



Activated Sludge Process Control: Nitrification

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Agenda

Overview of the Utopia Plant Upgrade Path

- Nitrification Limits with wet weather flow improvements
- Nitrification Limits and Phosphorus
- Total Nitrogen and Phosphorus

Process Control for Nitrification:

- How much do I waste?
- What should the dissolved oxygen be?
- What should the RAS rate be?

Process Upgrades

- Anaerobic selector
 - How to optimize sludge quality with an anaerobic selector.
- Step feed for peak flows
 - How Step Feed can reduce solids loading to the secondary clarifiers.

Questions

Regulatory Compliance in Kentucky

1972 Clean Water Act and NPDES Program

- The Division of Water was created by Executive Order on August 1, 1980, by combining the divisions of Water Quality, Water Resources, and Sanitary Engineering. The Division regulates the withdrawal and diversion of all public waters, construction and maintenance of dams, and all construction activities across, along, or in the floodplain of any water body in the state. The Division is responsible for programs for the certification of wastewater treatment plant operators, drinking water treatment plant operators, and water well drillers.
- The Division of Water is the administering agency for the National Pollutant Discharge Elimination System (NPDES). Program delegation was made on September 30, 1983, by the U.S. Environmental Protection Agency, Region IV. Kentucky's program is entitled the Kentucky Pollutant Discharge Elimination System (KPDES).

Regulating Phosphorus and Nitrogen in the Effluent

- Phosphorus is a nutrient to aquatic plants.
- All forms of nitrogen are available as a “nutrient” to aquatic plants. Eutrophication contributes both directly to oxygen sags in the stream (photosynthetic plants) during no light and indirectly through aquatic decomposition and subsequent oxidation.
- The TMDL process will eventually implement total nitrogen limits based on the nutrient impact of nitrogen. Ammonia oxidation to nitrate eliminates toxicity but still results in nutrient impact to the stream. Eventually we will have to control the nitrate discharge from ammonia oxidation.

Evolution of the Utopia Plant

Responding to the 1972 Clean Water Act and changing KPDES limits

Tightening Regulations and changes in KPDES limits:

- Unit process type, size, and process control (and even facility name)

Utopia Sewer Plant

- Activated Sludge Process Control with Nitrification Limits
- Upgrade for improved settling and peak flows

Utopia Wastewater Treatment Plant

- Activated Sludge Process Control with Nitrification & Phosphorus Limits

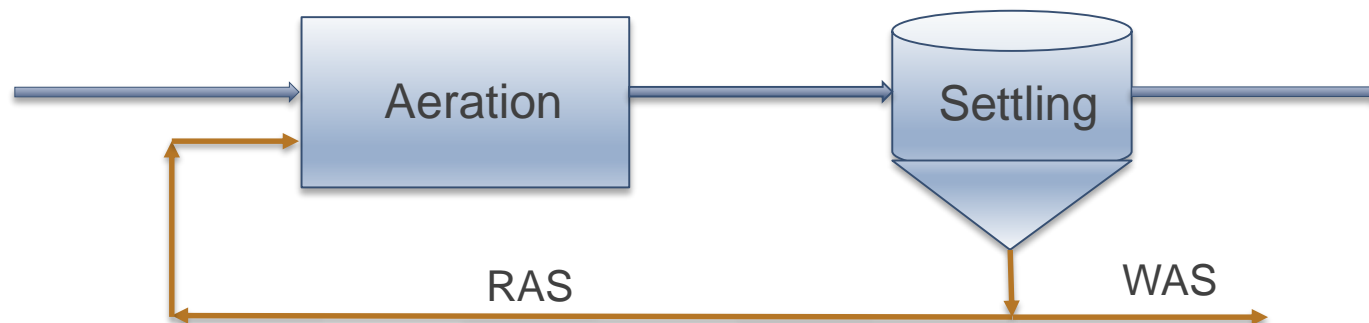
Utopia Water Reclamation Facility

- Activated Sludge Process Control with Total Nitrogen & Phosphorus Limits

Utopia Sewer Plant with Nitrification Limits

Utopia Sewer Plant prior to initial upgrade to increase wet weather flow handling.

Utopia Sewer Plant



Utopia Sewer Plant

Upgrade Path for increased flow through plant

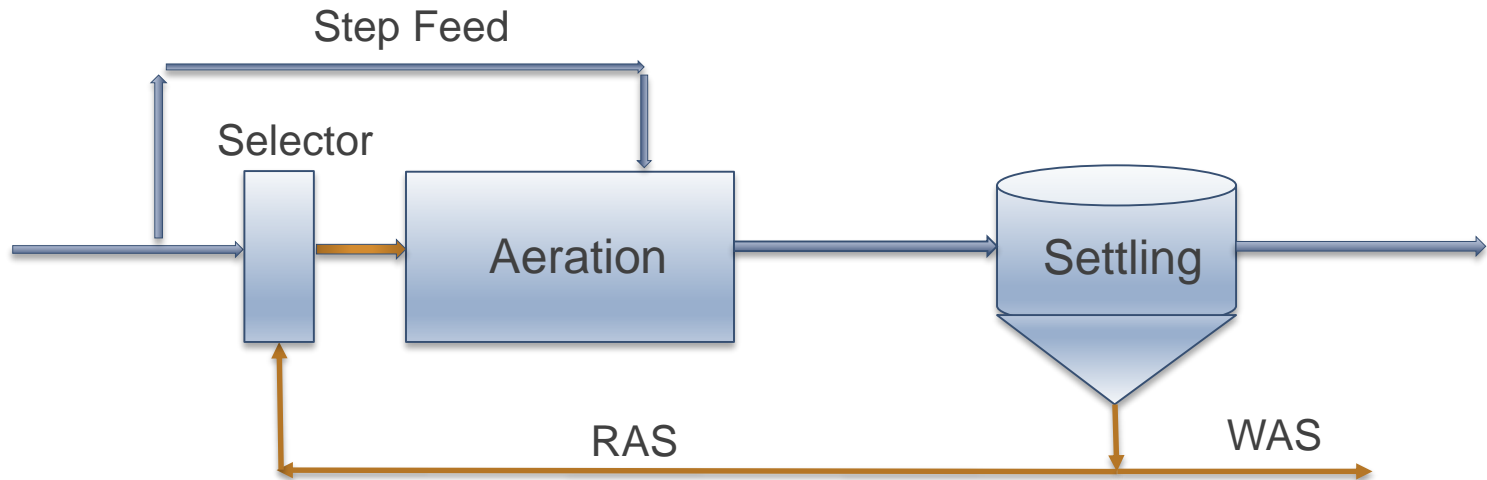
First Upgrade to Sewer Plant

- The Utopia plant has SSO (sanitary sewer overflows).
- Although the sewer system was separate, it was old and leaky. The engineering consultant recommended to first increase flows through the plant.
- Settling was not optimum, and an anaerobic selector was installed to improved settleability to improve flow handling capability and in general improve effluent quality.
- Step Feed was provided to reduce solids loading to the clarifiers during wet weather peak flows.
- Effluent quality was improved to meet: 15 mg/L cBOD5, 18 mg/L TSS and 1.5 mg/L ammonia.

Utopia Sewer Plant with Nitrification Limits

Upgraded for Improved Settling and Peak Flows

Utopia Sewer Plant Upgraded for Peak Flow Processing



Utopia Wastewater Treatment Plant

Upgrade Path for maintaining flow rates and provide for biological phosphorus removal

Second Upgrade to Utopia Wastewater Treatment Plant

- The Utopia plant had increased wet weather peak flow processing, allowing time for sewer rehabilitation to slowly reduce I&I without breaking the bank.
- Phosphorus limits (1 mg/L) were imposed in the new KPDES permit.
- Settling has been improved with an anaerobic selector and step feed allowed the staff to further increase flows through the facility during wet weather.
- The first upgrade had provided for increasing the size of the anaerobic selector to an anaerobic biological phosphorus tank.
- Effluent quality was improved to meet: 15 mg/L cBOD₅, 18 mg/L TSS and 1.5 mg/L ammonia.

Utopia Wastewater Treatment Plant

Upgrade Path for maintaining flow rates and provide for biological phosphorus removal

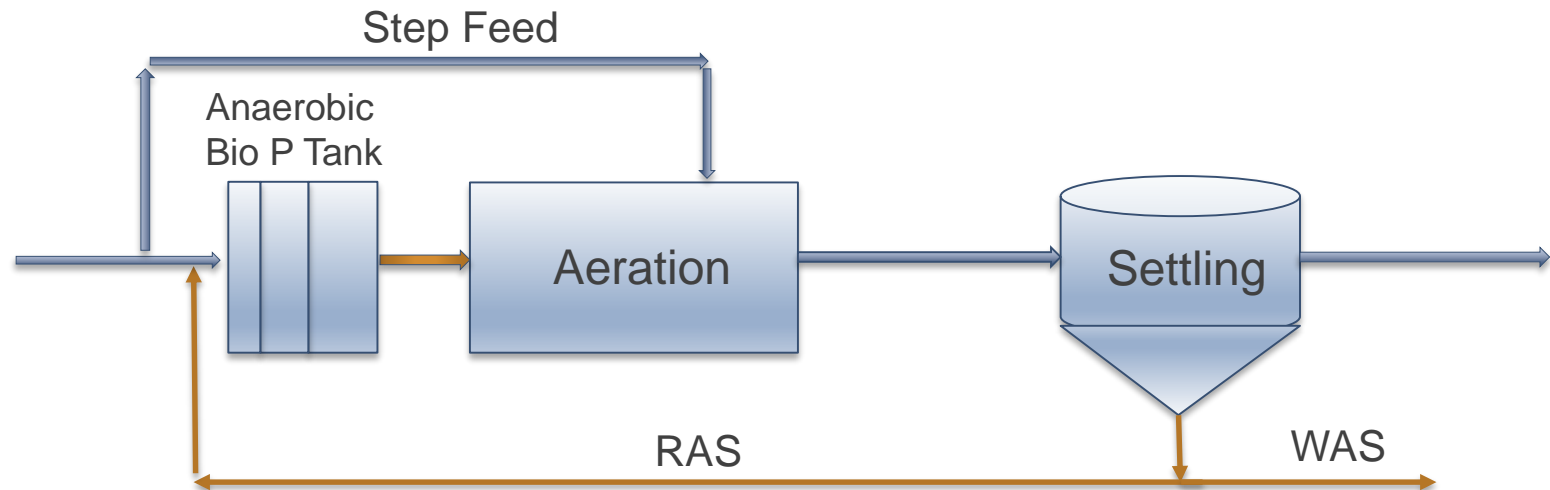
Second Upgrade to Utopia Wastewater Treatment Plant

- The first upgrade also provided for peak flow bypassing of the anaerobic selector and enabled the plant to temporarily suspended anaerobic selector operation during peak flows and protect the biosolids conditioning during peak flows.
- The anaerobic biological phosphorous selector tank (or Bio P Tank) as called by staff received only RAS flow during wet weather.
- Effluent quality was improved to meet: 15 mg/L cBOD5, 18 mg/L TSS, 1.5 mg/L ammonia and 1 mg/L phosphorus.

