Planning for Low Effluent Nutrient Limits: Case Studies for Meeting Nutrient Limits in New England through Model Based Evaluation

Edwin Castilla Ph. D., P. E.

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Jacobs Challenging today.
Reinventing tomorrow.

NEW ENGLAND WATER ENVIRONMENT ASSOCIATION
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Agenda

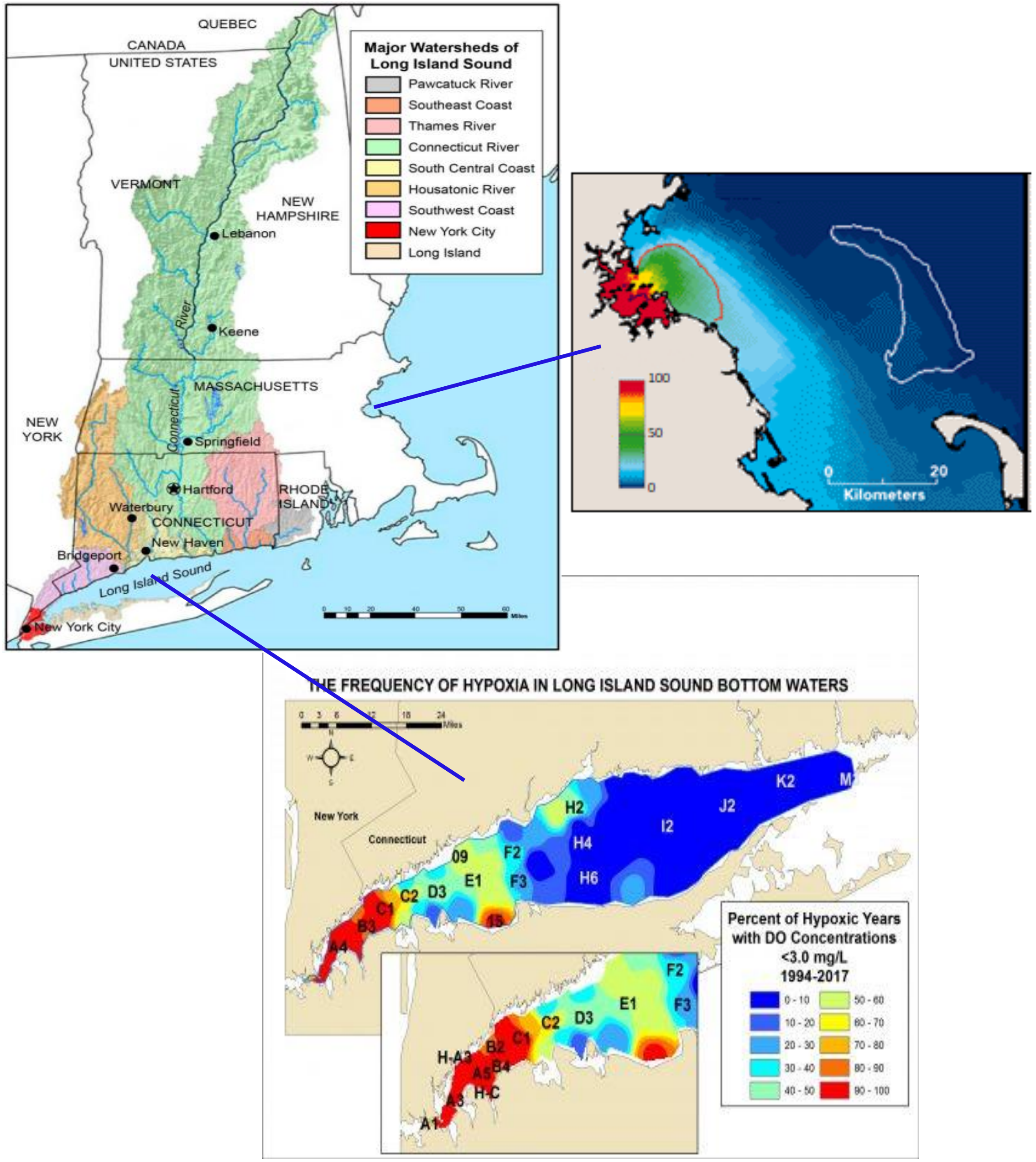
- Planning for Low Nutrient Limit
- Current and Future Permit
- Model-Based Analysis Approach
- Model Development and Calibration
- Model Constraints
- Model Scenarios
- Case Study
- Conclusions

Planning for Low Nutrient Limit

- Planning and designing for future conditions
  - Increase WWTF treatment capacity to accommodate future population growth and sewer connections
  - Nutrients removal upgrades at the facility to meet future effluent permit
  - Robust model-based analysis that predicts performance of existing, future infrastructure and technologies
  - Model-based method that minimize risks associated to uncertainties in designs
  - Model-based method that aids facility planning and assists in the development of facility upgrades strategies

Current and Future Permits

- TMDL based limits
  - Nutrient loading thresholds that protect the receiving water bodies
  - Permits are based on nutrient loading
  - Set 6-month average periods (May - October and November - April)
- Future flows based on growth projections
- Increased flow – reduced concentration
- Interstate state future nutrient permits
  - More stringent TMDL for most utilities
    - Long Island Sound
    - Massachusetts Bay



http://longislandsoundstudy.net/2010/07/frequency-of-hypoxia/

Model Based-Analysis Approach

Develop & Calibrate Plant Model

- Plant operational and physical data
- Water quality data
- Facility mass balance
- Calibrated model mimics plant performance

Check Constrains for Modeling Scenarios

- Equipment and process limitations
- Environmental and water quality limitations

Performance Indicators

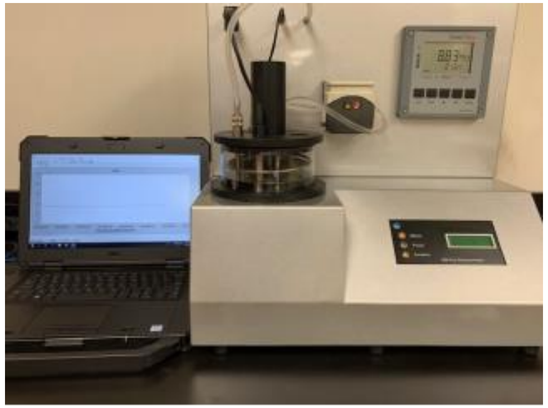
- Effluent quality
- Performance goals
- Energy consumptions goals

Modelling Scenarios

- Optimization of existing infrastructure
- Determination of plant maximum capacity
- Identification of modelling scenarios

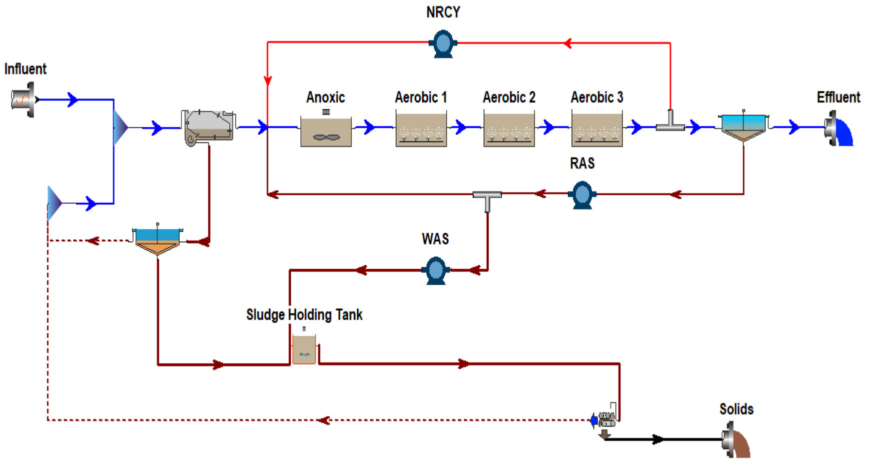
Model Development and Calibration

- Plant historical operational and physical data
  - Liquid and solid streams flows
  - Process unit dimensions and equipment capacity
- Influent wastewater characterization
  - Carbon : COD, sCOD, ffCOD, VFA, BOD, sBOD
  - Nitrogen : TKN, NH_3, NOx and Phosphorus : TP, sP
  - Others : TSS, VSS, Alkalinity, pH, Harness
- Kinetic and stoichiometric parameters
  - Adjusted for potential inhibiting components (incinerator scrubber water with cyanide)



