EXPANSION OF SPECIAL PLANNING AREA (SPA) I WATER RECLAMATION FACILITY (WRF) FOR THE CITY OF SURPRISE

NAU
NORTHERN ARIZONA UNIVERSITY
Civil and Environmental Engineering

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486 FINAL PRESENTATION

05/02/2025

WALNUT CANYON WASTEWATER

PROJECT LOCATION

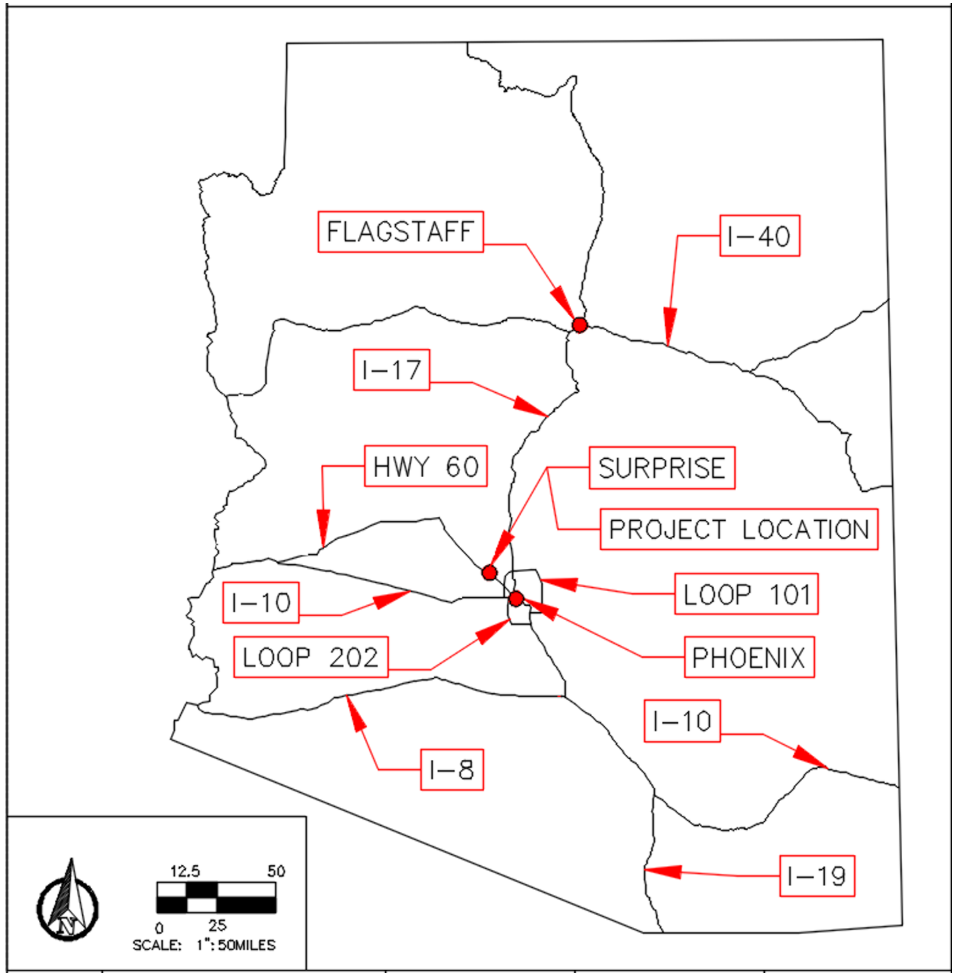

Figure 1: Location Map