Utopia Wastewater Treatment Plant with Nitrification and Phosphorus Limits

Second Upgrade for Phosphorus Limits

Utopia Wastewater Treatment Plant Upgraded for Biological Phosphorus Removal



Utopia Water Reclamation Facility

Upgrade Path for maintaining flow rates and provide both total nitrogen and biological phosphorus removal

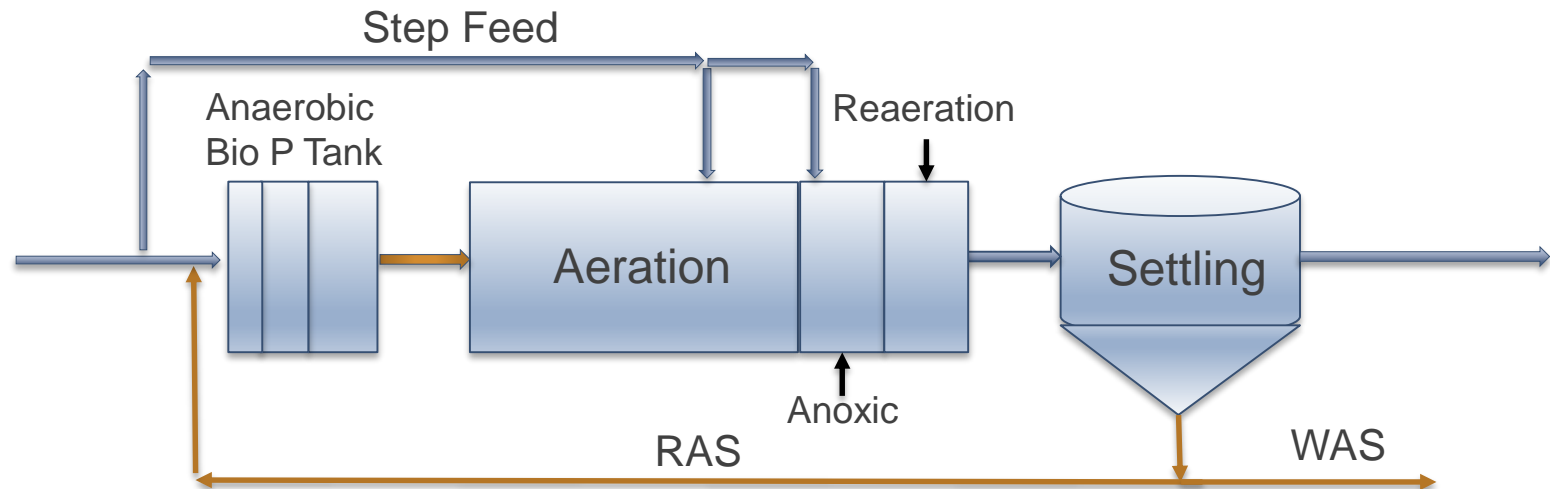
Third Upgrade to Water Reclamation Facility

- Sewer improvements continued and another KDPES cycle had also imposed total nitrogen limits in addition to cBOD5, TSS, ammonia and phosphorus.
- Total Nitrogen Limits of 7 mg/L were imposed in the new KPDES permit. The total of ammonia, nitrate and nitrite could not exceed 7 mg/L. Ammonia could not exceed 1.5 mg/L while nitrate and nitrite could not cause the total to exceed 7 mg/L.
- Settling was excellent and the previous biological phosphorus removal operation prepared staff for an even tighter process control program.
- Effluent quality was improved to meet: 15 mg/L cBOD5, 18 mg/L TSS, 1.5 mg/L ammonia with TN less than 7 mg/L.

Utopia Wastewater Treatment Plant with Total Nitrogen and Phosphorus Limits

Third Upgrade for Total Nitrogen and Phosphorus Limits

Utopia Wastewater Treatment Plant Upgraded for full BNR Operation



Utopia Water Reclamation Facility

Process Control following each phase of construction improvements.

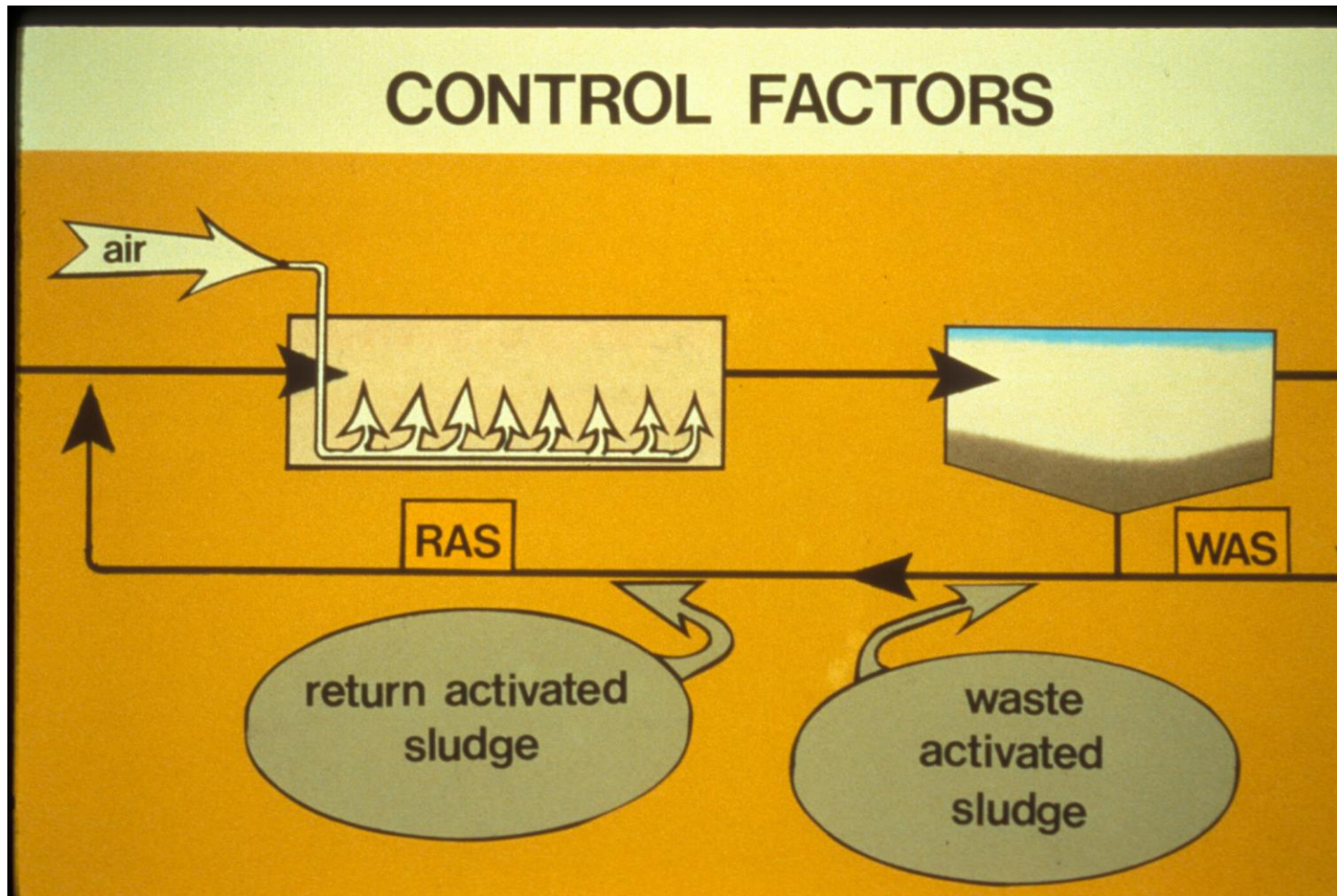
Process Control had to also improve to take advantage of each upgrade at Utopia.

Construction provided additional unit process tankage to improve:

1. Settleability to improve settling effluent quality.
2. Step feed to decrease solids loading to the clarifiers while increasing wet weather flows.
3. Biological Phosphorus tankage to provide effluent quality less than 1 mg/L P with minimal chemical addition.
4. Total Nitrogen operation required additional tankage, monitoring and control to meet permit requirements.

Secondary Treatment Basic Controls

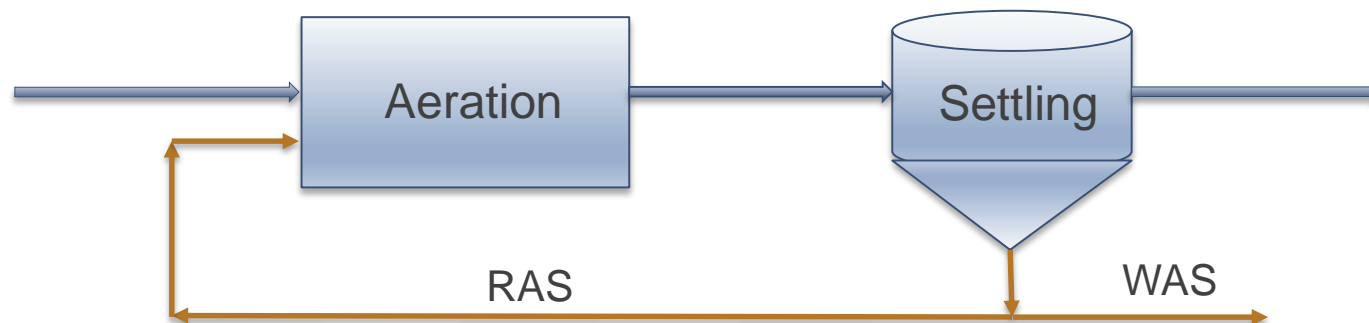
Air, Return and Wasting



Utopia Sewer Plant with Nitrification Limits

Utopia Sewer Plant prior to initial upgrade to increase wet weather flow handling.

Utopia Sewer Plant



Remaining Ammonia Removal - Nitrification

- The WWPT nitrogen removal must count on additional microbiology other than assimilation (cBOD₅) if an effluent ammonia limit is to be met.
- Municipal plants rely on a separate culture of nitrifying bacteria must be optimized for ammonia removal (to remove ammonia that is left after assimilation and growth).
- Nitrification converts ammonia to nitrite, then nitrite to nitrate.

Ammonia Oxidation - Nitrification

- Nitrifiers are thought to typically range from 1-4% of the population.
- AOB (referred to in general as Nitrosomonas) is responsible for the loss in alkalinity with the production of nitrous acid (destroying approximately 7.14 mg/L of alkalinity for mg/L of ammonia oxidized).
- Nitrification can be stopped with a loss in available alkalinity. Total alkalinity results below pH operating range (total alkalinity is titrated to a pH of 4.5 S.U. Alkalinity below 6.8 S.U. begins inhibiting nitrification rates.

Ammonia Oxidation - Nitrification

- Nitrification inhibition due to loss of alkalinity is most often seen in aerobic digestion where water chemistry results in high nitrates, high nitrites and high ammonia results. Dissolved oxygen is typically considered the limitation.
- Nitrification is expected to use 4.57 mg/L of dissolved oxygen for each mg/L of ammonia.
- Nitrification rates vary significantly based on the residual oxygen levels. If high ORP levels are present, lower dissolved oxygen levels are required. If low ORP values are present, high residual oxygen levels are required to maintain the same nitrification rate.

