Sludge Densification with Hydrocyclones

KU Environmental Engineering Conference

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Agenda

1. Introduction to Densified Activated Sludge
2. Case Study for Peak Flow Intensification
3. Case Study for Foam Control and Process Resiliency
4. Case Study of Full-Scale Design
5. Summary

Introduction to Densified Activated Sludge

For Further Reading:
WRF Project #4870 (Sturm, 2020)
WRF Project #5130 (Regmi, 2024)

The Spectrum of Settleability

Conventional Sludge

Few particles > 200 µm

No discrete settling

$SVI_5/SVI_{30} > 1.5$

$SVI_{30} > 100$ ml/g

Densified Sludge

10% particles > 200 µm

Some bioflocculation

$SVI_5/SVI_{30} \sim 1.5$

$SVI_{30} < 100$ ml/g

Aerobic Granular Sludge

70% particles > 200 µm

Settles discreetly

$SVI_5/SVI_{30} = 1.0$

$SVI_{30} \sim 50\text{-}80$ ml/g

Filaments — *Light Flocs* — *Dense Flocs* — *Granules*

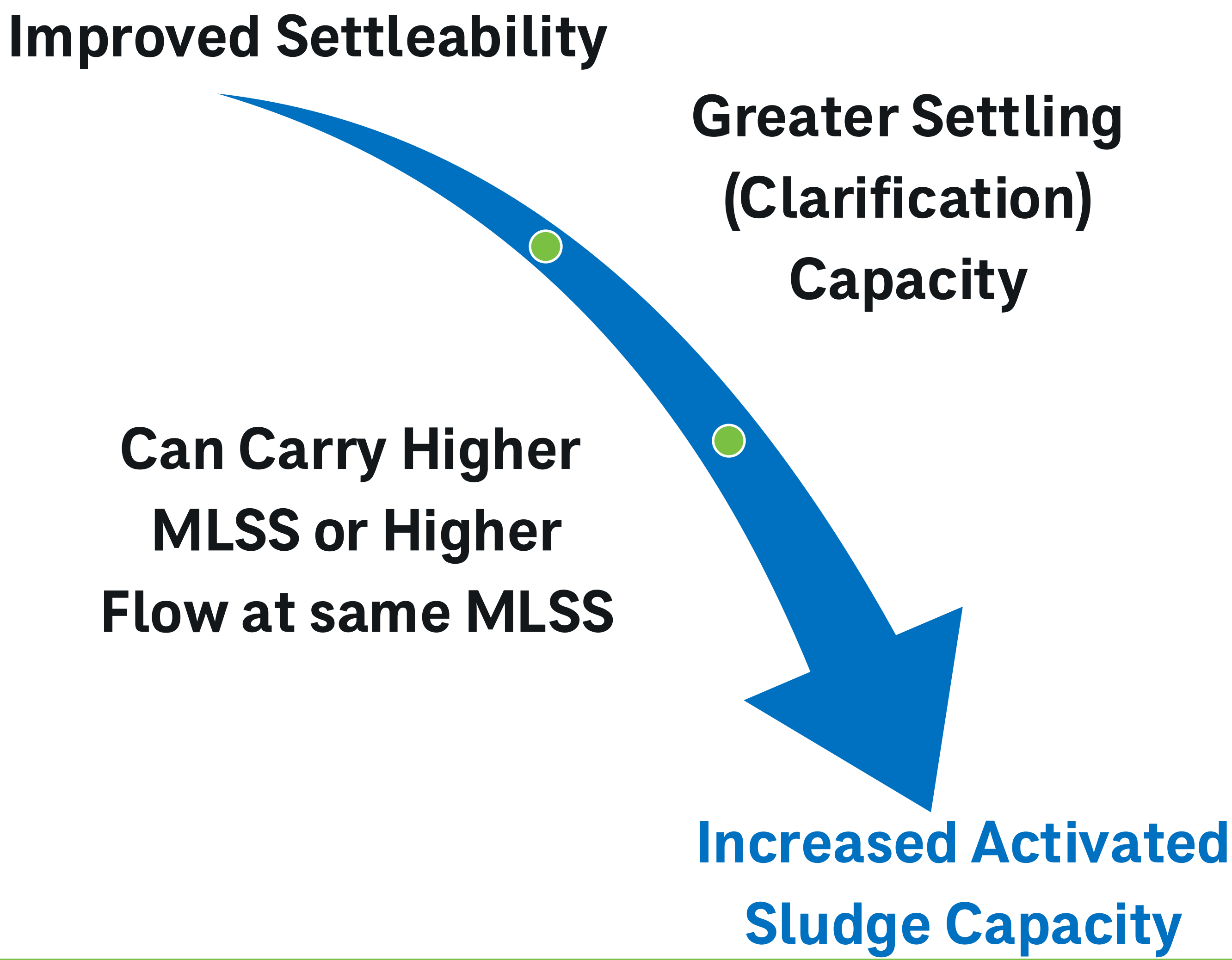
Slowest Settling

Increasing Kinetic Selection

Increasing Physical Selection

Fastest Settling

Why do we Care about Settleability?



How Can a Densified Sludge be Achieved?

Kinetic Selection

- Feast-to-famine conditions promote granule formation

Design features:

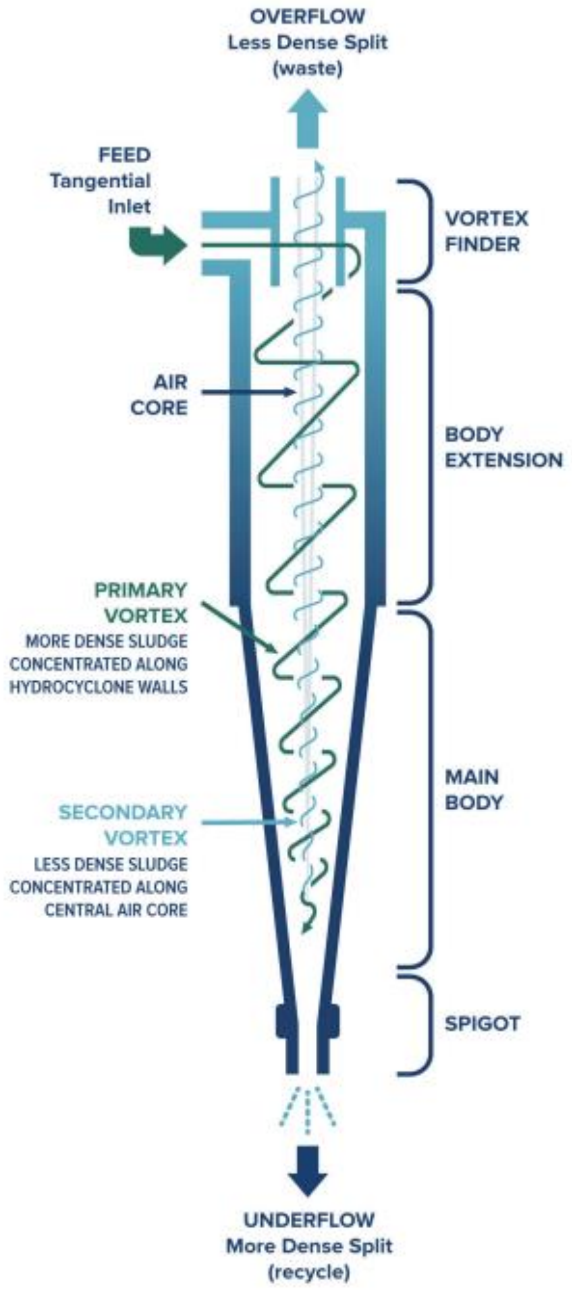
- Bioselectors with High Food-to-Microorganism (F/M) Ratio
- Plug flow reactors
- Anaerobic zones for Biological Phosphorus removal

Physical Selection

- Any mechanism that retains the good-settling bugs and wastes filaments

Design features:

- Surface wasting of mixed liquor instead of Return Activated Sludge (RAS)
- Devices that use gravimetric separation of lighter vs. heavier solids