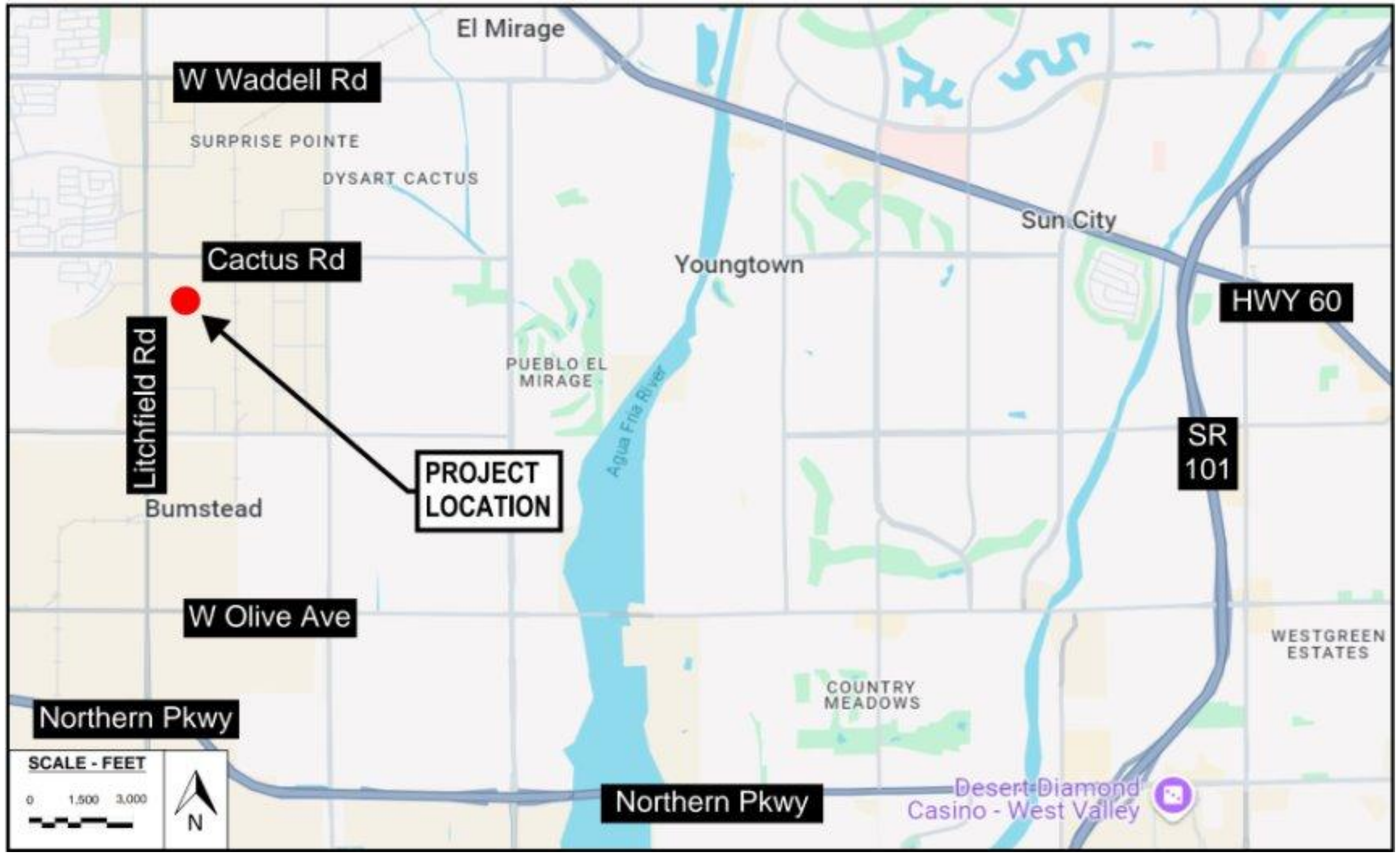

Figure 2: Vicinity Map [1]

PROJECT INTRODUCTION

- Purpose
  - Compete in the Arizona Water Association (AZWA) Student Design Competition
  - Expand functional treatment capacity of SPA 1 WRF in Surprise, AZ from 12.8 million gallons per day (MGD) to 16.3 MGD
    - Focusing on upgrading Plants 4 and 5

