Willamette Water Supply
Our Reliable Water


# Taking a test drive – How physical modeling can help achieve optimal performance and maximize existing infrastructure

April 26, 2018

# Acknowledgements


- Mike Britch, P.E. – WWSP
- Matthew Gribbins, P.E. – WWSP
- Darren Hinton, P.E., Ph.D – NHC
- Thomas Demlow, M.S., P.E. – NHC

# Agenda

- Project background
- Physical model testing plan
- Results
- Conclusions and next steps

# PROJECT BACKGROUND

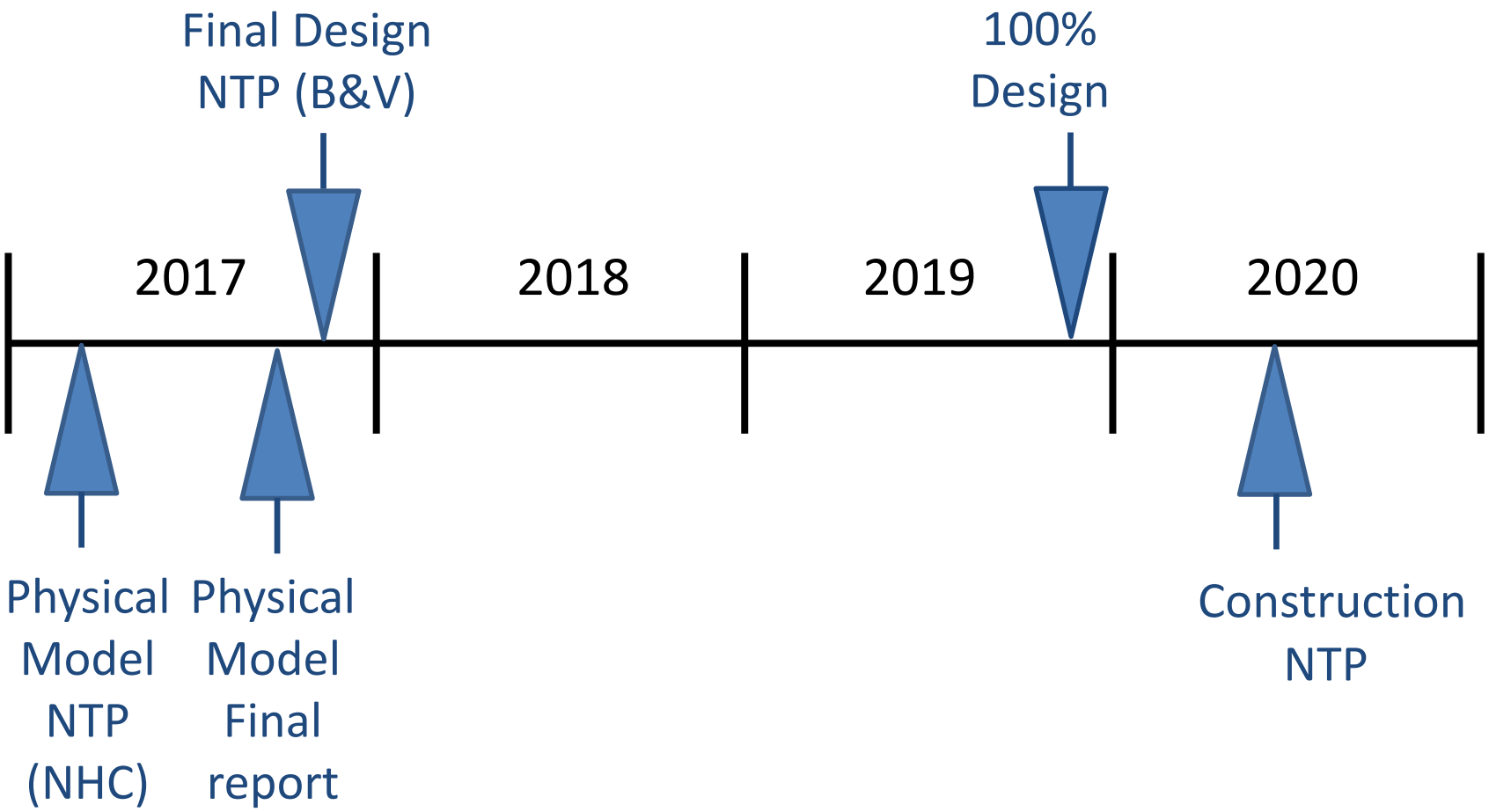

# WWSP Program Components

- Modified water intake
- New water filtration plant
- Water reservoirs
- 30+ miles of large diameter pipeline