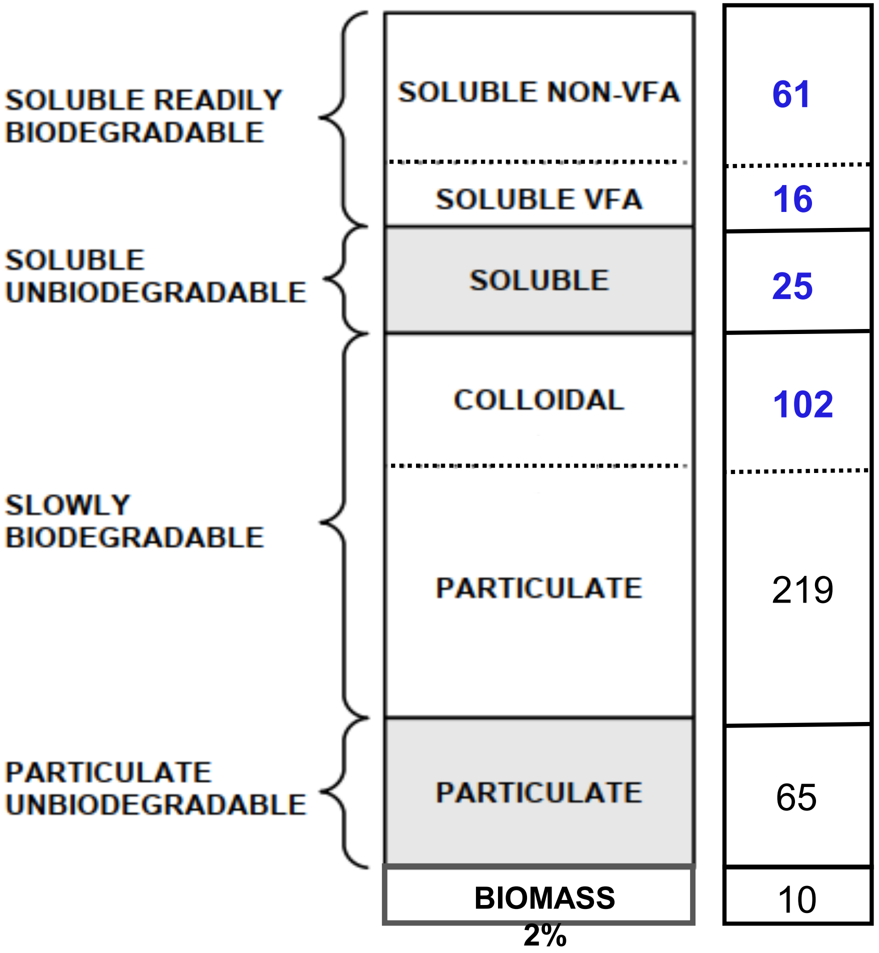
Model Development and Calibration - Sampling

Analyte	**Average Flows and Concentrations – Sampling Period**					
	Raw Influent	Primary Influent	Primary Effluent	GT Overflow	Dewater Filtrate	Second Effluent
Flow (mgd)	✓	✓	✓	✓	✓	✓
TSS (mg/L)	245	✓	✓	✓	✓	✓
VSS (mg/L)	180	✓	✓			
COD (mg/L)	500	✓	✓			
sCOD (mg/L)	**205**	✓				**25**
FFCOD	**102**	✓				
BOD_5 (mg/L)	235	✓	✓	✓	✓	✓
$sBOD_5$ (mg/L)	110	✓				
TKN (mg/L)	40	✓	✓	✓	✓	✓
sTKN (mg/L)	**32.9**					**0.8**
Ammonia (mg/L)	28	✓				✓
NOx (mg/L)	0	✓	✓			✓
TP (mg/L)	6.5	✓	✓	✓	✓	✓
Ortho-P (mg/L)	3.3	✓	✓			✓
VFA (mgOD/L)	**16**	✓	✓			
pH	7.0	✓				



- Water quality of other treatment units

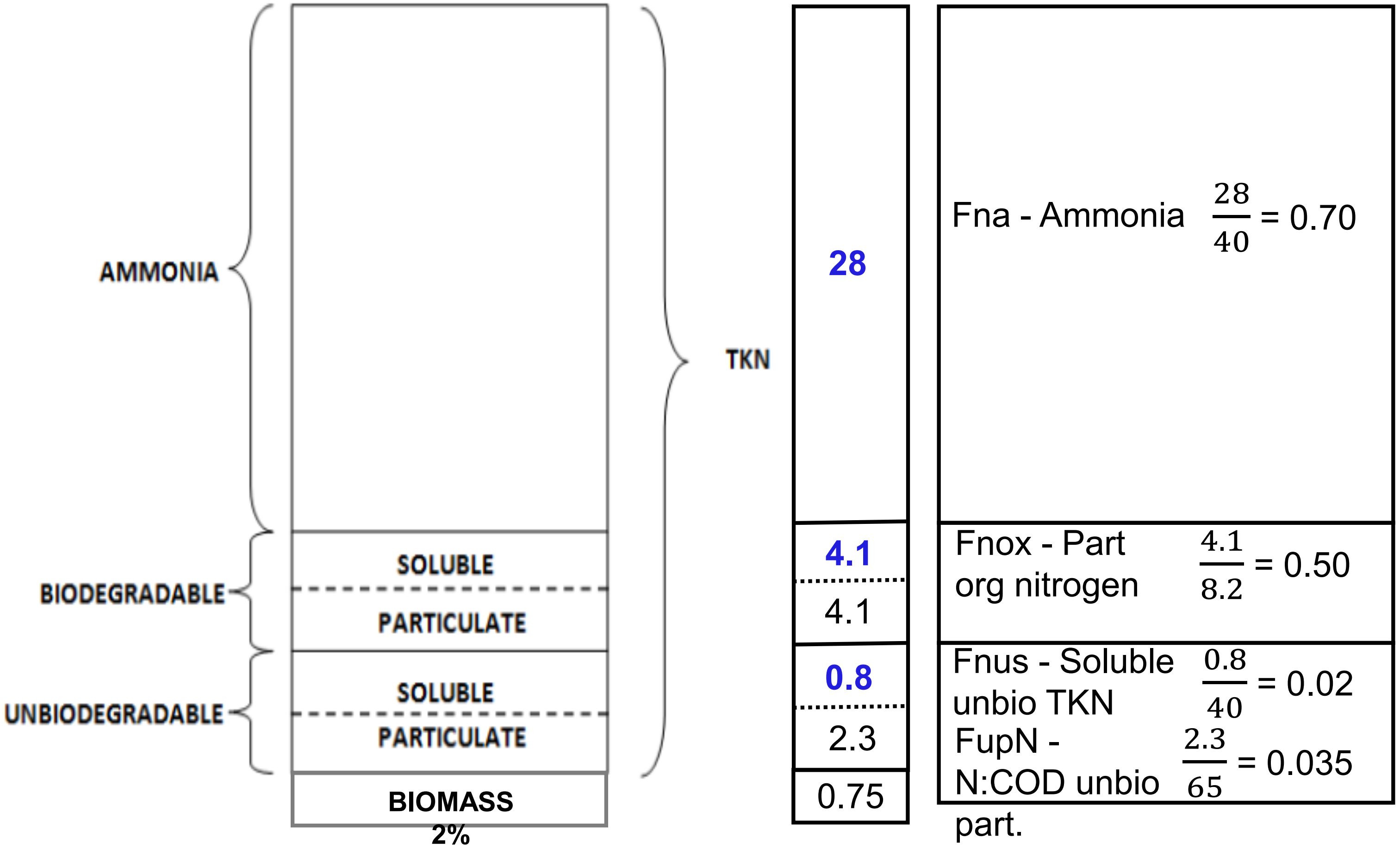
Wastewater Characteristic – Observations



Fbs - Readily biodegradable	$\frac{77}{500} = 0.154$
Fac - Acetate	$\frac{16}{77} = 0.208$
Fus – Unbio soluble	$\frac{25}{500} = 0.05$
Fxs – colloidal slowly bio	$\frac{102}{321} = 0.32$
Fxsp - Non-colloidal slowly bio	$\frac{219}{321} = 0.68$
Fup – Unbio particulate	$\frac{65}{500} = 0.13$

- Determine the influent wastewater characterization
  - COD fractions
    - bCOD ~ 1.69 BOD
    - rbCOD – impact denitrification, VFA - Bio P removal
    - snbCOD – impact effluent sCOD
    - sbCOD – particulate/colloidal COD impact PST solids removal. Colloidal can be flocculated.
    - pnbCOD – Inert COD impacts sludge production

