = +/- 10\%$$

Dye Studies: See how the flow reacts in a dynamic situation. Don't rely only on instrument data.

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Photo 5-1 Flow Starts Circulating After Existing Elbow (long pipe)

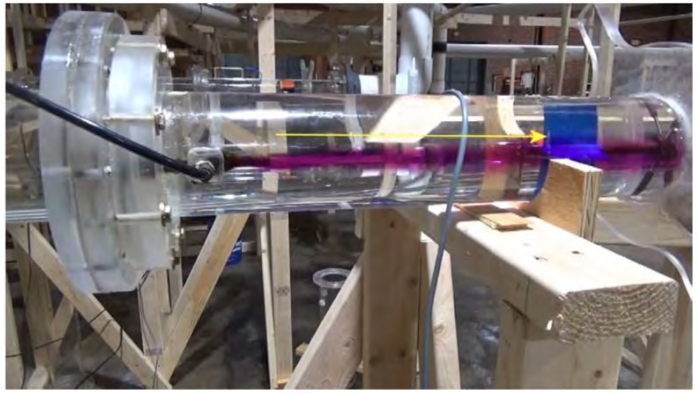
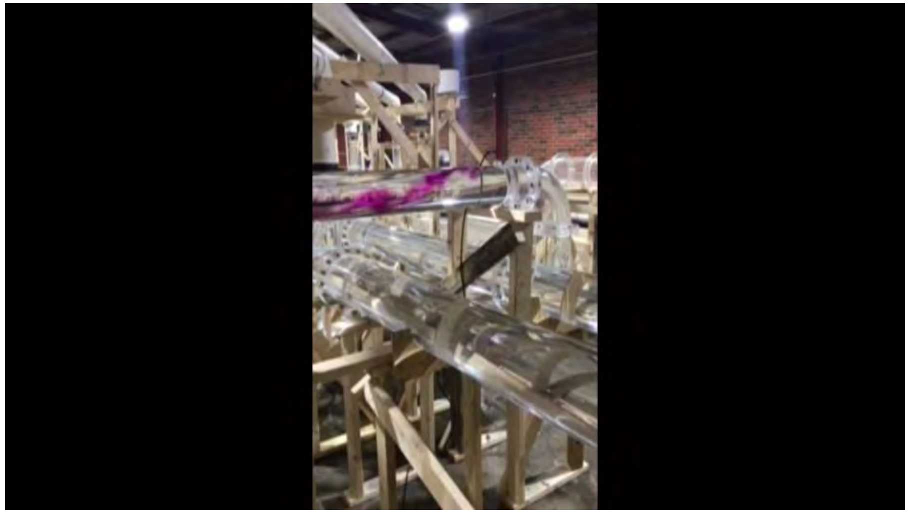


Photo 5-11 Very Uniform Flow with Grid Installed

Photo 5-2 Flow Starts Circulating After Exiting Elbow (short pipe)



Philosophy for Modifications and Typical Modifications

Existing Facilities:

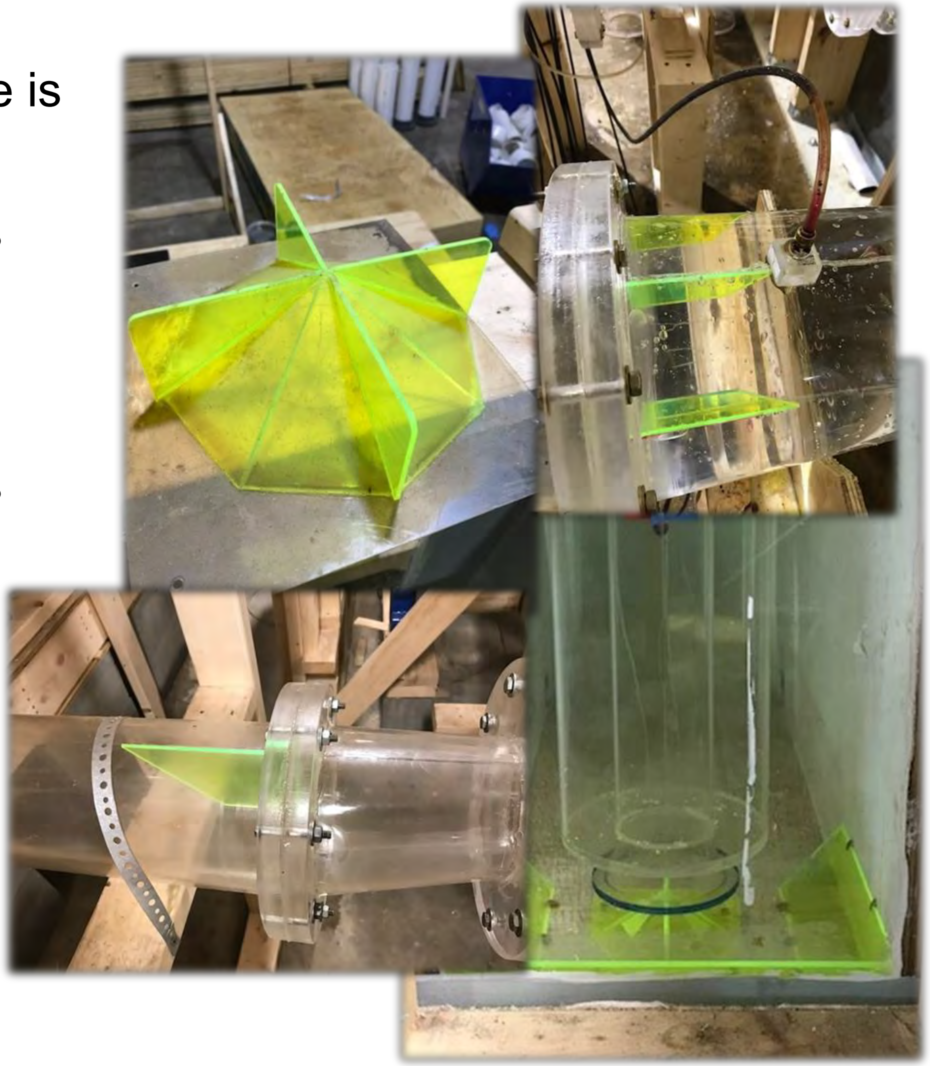
- What are the issues and what evidence is there…pump performance, wear?
- Goal: No major structural modifications