inDENSE Hydrocyclones for Selective Wasting

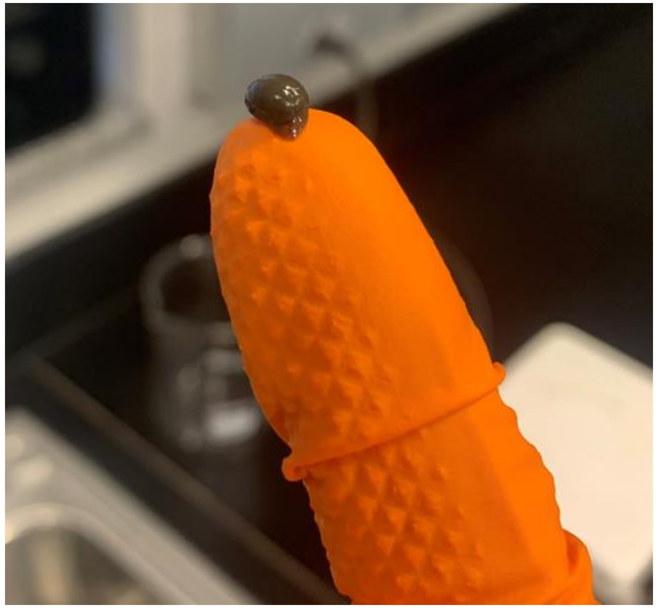
Hydrocyclone
Feed
Biomass

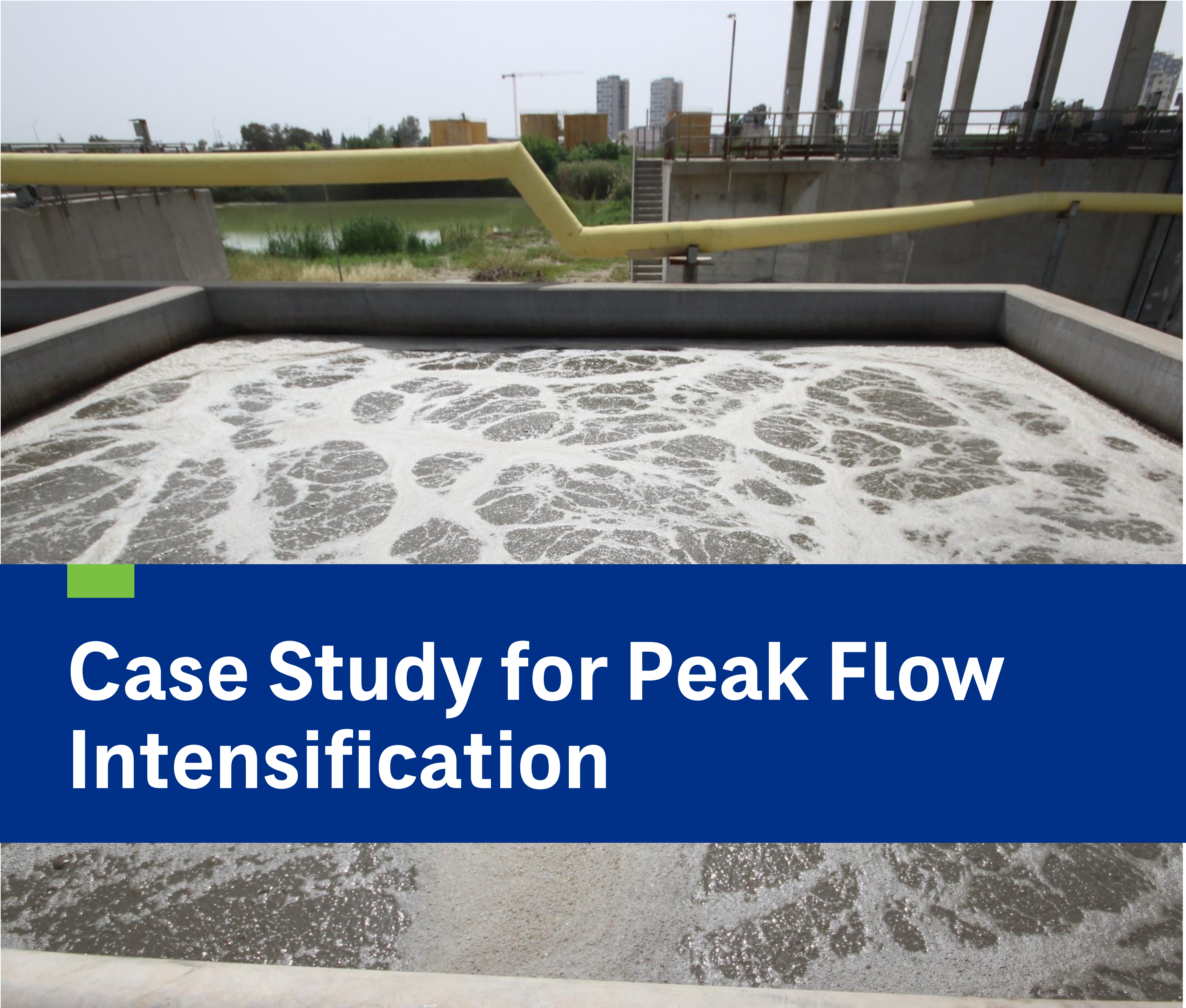
Overflow (WAS)
Biomass

Retained Biomass

Benefits of Selective Wasting with Hydrocyclones

- **Improved settleability**
- **Increased activated sludge system capacity:**
  - Higher Mixed Liquor Suspended Solids (MLSS)
  - Or Higher Flow at same MLSS
  - BNR inside granules under aerobic conditions
- **Enhanced Process Resiliency:**
  - Selectively retain the good bugs (Nitrifiers, PAOs)
  - Waste out the bad bugs (filaments, foam)

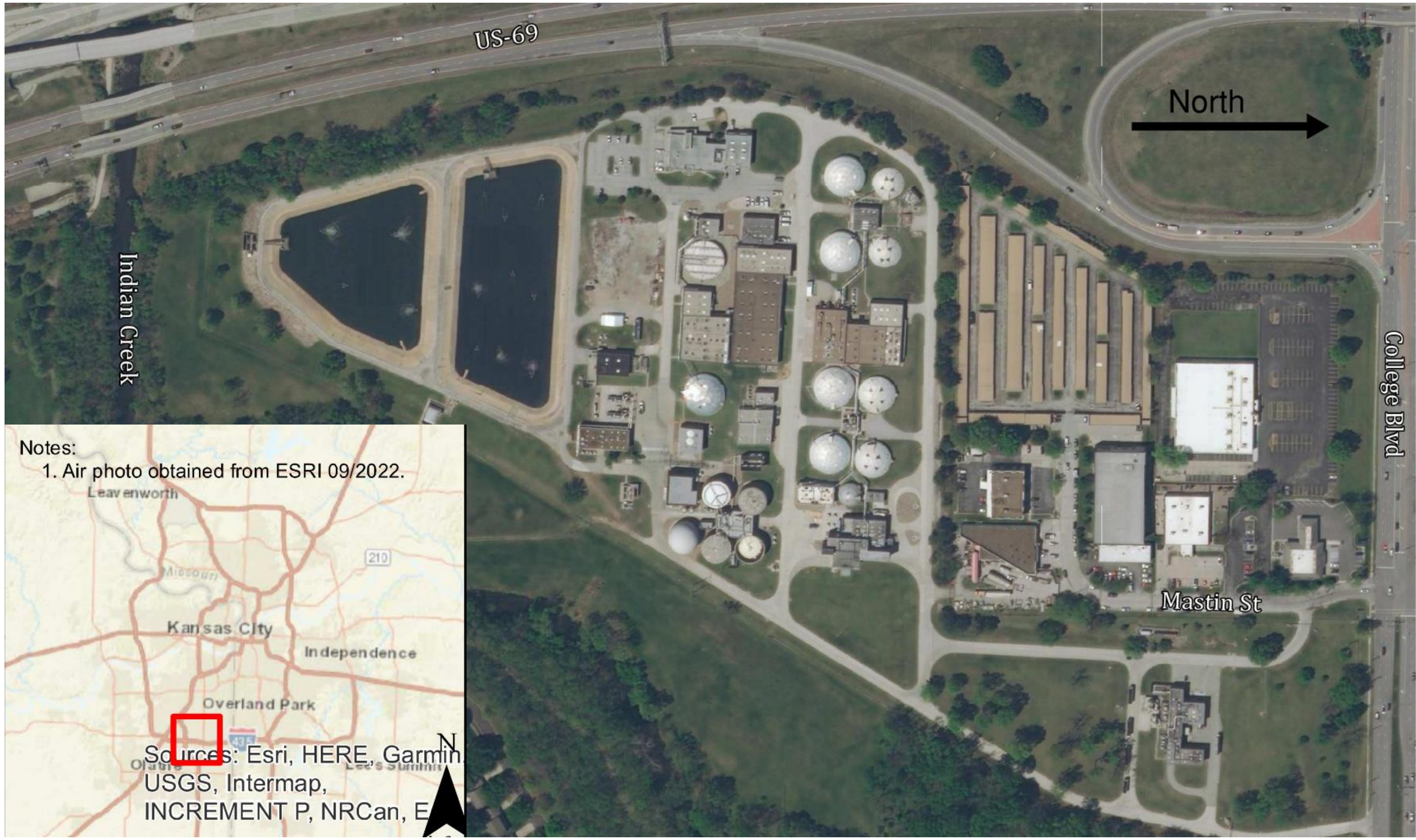




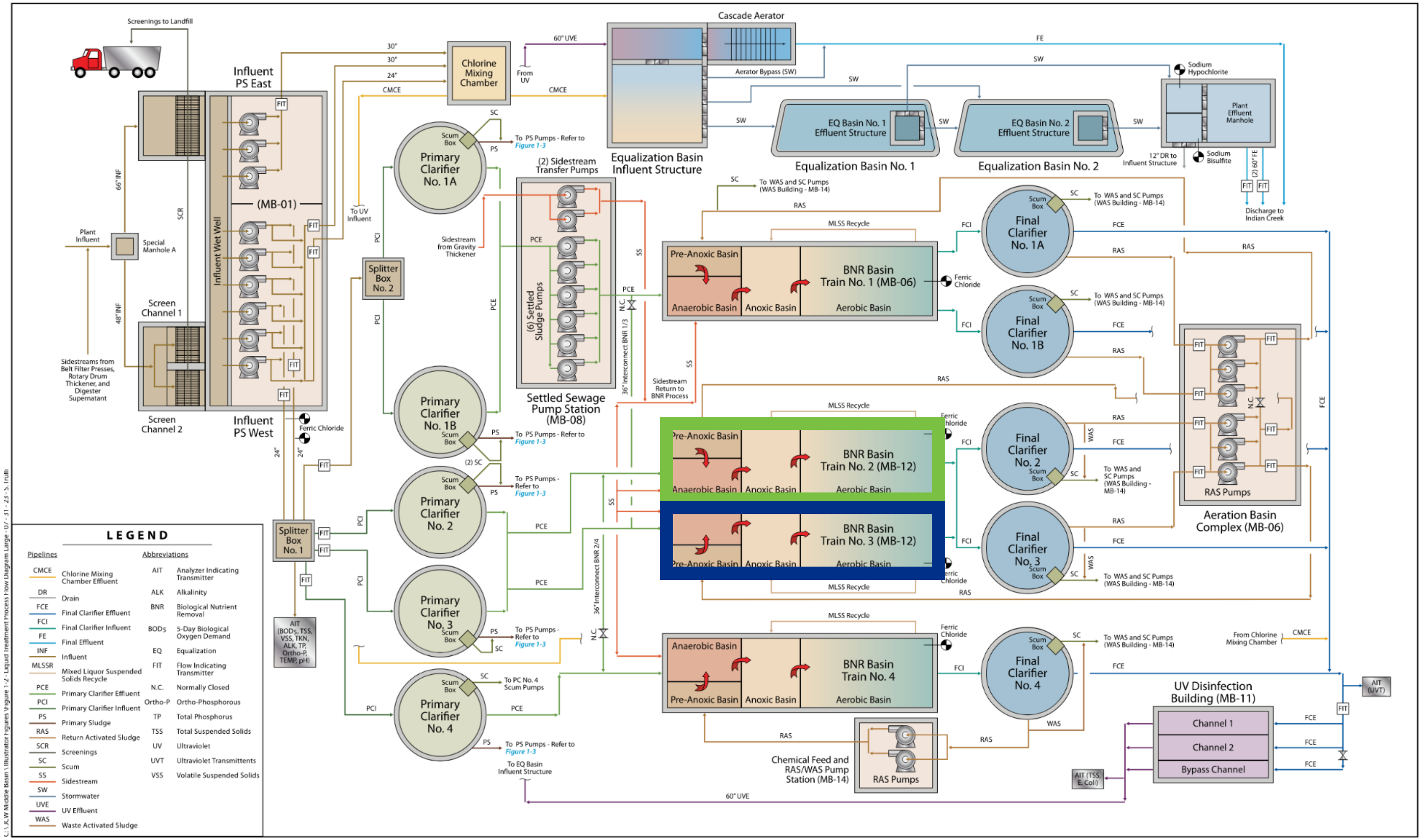
Case Study for Peak Flow Intensification

JCW Douglas L. Smith Middle Basin WWTF

- **Train 1** built in 1980 with biotower trickling filter, polishing lagoons, later converted to Conventional Activated Sludge (CAS)
- **Trains 2 and 3** CAS in 1984
- **Train 4** built in 2010 due to excessive lagoon discharges
  - Voluntarily added BNR
- **Lagoons:**
  - Used when capacity of mechanical plant exceeded
  - When lagoons fill, discharge to Indian Creek after dosing Sodium Hypochlorite (SHC)