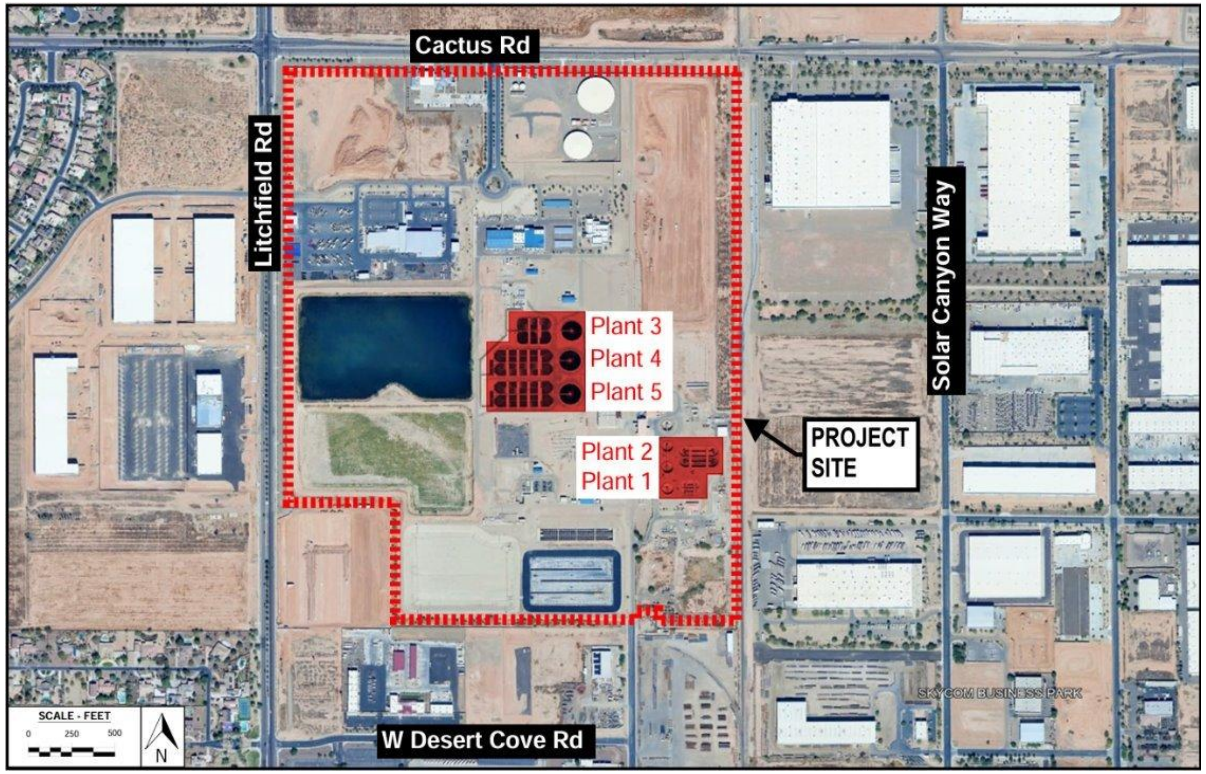

Figure 3: Special Planning Area 1 Map [1]

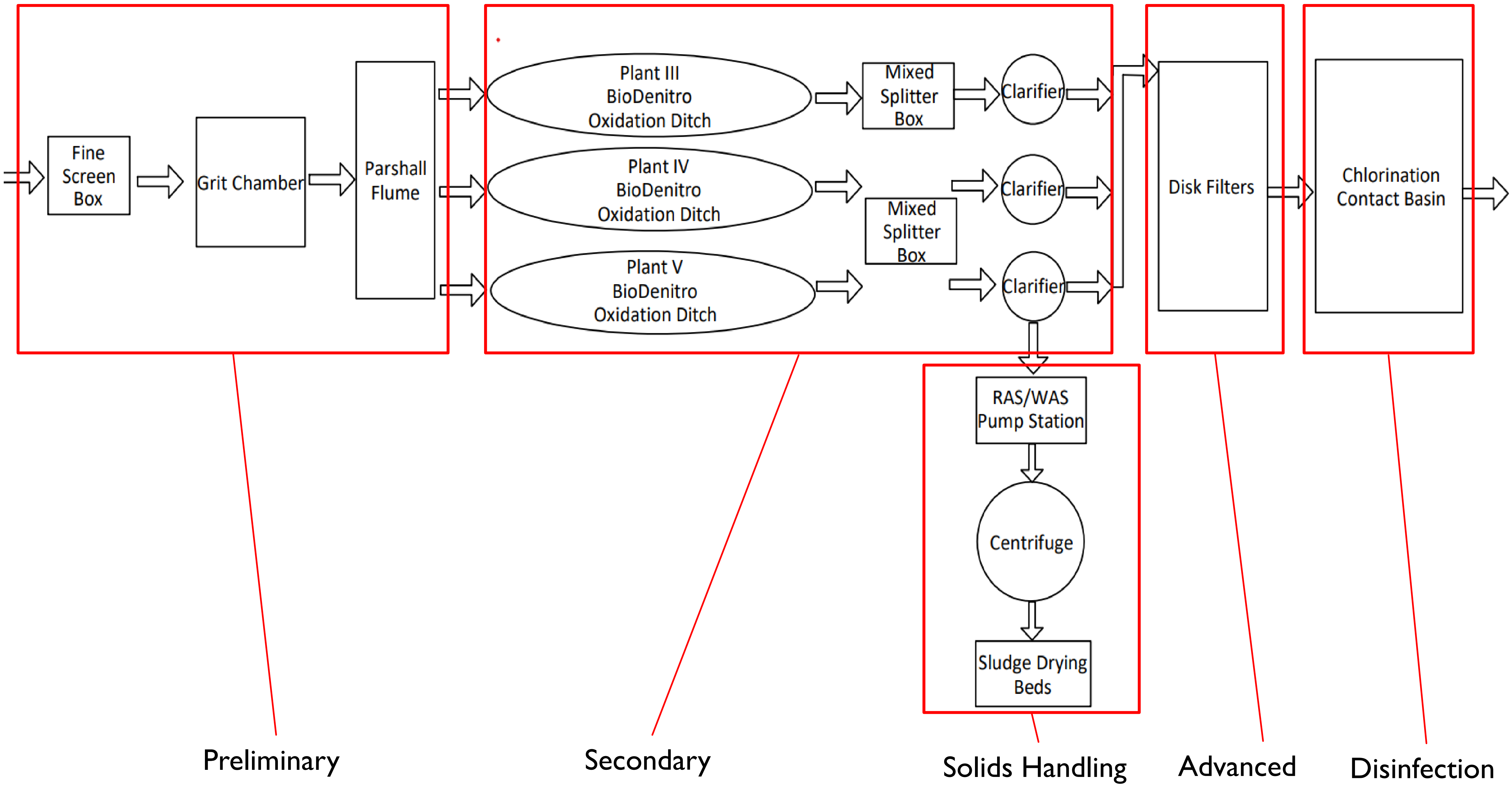

Figure 4: Existing Process Flow Diagram

EXISTING PRELIMINARY TREATMENT

- Three JWC Environmental Finescreen Monsters
  - 3mm perforations
- Rags getting through preliminary treatment and damaging brush aerators downstream
- Overflow channel with bar screens