New Facilities:

- Goal: No major structural modifications

Design Modifications:

- Practical
- Simple to construct or fabricate
- Easy to install
- Suitable for the service, clean water or solids bearing fluids



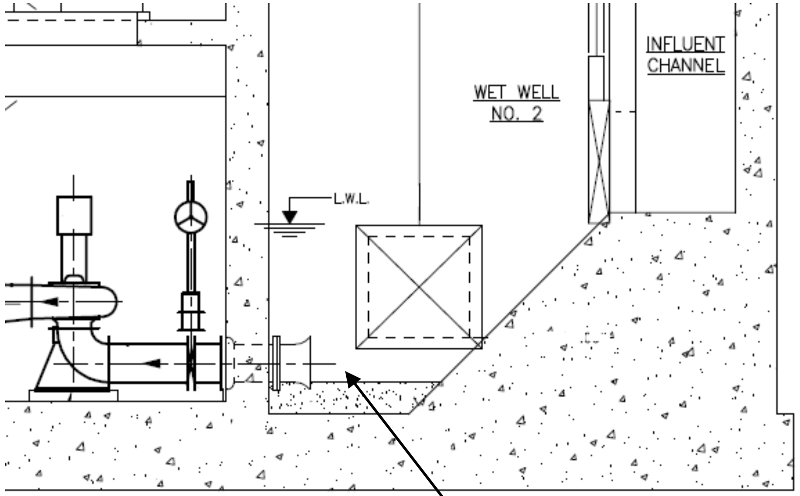
Typical Modifications:

- Baffles
- Curtain walls
- Filets
- Cones and Vaned Cones
- Vaned Baskets
- Vanes in piping
- Reducing elbows
- Flow Straightening Grids
- Surface vortex breakers
- Opening/Gate sizes and locations

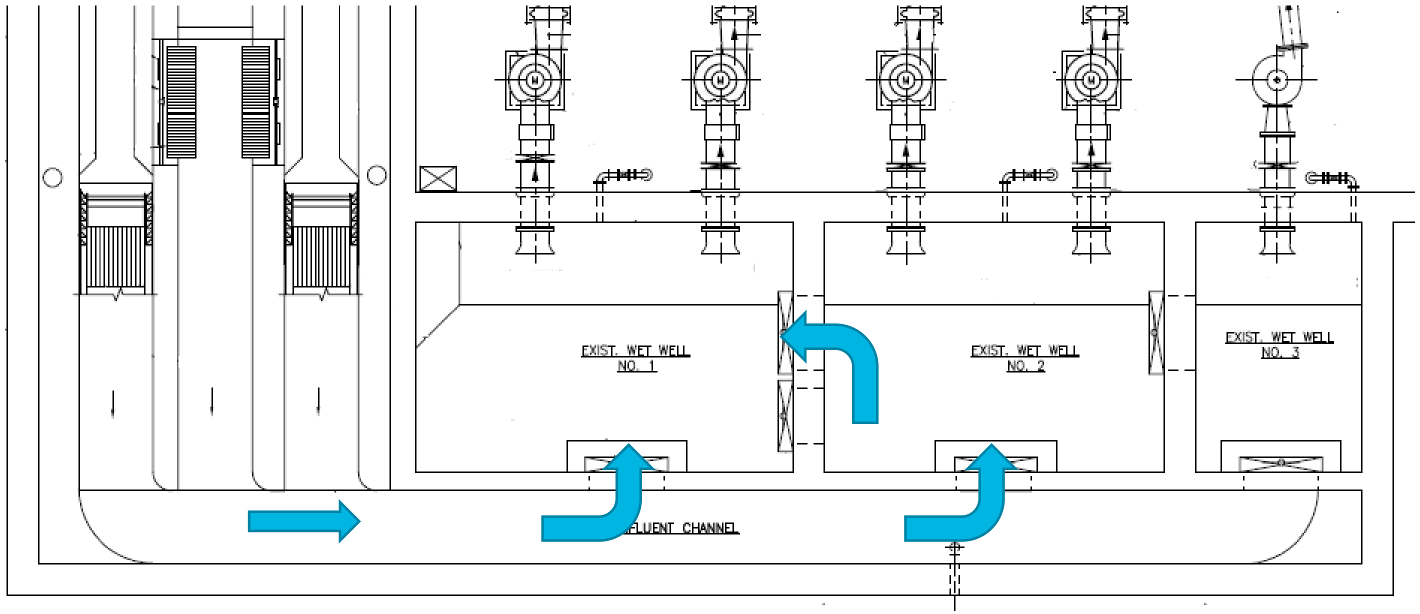
Example – Upgrade Existing Intake

Existing Design:

- Raw Wastewater PS, 34 mgd
- 4 pumps each 7,900 gpm
- 1 Pump 1,700 gpm
- 2 Screen channels
- 3 Wet Wells-rectangular