Side-by-Side Comparison of Pilot and Control

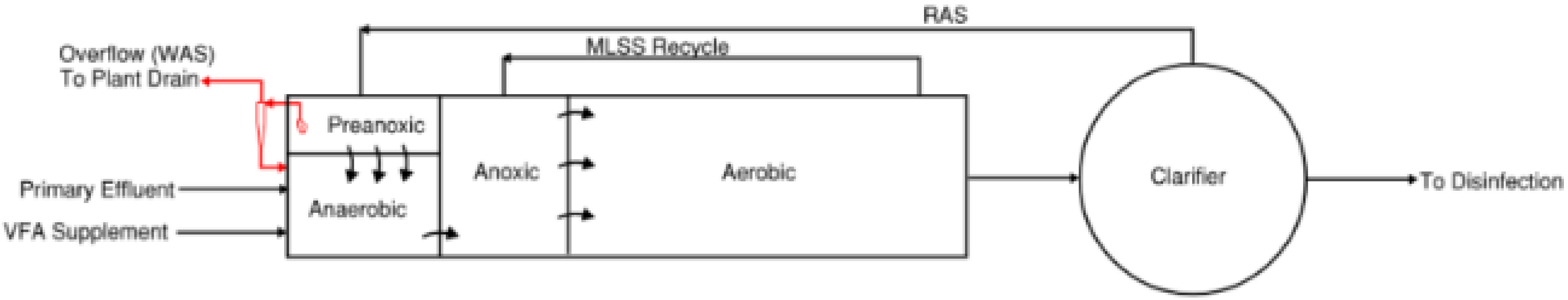


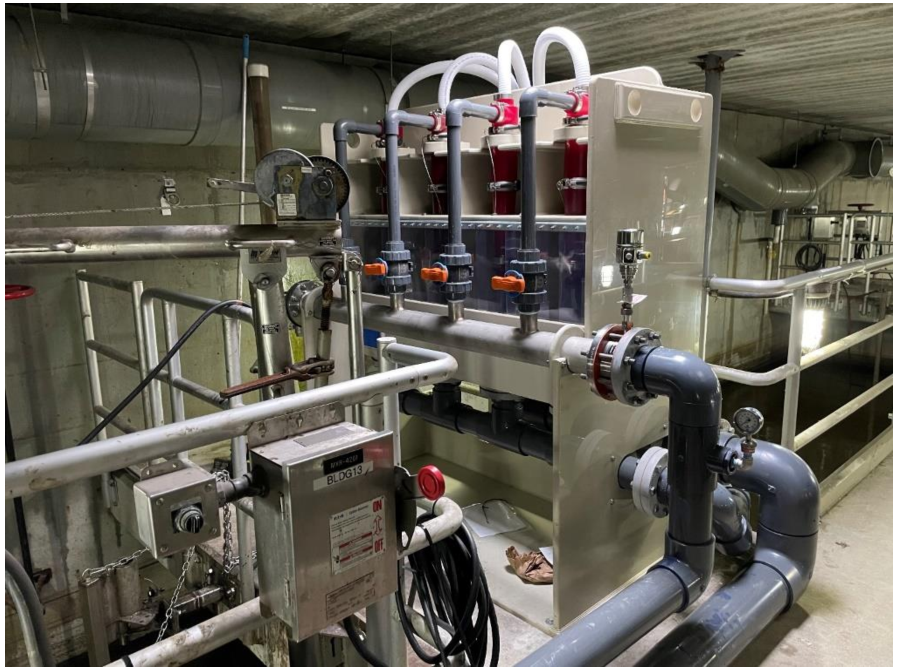
BNR Train 2 = Pilot

BNR Train 3 = Control

- BNR 2 and 3 are the two worst-performing trains for sludge blanket rise
- BNR 2 and 3 are nearly identical
  - Influent flow and SRT were very similar throughout pilot

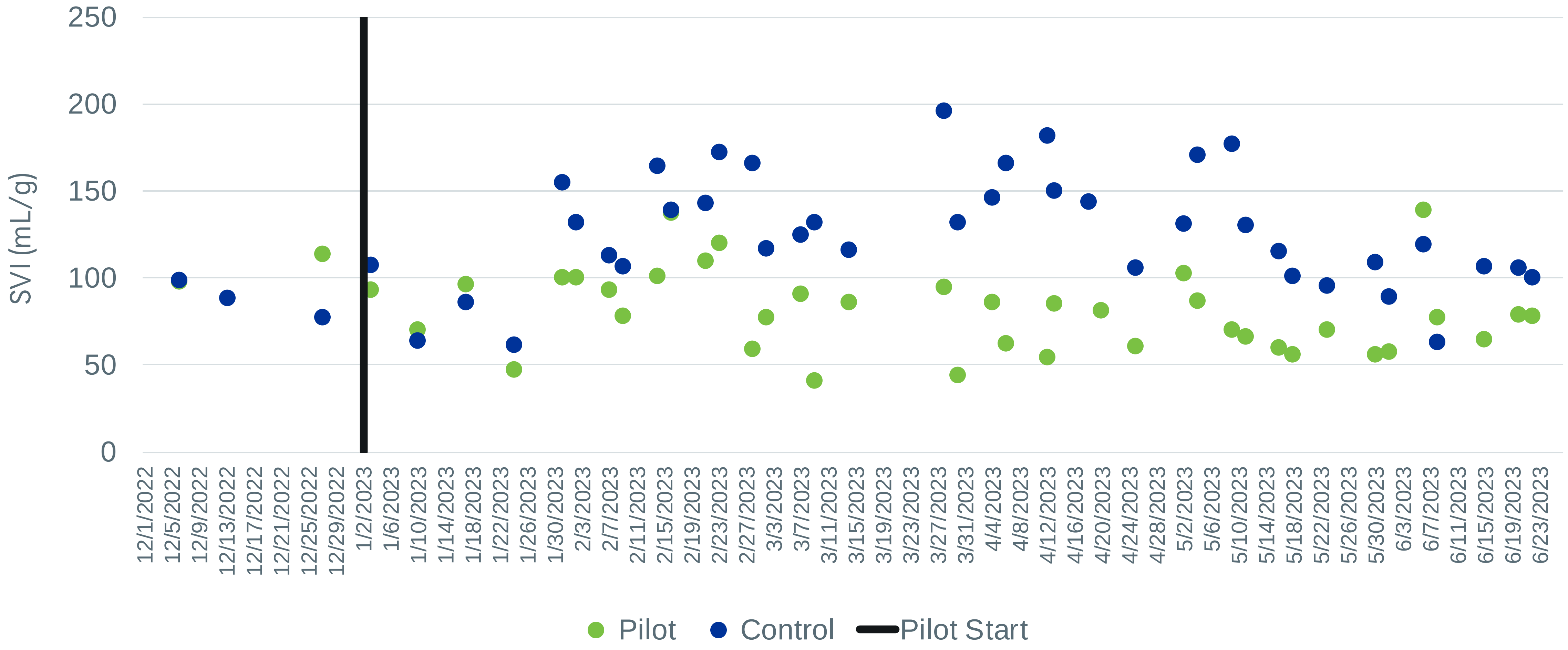
Hydrocyclone Pilot Set-Up at BNR Train 2





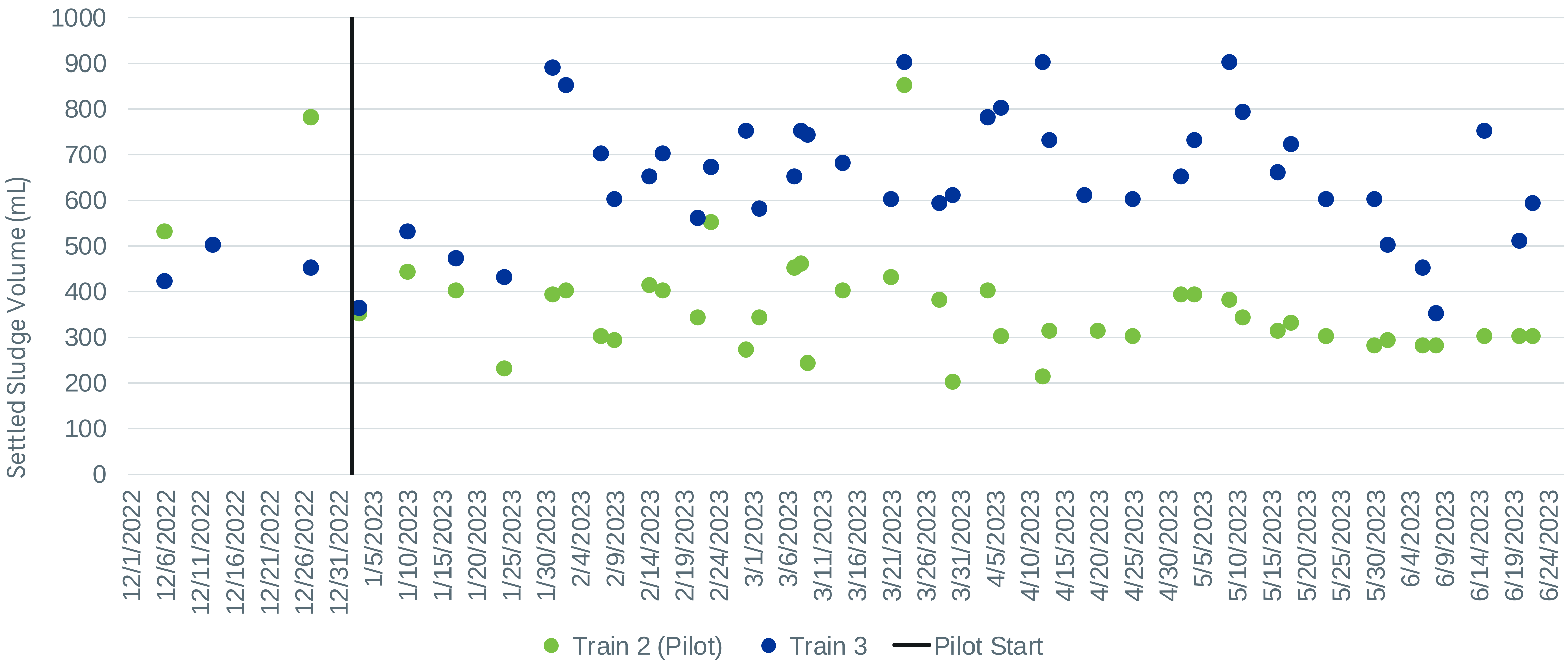
- Submersible RAS feed pump
- Four cyclones:
  - Two with 20-mm tips
  - Two with 18-mm tips
- Monitor inlet feed pressure
- Skid leased for 6 months (Jan to Jun 2023)

Pilot Results: 30-Minute Sludge Volume Index (SVI)



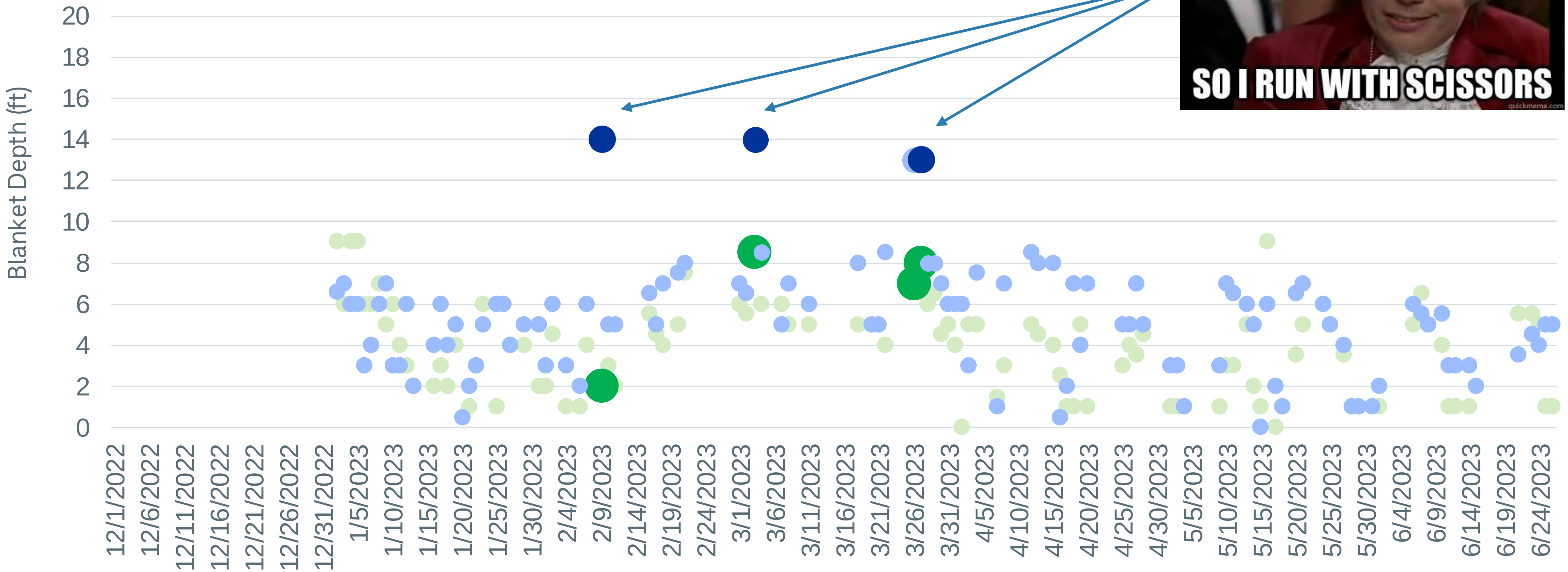
- SVI improvements observed about three weeks after pilot start
- inDENSE SVI was more stable and lower than Control Train SVI