Oxygen Supply and Oxygen Demand

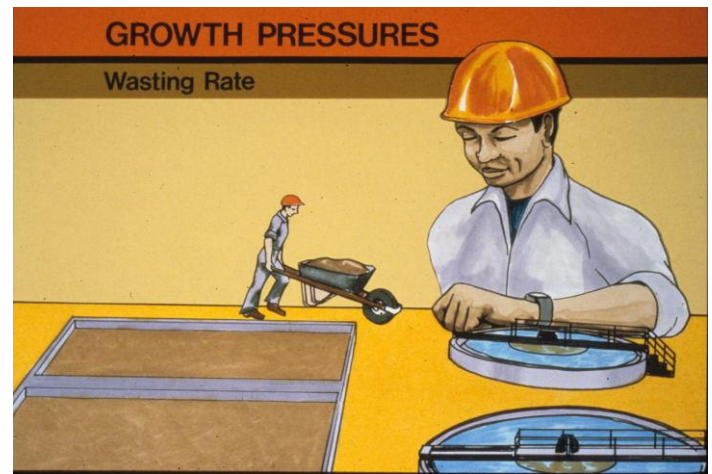
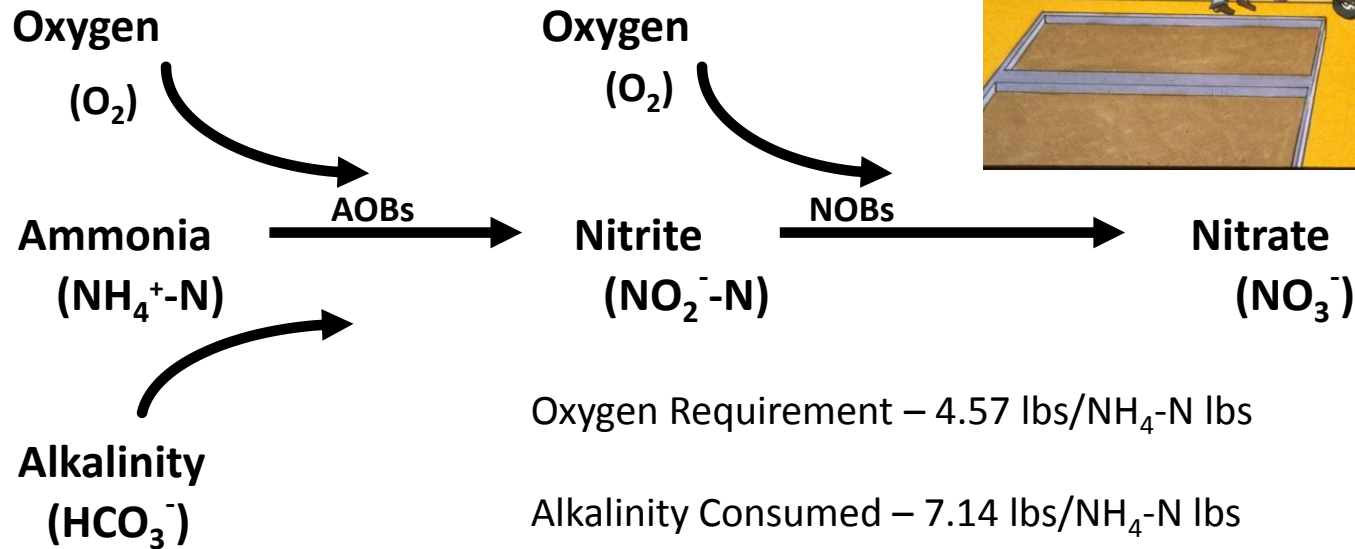


How much do I waste?

Control by.....

1. F/M is a concept/condition. The measured values for both food and biomass are problematic due to timing and accuracy.
 1. cBOD_5 as food
 2. MLVSS as Microorganisms
2. Sludge Quality – dependent on other factors, but MLSS must be in an acceptable range. If driven by filaments, out of range.
3. Constant MLSS – if loading is variable, constant MLSS will cause performance changes. If loading increases, the process will need to adjust and increase biomass to adequately treat.
4. Aerobic SRT – assuming nitrification is a compliance objective, using the aerobic volume of the biomass will provide the critical biomass concentration based on tank volume, temperature and biomass concentration. Those three (3) conditions must be taken into consideration when adjusting for treatment.
5. Nitrification is the controlling MLSS concentration factor even if biological phosphorus removal and total nitrogen control are necessary.

Wasting for Nitrification



- Nitrifiers are temperature sensitive, slow growing and dictate MLSS and number of basins online
- Dictates the Aerobic SRT required



Nitrification



Easy



More Difficult

Nitrification Requirements

- Key Factors:
 1. Slow growth requires adequate aerobic SRT
 2. DO typically ≥ 2 mg/L
 3. pH 6.8 - 7.5 S.U.

- Target effluent alkalinity of > 75 mg/L as CaCO_3

Solids Retention Time (SRT)

Definition: Average amount of time “bugs” spend in the aeration basin

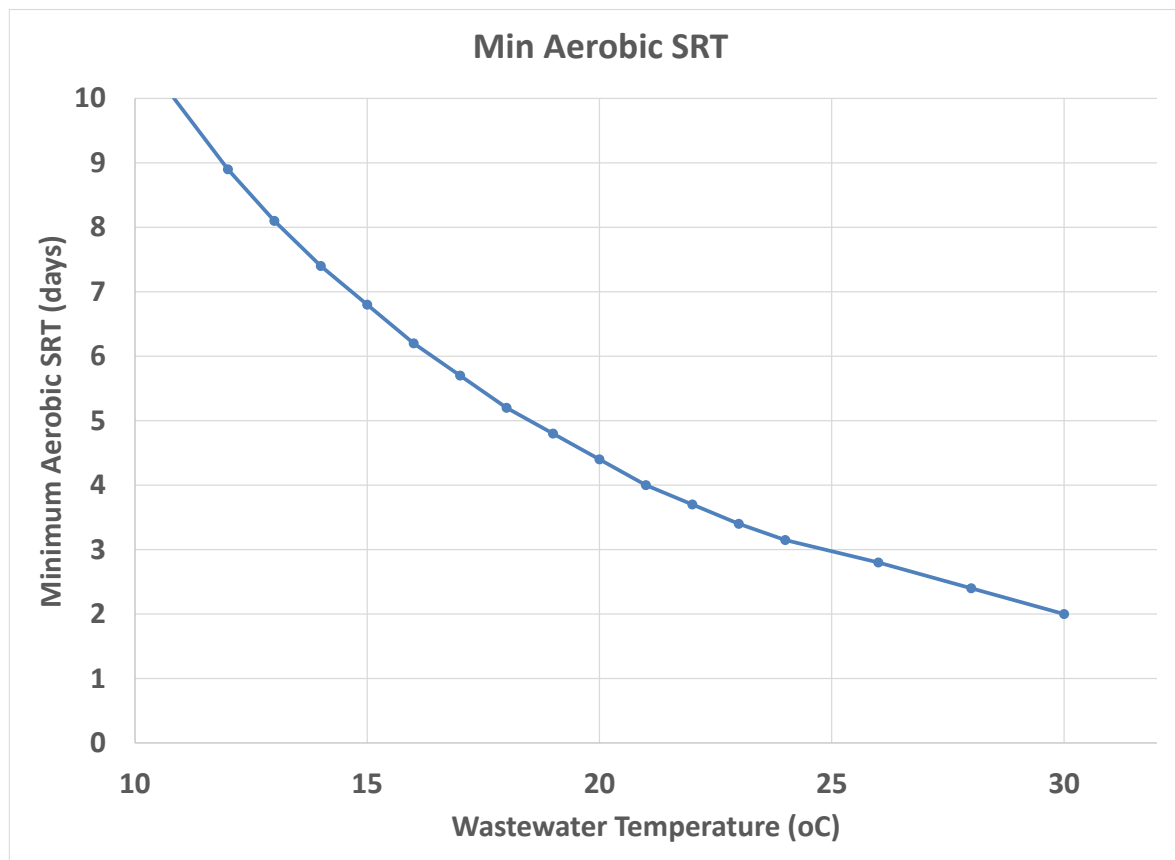
Dependent on (controlled by) wasting rate

$$\text{SRT (d)} = \text{solids in bioreactors (lbs)} \div \text{solids wasted (lbs/d)}$$

- Nitrifiers are “slow growers” and therefore dictate system aerobic SRT (temperature dependent)
- Aerobic SRT vs. Total SRT
 - Total SRT provides additional tank volume and mass if nutrient control tankage is in operation. Additional bioreactors used in nutrient control are typically are mixed and not aerated. Tracking total SRT versus Aerobic SRT is necessary.

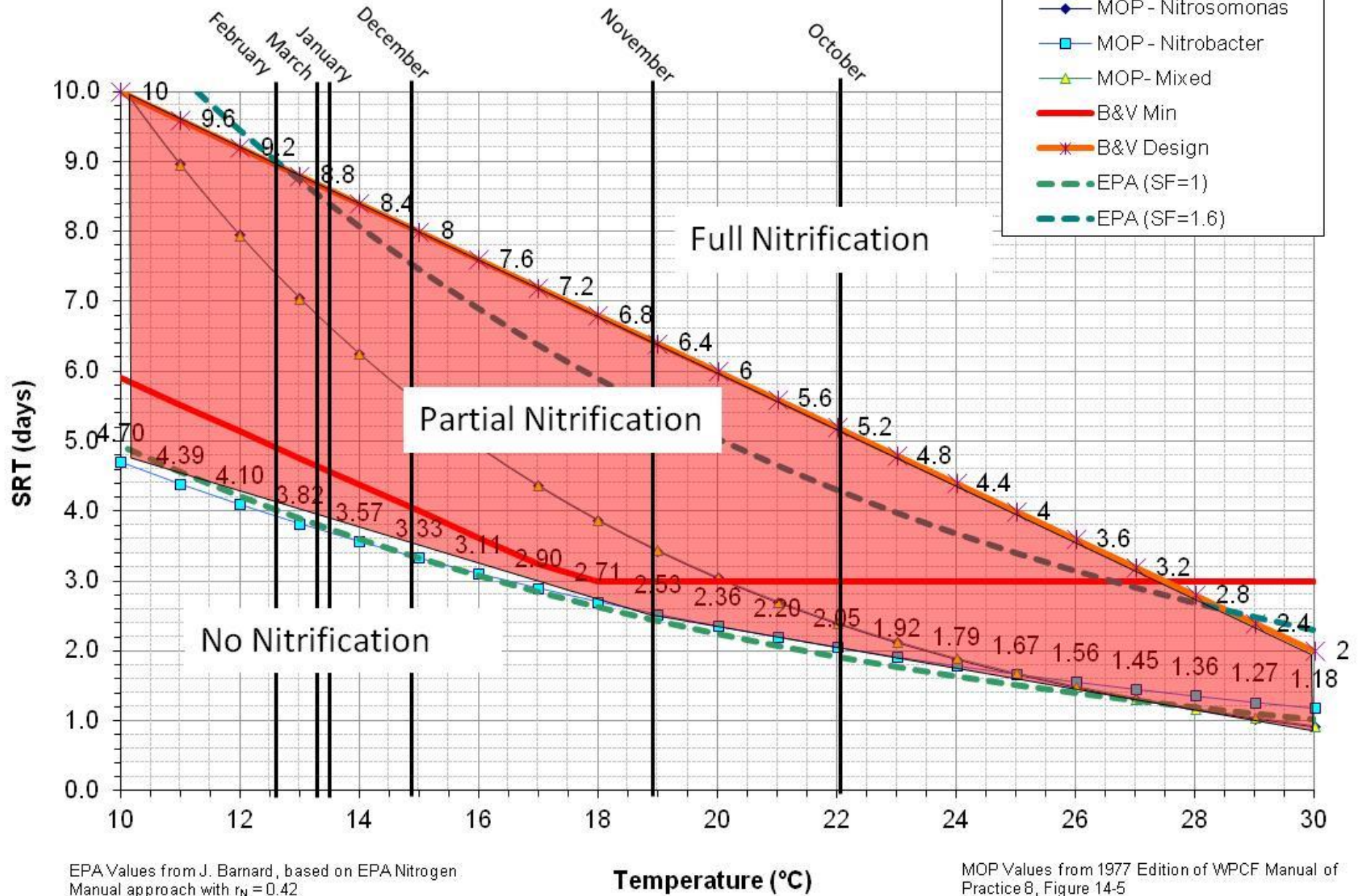
Nitrification Requirements, Solids Retention Time (SRT)