Straight Flare

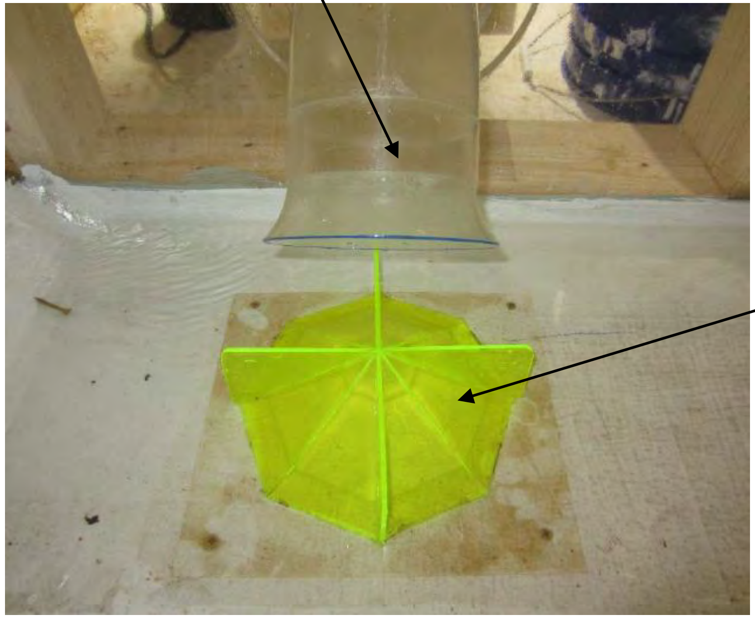


Example – Upgrade Existing Intake

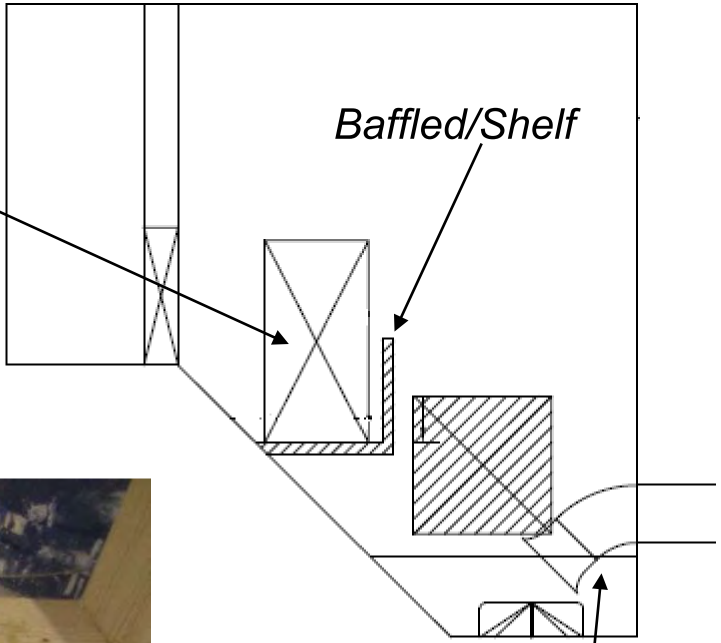
Design Modifications:

- Add baffled shelf and new openings
- Add 45 deg bend and flare
- Add vaned cone
- Close lower crossover gate

Vortices Forming with Existing Intake Arrangement



Modified Pump Intake Arrangement

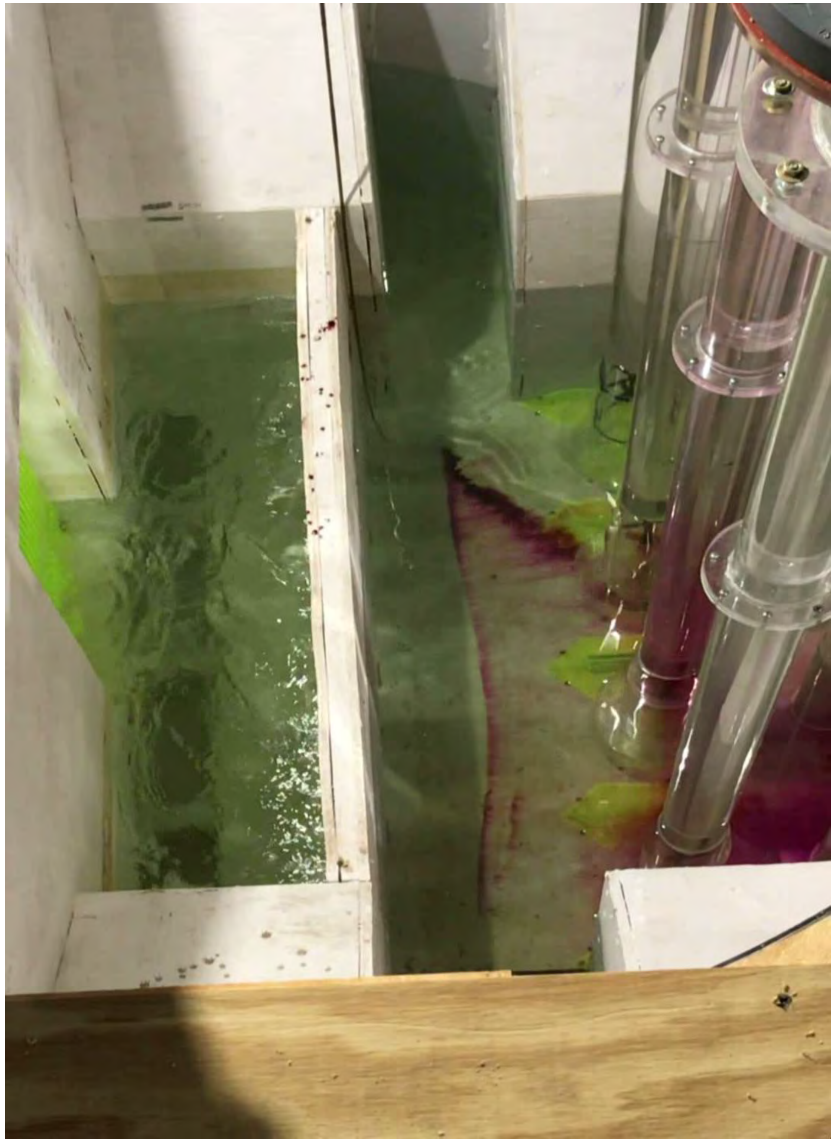


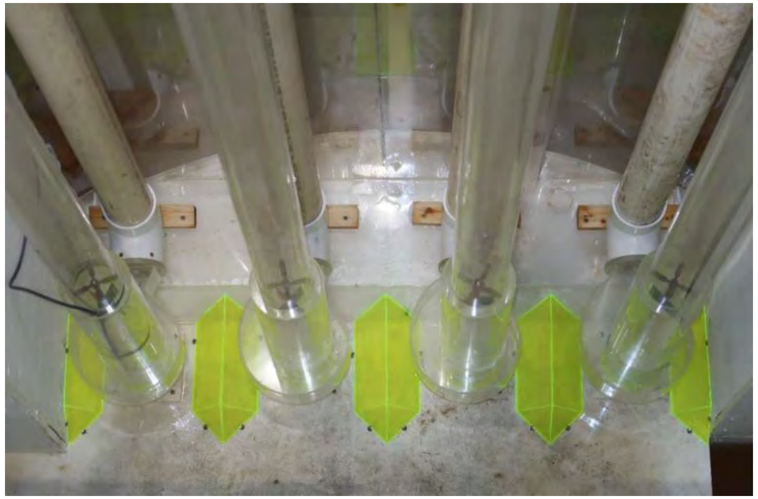
Example – Confirm Intake Design

Design:

- 42 mgd
- Stormwater Pumping Station
- 4 pumps each 9,725 gpm
- 1 Screen channel
- Baffled Wet Well

Confirming the baffled wet well design, ANSI/HI 9.8 Appendix E, in a circular intake, w/4 pumps >5,000 gpm

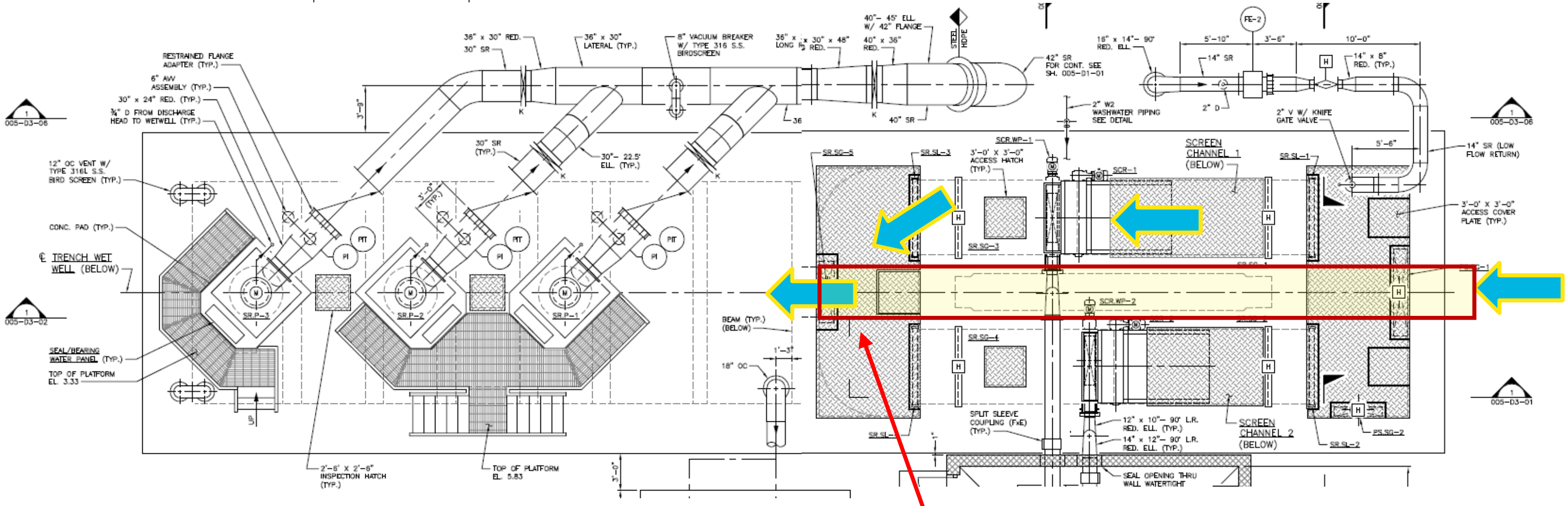




Example – Confirm Intake Design & Pumping Station Optimization

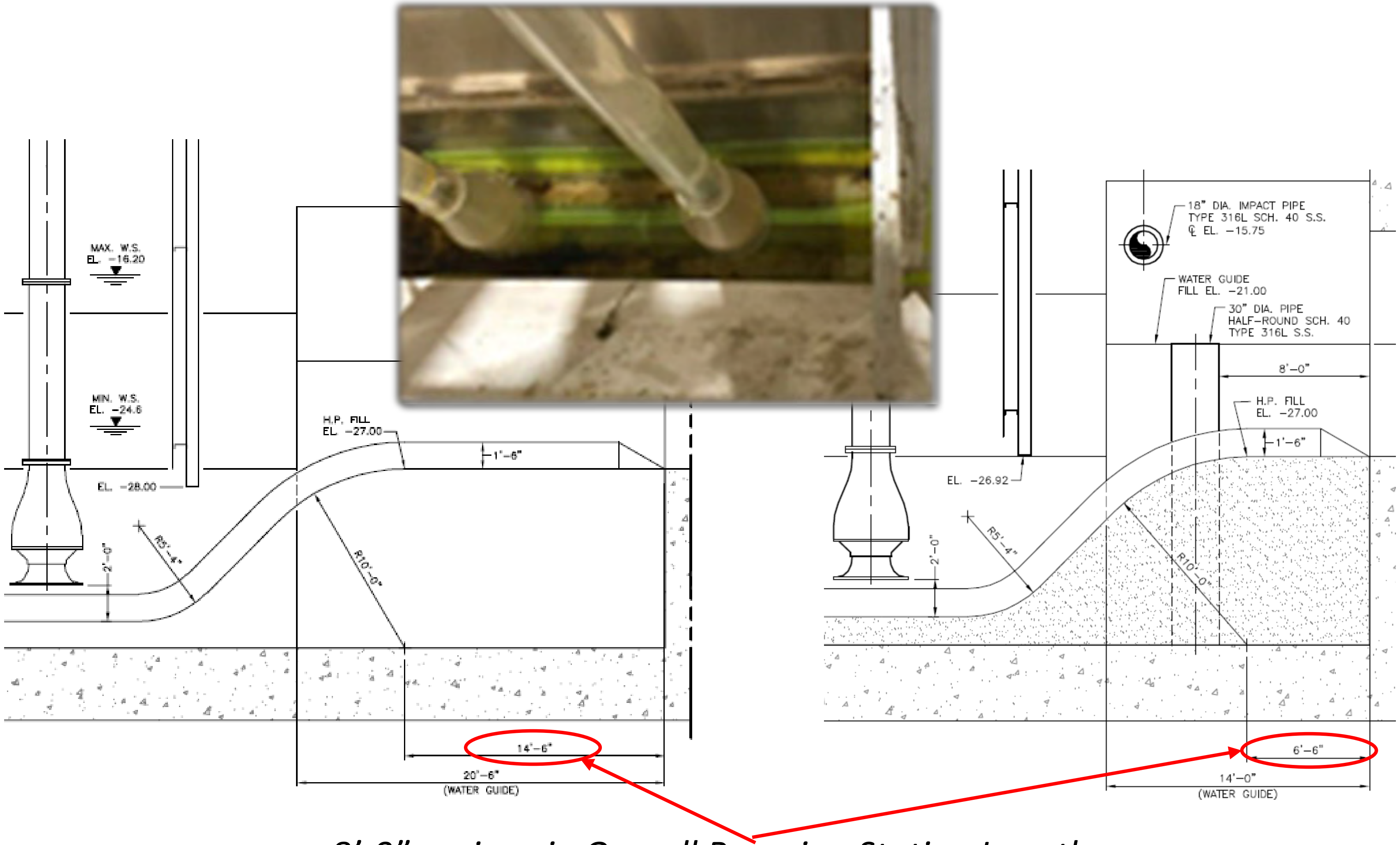
Design:

- 50 mgd
- Raw Wastewater Pumping Station
- 2 Screen channels, 1 operating, 1 standby
- Self-Cleaning Trench Wet Well
- Approach length issues and options



*ANSI/HI 9.8 recommends **8 x Dp** Straight Run Upstream of Wet Well*

Example – Confirm Intake Design & Pumping Station Optimization



8'-0" savings in Overall Pumping Station Length

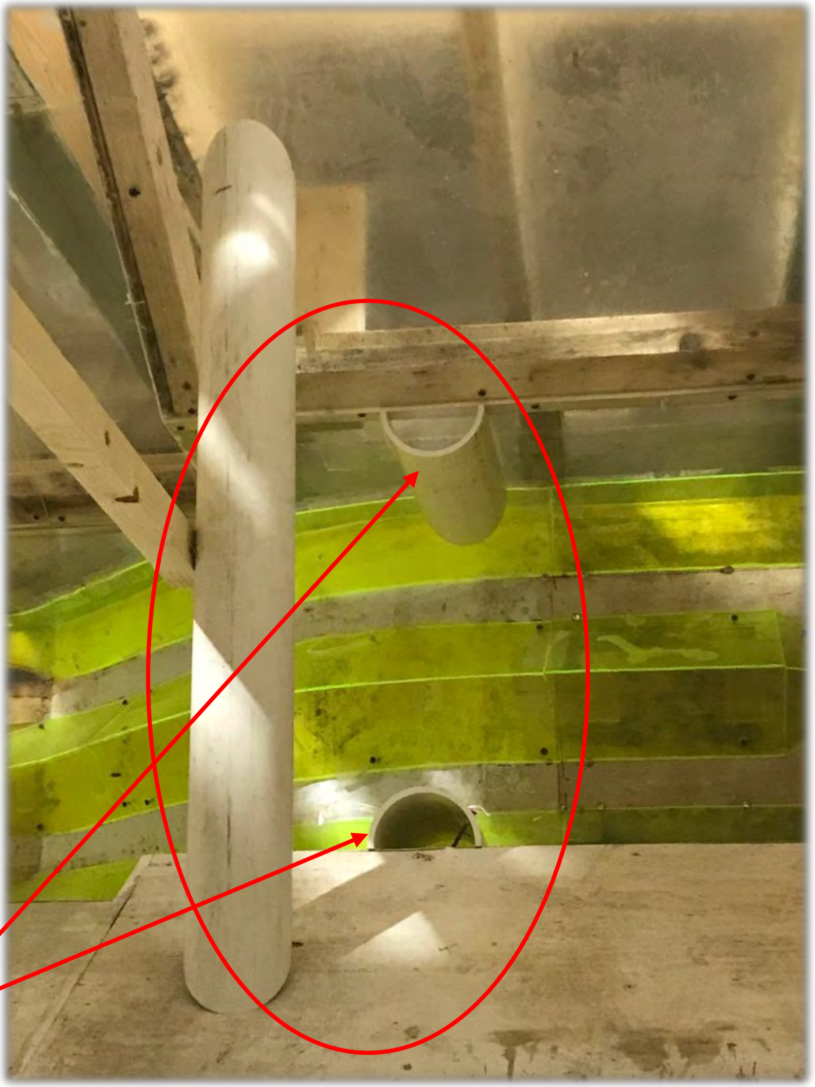
Example – Confirm Intake Design & Pumping Station Optimization

Design:

- Wet well can't be constructed with a length in accordance with ANSI/HI 9.8 or is a wet well length increased by 8'-0" required to compensate for the lack of straight approach?
- Can the station be reduced in length on the confined site and can we reduce construction cost?
- Conduct physical modeling to confirm

Results:

- Modeling showed shorter wet well adequate
- Modeling showed skewed flow pattern into the wet well, 30" diameter half rounds added to mitigate issue and use shorter wet well