Pilot Results: 5-Minute Settled Sludge Volume



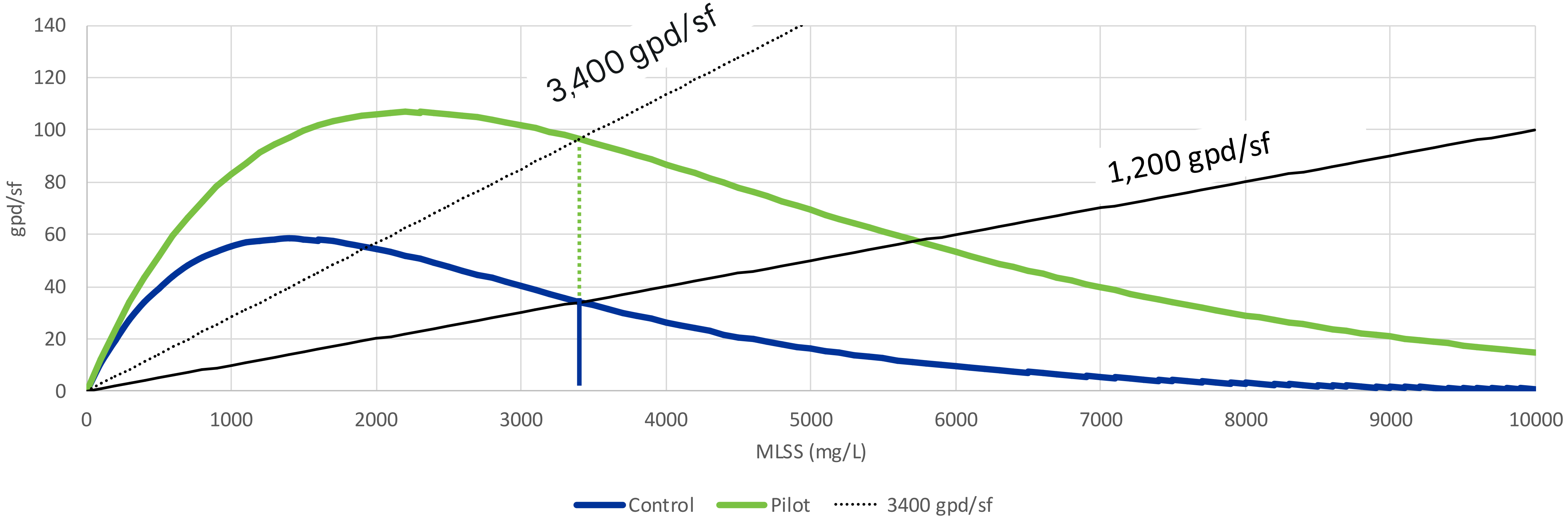
- Substantial difference in settling within 5 minutes between inDENSE vs control train

Pilot Results: Sludge Blankets



- Sludge blanket measurements not normally captured, but collected during pilot
- Lower sludge blankets in inDENSE train compared to control train

Settling Column Tests: Clarifier Solids Flux Curve



- Comparison based on bench-scale settling velocity measurements in July 2023
- Demonstrates inDENSE allows for clarification at higher flow in existing clarifiers

Settling Column Tests: Unexpected Findings

- In comparison to past studies (Daigger, 1995) both the control and inDENSE trains had:
  - Faster settling velocity
  - Worse compaction and thickening

Practical implication:

Higher RAS rates may be needed at some DAS facilities

253 G. T. Daigger *et al.* | Enhanced settling in activated sludge: design and operation considerations | Water Science & Technology | 78.2 | 2018

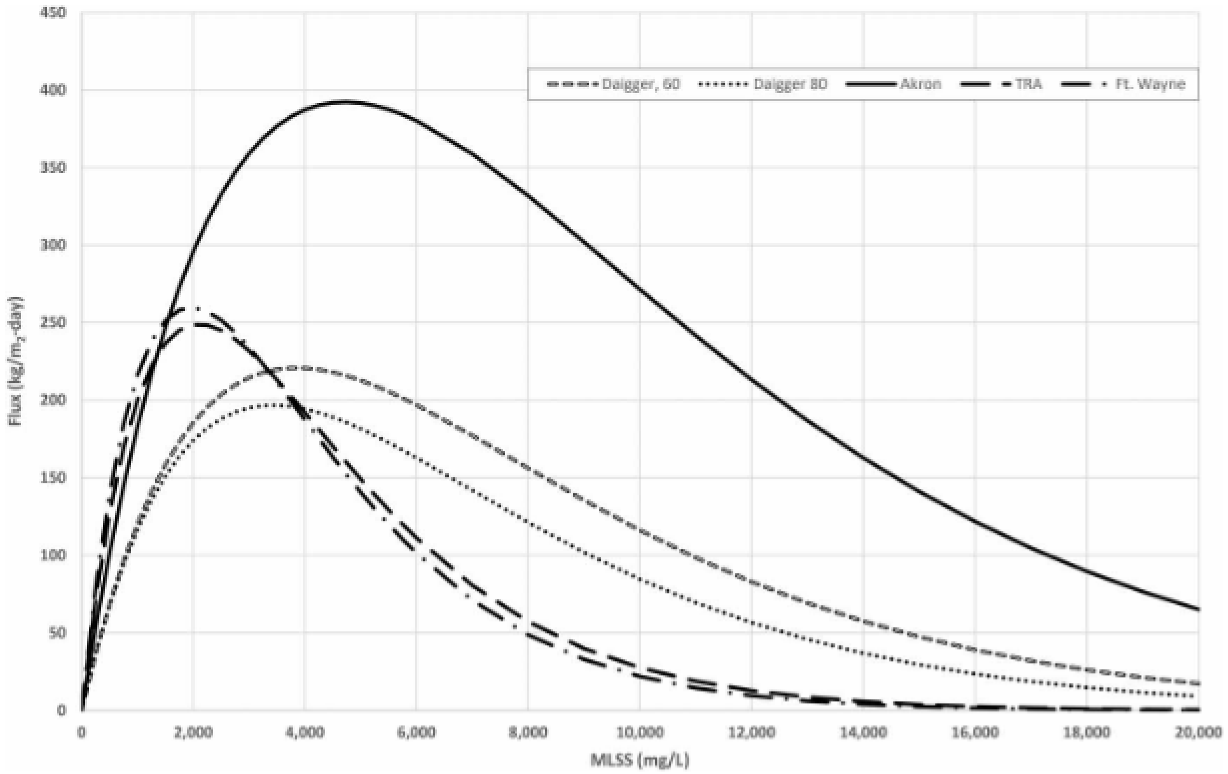
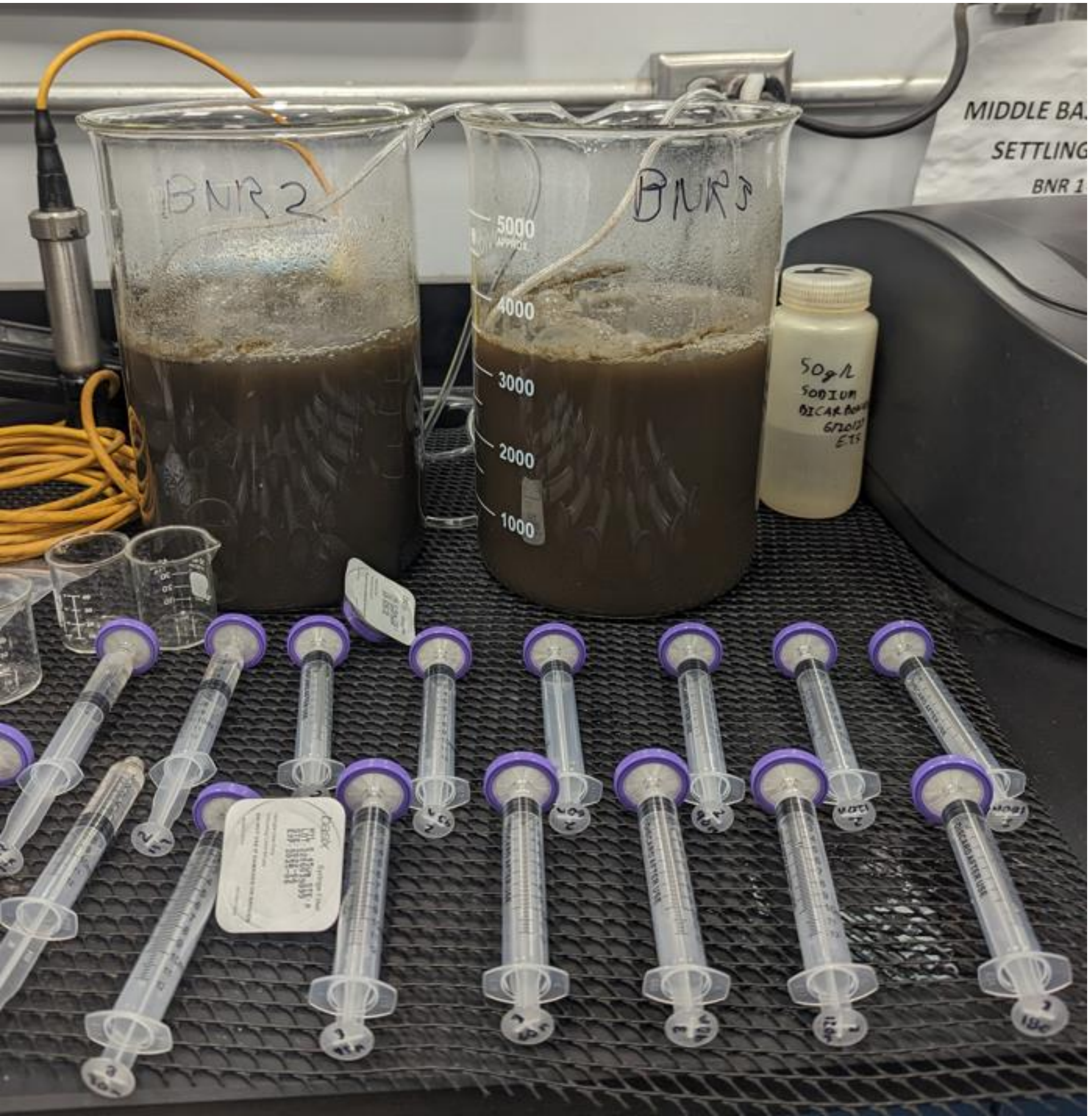


Figure 3 | Flux curves for Akron, TRA, and Ft. Wayne sludges, as compared to those predicted by the Daigger (1995) relationship for SVI values of 60 and 80 mL/g.