Figure 5: Existing Fine Screen

Figure 6: Damaged Brush Aerators

EXISTING SECONDARY TREATMENT

- Oxidation Ditches and Secondary Clarifiers
- Krüger's BioDenitro Mode
  - Four phases to accomplish nitrification and denitrification
- Weaknesses: time between phases, batching phases

Figure 8: Image of Half of Plant IV

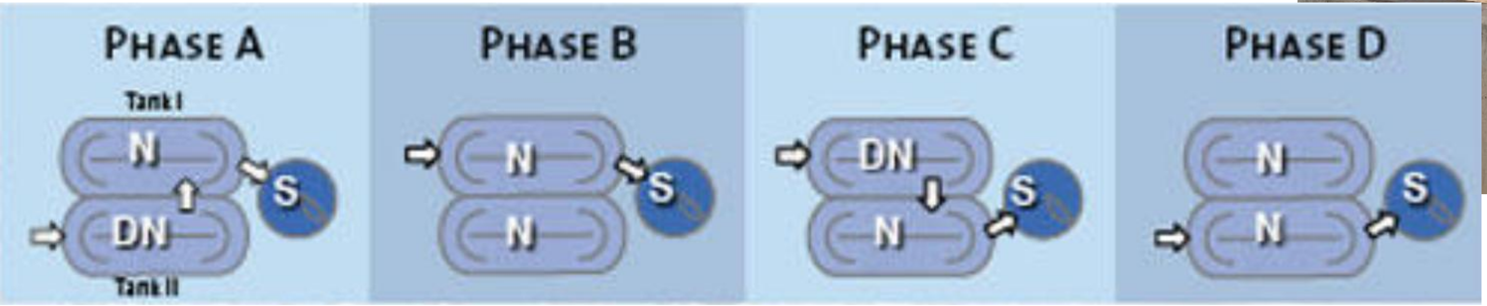

Figure 7: BioDenitro Process Diagram [9]

NITROGEN REMOVAL

- Two Step Process
- Nitrification
  - Ammonia (NH_4) → Nitrate (NO_3)
  - Aerobic, needs oxygen
  - Substrate: Ammonia
  - Carbon Source: Carbon Dioxide
- Denitrification
  - Nitrate (NO_3) → Nitrogen Gas (N_2)
  - Anaerobic, does not need oxygen
  - Substrate: Biochemical Oxygen Demand (BOD)
  - Carbon Source: BOD