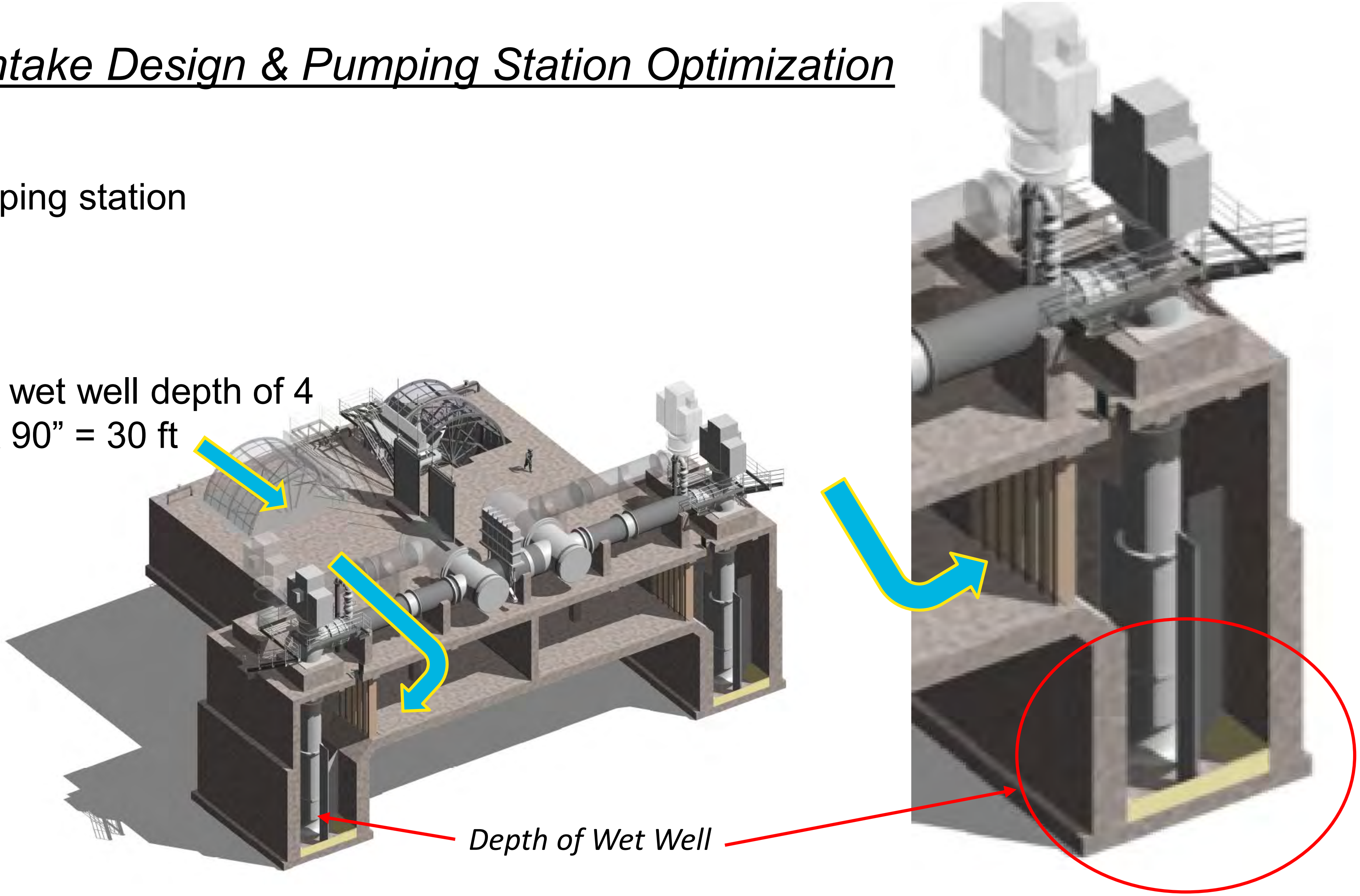


30" Half Rounds

Example – Confirm Intake Design & Pumping Station Optimization

Design:

- 646 mgd Filter Influent pumping station
- Confined wet well
- Pump Bell Diameter: 90”
- ANSI/HI 9.8 recommends a wet well depth of 4 x D which in this case is 4 x 90” = 30 ft



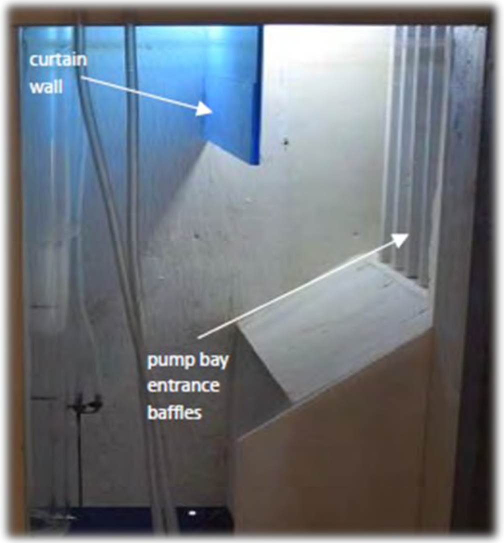
Example - Confirm Intake Design & Pumping Station Optimization

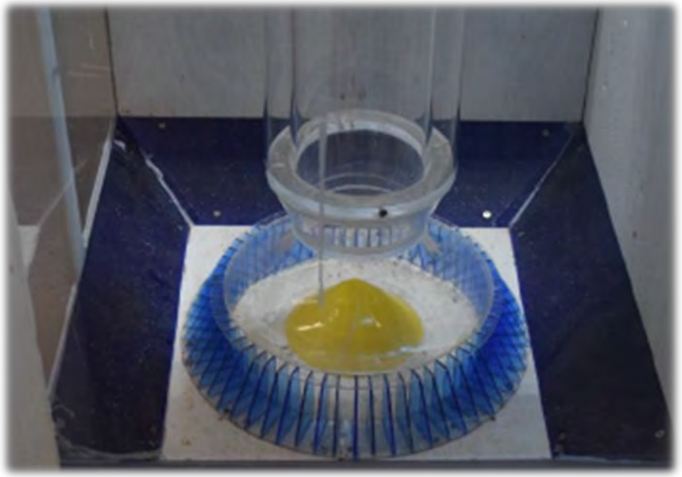
Design:

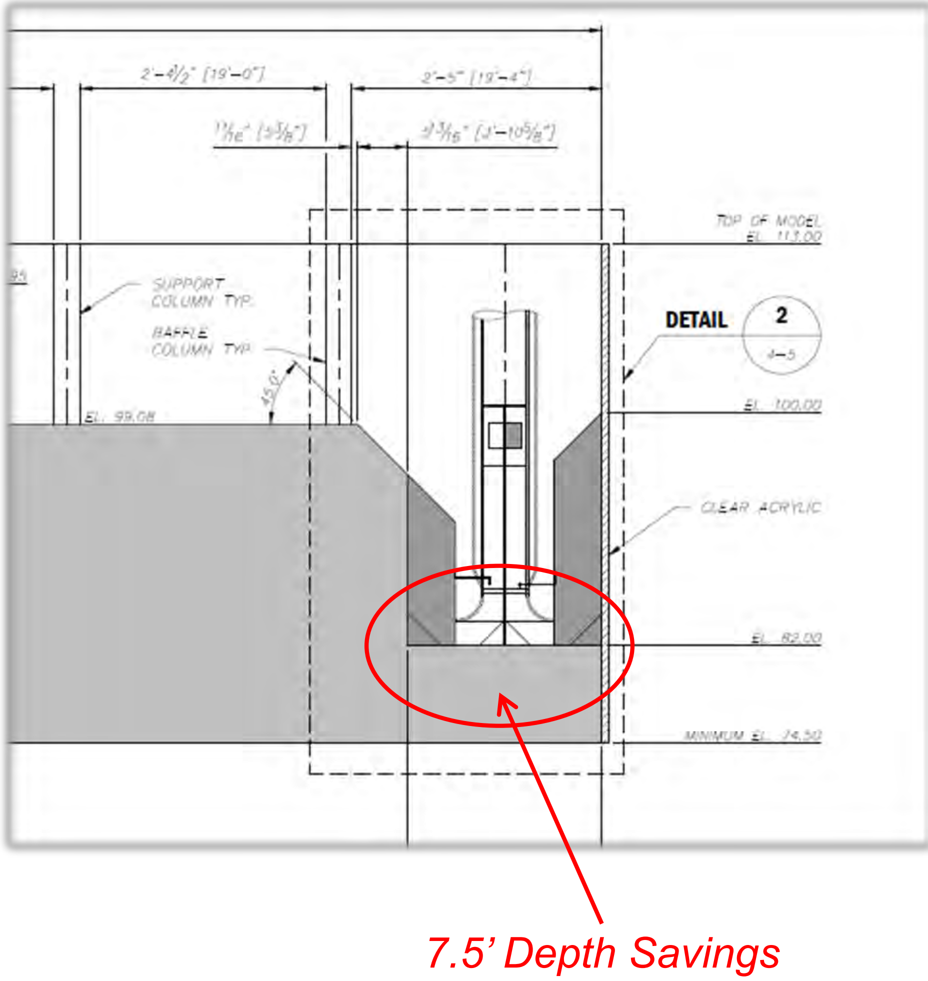
- Can the wet well be constructed with a depth of 3 x D, saving 7’-6” of depth and reduce construction cost?
- Conduct physical modeling to confirm