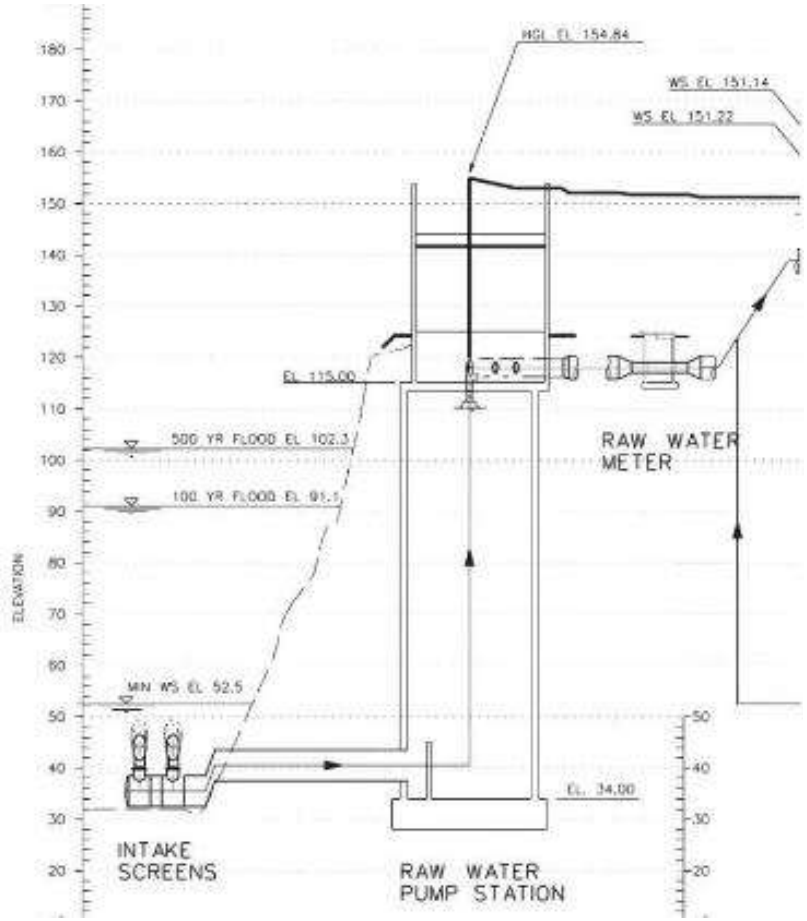
# Raw Water Facilities (RWF_1.0) Background

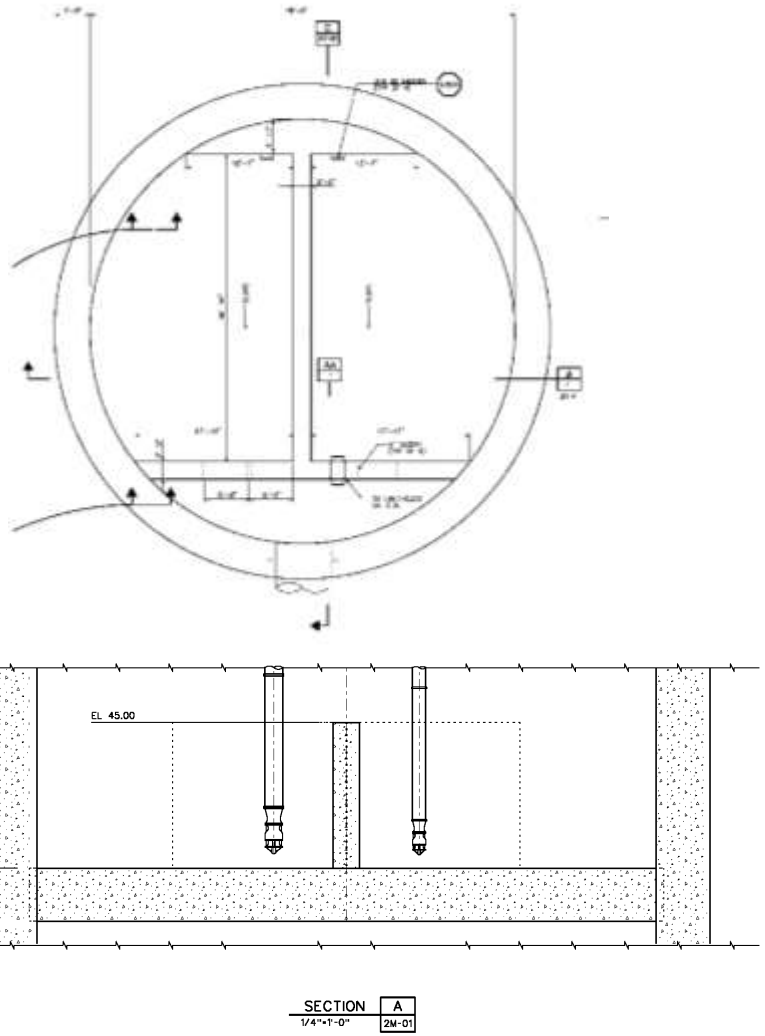
## Expansion of existing raw water facilities at the WRWTP