- **Key Performance Indicator for Nitrification**
 - Slow growth requires adequate AEROBIC SRT
 - **MAINTAIN ADEQUATE SOLIDS INVENTORY**

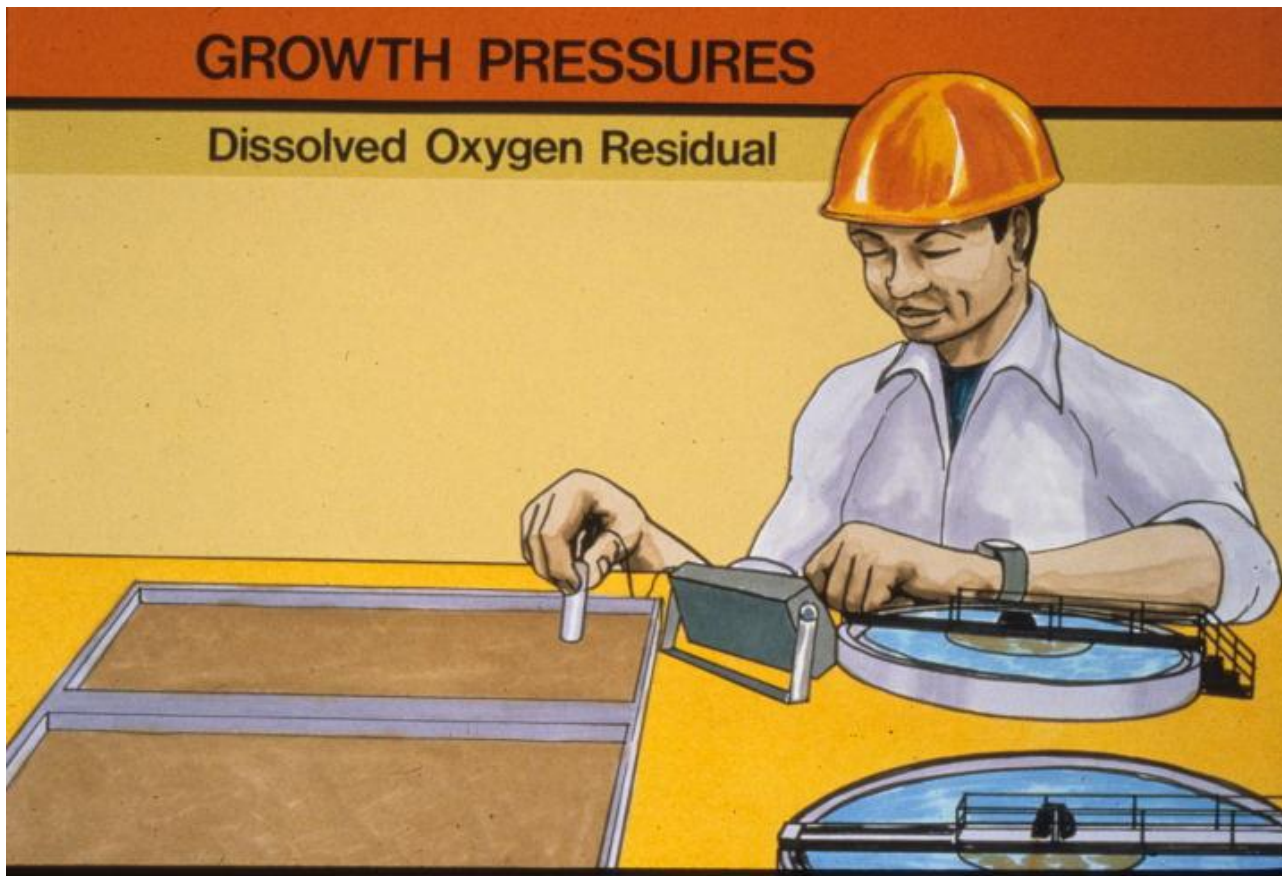


Seasonal
Aerobic SRTs

Minimum SRT for Nitrification



Dissolved Oxygen and ORP



Estimating Oxygen Supply

Oxygen supply approximations:

Mechanical aeration – USEPA rule of thumb (combined horsepower):

- Surface mechanical aerators: 3.0 lbs O₂ / hp – hr
- Submerged turbine aerators: 2.0 lbs O₂ / hp – hr
- Jet Aerators: 2.8 lbs O₂ / hp – hr

Diffused aeration transfer efficiency (rule of thumb)

Coarse bubble	= 0.5% per foot submergence
Medium bubble	= 0.8% per foot submergence
Fine bubble	= 1.2% per foot submergence

Calculate oxygen per SCFM

Specific weight of air = 0.075 lb/cf

Oxygen in air = 20% by weight

$$\text{lbs O}_2/\text{day} = \text{SCFM} * 1,440 \text{ mins/day} * 0.075 \text{ lb/cf} * 0.20 \text{ O}_2 * \text{transfer}$$

Estimating Oxygen Requirements

Oxygen requirements in pounds/hr with a denitrification credit at 8 MGD flow rate

$$(1.1) * (\text{BOD}_5 \text{ mg/L}) * (8.34) + (4.6) * (\text{NH}_4^+ \text{-N mg/L}) * (8.34) - (2.86) * (\text{NO}_2^- \text{ NO}_3^- \text{- N mg/L}) * (8.34)$$

$$8 \text{ MGD} * \underline{\hspace{1cm}} \text{ mg/L} * 8.34 * 1.1 = \underline{\hspace{2cm}} \text{ lbs/O}_2\text{/day}$$

$$8 \text{ MGD} * \underline{\hspace{1cm}} \text{ mg/L} * 8.34 * 4.6 = \underline{\hspace{2cm}} \text{ lbs/O}_2\text{/day}$$

$$8 \text{ MGD} * (\underline{\hspace{1cm}} \text{ mg/L} - \underline{\hspace{1cm}} \text{ mg/L} = \underline{\hspace{1cm}} \text{ mg/L}) * 8.34 * 2.86 = \underline{\hspace{2cm}} \text{ lbs/O}_2\text{/day}$$

 lbs/O₂/day

carbon % of oxygen demand

+ lbs/O₂/day

nitrification % of oxygen demand

- lbs/O₂/day

denite saves % of oxygen demand

 lbs/O₂/day or **lbs O₂/hr**

How extra air do I need (dissolved oxygen) Floc Condition based on Load/Oxygen/Time

 Anaerobic  Anoxic  Aerobic

The 3-D Floc concept distinguishes between floc condition and the liquid dissolved oxygen. Nitrification rates with the same dissolved oxygen in the liquid vary due to load, time and floc condition.



Aerobic

F/M: 0.1 D.O.: 1.0 mg/L ORP: +200 mv

Fully aerobic, no load at the end of aeration. All nitrifiers throughout the floc have oxygen and are nitrifying. High nitrification rate.



Anoxic

F/M: 0.4 D.O.: 1.0 mg/L ORP: +10 mv

Only partially aerobic due to high load and anaerobic floc condition at the beginning of aeration (E/F). Not all nitrifiers in the floc have oxygen and are not capable of nitrifying.



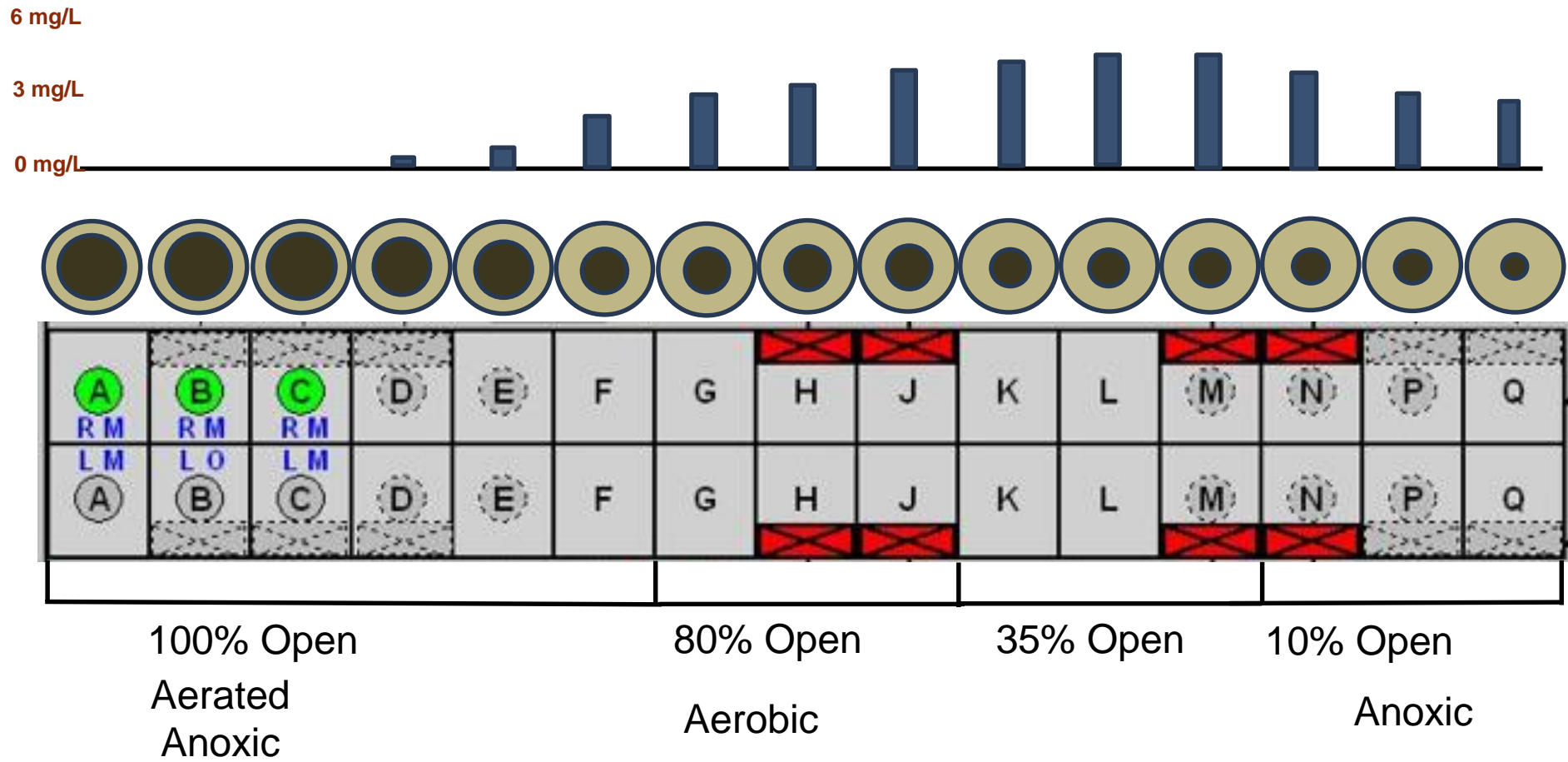
Aerobic

F/M: 0.2 D.O.: 5.0 mg/L ORP: +150 mv

Largely aerobic, high load at the end aerated high D.O. section. Nitrifiers throughout the majority of the floc have oxygen and are nitrifying. High nitrification rate.