Wastewater Characteristic – Observations



Fna - Ammonia $\frac{28}{40} = 0.70$

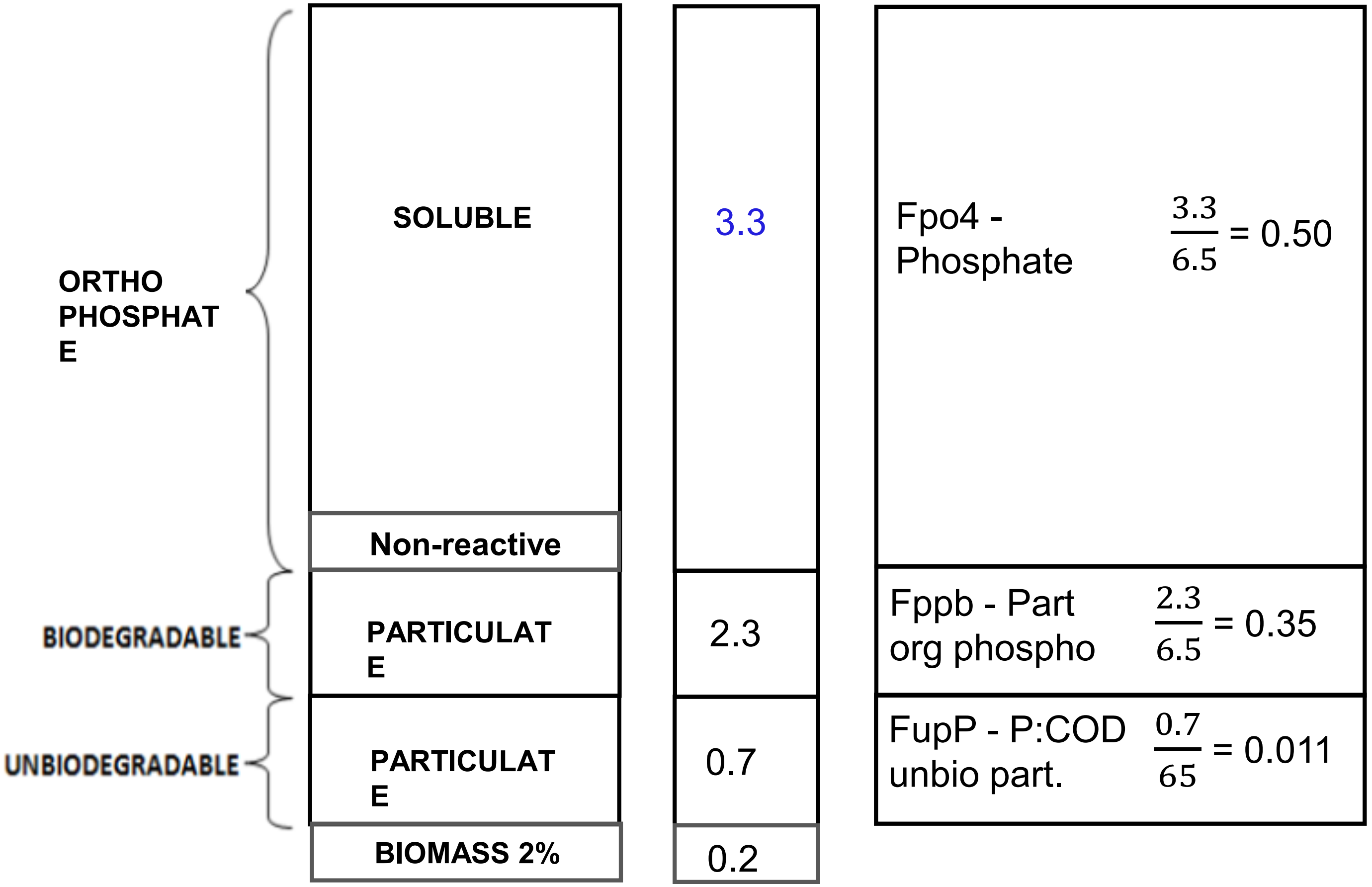
Fnox - Part org nitrogen $\frac{4.1}{8.2} = 0.50$

Fnus - Soluble unbio TKN $\frac{0.8}{40} = 0.02$

FupN - N:COD unbio part. $\frac{2.3}{65} = 0.035$

- Nitrogen fractions
  - NH3-N/TKN – majority is Ammonia-N
  - snbTKN – important for low effluent TN
  - pnbTKN – part of unbiodegradable particulate COD

Wastewater Characteristic – Observations



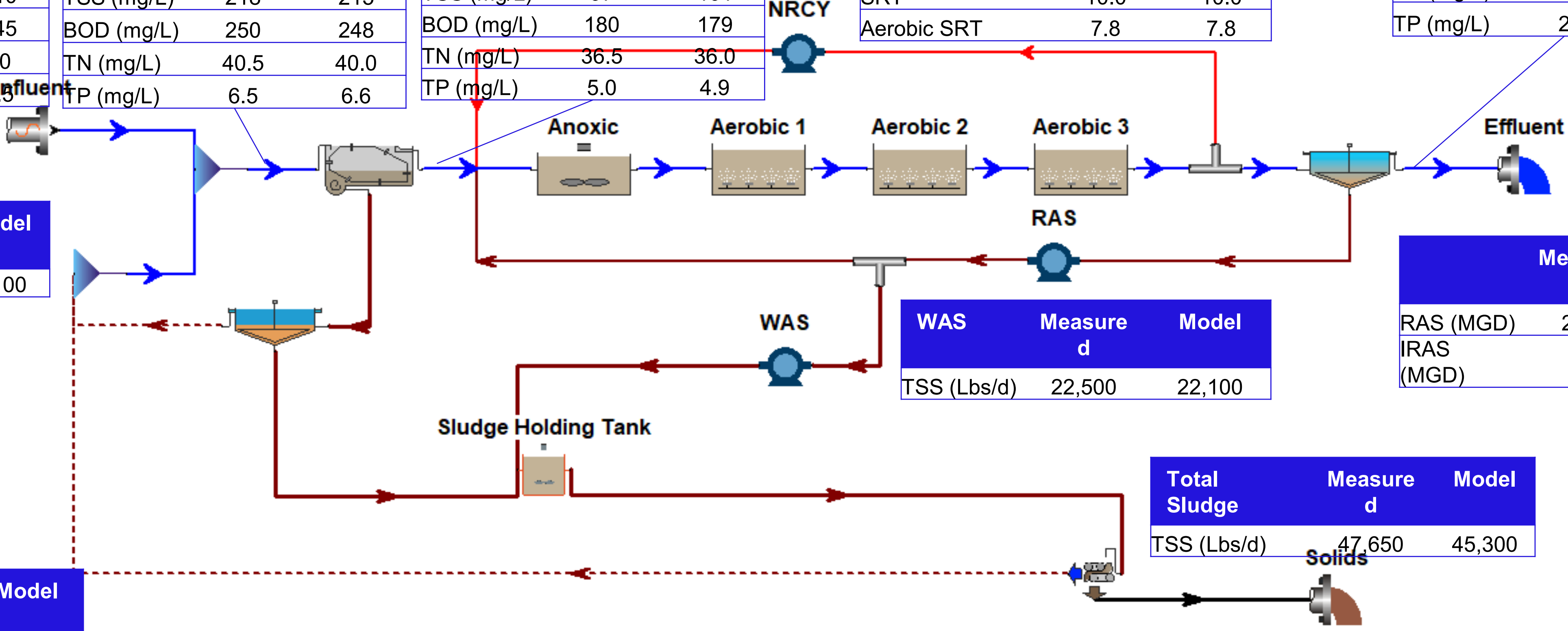
ORTHO PHOSPHATE	SOLUBLE	3.3	Fpo4 - Phosphate	$\frac{3.3}{6.5}$ = 0.50
	Non-reactive			
BIODEGRADABLE	PARTICULATE	2.3	Fppb - Part org phospho	$\frac{2.3}{6.5}$ = 0.35
UNBIODEGRADABLE	PARTICULATE	0.7	FupP - P:COD unbio part.	$\frac{0.7}{65}$ = 0.011
	BIOMASS 2%	0.2		

- Phosphorus fractions
  - PO4-P/TP
  - Soluble ortho-phosphate reactive & non-reactive (sNRP) (important for low effluent TP)
  - Particulate bio and unbiodegradable phosphorus – organically bound
- Compare wastewater analyte ratios with typical values such as TSS/BOD, TKN/BOD, TP/BOD, COD/BOD, VSS/TSS, etc

Influent Wastewater Characterization

Influent	**Value**	**Typical range**
Fbs - Readily biodegradable (including Acetate) [gCOD/g of total COD]	**0.154**	0.12 – 0.25
Fac - Acetate [gCOD/g of readily biodegradable COD]	**0.208**	0.150
Fxsp - Non-colloidal slowly biodegradable [gCOD/g of slowly degradable COD]	**0.680**	0.7 – 0.8
Fus - Unbiodegradable soluble [gCOD/g of total COD]	0.050	0.03 – 0.08
Fup - Unbiodegradable particulate [gCOD/g of total COD]	0.130	0.07 – 0.22
Fna - Ammonia [gNH3-N/gTKN]	**0.700**	0.5 – 0.8
Fnox - Particulate organic nitrogen [gN/g Organic N]	0.500	0.500
Fnus - Soluble unbiodegradable TKN [gN/gTKN]	0.020	0.020
FupN - N:COD ratio for unbiodegradable part. COD [gN/gCOD]	0.035	0.035
Fpo4 - Phosphate [gPO4-P/gTP]	0.500	0.3 - 0.6
FupP - P:COD ratio for unbiodegradable part. COD [gP/gCOD]	0.011	0.011
COD/BOD	2.12	2.05 - 2.5
VSS/TSS	0.73	0.7 - 0.9
TSS/BOD	1.04	0.7 - 1.2
TKN/BOD	0.17	0.14 - 0.24
TP/BOD	0.028	0.02 - 0.05

Model Calibration and Validation



Influent	Measured	Model
Flow (MGD)	26.0	26.0
TSS (mg/L)	210	210
BOD (mg/L)	245	245
TN (mg/L)	40	40
TP (mg/L)	6.5	6.5

Pri Inf	Measured	Model
Flow (MGD)	27.8	27.8
TSS (mg/L)	218	215
BOD (mg/L)	250	248
TN (mg/L)	40.5	40.0
TP (mg/L)	6.5	6.6

Pri Eff	Measured	Model
Flow (MGD)	26.4	26.4
TSS (mg/L)	97	101
BOD (mg/L)	180	179
TN (mg/L)	36.5	36.0
TP (mg/L)	5.0	4.9

Aeration Tanks	Measured	Model
MLSS (mg/L)	3,050	3,100
MLVSS (mg/L)	2,500	2,550
SRT	10.0	10.0
Aerobic SRT	7.8	7.8

Effluent	Measured	Model
Flow (MGD)	25.9	25.9
TSS (mg/L)	12	10
BOD (mg/L)	7.5	5.0
NH3 (mg/L)	0.2	0.4
TN (mg/L)	7.4	7.6
TP (mg/L)	2.0	2.4