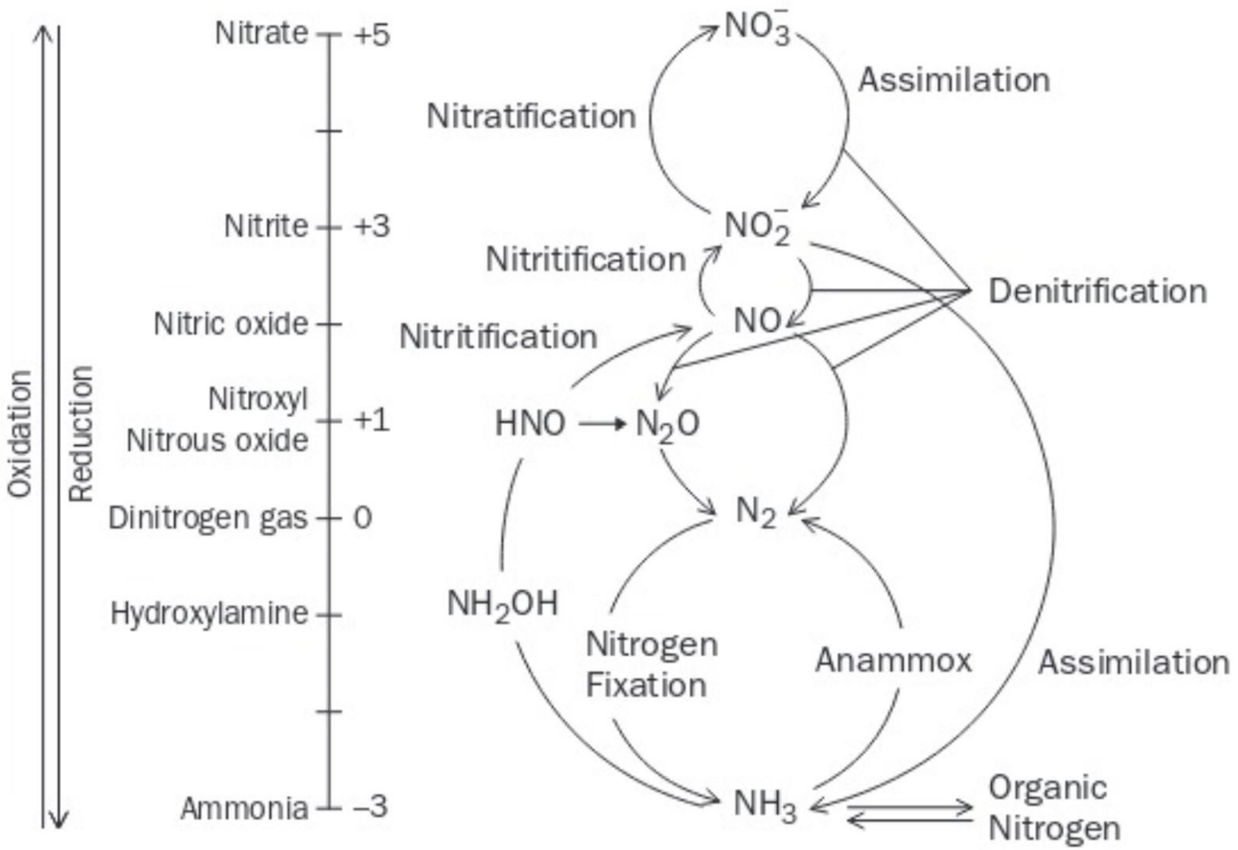

Figure 9: Nitrogen Transformation Pathways [12]

EXISTING ADVANCED TREATMENT

- Disk filters
  - 12 units
  - 1.6 MGD/unit
  - 19.2 MGD total
- Unused sand filters

Figure 10: Disk Filter Unit

Figure 11: Disk Filter Replacements

EXISTING DISINFECTION

- Existing Conditions
  - On-site hypochlorite generation system for chlorine disinfection, refer to *Figure 12*
  - No dechlorination
  - Two contact basins, using weighted tension covers
    - Only one used at a given moment
    - Volume of basin no. 2
      - 12 million gallons (MG)

Figure 12: Microchlor Technology

EXISTING SOLIDS HANDLING

- Dewatering centrifuges in combination with solar drying beds
  - Product of 80% dry solids [2]

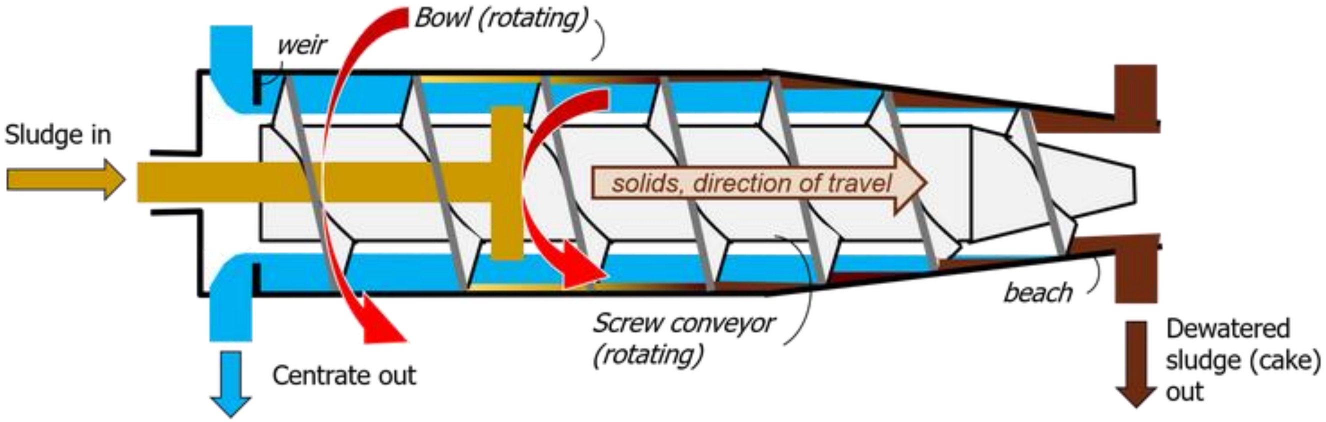

Figure 13: Dewatering Centrifuge Diagram [3]

Figure 14: Solar Drying Bed Conveyer

EXISTING HYDRAULICS

- Gravity fed system
- Open channel flow
  - Used for flow equalization
  - Preliminary to Secondary
- Pipe Flow
  - Secondary to Disinfection
  - Ductile Iron Pipe (DIP)
- Pumps
  - Influent pump station
  - Plant 4 and 5 pump station
    - 5 RAS pumps
    - 3 WAS pumps

Figure 15: Open Channel Trough to Secondary Treatment

Rating					
Criterion	5	4	3	2	1
Capital Cost	No additional costs	Less than 1 million	Less than 2 million	Less than 3 million	Greater than 3 million
O&M and Lifetime Cycle Costs	50% less expensive than current costs	25% less expensive than current costs	Within 5% of current costs	25% more expensive than current costs	50% more expensive than current costs
Ability to Meet Permit Limits	Far exceeds permit requirements		Exceeds permit requirements		Meets permit requirements
Minimizing Construction Time	Less than a month	Less than six months	Less than a year	Less than two years	Greater than two years