SRT Decoupling: Activity Measured with SNR test



- Measure nitrification rate

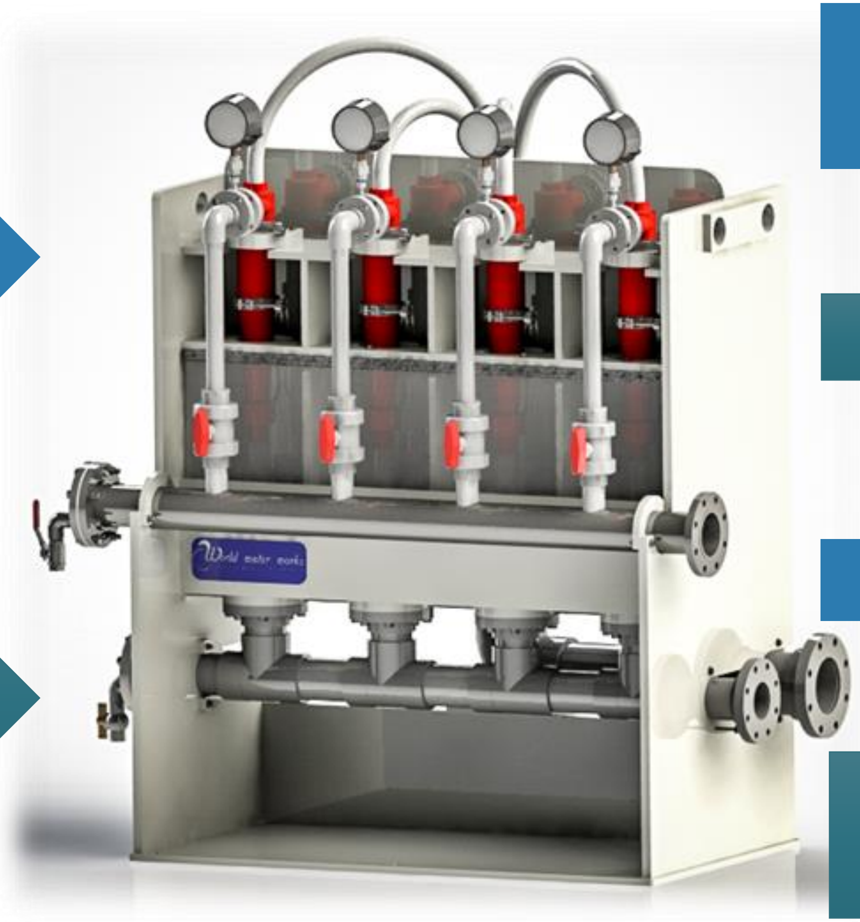
$$NH_3 \rightarrow NO_2 \rightarrow NO_3$$

- Mix biological sample, PE, sodium bicarbonate (alkalinity)
- Aerate for 3 hours
- Collect samples by filtration to stop biological activity
- Measure, pH, DO, temp, NH3, NO2, NO3
- Measure TSS and VSS at the end of the test

Selective Wasting Observed Impact on NOBs

Biomass

NOB



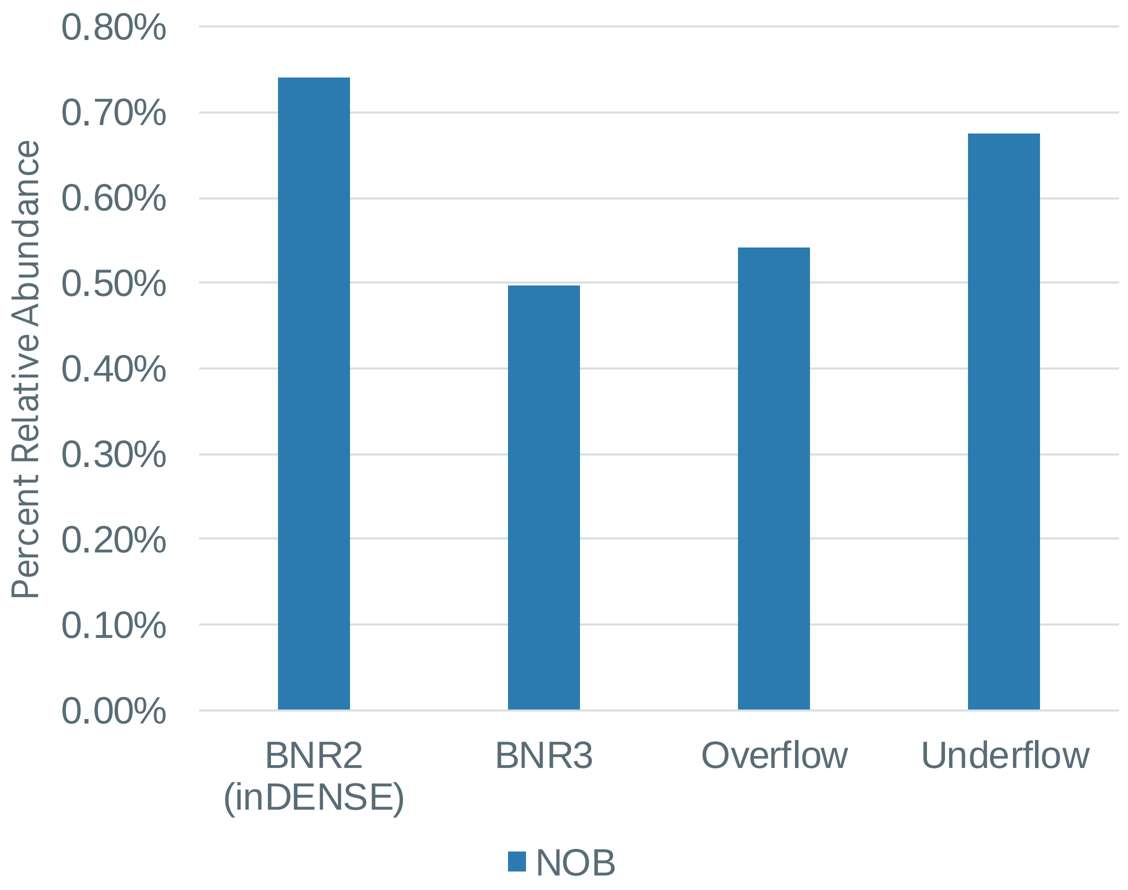
Biomass

NOB

Biomass

NOB

Relative Abundance



- inDENSE vs. Control train shows more NOB
- inDENSE overflow vs. underflow shows selective retention of NOB
- Define SRTs:

$$SRT = \frac{mass\ in\ aeration}{waste\ mass}$$

$$SRT_{NOB} > SRT_{overall}$$

JCW Middle Basin Next Steps

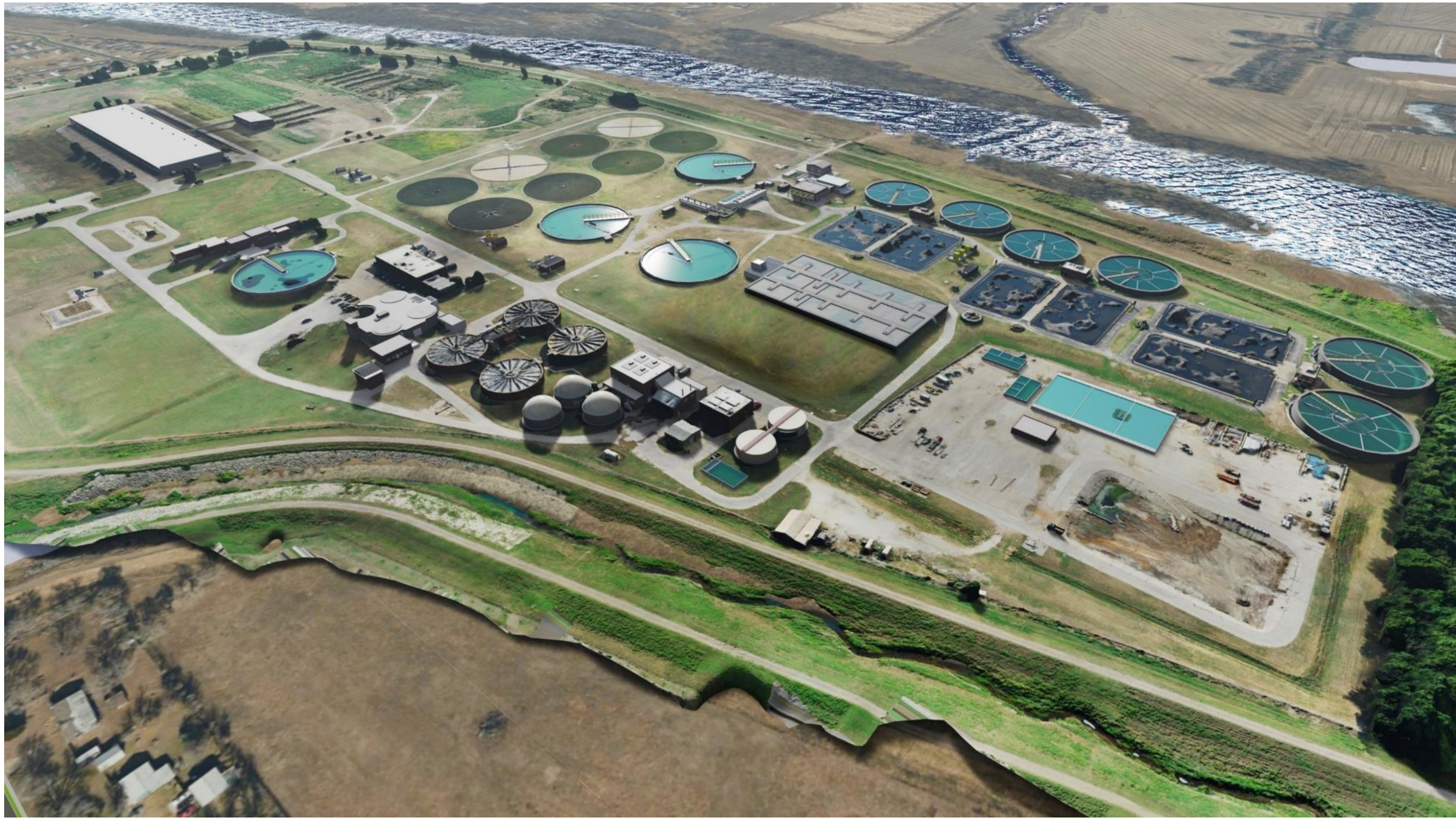
- A more permanent InDense facility CIP project recommended for implementation for full plant flow

- Second skid purchased and installed in 2024 to use InDense for half of plant flow until capital funding is available for more permanent facilities