Returns	Measured	Model
TSS (lbs/d)	4,250	4,100

	Measured	Model
RAS (MGD)	26.4	26.4
IRAS (MGD)	80	80

WAS	Measured	Model
TSS (Lbs/d)	22,500	22,100

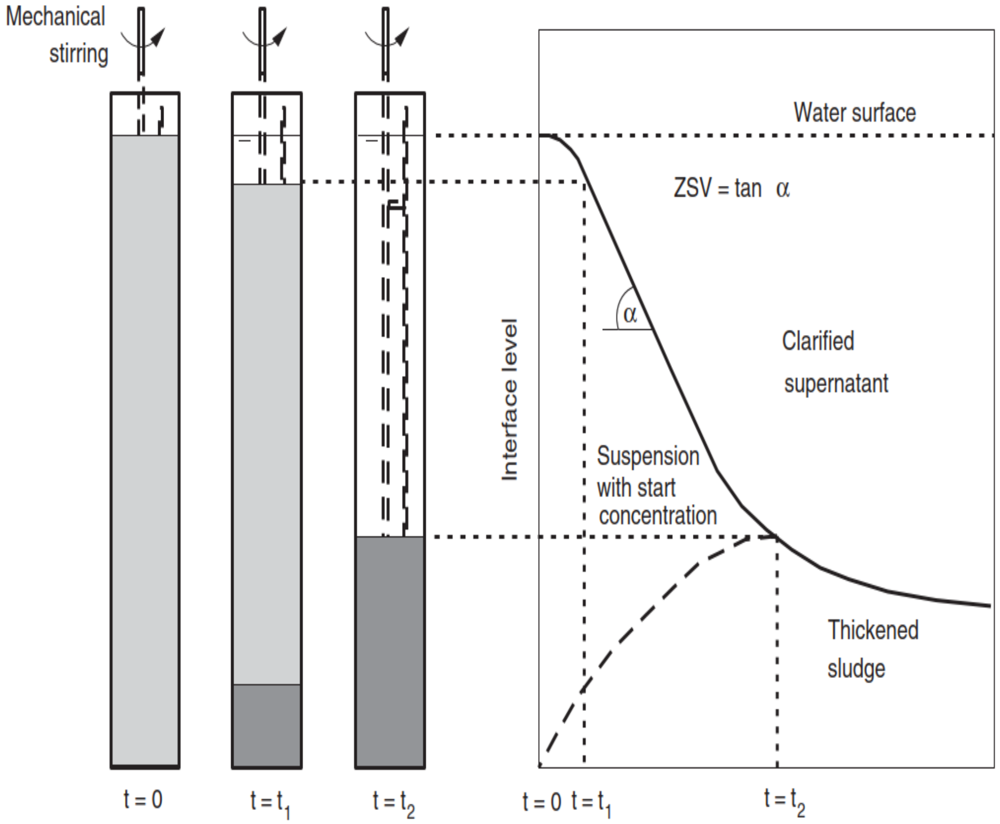
Total Sludge	Measured	Model
TSS (Lbs/d)	47,650	45,300

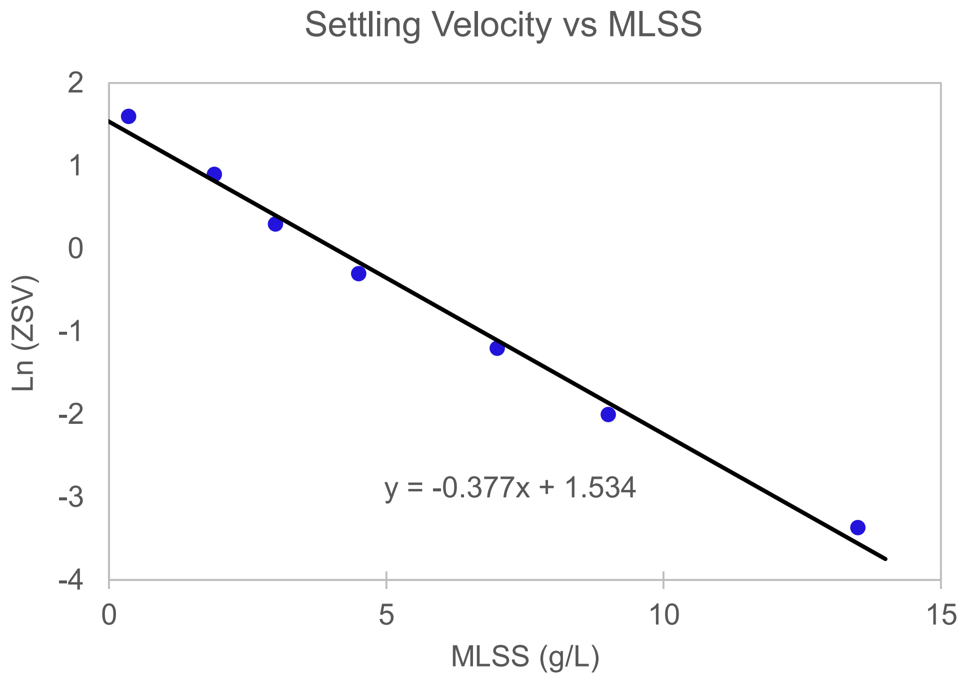
P Sludge	Measured	Model
TPS	Measured	Model
TSS (Lbs/d)	25,150	24,600

BFP	Measured	Model
Cake (Lbs/d)	46,100	43,900

Calibrated model : measured and model data discrepancy less than 5%

Secondary Treatment – Sludge Settling Behavior





ZSV = Vo Exp$^{(-KX)}$

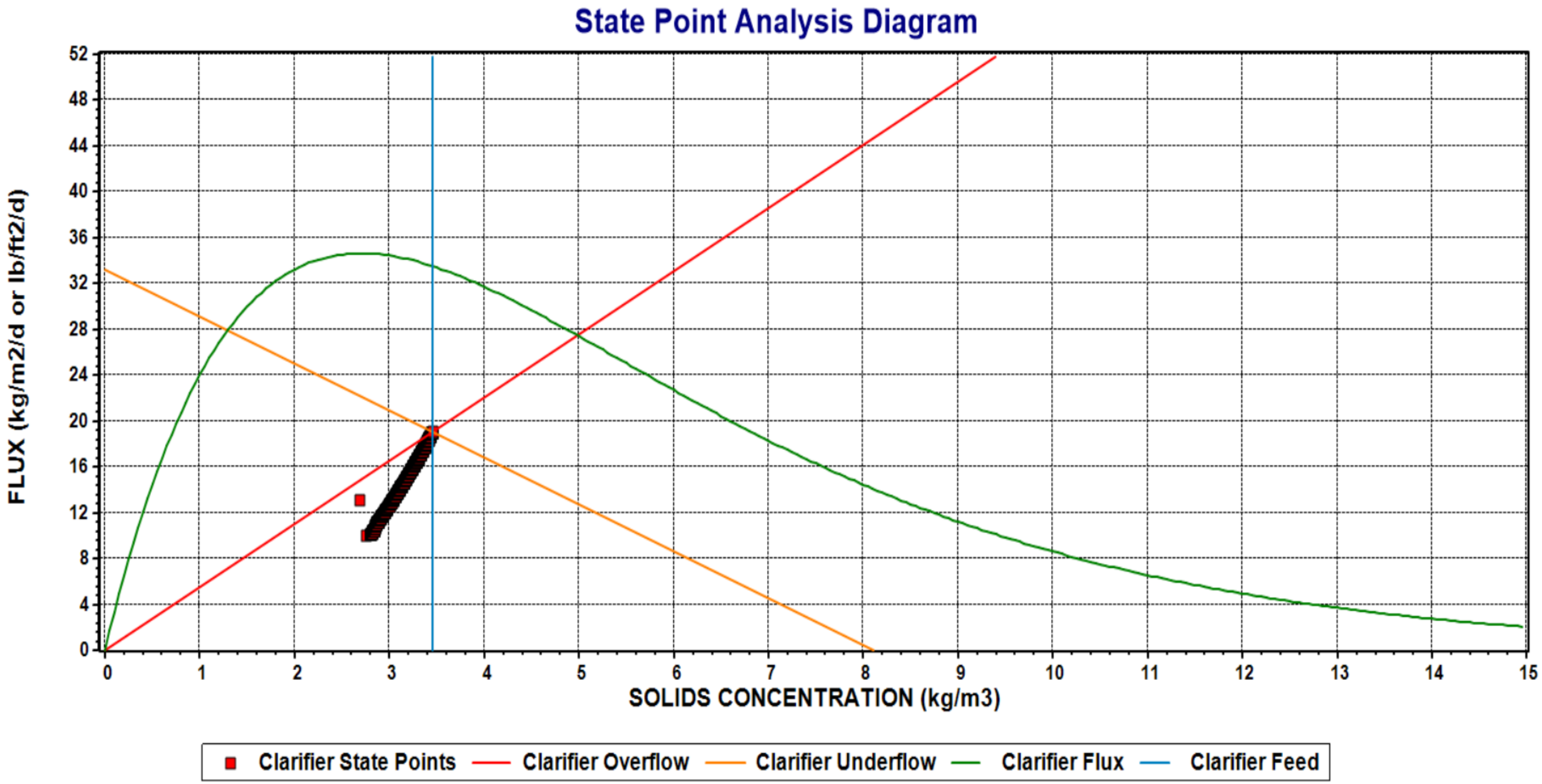
Where : ZSV : zone settling velocity, X : MLSS concentration