DECISION MATRICES SETUP

PRELIMINARY TREATMENT SELECTION

Table 1: Preliminary Decision Matrix

Criterion	Weight	Alternative 1: No change to treatment technology	Alternative 2: Band screen from JWCE	Alternative 3: Add grinder to the preliminary treatment process
Life Cycle Costs (Captial Cost and O&M)	30%	3	2	1
Removal Efficiency	30%	1	3	4
Minimizing Construction Time	20%	5	4	3
Adaptable Capacity	20%	1	3	2
Total	100%	2.4	2.9	2.5

PRELIMINARY TREATMENT DESIGN

Figure 16: JWC Environmental Finescreen Monster

Figure 17: JWC Environmental Bandscreen Monster

- Existing conditions:
  - 3 JWC Environmental Finescreen Monsters, refer to *Figure 16*
- Proposed Design
  - Replace all 3 JWC Environmental fine screens with JWC Environmental band screens, refer to *Figure 17*
  - Minimize pass through of rags that damage downstream equipment
- Proposed Design Capacity:
  - 7 MGD per unit
  - 21 MGD total

PRIMARY TREATMENT SELECTION

Table 2: Primary Decision Matrix

Criterion	Weight	Alternative 1: No change to treatment technology	Alternative 2: Primary clarifier
Life Cycle Costs (Captial Cost and O&M)	30%	3	1
Downstream Effects	40%	1	2
Minimizing Construction Time	30%	5	2
Total	100%	2.8	1.7

SECONDARY ALTERNATIVE #1

- Conventional oxidation style with denitrification stage
- Pros:
  - Limited capital cost/ no increase to operation and maintenance costs (O&M)
  - Improved redundancy
  - Directs biochemical oxygen demand (BOD) to denitrification
- Cons:
  - Nitrogen removal limited by BOD concentration (within permit levels)

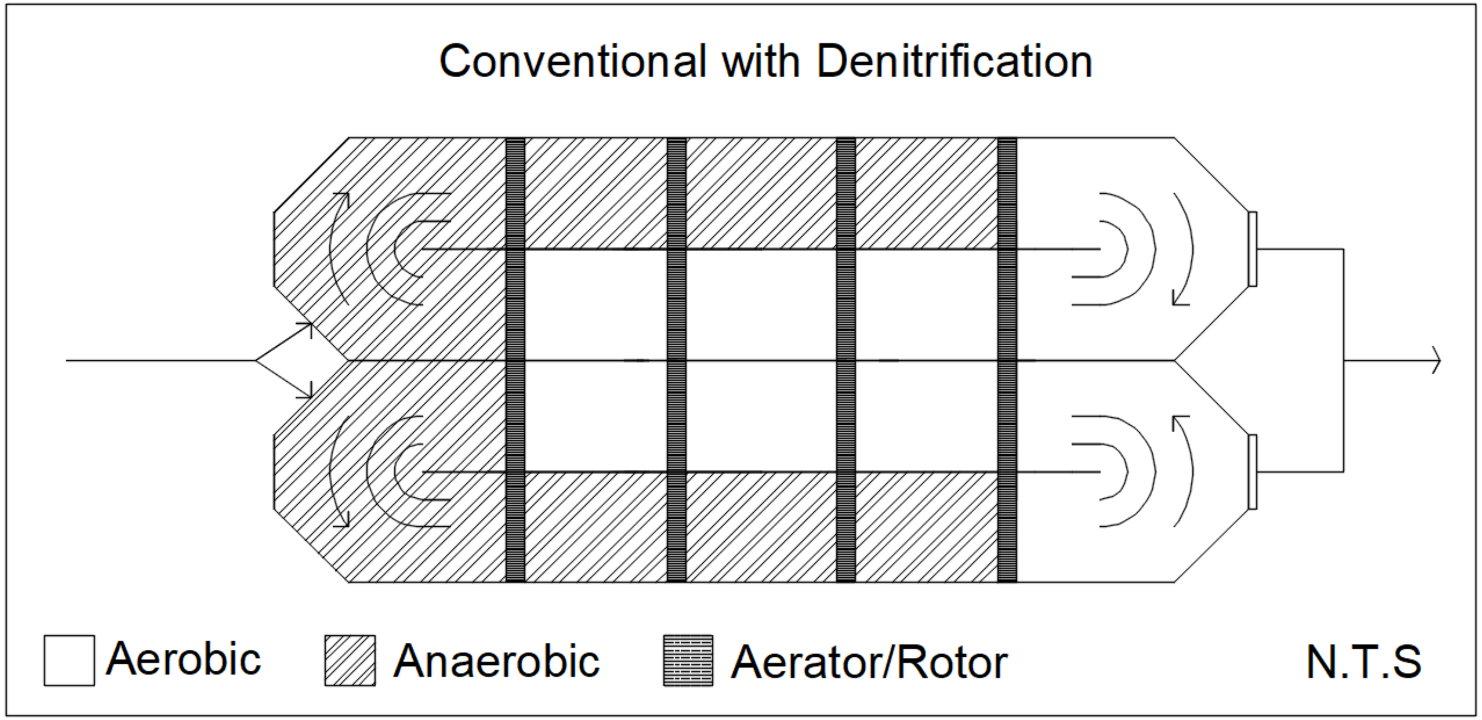

Figure 18: Alternative 1 Conceptual Sketch

SECONDARY ALTERNATIVE #2

- Sequential aerobic and anaerobic tanks
- Pros:
  - Limited capital cost
  - Limited increase to O&M (compared to alternative 3)
  - Better nitrogen removal (controlled by BOD feedstock)
- Cons:
  - Requires BOD feedstock (methanol)
  - No additional redundancy