Case Study for Foam Control and Nitrification Resiliency

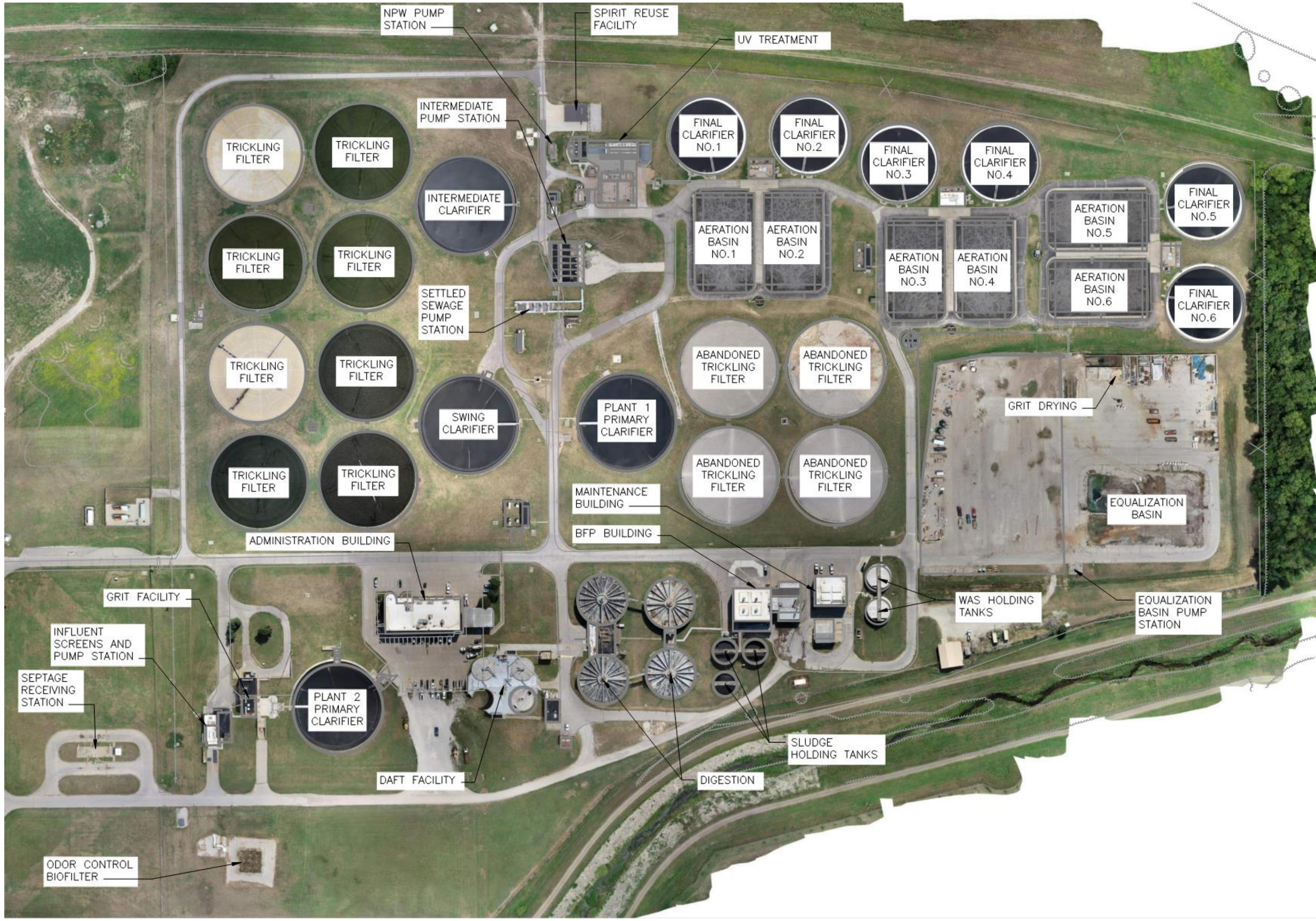
City of Wichita, Kansas Sewage Plant 2

- **Permitted Capacity:** 54 mgd
- **Current Annual Average Flow:** 30 mgd
- About 2/3 of plant flow is pumped from Plant 1 to Plant 2 for treatment
- Discharges to Lower Arkansas River



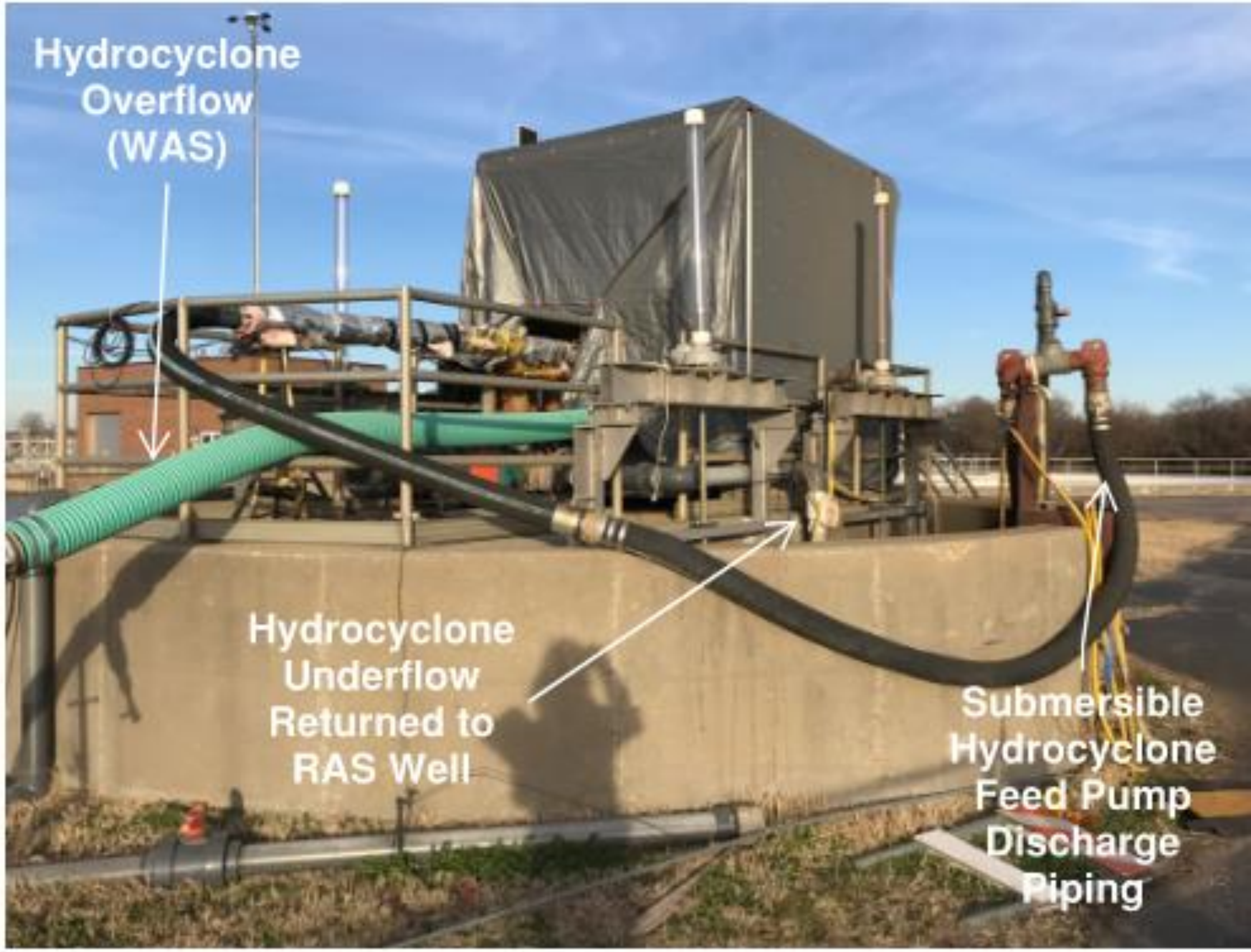
Existing Secondary Treatment: Trickling Filters and Nitrifying Activated Sludge

- Nitrifying activated sludge facilities were built in the late 1980s
- Existing aeration basins are not designed for BOD removal or BNR
- Three separate sludges:
  - Aeration Basins 1 and 2
  - Aeration Basins 3 and 4
  - Aeration Basins 5 and 6
- Trickling filters will be abandoned after construction is complete



Hydrocyclone Pilot at Aeration Basin 6

- Installed in Fall 2020 at RAS distribution box to Trains 5 and 6
- Equipment installed:
  - A four-cyclone InDense Skid
  - A feed pump in RAS well
  - A cyclone underflow return pipe to effluent dropbox to Train 6
  - A cyclone overflow pipe to drain for sludge wasting
- Expanded in 2021 to perform all sludge wasting for ABs 5 and 6 through InDense

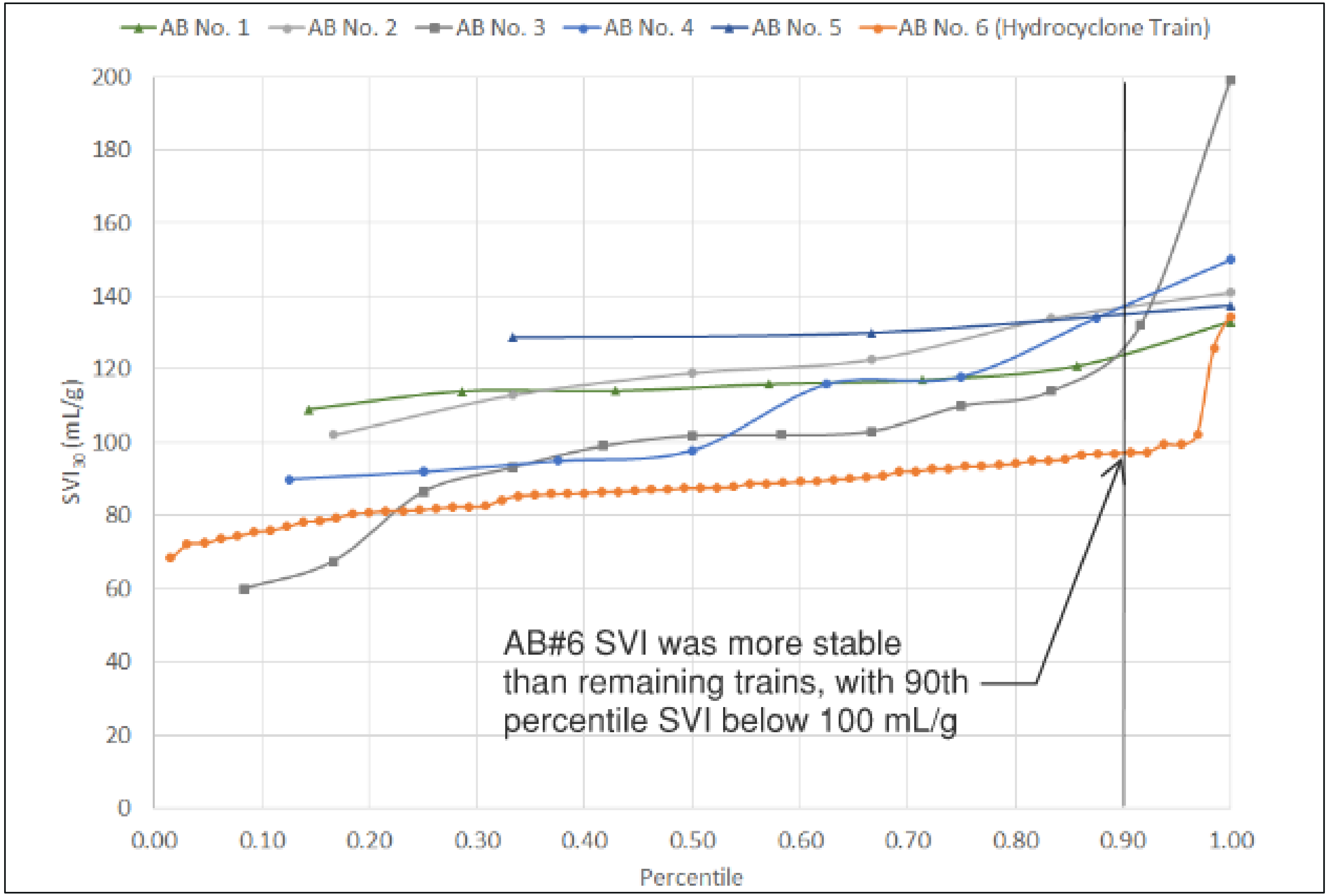


Pilot Results: Settleability

- Pilot basin (AB6) had mixed liquor and consistently **lower Sludge Volume Index** measurements throughout 2021
- **90th percentile SVI_{30}:**