# RWF Project Timeline



# Existing Infrastructure Sized for Expansion



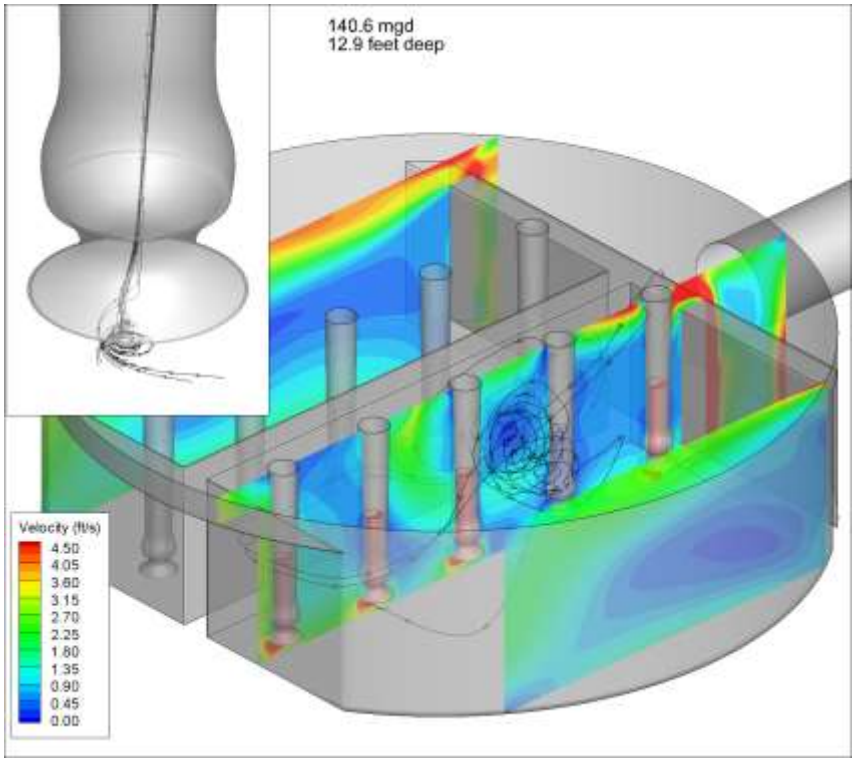
# Existing Raw Water Pump Station

# Physical Modeling Provides Confidence to System Owners

- Original capacity of 120 mgd
- Desired capacity of 150 mgd
- CFD modeling indicates pumps do not meet all Hydraulic Institute (HI) metrics
- Potential solution identified
- HI ANSI 9.8 recommends physical model for pump station with flows over 100,000 gpm or 144 mgd

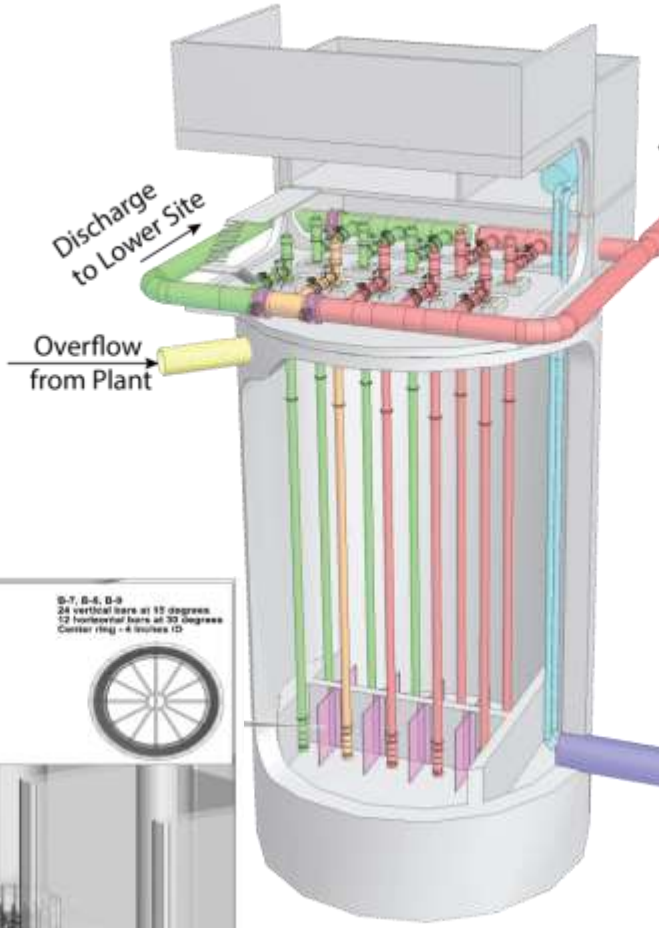
# Computational Fluid Dynamic Modeling of Proposed Upgrade

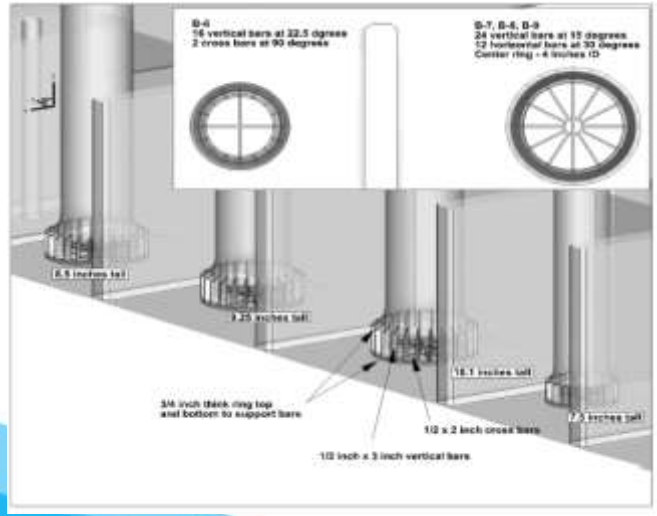
- Used for preliminary hydraulic evaluation
- Found no fatal flaws with pump intake hydraulics