Vo & K : sludge settleability constants

Ln Vo = 1.53 ➔Vo = 557 ft/d

K = 0.37

Secondary Treatment – Sludge Settling Behavior

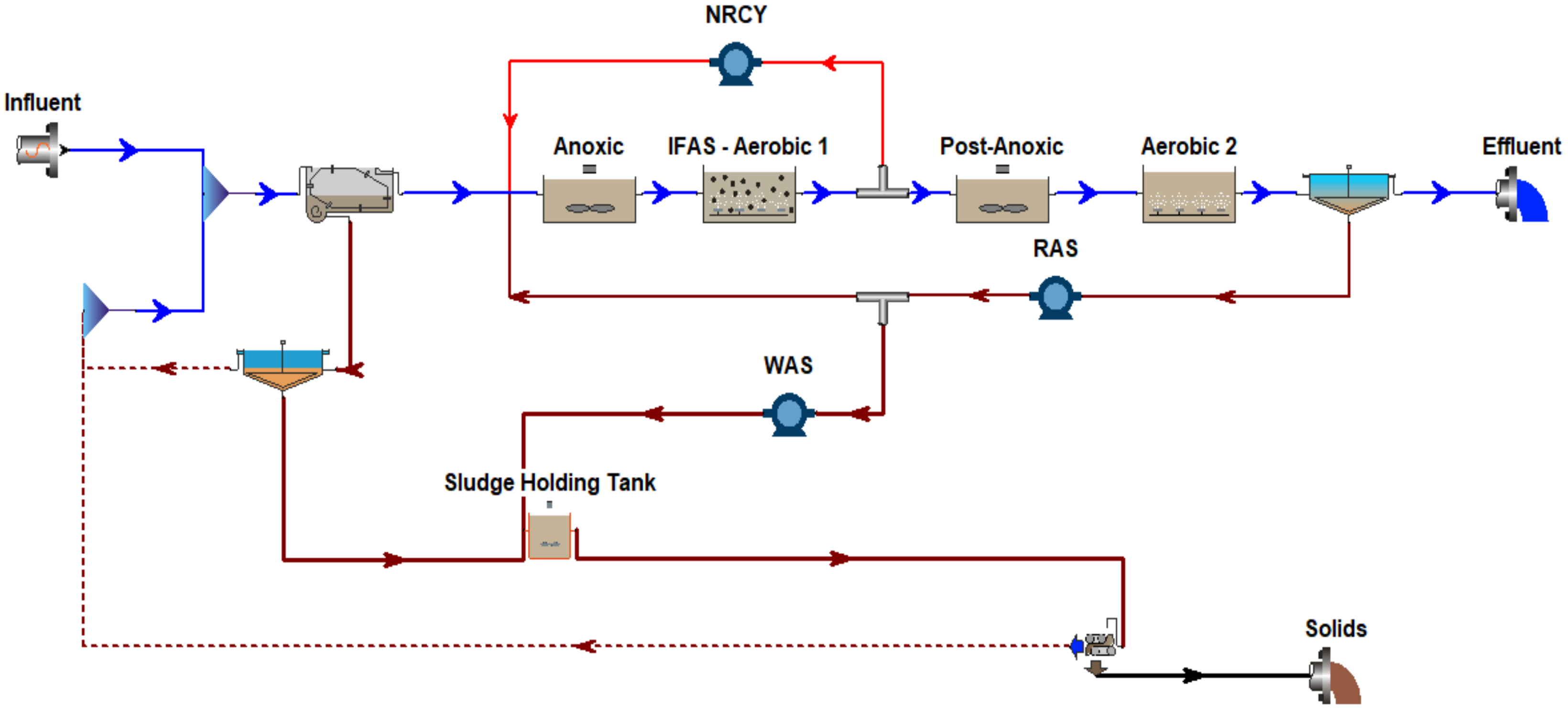


K = 0.3700 m3/kg
Vo = 557.7 ft/d

Model Process and Equipment Constrains

- Process constraints
  - Wastewater fractions to meet process goal
  - Inhibitors & bacteria maximum specific growth rate
  - Operating SRT for process goals - nitrification
  - Sludge thickening and dewatering achievable performance
  - Impact of the return flows (TN and TP)
  - Impact of the RAS (nitrate) in Bio-P process
  - Reactor type & mixing
- Equipment constraints
  - Blower capacity – air supply – DO concentrations
  - Mixing/aeration capacity
  - Pumping capacity – RAS, IRAS, etc.
  - Hydraulic capacity of each process unit

Model Scenarios - 4 Stage BNR & 4 Stage IFAS BNR



4 Stage BNR

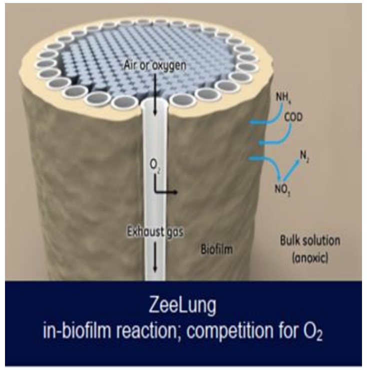
- Can meet more stringent TN limits

IFAS/MOB

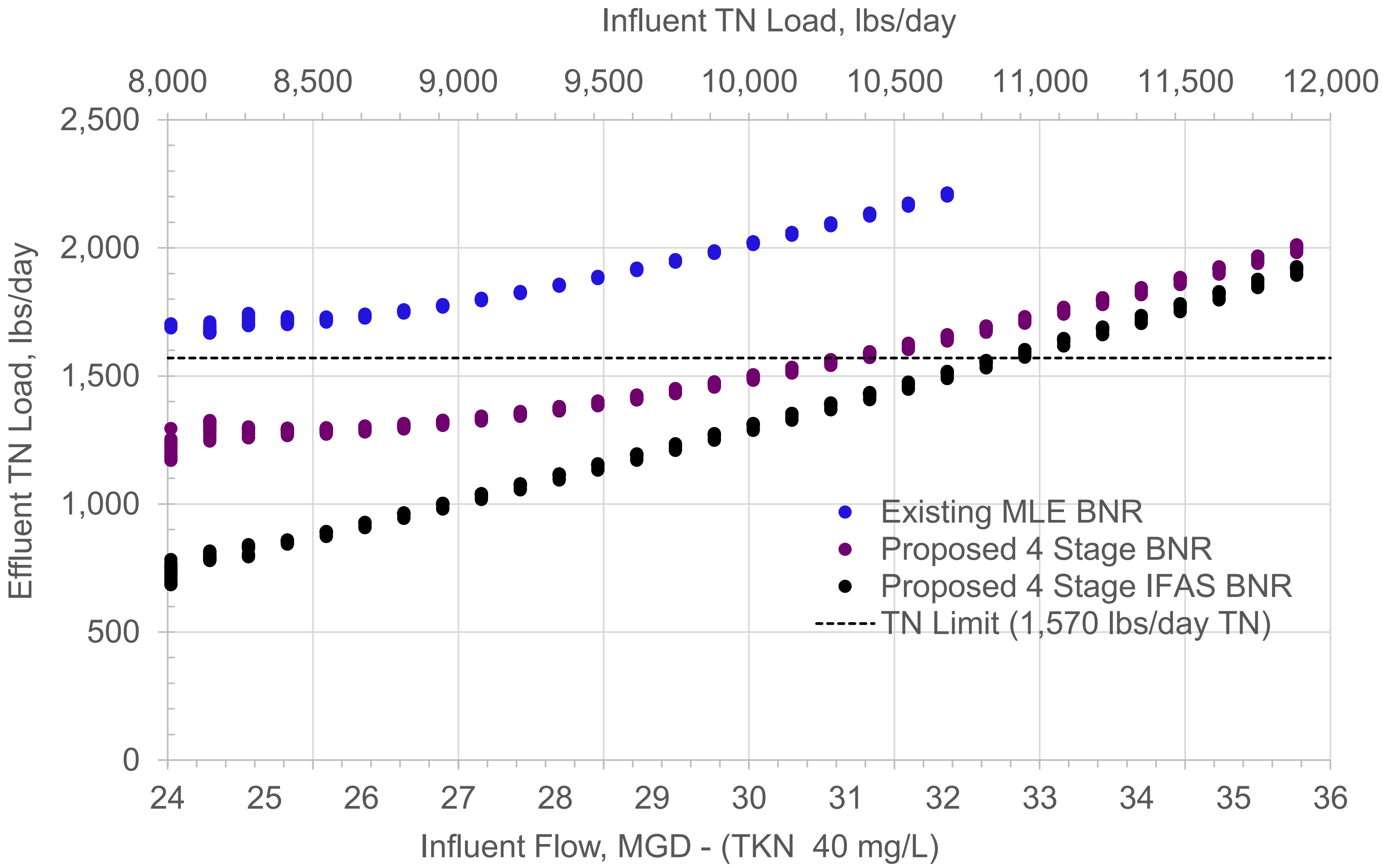
- Can meet more stringent TN limits
- Similar configuration to AS
- Requires more aeration capacity
- Requires internal screening

MABR

- Similar configuration to AS
- Requires less aeration capacity
- Membranes installed in anoxic zone