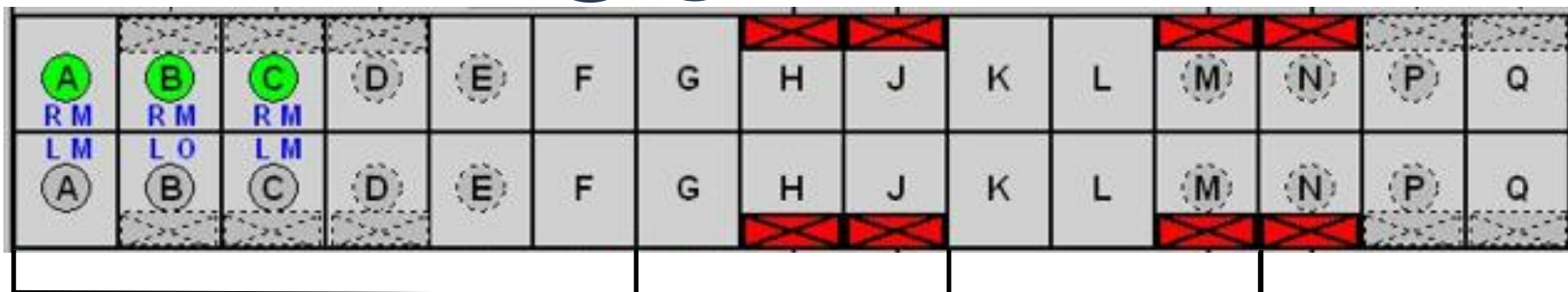
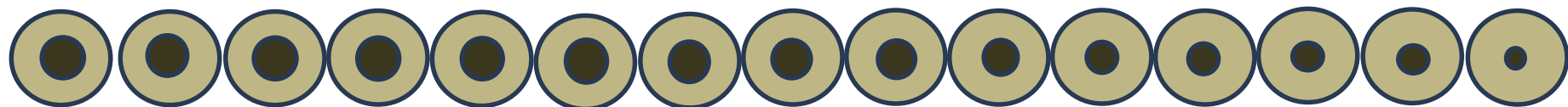
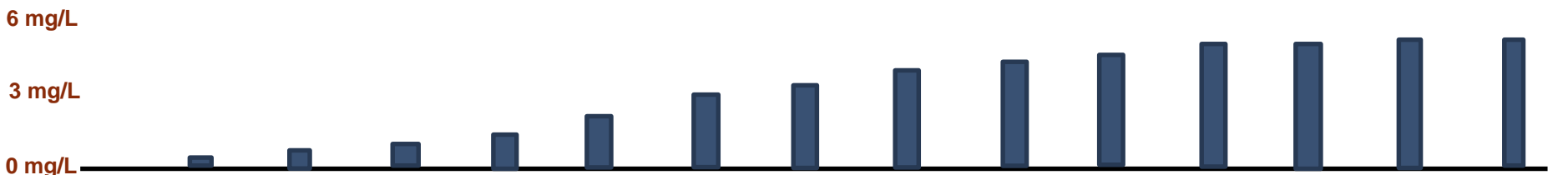
Floc Condition with Tapered Aeration Maintain Aerobic Condition

 Anaerobic
  Anoxic
  Aerobic



Floc Condition with less Tapered Aeration Over-Aerated Aerobic Condition

 Anaerobic
  Anoxic
  Aerobic



100% Open
Aerated
Anoxic

80% Open
Aerobic

60% Open

40% Open
Aerobic

Sludge Quality was not optimum

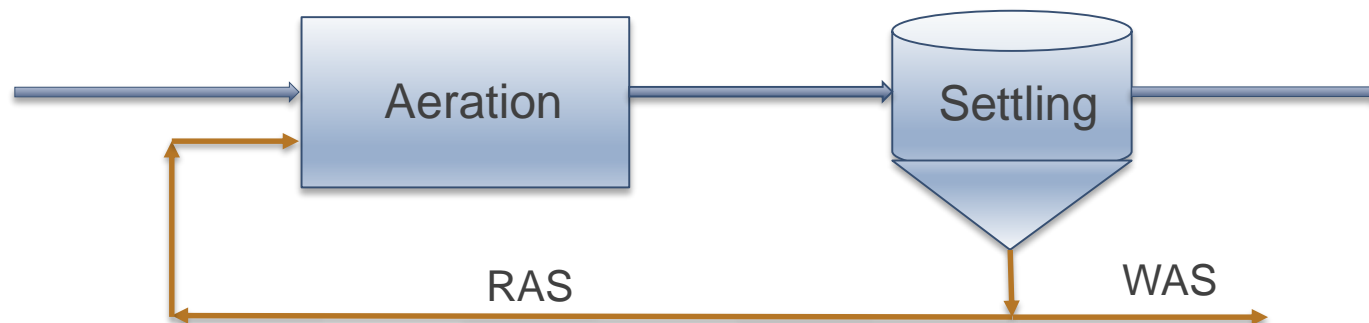
MLSS concentrations were kept low to minimize bulking

- Plant design discharged RAS directly into the aeration tank.
- F/M was low due to the dilution of influent prior to contact with the RAS.
- Dissolved oxygen was marginal where RAS and Influent mixed in the aeration tank.
- If sludge wasting did not keep up, the SVI increased and sludge quality impacted final effluent quality.

Utopia Sewer Plant with Nitrification Limits

Utopia Sewer Plant prior to initial upgrade to increase wet weather flow handling.

Utopia Sewer Plant



Optimize Anaerobic Selector

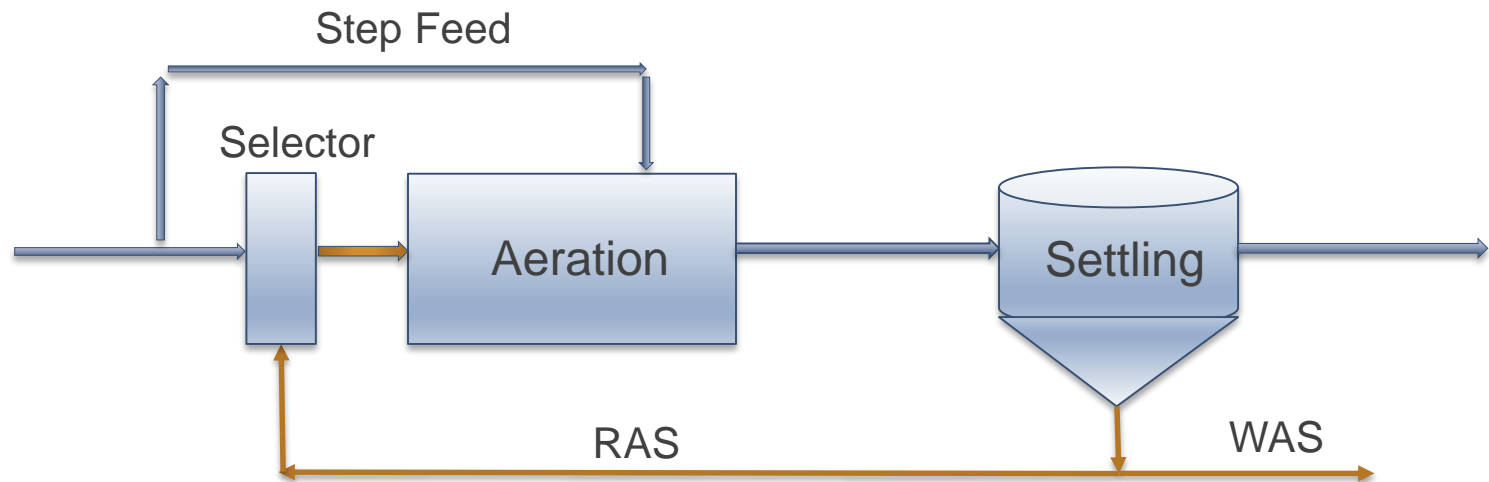
Sludge quality improved if not in over aerated condition before discharging into the selector

- RAS is combined with influent before dilution in aeration tank.
- Anaerobic selector improves sludge quality by providing floc formers a competitive advantage for soluble cBOD₅ uptake under zero dissolved oxygen conditions. Filaments cannot compete.
- Too high of aerobic conditions in aeration will not provide optimum conditions in a small selector zone (only 30 minutes of detention time).

Utopia Sewer Plant with Nitrification Limits

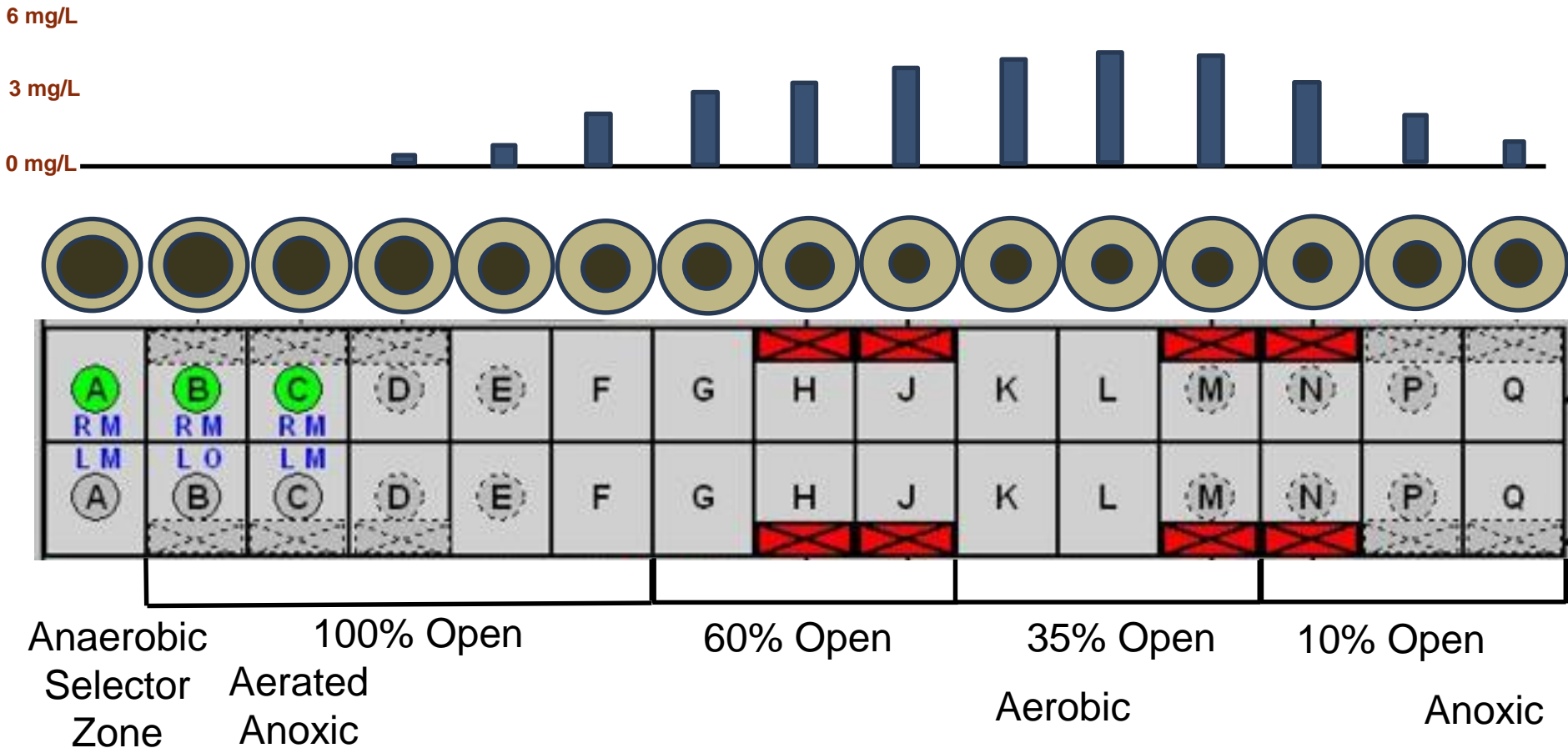
Upgraded for Improved Settling and Peak Flows