Results:

- Modeling showed 3 x D could be utilized with adding simple curtain wall and vaned basket







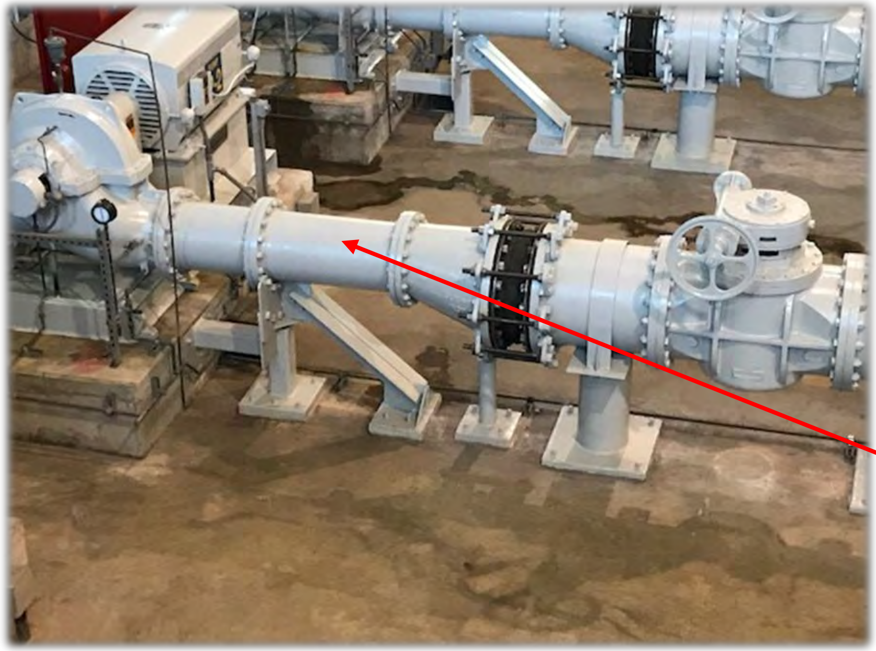
Example - Troubleshooting Problems with an Existing Facility

Problem:

- Premature pump wear and of interior of pump casing
- Pump suction piping arrangement not in accordance with good practice or in accordance with ANSI/HI 9.6.6

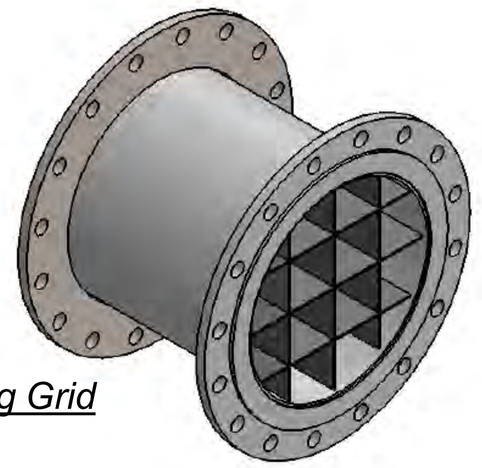
Existing Suction Piping with Eccentric Reducer at Pump Suction Nozzle

Example - Troubleshooting Problems with an Existing Facility



Solution:

- Move eccentric reducer from pump suction nozzle to upstream location at least as much as HI 9.6.6 recommends
- Conduct physical modeling to confirm
- Model recommended addition of flow straightening grid due to unstable flow patterns in suction piping due to multiple bends and plug valve with rectangular reduced area port opening



Flow Straightening Grid

Example - Troubleshooting Problems with an Existing Facility

Problem:

- Premature pump wear and damage to interior of pump casing
- Pump suction piping arrangement not in accordance with good practice and ANSI/HI 9.6.6