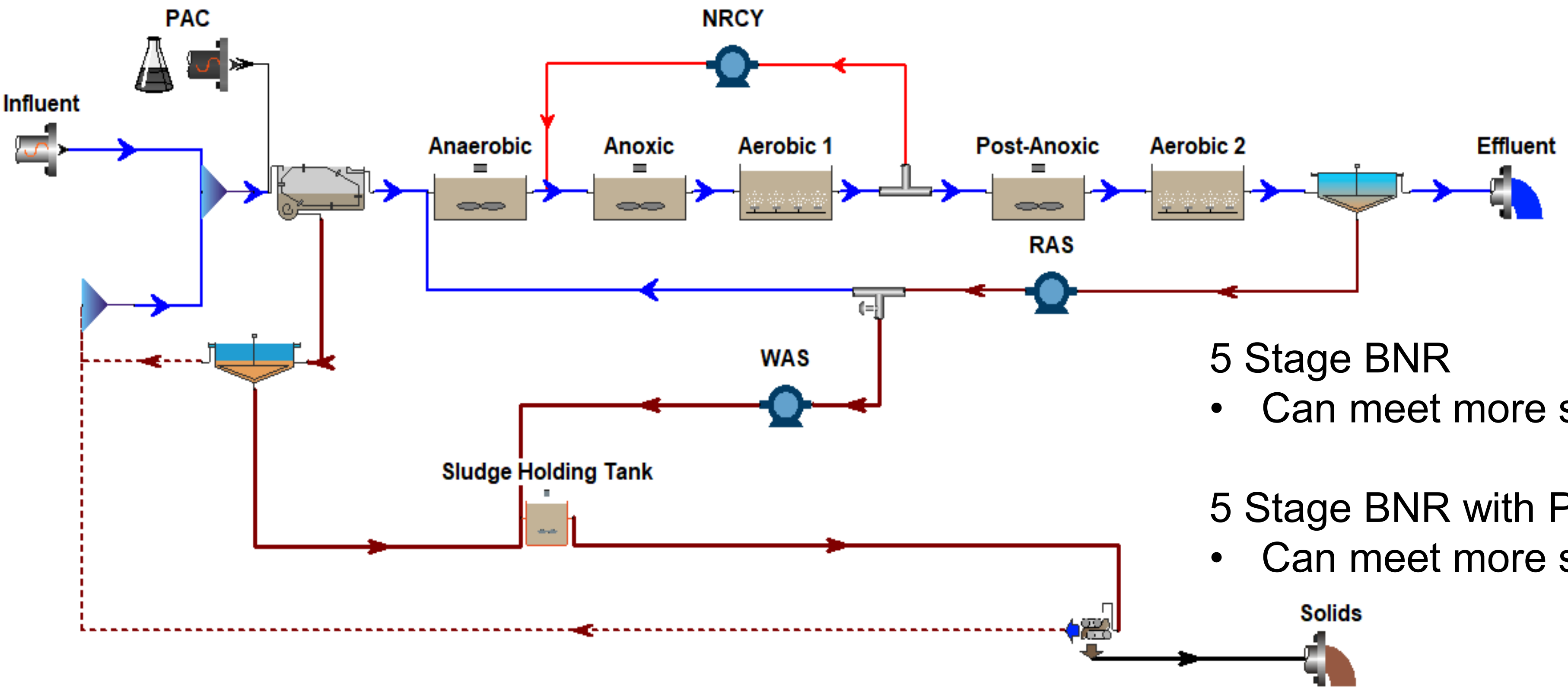
Model Scenarios – 4 Stage BNR & 4 Stage IFAS BNR



Treatment capacity periods

- TN limit of 1,570 lbs/d
- Annual Influent TN loading increment 133 lbs/day
- Projected annual flow increment of 0.4 MGD

Model Scenarios - 5 Stage EBNR & 5 Stage EBNR-PAC (N & P Removal)



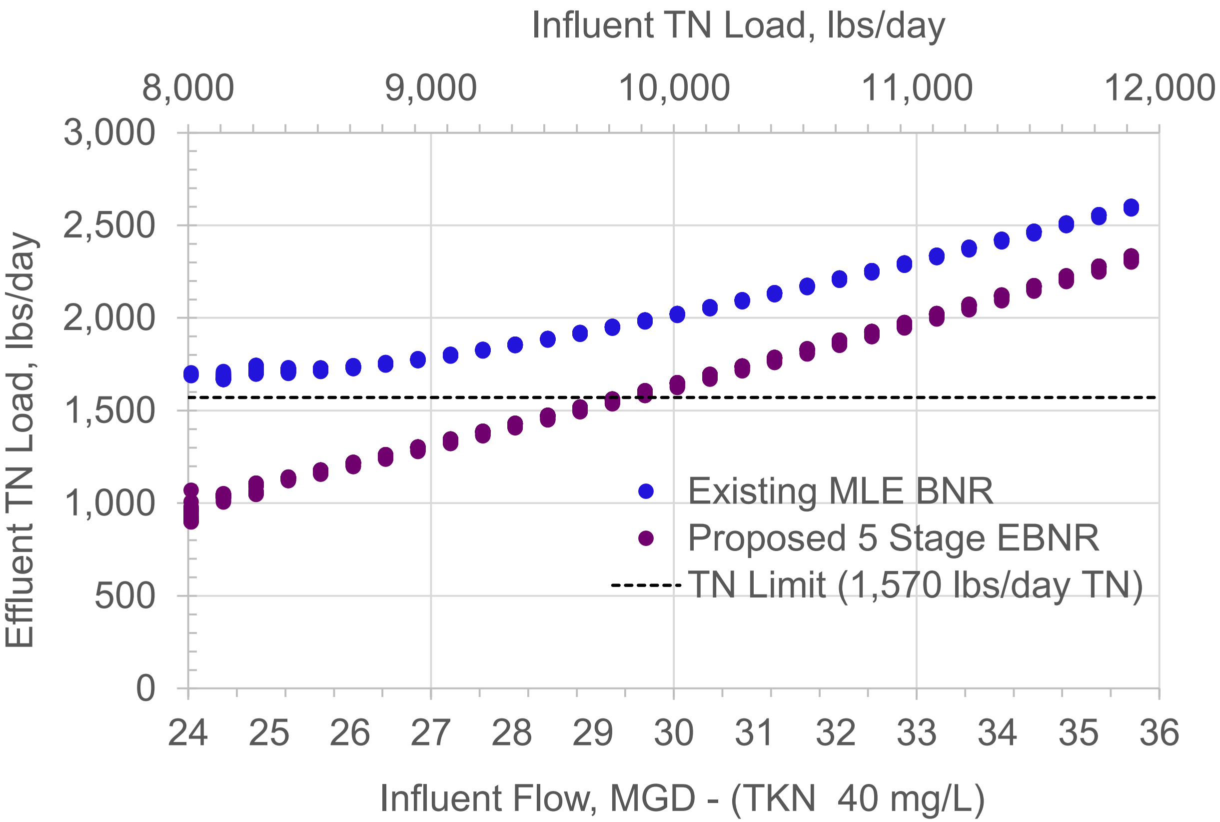
5 Stage BNR

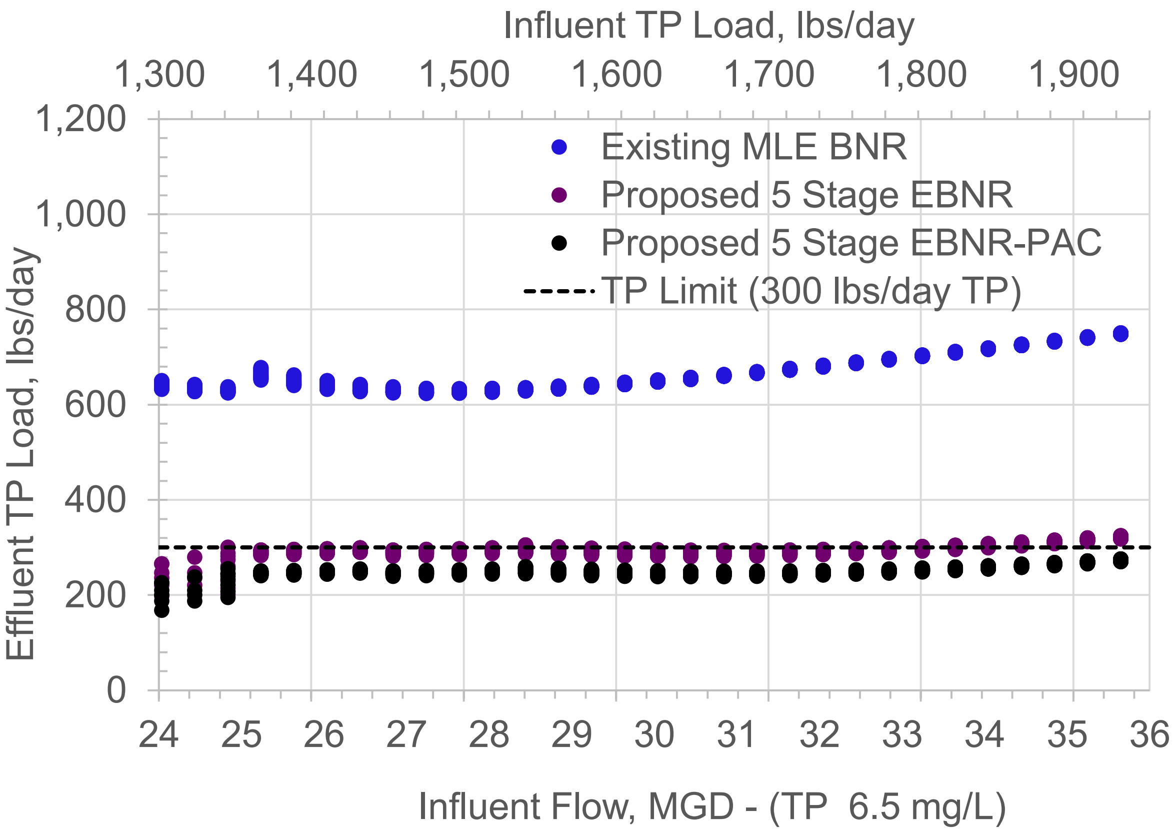
- Can meet more stringent TN limits

5 Stage BNR with PAC

- Can meet more stringent TN and TP Limits

Model Scenarios - 5 Stage EBNR & 5 Stage EBNR-PAC (N & P Removal)