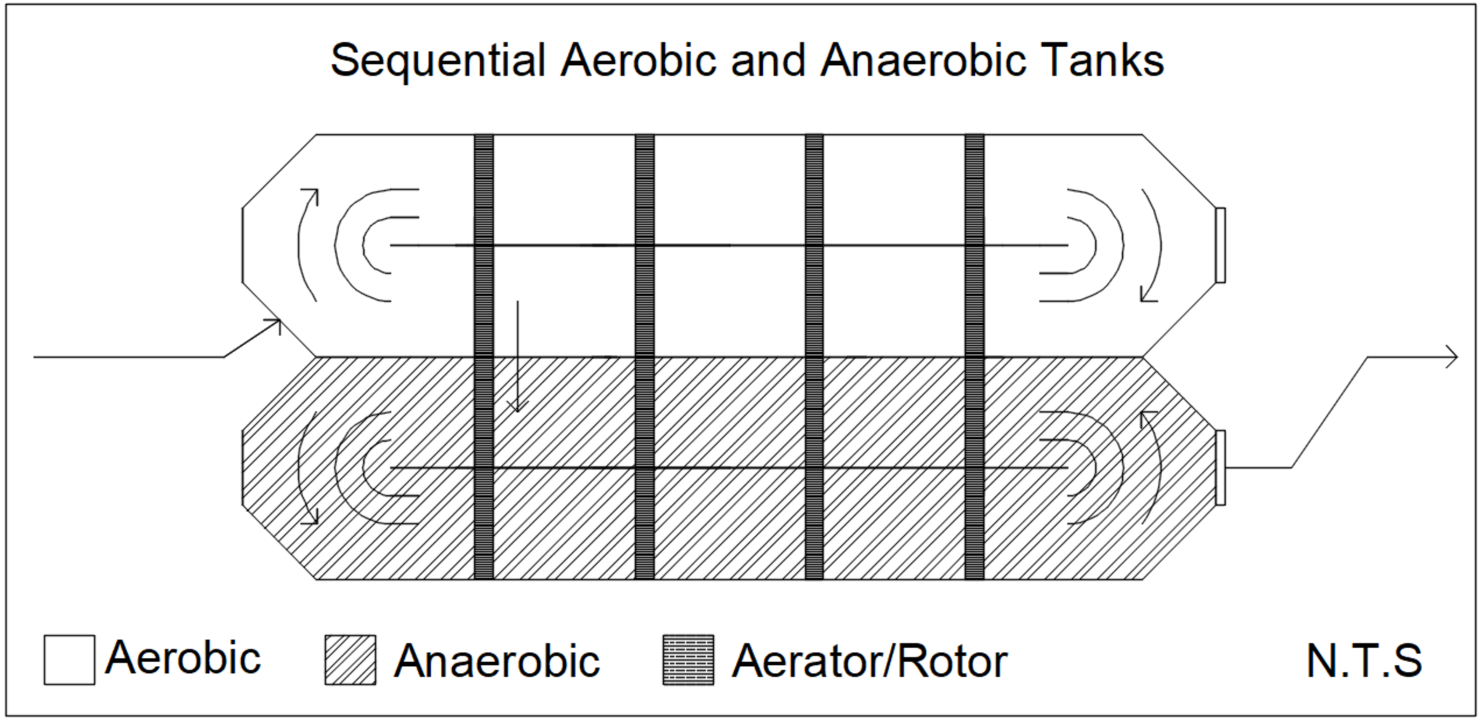

Figure 19: Alternative 2 Conceptual Sketch

SECONDARY ALTERNATIVE #3

- Addition of a sixth plant and clarifier
- Operates the same as Plants 4 and 5
- Increases treatment capacity by 4.0 MGD
- Hydraulics designed to model existing head loss

- Pros
  - Improved redundancy
  - Flow equalization
- Cons
  - Capital cost
  - Construction management