# Constraints of Existing Infrastructure

- Existing plant must maintain operations
- Need seismically resilient solution
- Structural changes are challenging



# Pre-Work to Inform Physical Model

- Survey of existing infrastructure
- Calculation of screen losses

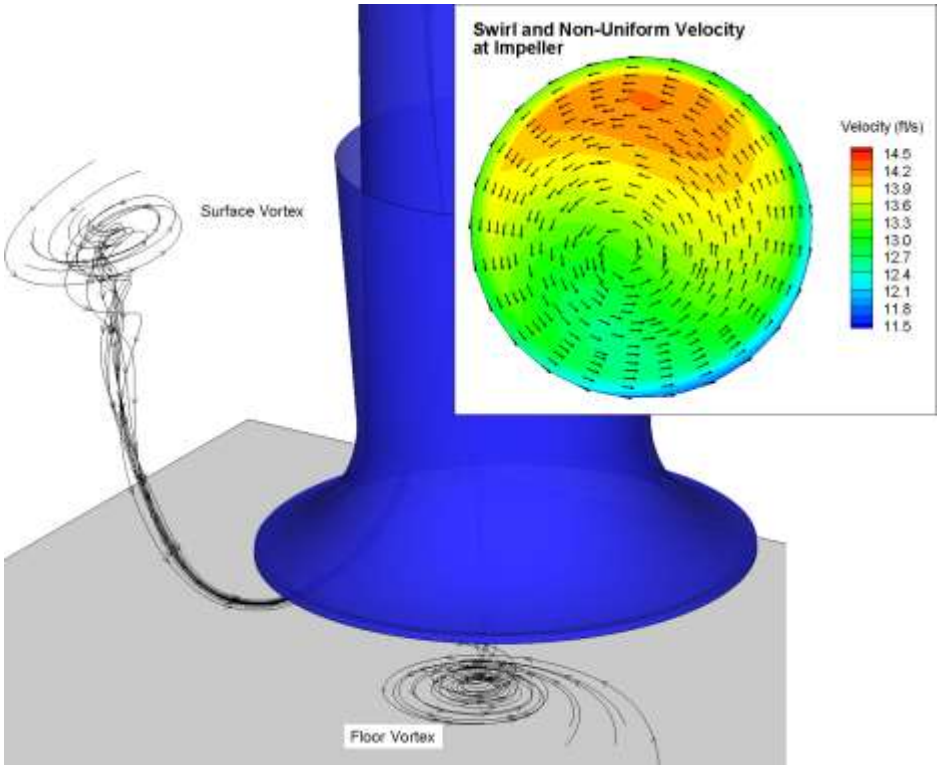
# PHYSICAL MODEL TESTING PLAN

# Objectives

- Determine if wet well provides satisfactory approach flow that meets 2012 ANSI/Hydraulic Institute (HI) 9.8 Pump Intake Design Standard
- If approach flow does not meet the HI Standard, then develop modifications to produce acceptable flow to the pumps

# Check Hydraulic Institute Standards for Problematic Pump Intake Conditions

- Vortex formation
- Air entrainment
- Pre-swirl
- Non-uniform velocity distribution at impeller
- Excessive turbulence at impeller



# Hydraulic Conditions Evaluated with a Scale Physical Model

- Model Recommendations
  - Free Water Surface:
    - >100,000 gpm total flow
    - >40,000 gpm pump flow
    - >5,000 gpm pump flow circular wetwell
  - Closed Conduit Pump Applications:
    - >5,000-10,000 gpm pump flow
- Model Scale Requirements:
  - F = 1:1
  - E: OK if R and W met
  - R > 6.4x 10^2
  - W > 240

Froude Number $F = \frac{U}{\sqrt{gL}} = \frac{\text{Inertial Force}}{\text{Gravity Force}}$

Euler Number $E = \frac{\Delta P}{\rho U^2} = \frac{\text{Pressure Force}}{\text{Inertial Force}}$

Reynolds Number $R = \frac{UL}{\nu} = \frac{\text{Inertial Force}}{\text{Viscous Force}}$

Weber Number $W = \frac{U}{\sqrt{\frac{\sigma}{\rho L}}} = \frac{\text{Inertial Force}}{\text{Surface Tension Force}}$

where:
- $U$ = characteristic flow velocity
- $g$ = gravitational acceleration
- $L$ = characteristic length
- $\rho$ = density of fluid
- $\Delta P$ = pressure difference
- $\nu$ = kinematic fluid viscosity
- $\sigma$ = surface tension of the fluid