  < 100 mL/g in AB6

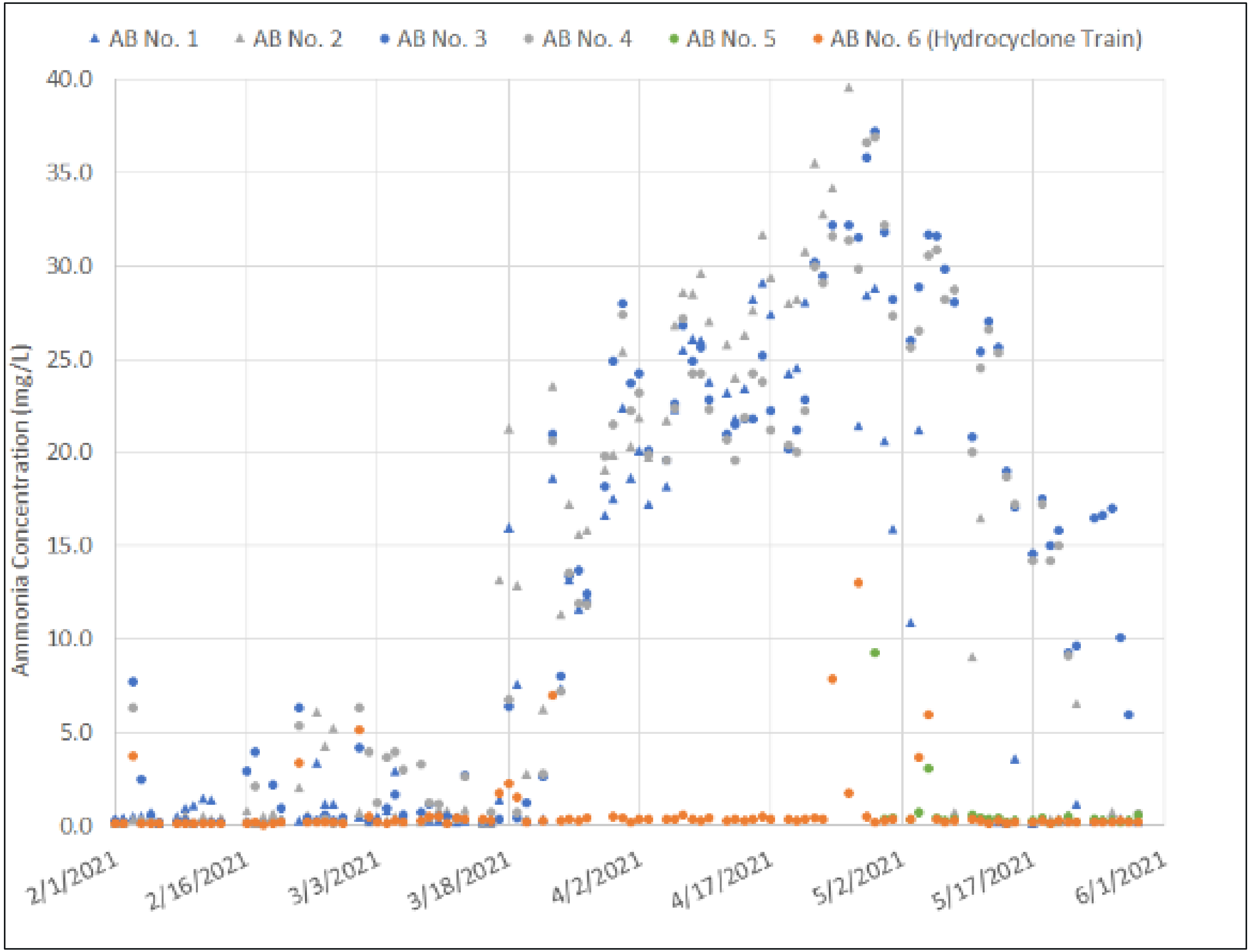
  >120 mL/g in ABs 1-5



Winter Storm Uri – February 2021

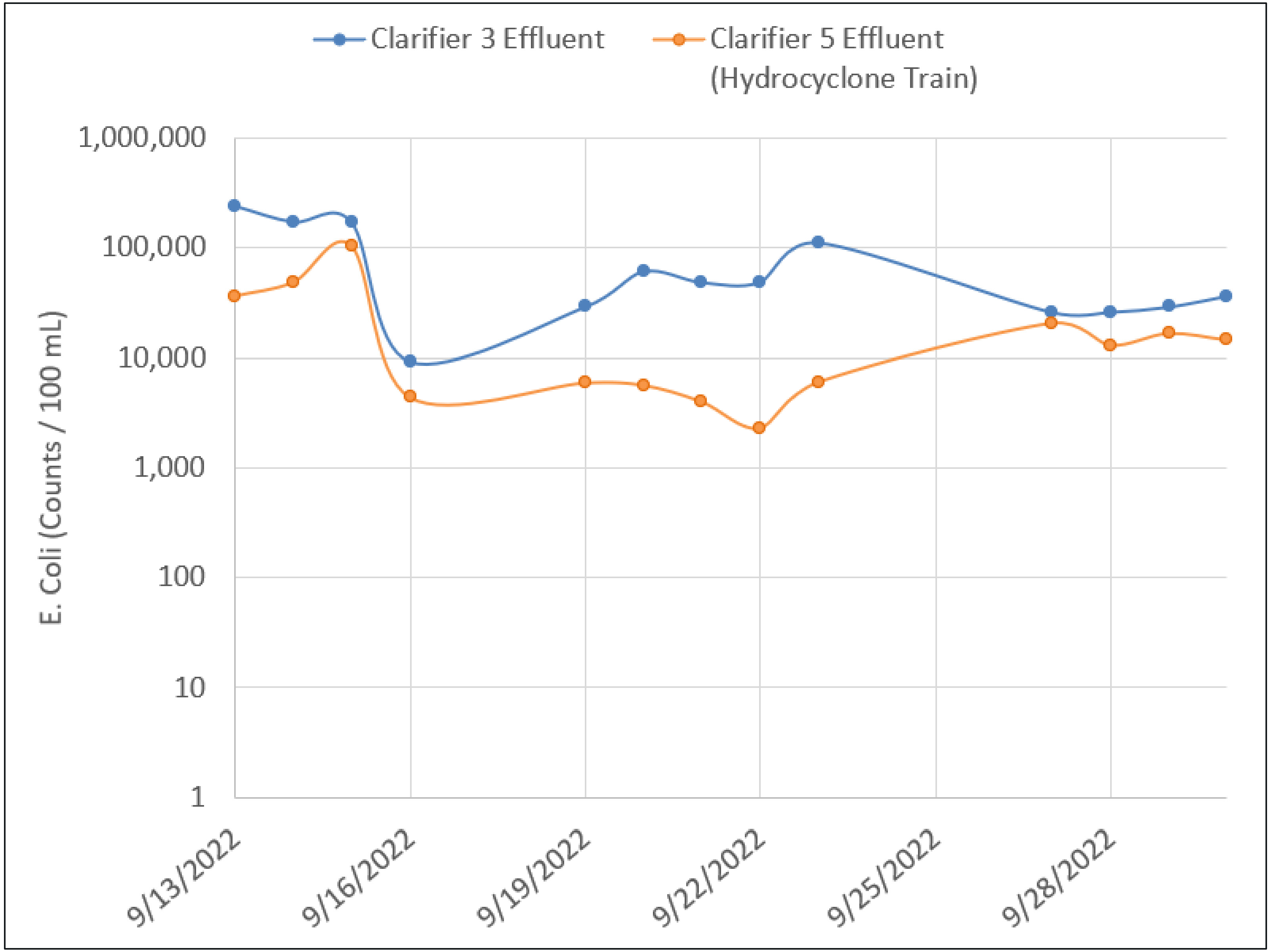
Pilot Results: Ammonia Removal

- All basins except AB #6 had bulking sludge in response to increased BOD load after winter storm
  - Pilot basin (AB #6) did not have the same level of sludge bulking
- **AB #6 retained nitrification** while **other basins stopped nitrifying** for over two months due to bulking event
- City spent substantial funds and over 400 hours re-seeding the remaining five basins to bring facility back into compliance



Pilot Results: Secondary Effluent Bacteria Counts

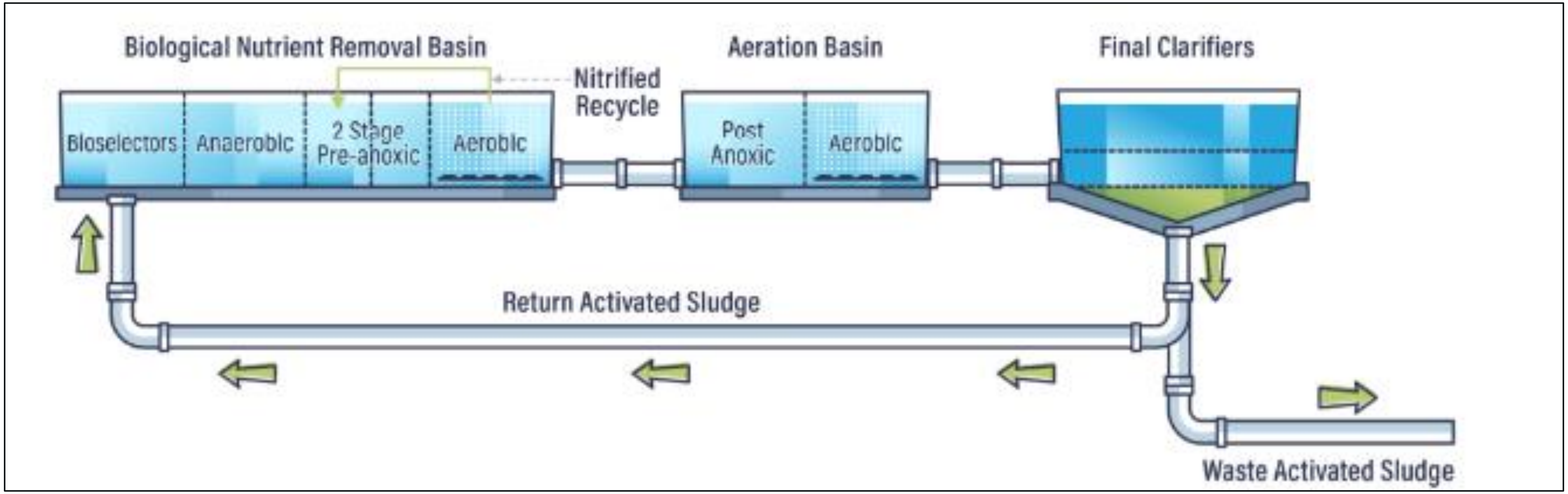
- As observed through side-by-side measurements, E. coli counts were consistently lower in hydrocyclone train:
  - Average = 0.65-log reduction
  - Geomean = 0.46-log reduction
- Potential Mechanisms:
  - Adsorption to granules
  - Longer SRT → Predation