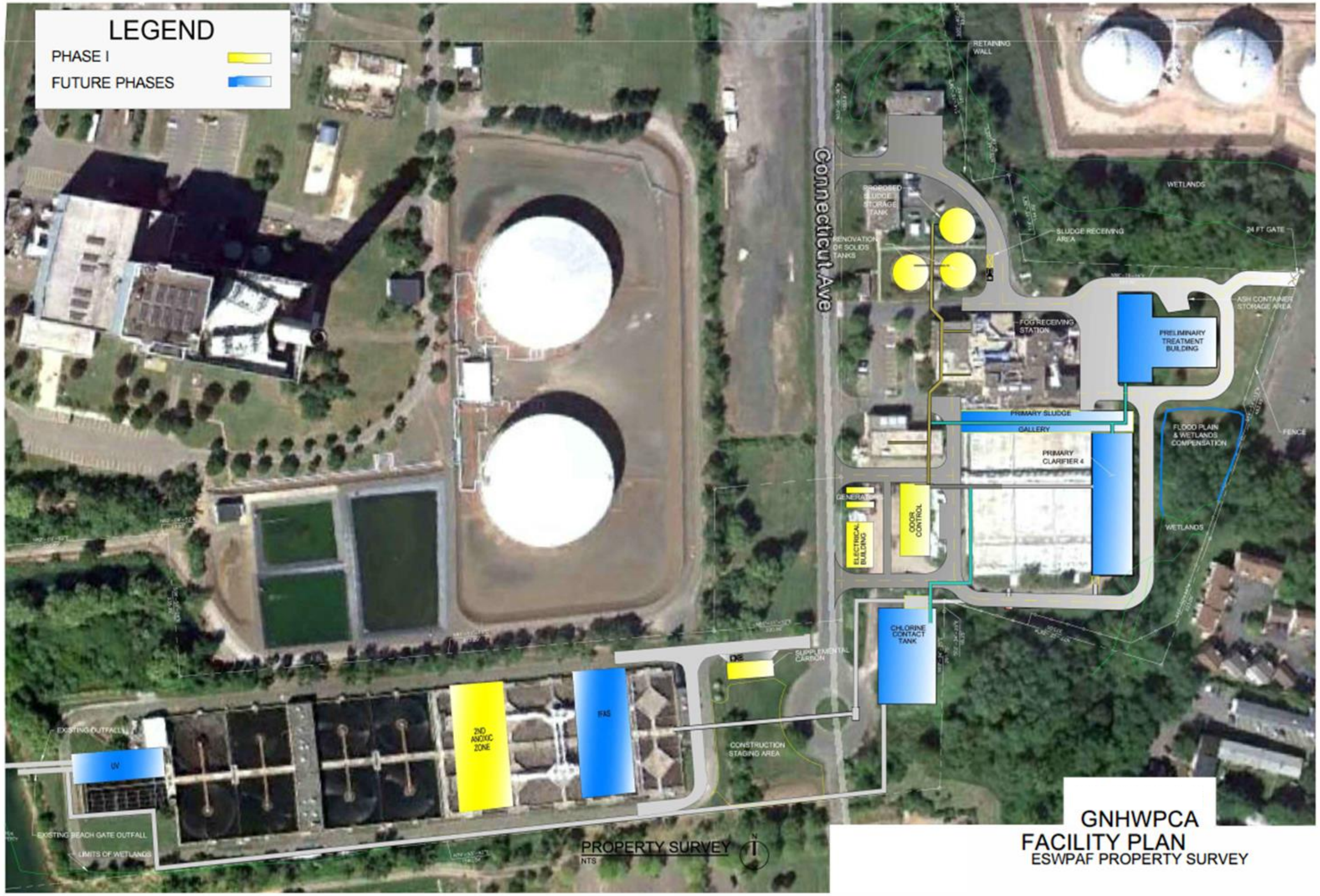
Treatment capacity periods

- TN limit of 1,570 lbs/d and TP limit of 300 lbs/d
- Annual Influent TN loading increment 133 lbs/day
- Annual Influent TP loading increment 21.7 lbs/day
- Projected annual flow increment of 0.4 MGD

Model Scenarios – Screening Analysis

Nitrogen Removal Options	Treatment Objective		Technology		LCC		Final
	Meet Goal	Proven	Operation	Construction	Capital Cost	O & M	Screening
Conventional BNR	✓	✓	✓	✓			
IFAS BNR	✓	✓	✓	✓	✓		
MOB BNR	✓		✓	✓	✓		
MABR BNR	✓	✓	✓	✓			
CEPT BNR	✓	✓	✓	✓	✓		
New Technology BNR	✓						
Nitrogen and Phosphorus Removal Options							
Conventional EBNR	✓	✓	✓	✓			
IFAS EBNR	✓	✓	✓	✓	✓		
MABR EBNR	✓	✓	✓	✓			
Fermenter - EBNR	✓	✓	✓	✓			
Chemical - EBNR	✓	✓	✓	✓	✓		
New Technology	✓						

Case Study – New Haven, CT – ESWPAF



Low-Nitrogen Requirements

- Meet existing standard : 5.5 to 6.5 mg N/L
- Meet future limit : 5.0 to 5.5 mg N/L

Low-Nitrogen Process Alternatives

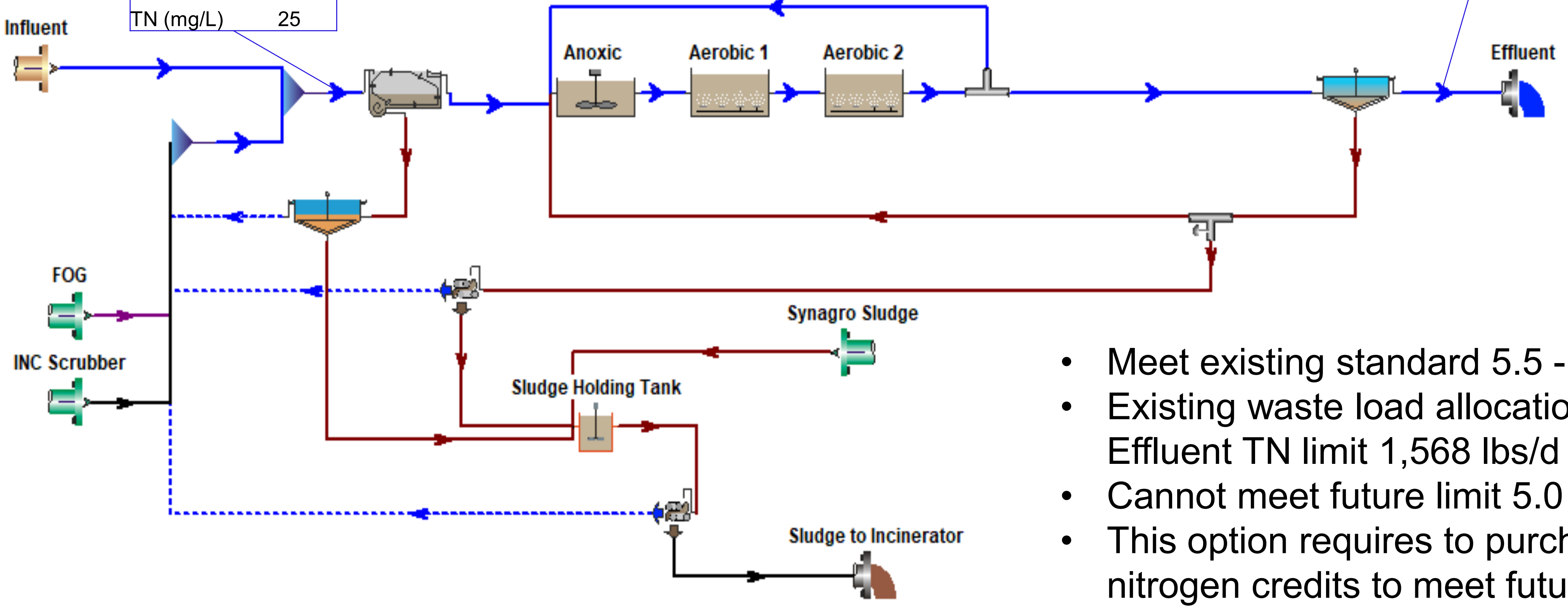
1. Existing MLE process
2. 4 Stage Bardenpho
3. 4 Stage IFAS Bardenpho