# HI Model Pump Performance Criteria

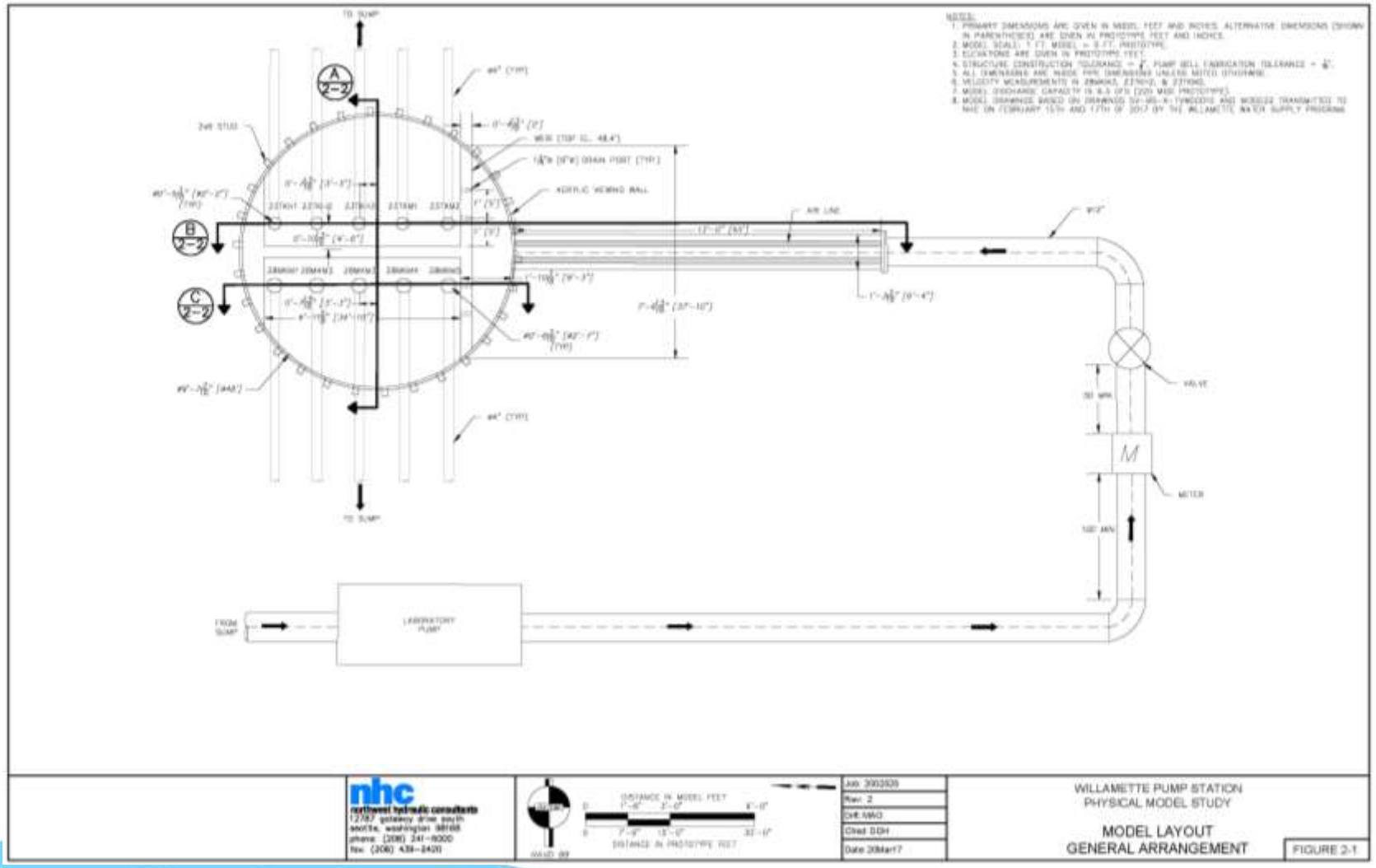
- Velocity within ±10% of mean at pump throat
- Turbulence intensity less than 10%
- Flow swirl less than 5 degrees from axial
- Minimal vortex activity