Utopia Sewer Plant Upgraded for Peak Flow Processing



Floc Condition with Anaerobic Selector Tapered Air with same Aerobic SRT

Anaerobic
 Anoxic
 Aerobic



Optimize Anaerobic Selector

Sludge quality will not improve if RAS is too low in concentration/too high of a flow rate

- RAS concentration also requires more optimization.
- Thin RAS will reduce anaerobic detention time in the selector.
- Thin RAS also carries too much dissolved oxygen and nitrates. The anaerobic selector can be washed out.
- Some sludge blanket required to start allowing RAS to lower in ORP.

Sludge Quality

Optimizing Nitrification typically produces good sludge quality



Traditional Concepts – Sludge Quality

What is good sludge quality?

A sludge that settles well and produces an effluent low in BOD₅ and Suspended Solids.

- “Normal Sludge Quality”: non-bulking but still has some filaments for structure - 100-500 microns in diameter. Good balance between environmental and physical conditions.
- “Bulking Sludge Quality”: Feathery floc, with 30 minute SVI's above 200 mls/gm.
- “Pin Floc”: Little growth pressures, small and dense floc - 50-70 microns with 30 minute SVI's near 50 mls/gm.

Traditional Concepts – Sludge Quality

Sludge Quality

Quantified Sludge Quality

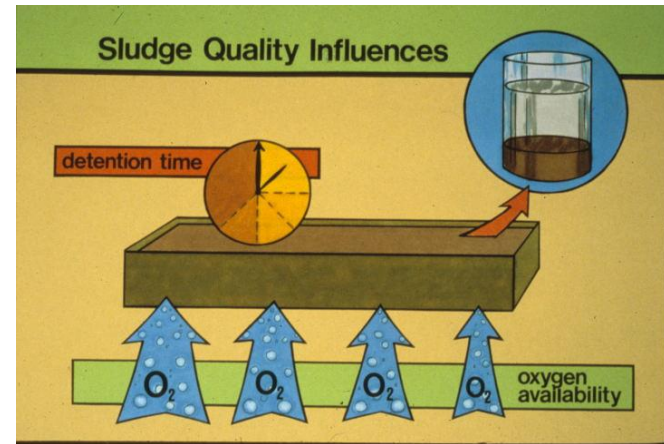
Sludge Volume Index (SVI)

- Quantify through comparison of solids weight and volume or space occupied during settling test.

Weight to Concentration Ratio (WCR)

- Quantify through comparison of solids weight and volume or space occupied after “spinning” at 3,000 rpm for 15 minutes.

Microscopic examination of morphology – qualitative determination of sludge quality.



Traditional Concepts – Sludge Quality

Volumetric Analyses

Settleometer

- Volumetric analyses in percent (Volume to Volume Comparison based on gravity and time constants)
- Location/Time of Sample Points
- Test is Based on Constant Separation (Gravity) / Constant Time/Variation is Sludge Mass and Quality
- Settled Sludge Volume Measurement Points/Trend Points
 - » Flocculation Time (5 Minutes)
 - » Settling Rate (30 Minutes)
 - » Compaction Rate (60 Minutes)
 - » Rise Time (Sludge Detention Minimum)

Process Control – Sludge Quality

Volumetric Analyses

Settleometer (con't)

- Qualitative and Quantitative Analyses
 - » Interface (readings and interface quality)
 - » Supernatant Quality (turbidity and clarity)
- Settled Sludge Volume (SSV) and Settled Sludge Concentration (SSC) determinations. Spin in % can be substituted for TSS

Settled Sludge Concentration

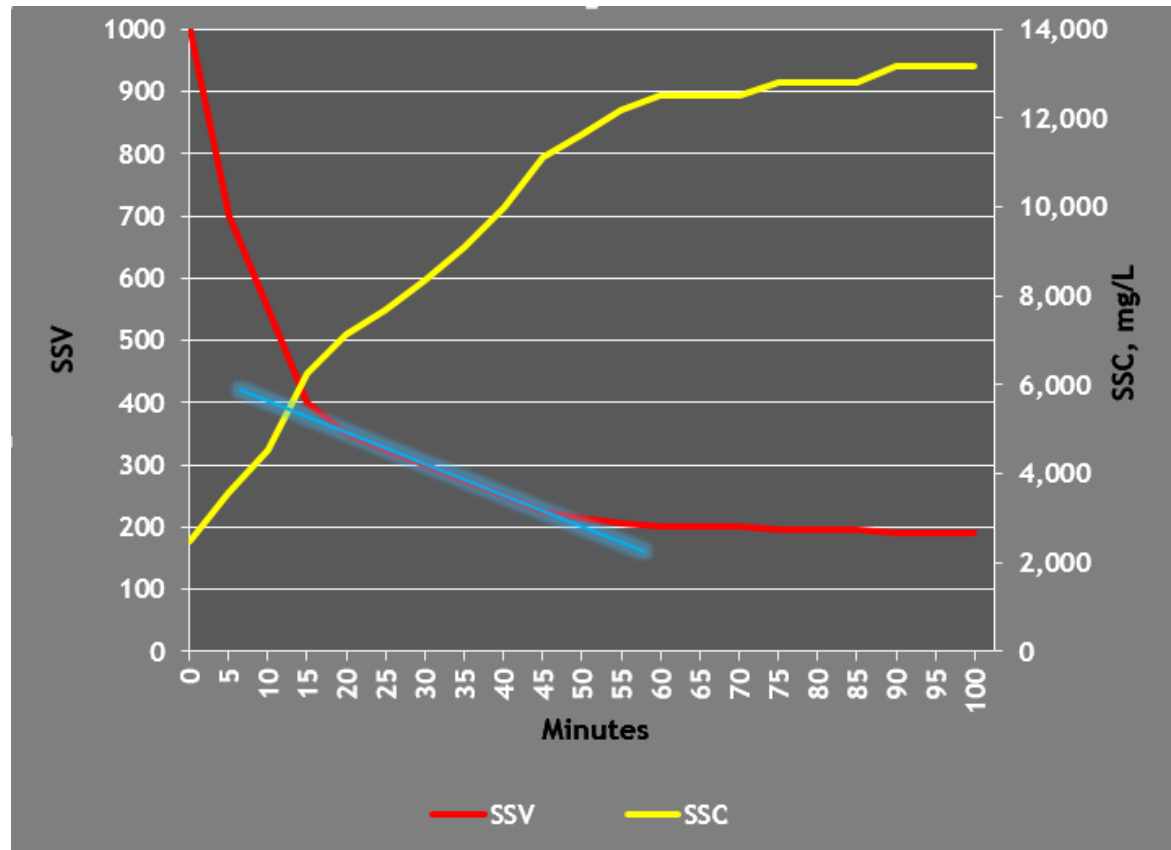
$$\text{SSC} = 1,000 * (\text{MLSS}) / \text{SSV}$$

- Diluted settling tests
- Stirred settling test

Traditional Concepts – Sludge Quality

Settling Curve for SVI of 120 mls/gm

Mins	SSV	SSC	
0	1000	2,500	mg/L
5	700	3,571	mg/L
10	550	4,545	mg/L
15	400	6,250	mg/L
20	350	7,143	mg/L
25	325	7,692	mg/L
30	300	8,333	mg/L
35	275	9,091	mg/L
40	250	10,000	mg/L
45	225	11,111	mg/L
50	215	11,628	mg/L
55	205	12,195	mg/L
60	200	12,500	mg/L
65	200	12,500	mg/L
70	200	12,500	mg/L
75	195	12,821	mg/L
80	195	12,821	mg/L
85	195	12,821	mg/L
90	190	13,158	mg/L
95	190	13,158	mg/L
100	190	13,158	mg/L



- Knee of the curve. Thickened 4 times in 45 minutes. After another 45 minutes, only thickened 1.3 times.

Lab Settleability Compared to Clarifier Performance

The Laboratory settling shows biological performance (Sludge Quality) without process interference / performance limiting factors from full scale operation:

- Hydraulic Loading
- Solids Loading
- Sludge Withdrawal
- Tank Geometry including Depth
- Velocity Currents
- Particle collision (flocculation zone)
- Baffling

MLSS Settleability and RAS Flow Rate

MLSS does not rise after 2+ hours of settling.

MLSS of 2,500 settles to 500 SSV or mls
(200 SVI).

Settled Sludge Concentration is 5,000 mg/L.

If RAS can be maintained at 5,000 mg/L, if influent flow is 8 MGD, RAS flow is 8 MGD.

RAS Flow in Equilibrium

$$\frac{(8 \text{ MGD} * 2,500 \text{ mg/L})}{(5,000 \text{ mg/L} - 2,500 \text{ MLSS mg/L})}$$

MLSS Settleability and RAS Flow Rate

If MLSS is maintained at 2,500 mg/L.

If SVI is improved to less than 120 mls/gm.

Settled Sludge Volume is 300.

Settled Sludge Concentration is 8,333

If RAS is thickened to 7,500 mg/L, RAS flow in equilibrium at an influent flow of 8 MGD is 4 MGD.