Damaged Pump Casing

Existing Suction Piping

Example - Troubleshooting Problems with an Existing Facility

Physical Modeling of Pump Intake

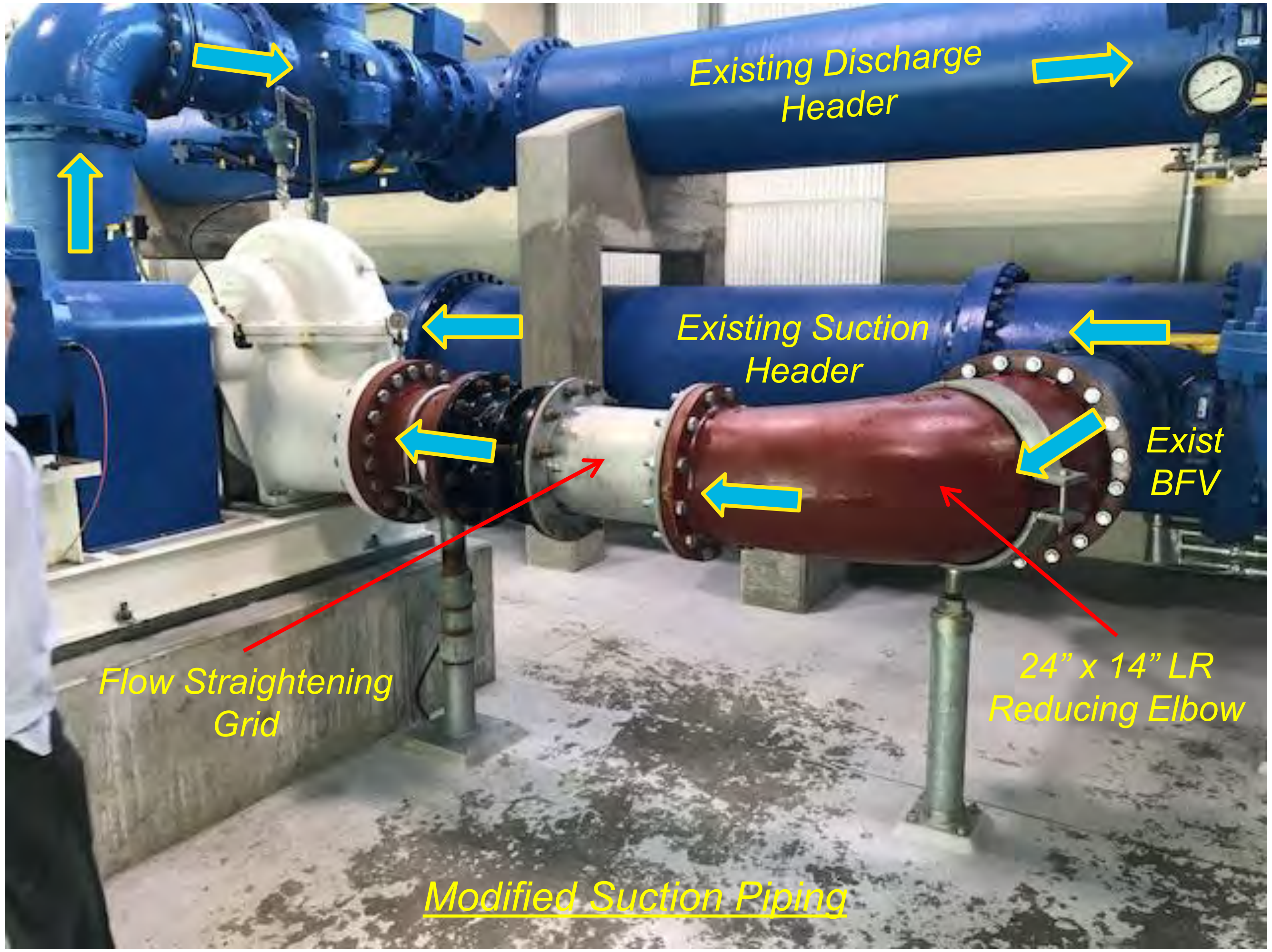
Solution:

- Keep suction piping header and pump in as installed configuration
- Eliminate eccentric reducer joint at pump suction nozzle
- Revise suction elbow to reducing elbow with a ratio of 1.6 in/out
- Add flow straightening grid
- Conduct physical modeling to confirm

Results:

- Modeling with subsequent field testing confirming model results
- Improved pump performance
- Increased pumping capacity approximately 1 mgd/pump
- Premature wear mitigated

Example - Troubleshooting Problems with an Existing Facility

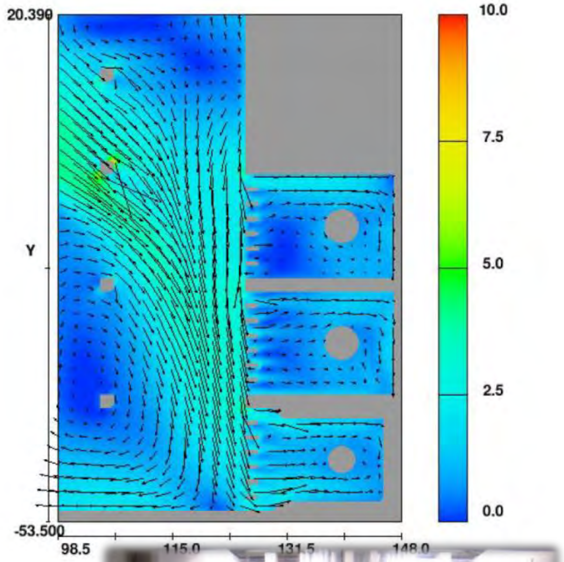


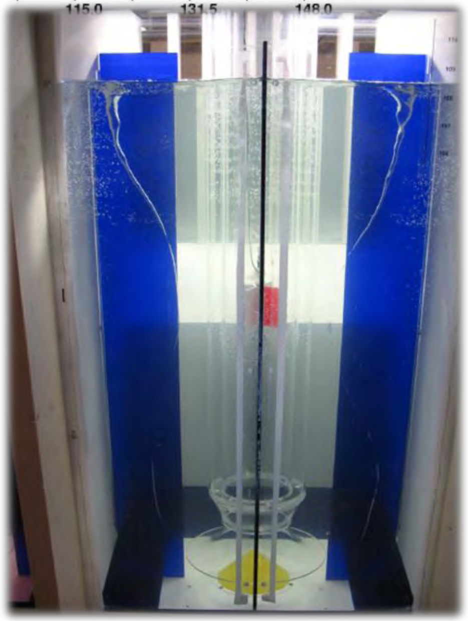
Physical Modeling or CFD ?

CFD and Physical hydraulic modeling are reliable tools for developing cost effective designs and design improvements to pump intakes and each need to be used as appropriate

CFD is a good tool to:

- Determine the type of intake where there are alternatives
- Define the controlling hydraulics for the physical model study
- Minimize extent of physical modeling
- To check areas of solids deposition and not good to simulate vortex activity





Physical model studies are conducted to ensure pump performance is in compliance with ANSI/HI 9.8 acceptance criteria, ***CFD is currently not an acceptable method to show compliance with ANSI/HI 9.8 acceptance criteria***.

Physical modeling is required for final verification of performance prior to construction, saves investment and gives peace of mind to the design engineers and facility owners

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