# 1 to 5 Scale Selected Based on Typical Pumps for the Planned Operation

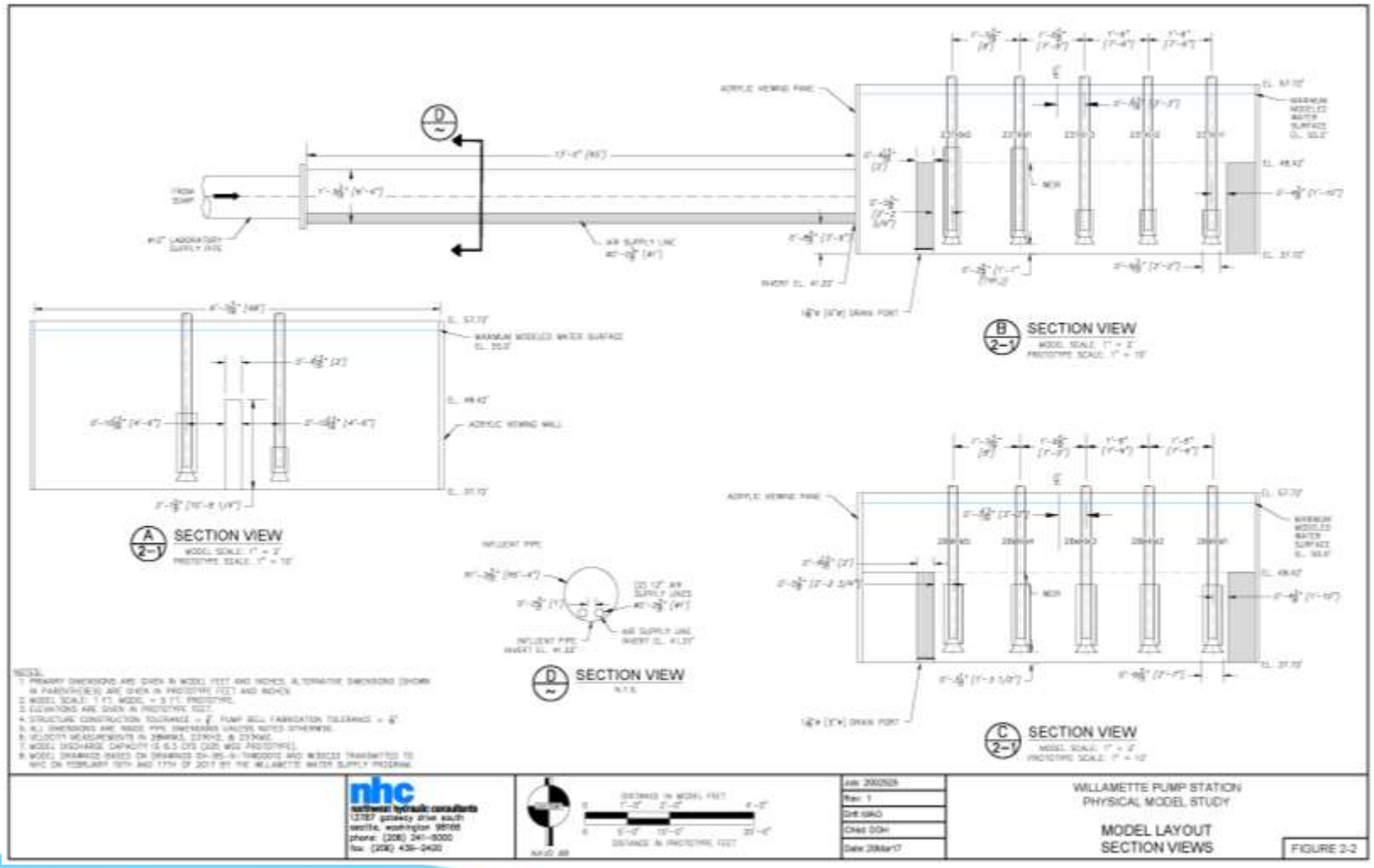
- 26-inch Bells at 13.3 mgd
- 31-inch Bells at 19.5 mgd

| Pump | Reynolds (bell) | Weber |
|---|---|---|
| Willamette 28MKM | $1.1 \times 10^5$ | 1,330 |
| Willamette 23TKH | $1.0 \times 10^5$ | 1,320 |
| Willamette 23TKM | $9.0 \times 10^4$ | 1,040 |

# Model Layout



# Model Layout



# Model Construction

# Physical Model Test Conditions

| Test No. | | Water Level in Wet Well | Operating Pumps, mgd | | | | | | | | | | Total Pump Station Discharge |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wet Well | | | | | | | | | | |
| | | (ft) | 28MKM1 | 28MKM2 | 28MKM3 | 28MKM4 | 28MKM5 | 23TKH1 | 23TKH2 | 23TKH3 | 23TKM1 | 23TKM2 | (mgd) |
| Initial Design Testing[a] | ID1 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | ID2 | 52.7 | - | 18.00 | 18.50 | 18.50 | 18.50 | 13.30 | 13.30 | 13.30 | 13.30 | 13.30 | 140.0 |
| | ID3 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | ID4 | 52.7 | - | - | - | - | 19.60 | - | - | 15.00 | 13.30 | - | 47.9 |
| | ID5 | 52.7 | 19.60 | 19.60 | 19.60 | - | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| Design Development Testing[a] | DD | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| Ultimate Capacity Testing | UC1 | TBD[c] | - | | | | | | | 30 | 13.30 | 13.30 | 140.0 |
| | UC2 | 52.7 | - | | | | | | | 00 | 13.30 | 13.30 | TBD[d] |
| Final Documentation Testing | FD1 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD2 | 52.7 | 19.60 | 19.60 | 19.60 | - | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD3 | 52.7 | 19.60 | - | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | - | 13.30 | 13.30 | 135.0 |
| | FD4 | 55.0 | 19.60 | - | 19.60 | 19.60 | 19.60 | | 15.00 | 15.00 | 13.30 | 13.30 | 135.0 |
| | FD5 | 52.7 | 19.60 | - | - | 19.60 | 19.60 | 15.00 | 15.00 | - | - | 13.30 | 102.1 |
| | FD6 | 52.7 | 19.60 | 19.60 | - | - | 19.60 | 15.00 | 15.00 | - | - | 13.30 | 102.1 |
| | FD7 | 52.7 | 19.60 | - | 19.60 | - | - | - | 15.00 | - | - | 13.30 | 67.5 |
| | FD8 | 52.7 | - | - | 19.60 | - | 19.60 | - | - | 15.00 | 13.30 | - | 67.5 |
| | FD9 | 52.7 | - | - | 19.60 | 19.60 | - | - | 15.00 | - | - | - | 54.2 |
| | FD10 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | FD11 | 52.7 | Max | Max | Max | Max | Max | - | - | - | - | - | 131.0 |
| | FD12 | 55.0 | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |

**Initial design testing**

# Physical Model Test Conditions

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Wet Well | | | | | | | | | | |
| | | (ft) | 28MKM1 | 28MKM2 | 28MKM3 | 28MKM4 | 28MKM5 | 23TKH1 | 23TKH2 | 23TKH3 | 23TKM1 | 23TKM2 | (mgd) |
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| | ID2 | 52.7 | - | 18.00 | 18.50 | 18.50 | 18.50 | 13.30 | 13.30 | 13.30 | 13.30 | 13.30 | 140.0 |
| | ID3 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | ID4 | 52.7 | - | - | - | - | 19.60 | - | - | 15.00 | 13.30 | - | 47.9 |
| | ID5 | 52.7 | 19.60 | 19.60 | 19.60 | - | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| Design Development Testing[a] | DD | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| Ultimate Capacity Testing | UC1 | TBD[c] | - | 18.00 | 18.50 | 18.50 | 18.50 | 13.30 | 13.30 | 13.30 | 13.30 | 13.30 | 140.0 |
| | UC2 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | TBD[d] |
| Final Documentation Testing | FD1 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD2 | 52.7 | | | | | | | | | | 13.30 | 150.0 |
| | FD3 | 52.7 | | | | | | | | | | 13.30 | 135.0 |
| | FD4 | 55.0 | | | | | | | | | | 13.30 | 135.0 |
| | FD5 | 52.7 | | | | | | | | | | 13.30 | 102.1 |
| | FD6 | 52.7 | | | | | | | | | | 13.30 | 102.1 |
| | FD7 | 52.7 | 19.60 | - | 19.60 | - | - | - | 15.00 | - | - | 13.30 | 67.5 |
| | FD8 | 52.7 | - | - | 19.60 | - | 19.60 | - | - | 15.00 | 13.30 | - | 67.5 |
| | FD9 | 52.7 | - | - | 19.60 | 19.60 | - | - | 15.00 | - | - | - | 54.2 |
| | FD10 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | FD11 | 52.7 | Max | Max | Max | Max | Max | - | - | - | - | - | 131.0 |
| | FD12 | 55.0 | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |

**Design development testing**

# Physical Model Test Conditions

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| | ID3 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | ID4 | 52.7 | - | - | - | - | 19.60 | - | - | 15.00 | 13.30 | - | 47.9 |
| | ID5 | 52.7 | 19.60 | 19.60 | 19.60 | - | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| Design Development Testing[a] | DD | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
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| | UC2 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | TBD[d] |
| Final Documentation Testing | FD1 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD2 | 52.7 | | | | | | | | | | 13.30 | 150.0 |
| | FD3 | 52.7 | | | | | | | | | | 13.30 | 135.0 |
| | FD4 | 55.0 | | | | | | | | | | 13.30 | 135.0 |
| | FD5 | 52.7 | | | | | | | | | | 13.30 | 102.1 |
| | FD6 | 52.7 | | | | | | | | | | 13.30 | 102.1 |
| | FD7 | 52.7 | 19.60 | - | 19.60 | - | - | - | 15.00 | - | - | 13.30 | 67.5 |
| | FD8 | 52.7 | - | - | 19.60 | - | 19.60 | - | - | 15.00 | 13.30 | - | 67.5 |
| | FD9 | 52.7 | - | - | 19.60 | 19.60 | - | - | 15.00 | - | - | - | 54.2 |
| | FD10 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | FD11 | 52.7 | Max | Max | Max | Max | Max | - | - | - | - | - | 131.0 |
| | FD12 | 55.0 | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |

**Ultimate capacity testing**

# Physical Model Test Conditions

| Test No. | | Water Level in Wet Well | Operating Pumps, mgd | | | | | | | | | | Total Pump Station Discharge |
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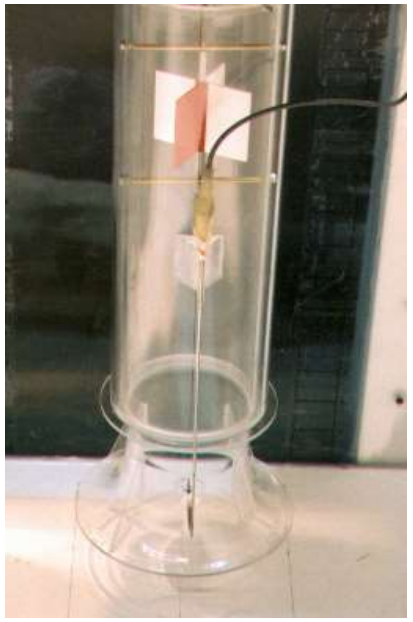
| | ID2 | 52.7 | - | 18.00 | 18.50 | 18.50 | 18.50 | 13.30 | 13.30 | 13.30 | 13.30 | 13.30 | 140.0 |
| | ID3 | 55.0 | | | | | | | | | | 7.00 | 24.5 |
| | ID4 | 52.7 | | | | | | | | | | - | 47.9 |
| | ID5 | 52.7 | | | | | | | | | | 13.30 | 150.0 |
| Design Development Testing[a] | DD | 52.7 | | | | | | | | | | 13.30 | 150.0 |
| Ultimate Capacity Testing | UC1 | TBD[c] | | | | | | | | | | 13.30 | 140.0 |
| | UC2 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | TBD[d] |
| Final Documentation Testing | FD1 | 52.7 | - | 19.60 | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD2 | 52.7 | 19.60 | 19.60 | 19.60 | - | 19.60 | 15.00 | 15.00 | 15.00 | 13.30 | 13.30 | 150.0 |
| | FD3 | 52.7 | 19.60 | - | 19.60 | 19.60 | 19.60 | 15.00 | 15.00 | - | 13.30 | 13.30 | 135.0 |
| | FD4 | 55.0 | 19.60 | - | 19.60 | 19.60 | 19.60 | | 15.00 | 15.00 | 13.30 | 13.30 | 135.0 |
| | FD5 | 52.7 | 19.60 | - | - | 19.60 | 19.60 | 15.00 | 15.00 | - | - | 13.30 | 102.1 |
| | FD6 | 52.7 | 19.60 | 19.60 | - | - | 19.60 | 15.00 | 15.00 | - | - | 13.30 | 102.1 |
| | FD7 | 52.7 | 19.60 | - | 19.60 | - | - | - | 15.00 | - | - | 13.30 | 67.5 |
| | FD8 | 52.7 | - | - | 19.60 | - | 19.60 | - | - | 15.00 | 13.30 | - | 67.5 |
| | FD9 | 52.7 | - | - | 19.60 | 19.60 | - | - | 15.00 | - | - | - | 54.2 |
| | FD10 | 55.0 | - | - | - | - | 10.00 | - | - | 7.50 | - | 7.00 | 24.5 |
| | FD11 | 52.7 | Max | Max | Max | Max | Max | - | - | - | - | - | 131.0 |
| | FD12 | 55.0 | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max | Max |