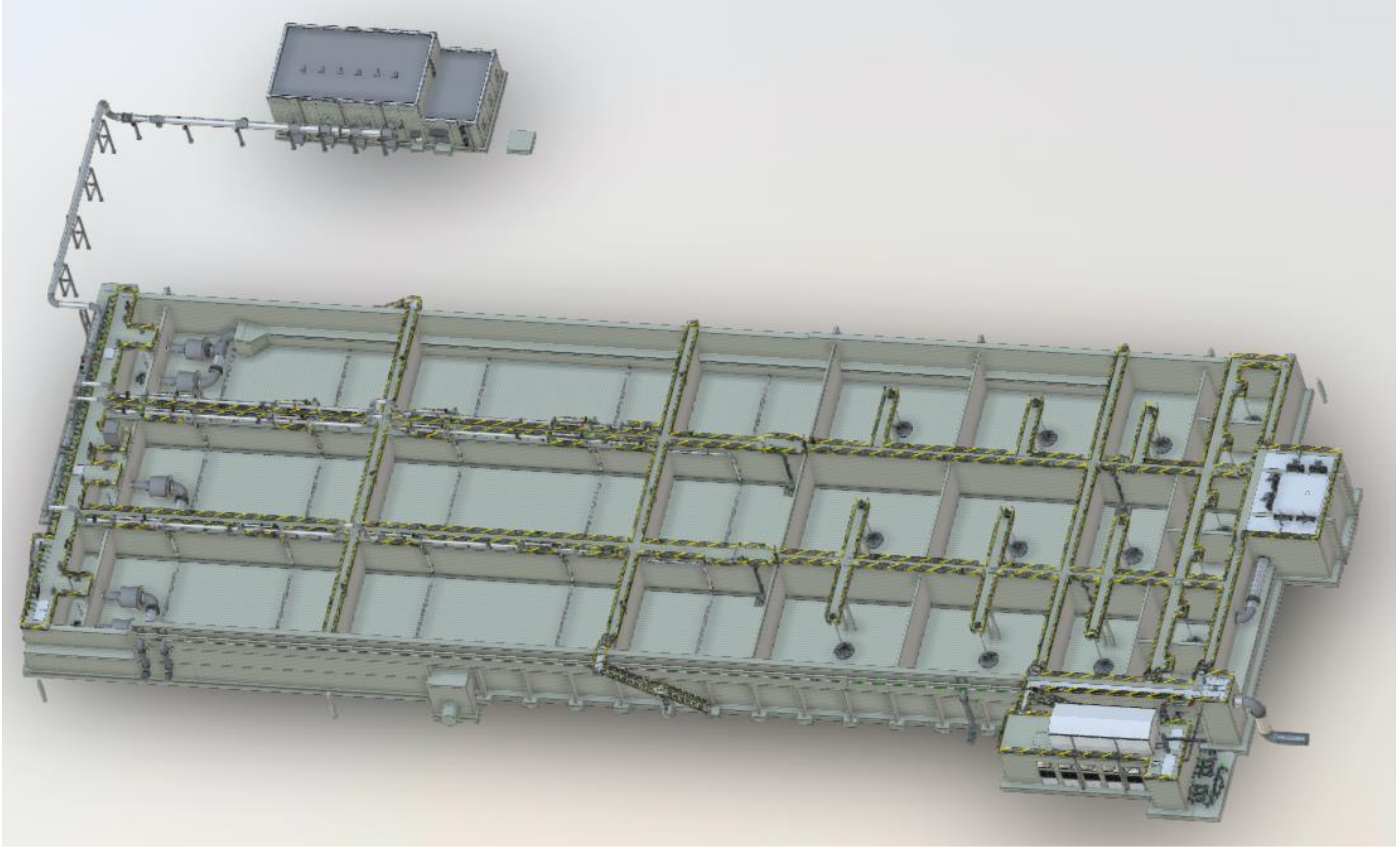
Case Study: Full-Scale Design

Key Features of Wichita 5-Stage BNR Process

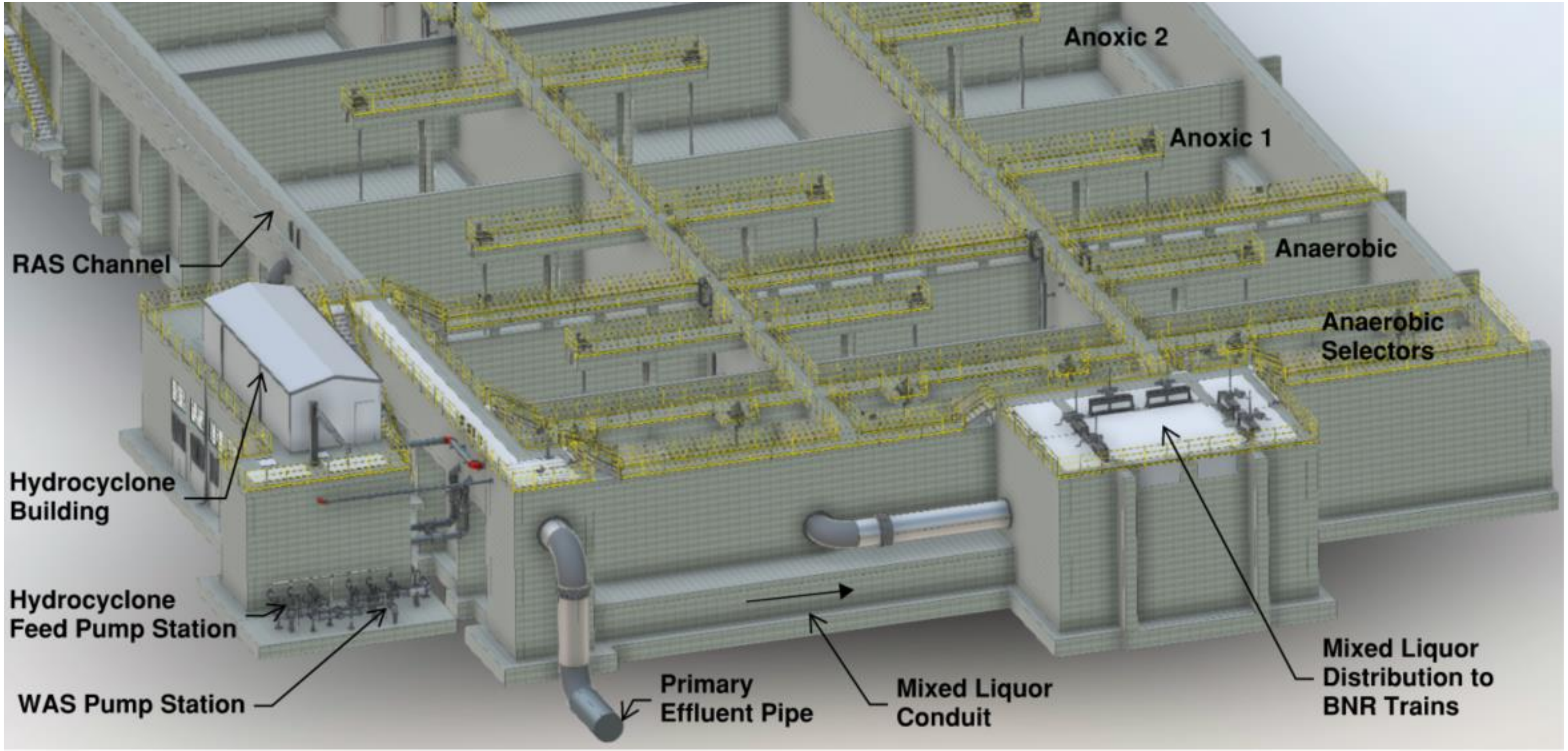
- Two stages of high F/M unaerated bioselectors to promote granulation
- Single-sludge process with common location for wasting via hydrocyclones



3D Model: New BNR Structure



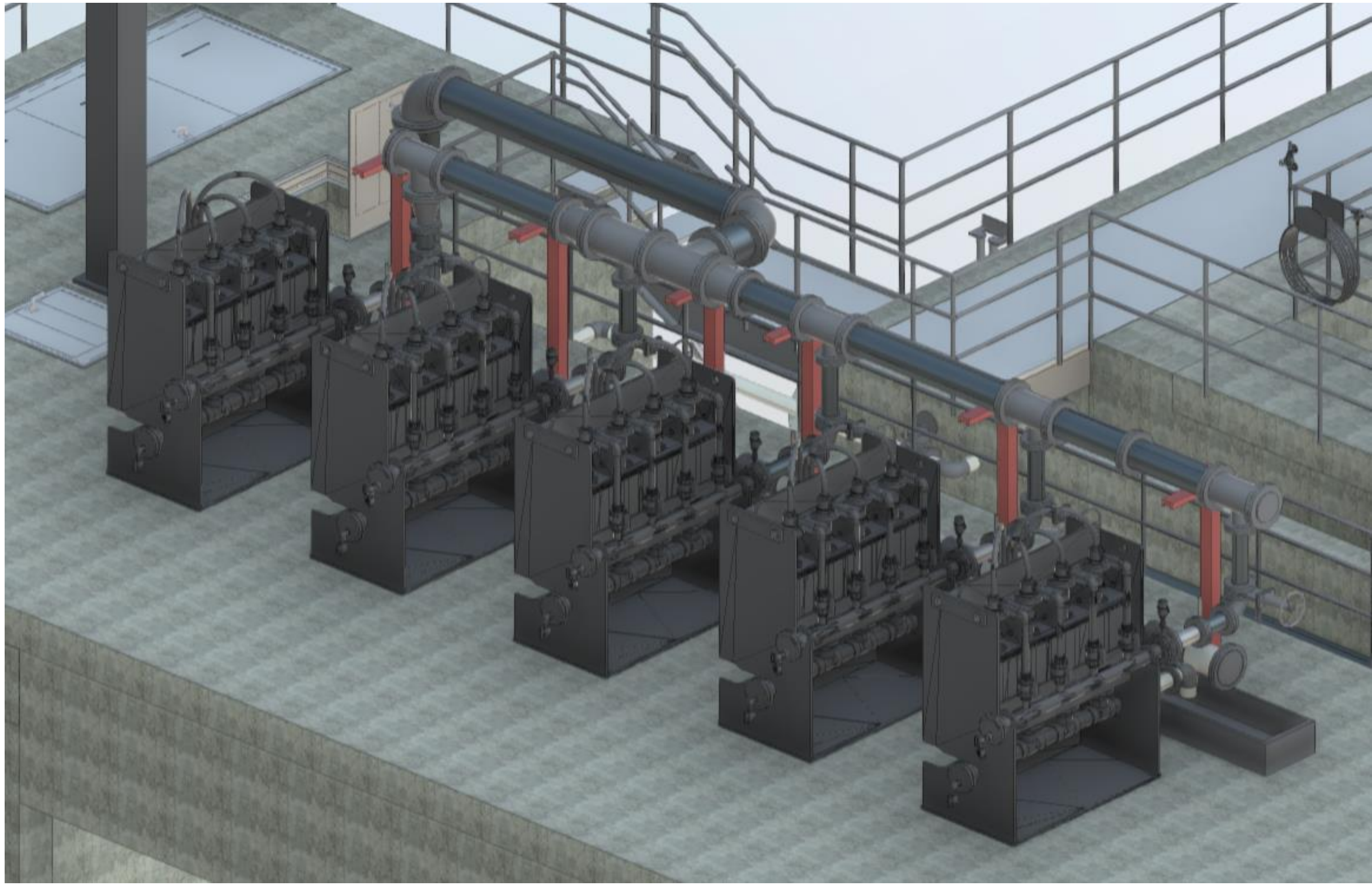
3D Model: BNR Structure & Hydrocyclones



3D Model of Hydrocyclone Room

20 hydrocyclones (Five InDense skids) will meet max month Waste Activated Sludge (WAS) flow needs

- Two InDense skids have been purchased by City;
- Existing skids to be relocated during improvements project
- Typical expected number of hydrocyclones needed will range from 12 to 18



Summary

Summary

Adoption and understanding of design concepts & tools to promote sludge densification in plug flow facilities is increasing

- "Feast-to-famine" design of bioreactors promotes formation of granules in flocculent sludges
- Selective wasting retains granules formed via kinetic selection

Hydrocyclones are a relatively low-cost and low-maintenance tool that can be implemented at many plants for numerous benefits

- Enhance settleability to maximize plant capacity (hydraulic or loading)
- Process resiliency for nitrification, BNR, and disinfection

QUESTIONS?

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