RAS Flow in Equilibrium

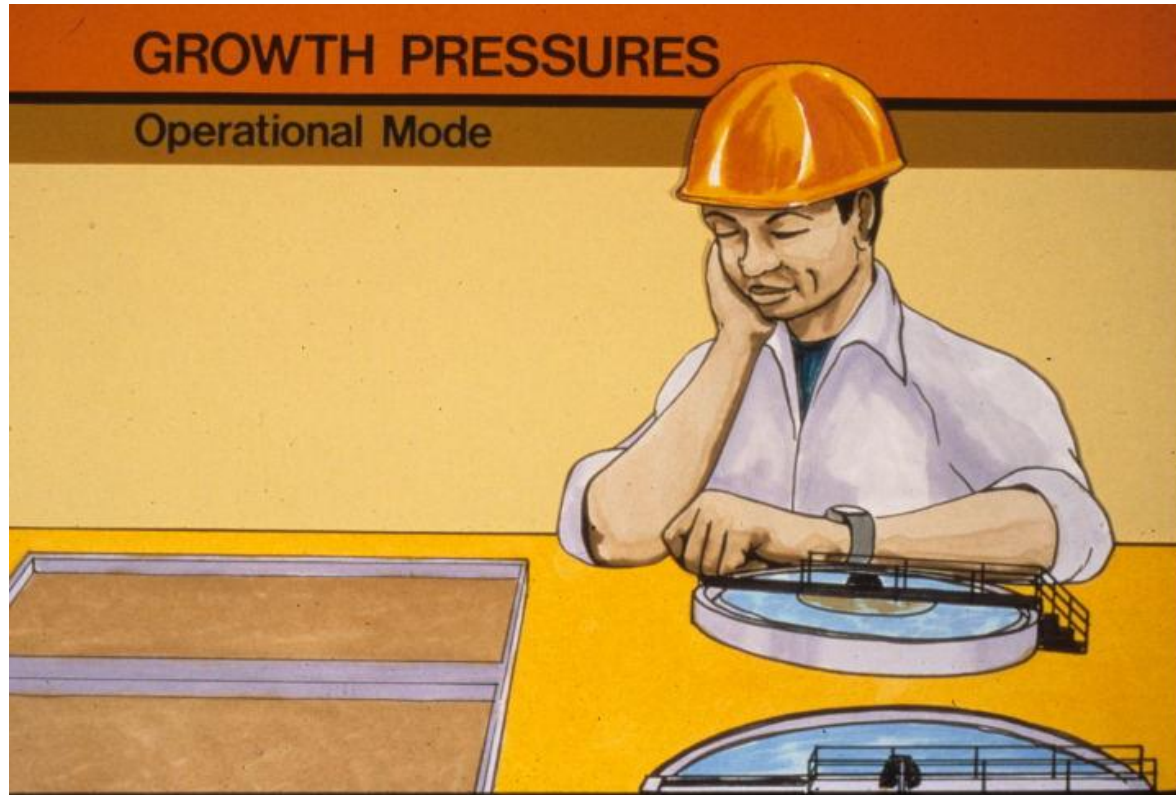
$$\frac{(8 \text{ MGD} * 2,500 \text{ mg/L})}{(7,500 \text{ mg/L} - 2,500 \text{ MLSS mg/L})}$$

RAS Flow Rate with Selector

RAS Flow Rate Control is more critical to ensure not over-aerated and reducing the positive impact of selector.

- Excessive RAS flow rate can wash selector.
- Excessive RAS flow rate increases hydraulics loading to the clarifier (measured by Solids Loading).
- Optimum RAS flow rate control will take advantage of the selector, help to improve sludge quality and provide for improved clarifier performance.
- Improved sludge quality and optimum RAS flow rates will enable plant to process more peak weather flow.

Changing Operational Mode for Wet Weather: Step Feed increases peak flow treatment capacity