Option 1– MLE Configuration

Primary Influent	
Flow (MGD)	38.0
TSS (mg/L)	172
BOD (mg/L)	179
TN (mg/L)	25

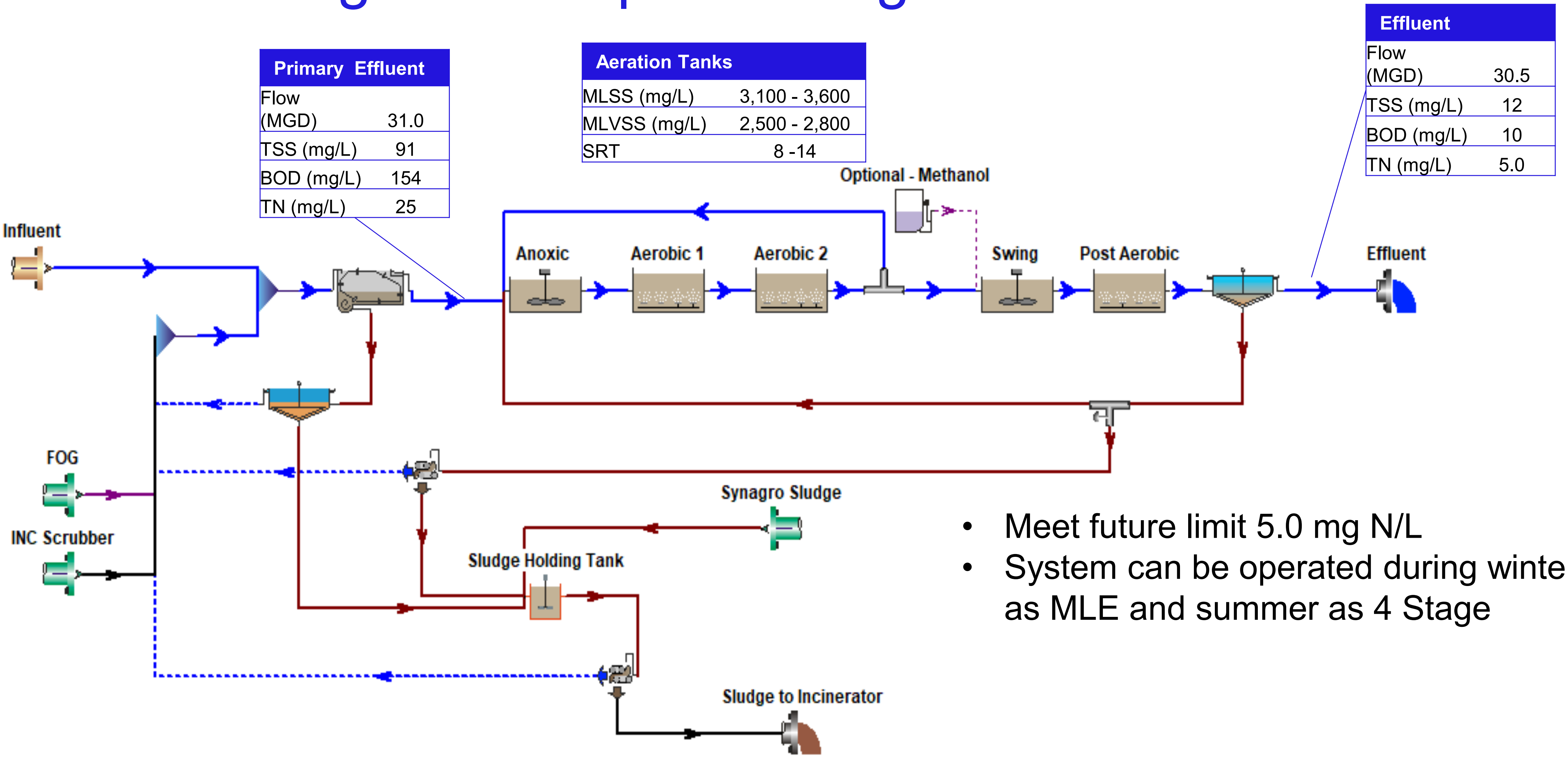
Aeration Tanks	
MLSS (mg/L)	3,800
MLVSS (mg/L)	2,800
SRT	8 -12

Effluent	
Flow (MGD)	33.4
TSS (mg/L)	12
BOD (mg/L)	10
TN (mg/L)	5.5 – 6.5



- Meet existing standard 5.5 - 6.5 mg N/L
- Existing waste load allocation (WLA) - Effluent TN limit 1,568 lbs/d
- Cannot meet future limit 5.0 mg N/L
- This option requires to purchase nitrogen credits to meet future limit

Option 2 – 4 Stage Bardenpho Configuration



Primary Effluent	
Flow (MGD)	31.0
TSS (mg/L)	91
BOD (mg/L)	154
TN (mg/L)	25

Aeration Tanks	
MLSS (mg/L)	3,100 - 3,600
MLVSS (mg/L)	2,500 - 2,800
SRT	8 -14

Effluent	
Flow (MGD)	30.5
TSS (mg/L)	12
BOD (mg/L)	10
TN (mg/L)	5.0

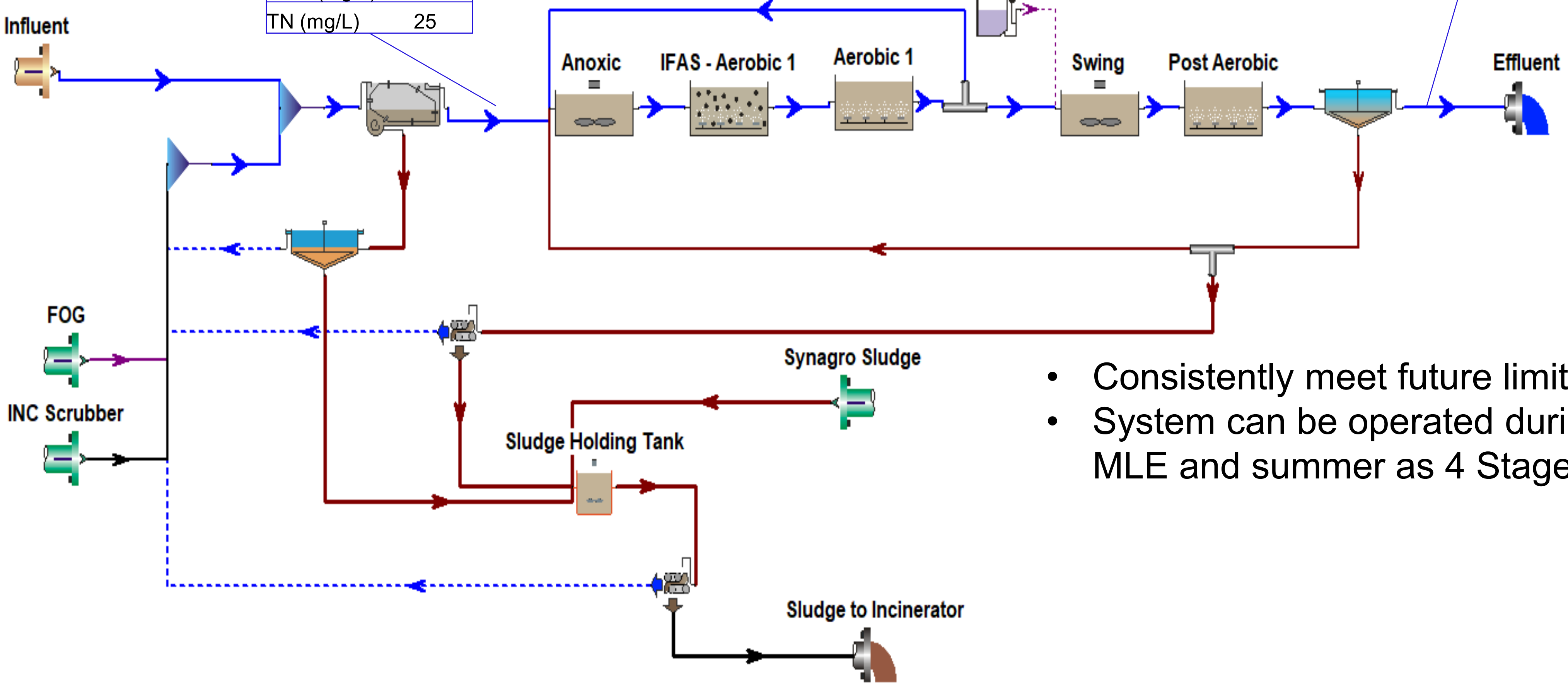
- Meet future limit 5.0 mg N/L
- System can be operated during winter as MLE and summer as 4 Stage

Option 3 –4 Stage IFAS Bardenpho Configuration

Primary Effluent	
Flow (MGD)	31.0
TSS (mg/L)	91
BOD (mg/L)	154
TN (mg/L)	25

Aeration Tanks	
MLSS (mg/L)	2,350 - 3,450
MLVSS (mg/L)	1,880 - 2,750
SRT	6 -10

Effluent	
Flow (MGD)	30.5
TSS (mg/L)	12
BOD (mg/L)	10
TN (mg/L)	5.0



- Consistently meet future limit 5.0 mg-N/L
- System can be operated during winter as MLE and summer as 4 Stage

Conclusions - New Haven, CT – ESWPAF

- Model-based analysis was driven by the TN permit
- Model-based analysis helped to:
  - Determine the maximize capacity of existing infrastructure
  - Optimize facilities operation and process performance
  - Develop treatment alternatives to meet TN permit
  - Select the right treatment alternative for the project

Conclusions

Model-based analysis is a strong tool that:

- Facilitate planning and designing for future conditions
- Helps to maximize the capacity of existing treatment infrastructure
- Helps to optimize facilities operation and process performance
- Provide basis in the development of facility upgrade strategies
- Helps to minimize design risk reducing design associated capital cost

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Questions?

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edwin.castilla@jacobs.com

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