**Witness test followed be Documentation testing**

# RESULTS

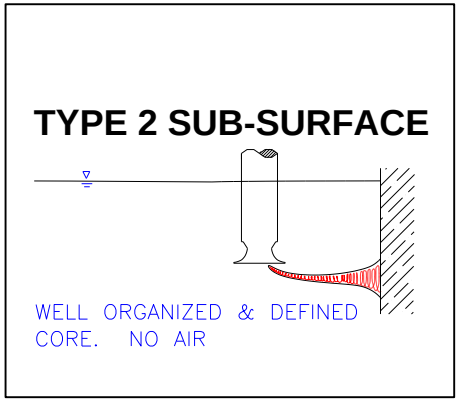
# Initial Test Results - Swirl

- Flow pre-swirl too high
  - 12° average, 14° maximum
    - Effective rotation difference leads to cavitation
    - Deviation from best efficiency point



# Initial Test Results, Continued

- Strong Type 2 Vortex Formation
  - Low pressure point leads to localized cavitation
  - Potential air entrainment




# Initial Test Results - Velocity and Turbulence

- Velocity distribution is OK
- Excessive turbulence at impeller
  - Up to 26%
    - Shaft and bearing problems
    - Cavitation
    - Impeller blade fatigue

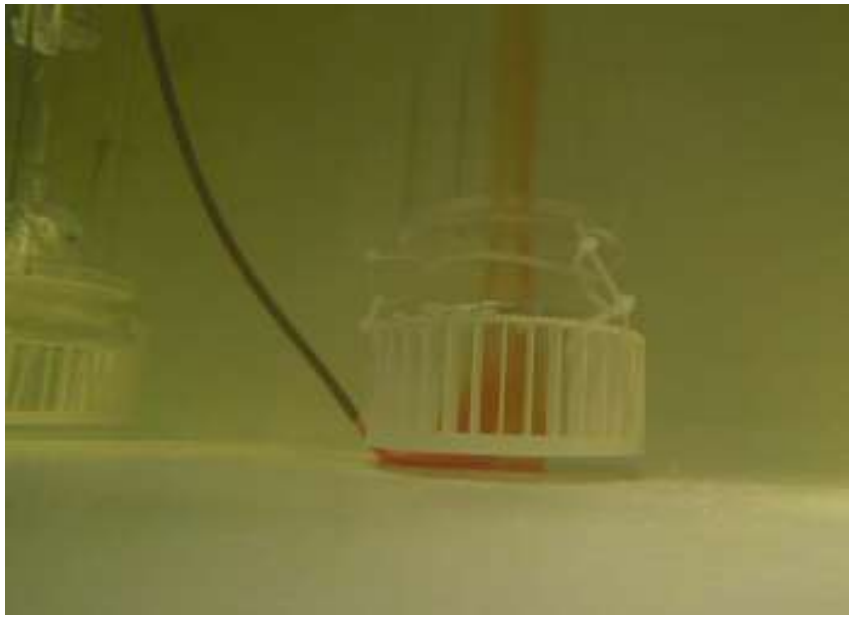
# Recommended Improvements

- Flow conditioning baskets
  - Uniform flow entering pump
  - Optimization of pump performance
  - HI criteria met
  - Extend equipment life
  - Limited shutdown for installation

# RWF_1.0 Physical Model Witness Test

# Flow Conditioning Baskets Addressed Pump Hydraulics

- Vortex's eliminated
- Swirl reduced to maximum of 3°
- Maximum turbulence reduced to 10%
- Maximum Capacity of 196 mgd tested
- Additional Bell Sizes Tested



# CONCLUSIONS AND NEXT STEPS

# Conclusions and Next Steps

- Physical modeling provided needed flow validation for system Owners
- Optimization of existing infrastructure beyond original anticipated capacity
- Basket details will be included in final design suitable for a range of pumps

# Thank you!

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