Utilizing Step Feed for Wet Weather



Assume Utopia has 2 aeration tanks

8 MGD Dry Weather – Plug Flow

4 MGD

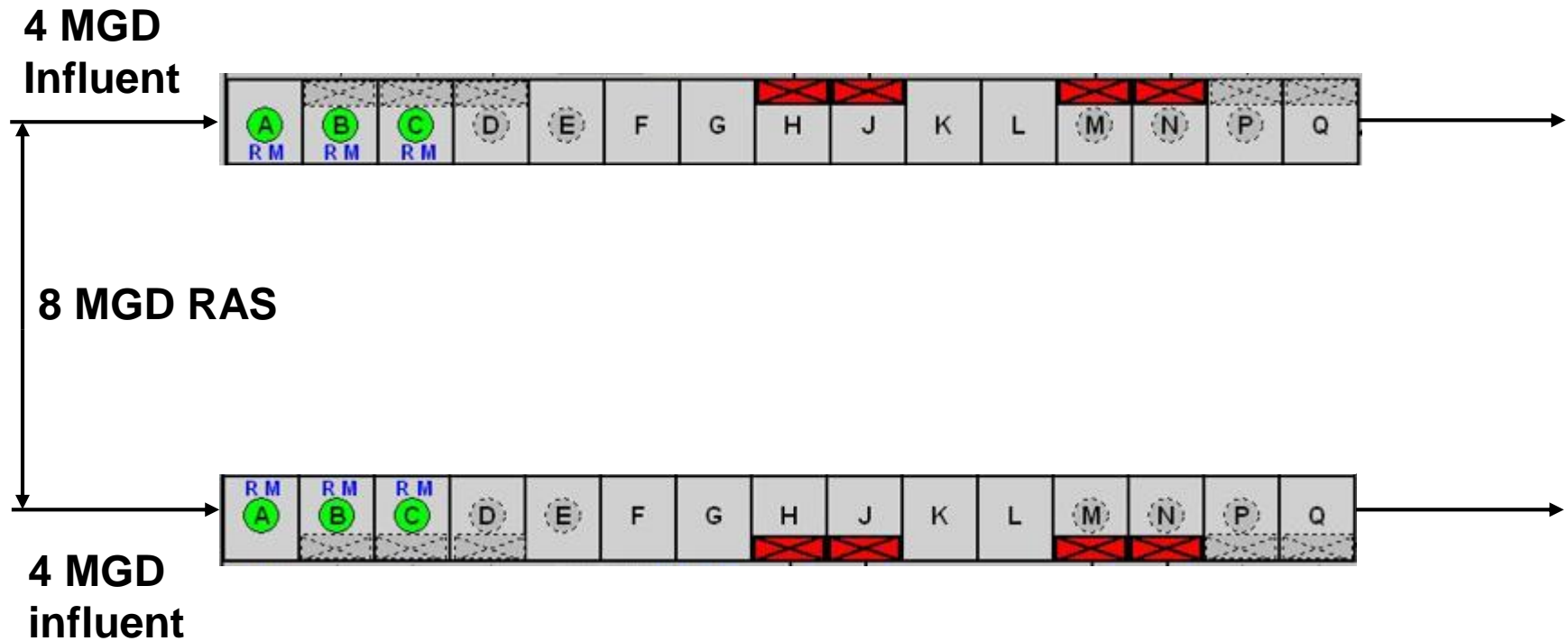


4 MGD



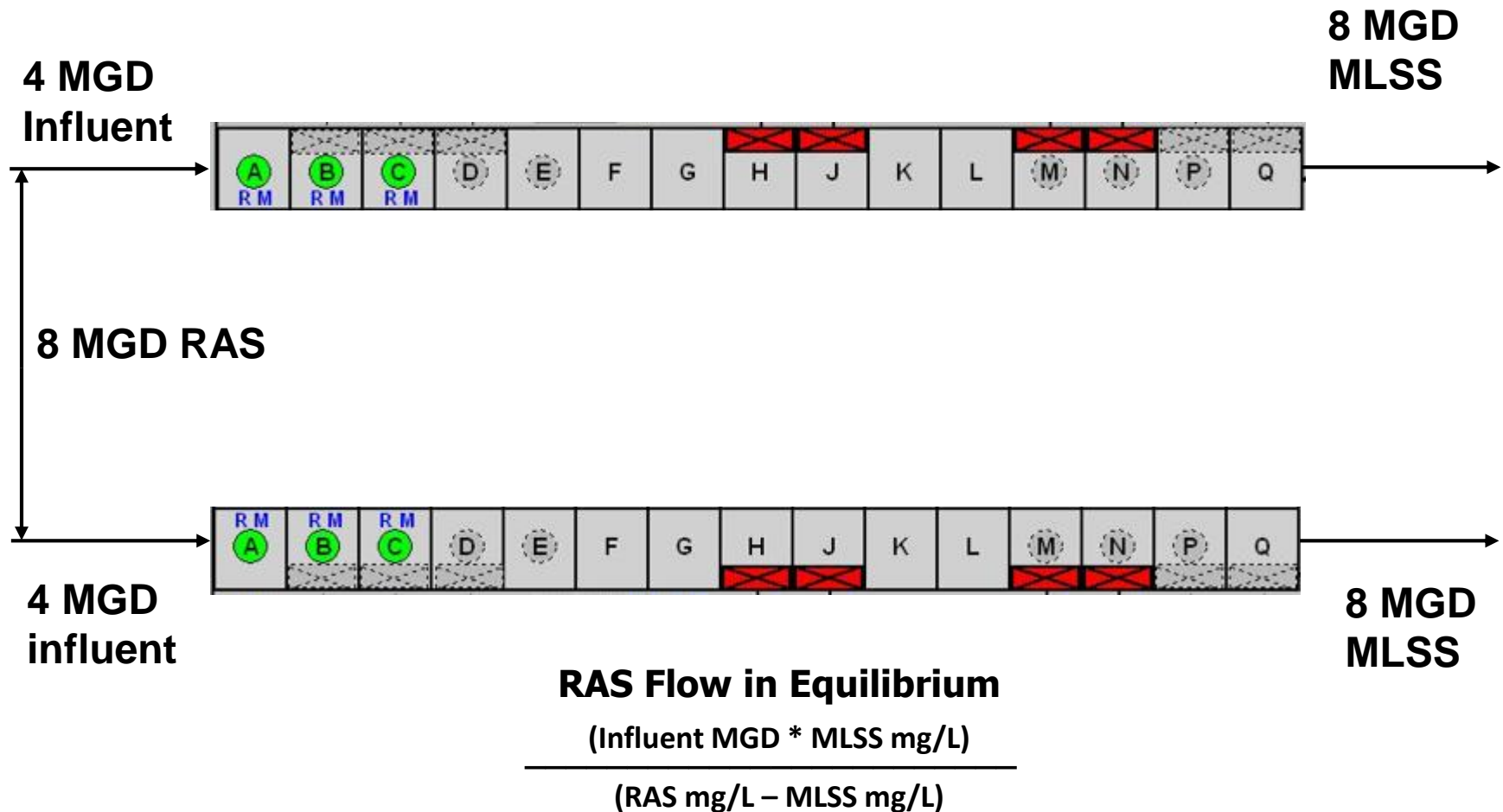
Step Feed for Wet Weather

8 MGD Dry Weather – Plug Flow



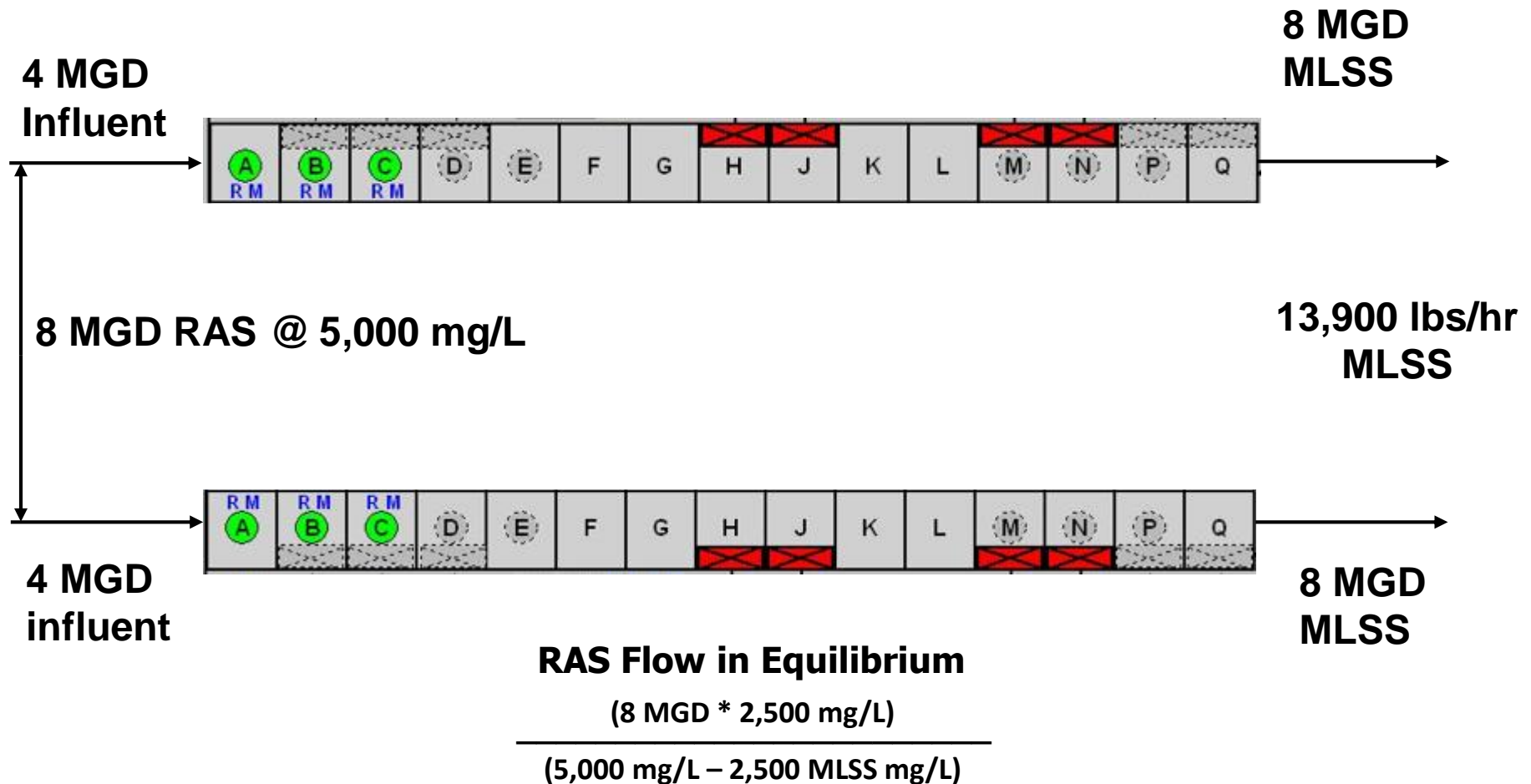
Step Feed for Wet Weather

8 MGD Dry Weather – Plug Flow



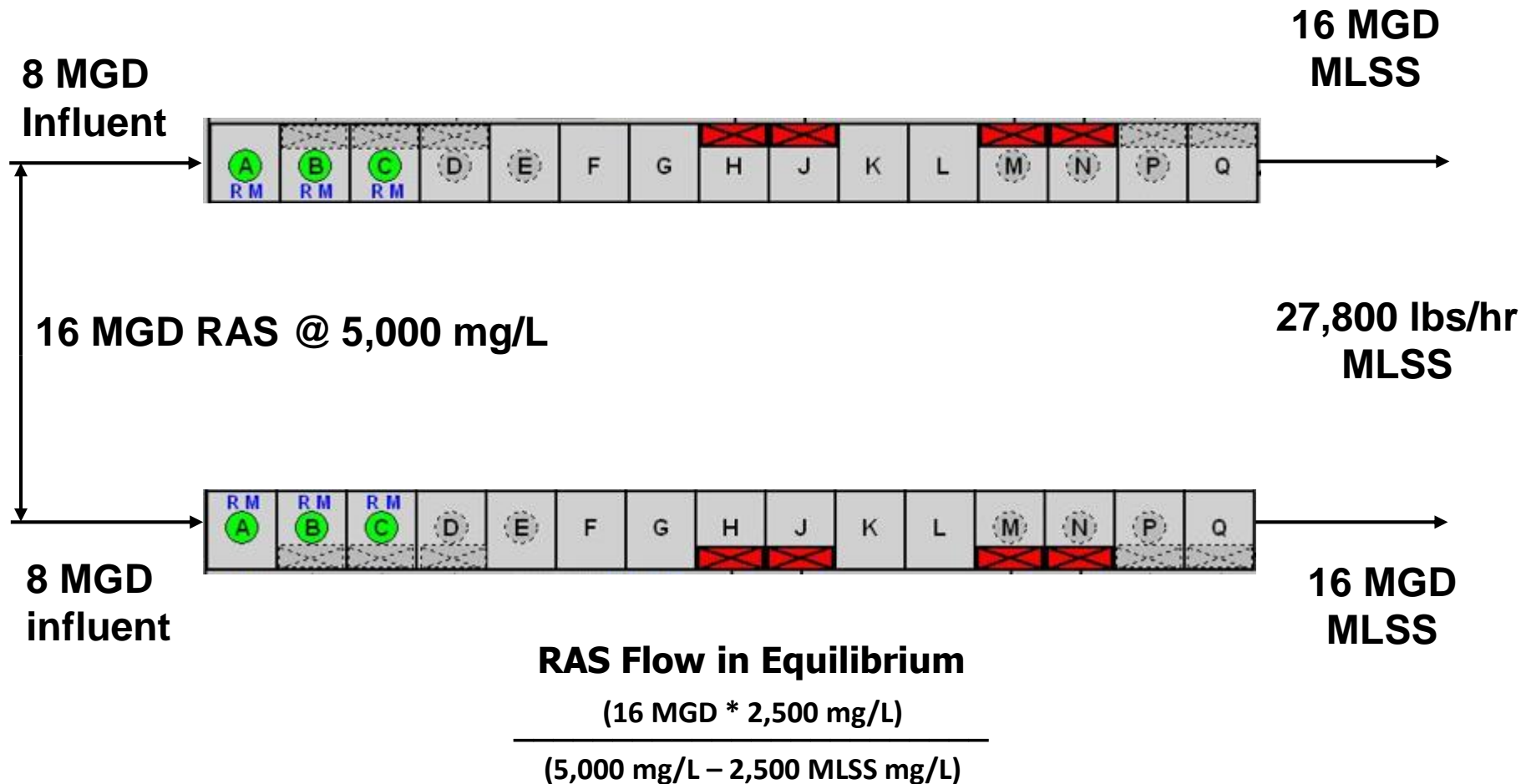
Step Feed for Wet Weather

8 MGD Dry Weather – Plug Flow



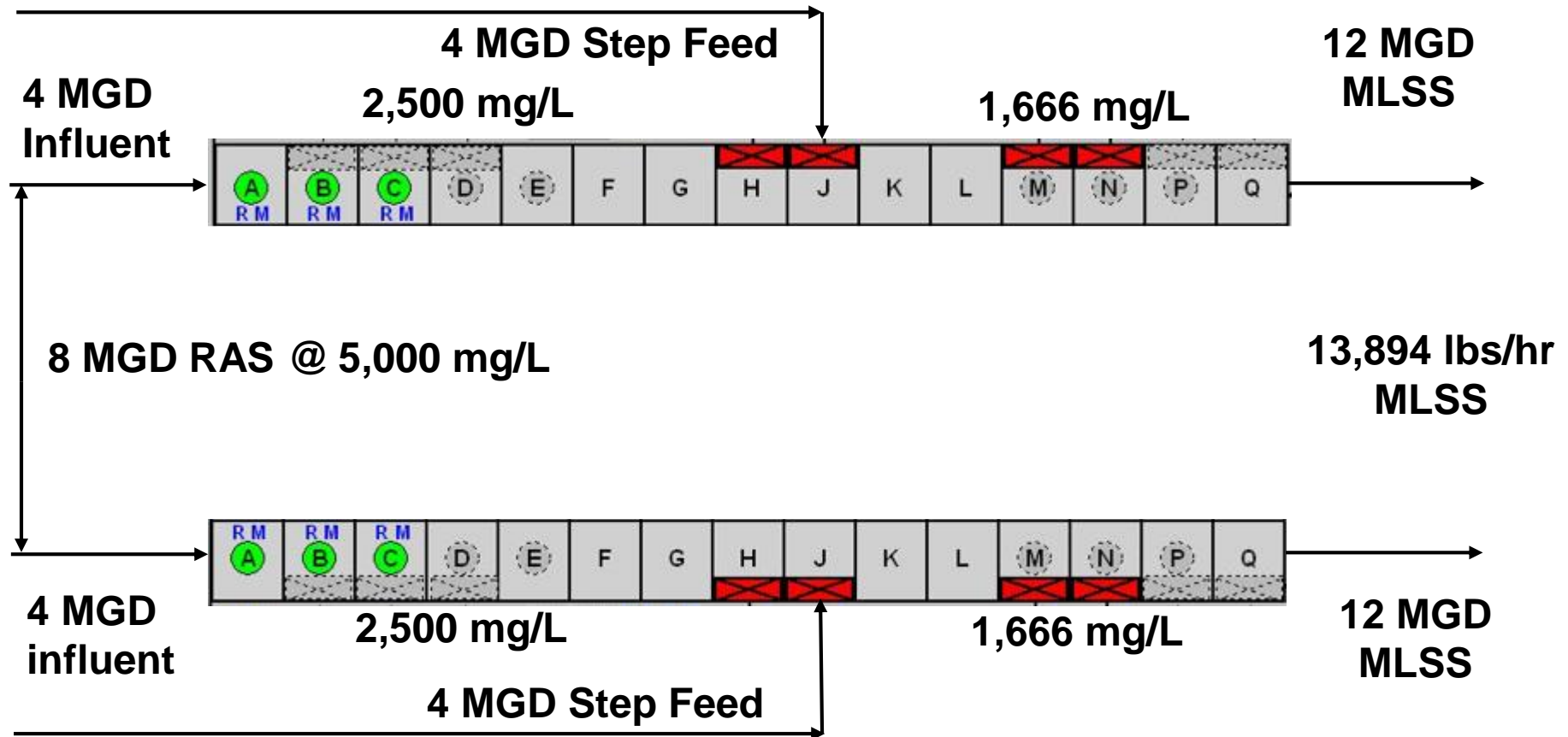
Step Feed for Wet Weather

16 MGD Wet Weather – Plug Flow



Step Feed for Wet Weather

Wet Weather – Step Feed Flow



RAS Flow in Equilibrium

$$(16 \text{ MGD} * 1,666 \text{ mg/L})$$

$$(5,000 \text{ mg/L} - 1,666 \text{ MLSS mg/L})$$

Step Feed Reduces Solids Loading to the Clarifiers

- If two (2) settling tanks are on line:
 - 120 feet in diameter
 - Solids Loading is lbs MLSS/sf/day (include RAS flow)
 - 11,304 sf/clarifier times 2 clarifiers (22,608 sf)
- 8 MGD with an 8 MGD RAS flow results in a 15 lbs/d/sf solids loading rate
- If plug flow is maintained at 16 MGD, RAS flow is doubled as solids are pushed into the clarifier. Solids loading rate is 30 lbs/d/sf
- If step feed is employed for 100% of the influent flow (can be adjusted as wet weather flows increase), RAS flow rate can be maintained at 8 MGD and solids loading rate is back to 15 lbs/d/sf. Sludge blankets are maintained as flow rates increase.

Utopia's new KPDES includes phosphorus

Utopia plans to use Enhanced Biological Phosphorous Removal.

- Plant upgrade will include additional “bio P” tankage.
- Utopia staff must adjust process control to optimize biological phosphorus removal while minimizing chemical feed.
- Staff has already begun “bio P” process control by optimizing the anaerobic selector process and improving sludge quality.

Questions



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