Table 3: Plant 6 Cost Items

Infrastructure	Unit Cost ($)	Total Cost ($)
Parshall Flume	$3,530	$3,530
Selector Basins (2) (concrete)	$147	$29,346
Heavy Duty Sluice Gate Assembly	$37,900	$37,900
9 Meter Maxi-Rotor	$60,000	$960,000
Baffle	$1,000	$16,000
Ditch Construction (concrete)	-	$570,600
Ditch Construction (Wire Mesh and rebar)	23 cents per sf for mesh and 40 cents per lf of concrete	$14,768
Concrete Forms	$6 per sf	$141,492
DIP (18" dia)	$211	$176,185
DIP (36" dia)	$222	$65,712
New Trough (concrete)	$147	$51,134
Structural Fill	$25	$352,326
Clarifier (concrete)	$147	$127,258
Clarifier Mechanism	-	$370,000
Scum Box	$39,375	$39,375
Glass Lined 12" DIP	$288	$80,640
DIP (6" scum drain line)	$163	$5,135
	Total:	**$3,041,401**

SECONDARY TREATMENT SELECTION

Table 4: Secondary Decision Matrix

Criterion	Weight	Alternative 1: Conventional oxidation with denitrification	Alternative 2: Sequential aerobic/anaerobic tanks	Alternative 3: Addition of a sixth plant
Capital Cost	25%	4	4	1
O&M and Lifetime Cycle Cost	25%	3	2	1
Ability to Meet Permit Limits	15%	1	2	1
Minimizing Construction Time	25%	5	5	2
Adaptable Capacity	10%	3	1	4
Total	100%	3.45	3.15	1.55

SECONDARY DESIGN ASSUMPTIONS

- Design goals
  - Returned activated sludge (RAS) and waste activated sludge (WAS) flowrates and concentrations
  - Aeration scheme
- One anaerobic pass and one aerobic pass
  - Each acts as a completely stirred tank reactor (CSTR)
- Typical values assumed
  - Monod kinetic coefficients
  - RAS rate
  - Internal velocity
  - Mixed liquor suspended solids (MLSS) concentration
  - Volatile suspended solids (VSS) / total suspended solids (TSS)

Table 5: Secondary Design Starting Values Excluding Microbial Kinetics

Starting Values		
Parameter	**Value**	**Source**
Design Flow per Tank , MGD	2.88	[4]
Influent Ammonia, mg/L N-NH4	72	[4]
Influent Soluble BOD, mg/L	300	[4]
Influent TSS, mg/L	300	[4]
MLSS, mg/L	3000	[5]
VSS/TSS, (mg/L)/(mg/L)	0.75	[5]
Return Activated Sludge, MGD	2.16	[5]
Internal Velocity, m/s	0.3	[5]

SECONDARY CALCULATIONS

- Determine BOD requirement to denitrify
  - 4.53g BOD/g NO_3-N
  - 5.83 mg/L NO_3-N in effluent
- Determine solids retention time (SRT) for complete nitrification
  - Determine fraction of MLVSS that is nitrifying
  - Specific substrate utilization rate
  - Solids retention time (SRT)- 8.93d
  - Safety factor of 2.5 applied [5]- 22.3d

Equation 1: BOD required to Denitrify [5]

$$\frac{g\ BOD}{g\ NO_3 - N} = \frac{2.86}{1 - 1.42Y}$$

Equation 2: Fraction of Biomass that are Nitrifiers [5]

$$f_n = \frac{0.16(NH_4\ removed)}{0.6(BOD\ removed) + 0.16(NH_4\ removed)}$$

Equation 3: Specific Substrate Utilization Rate [5]

$$U = \frac{S_0 - S}{\theta X}$$

Equation 4: Minimum Solids Retention Time [5]

$$\theta_{X\ min} = \frac{1}{YU - k_d}$$

SECONDARY CALCULATIONS CONT.

- Returned activated sludge rate assumed 75% of design flow
  - 8162 cubic meters per day
- RAS solids content- 6600 mg TSS/L
- Waste activated sludge calculated using excel solver
  - 125 cubic meters per day
- Required number of rotors to supply oxygen
  - 5463 kg oxygen/d required
  - Rotors supply 1771 kg/d each
  - 3.1 rotors required
  - Round to 4

Equation 5: Solids in RAS, adapted from [5]

$$X_r = \frac{X_{int}(Q_d + Q_r) - X_d Q_d}{Q_r}$$

Equation 6: SRT and WAS relation [5]

$$\theta_X = \frac{\bar{V}_{tank} X_{int}}{Q_w X_r + (Q_d - Q_w) X_e}$$

Equation 7: Mass of Oxygen Required per Day [5]

$$M_{O_2} = Q_d(S_d - S) - 1.42 P_x + 4.33 Q_d A_d$$

Equation 8: Oxygen Supply Per Rotor Constant

$$Oxygen\ Supply\ per\ Rotor = \frac{8.2\ kg\ O_2}{m * h}$$

SECONDARY TREATMENT DESIGN

- Effluent estimates
  - TN 6.6 mg/L
    - Permit: 8 mg/L average
  - Soluble BOD 0 mg/L
    - Permit: 10 mg/L
  - TSS depends on clarifier
- Aeration
  - 4 rotors acting as aerators
  - Rest submerged, moving flow
- Starting values
  - Adjusted by licensed operators
  - Less aeration if nitrate creeps up
  - More aeration during peak flow

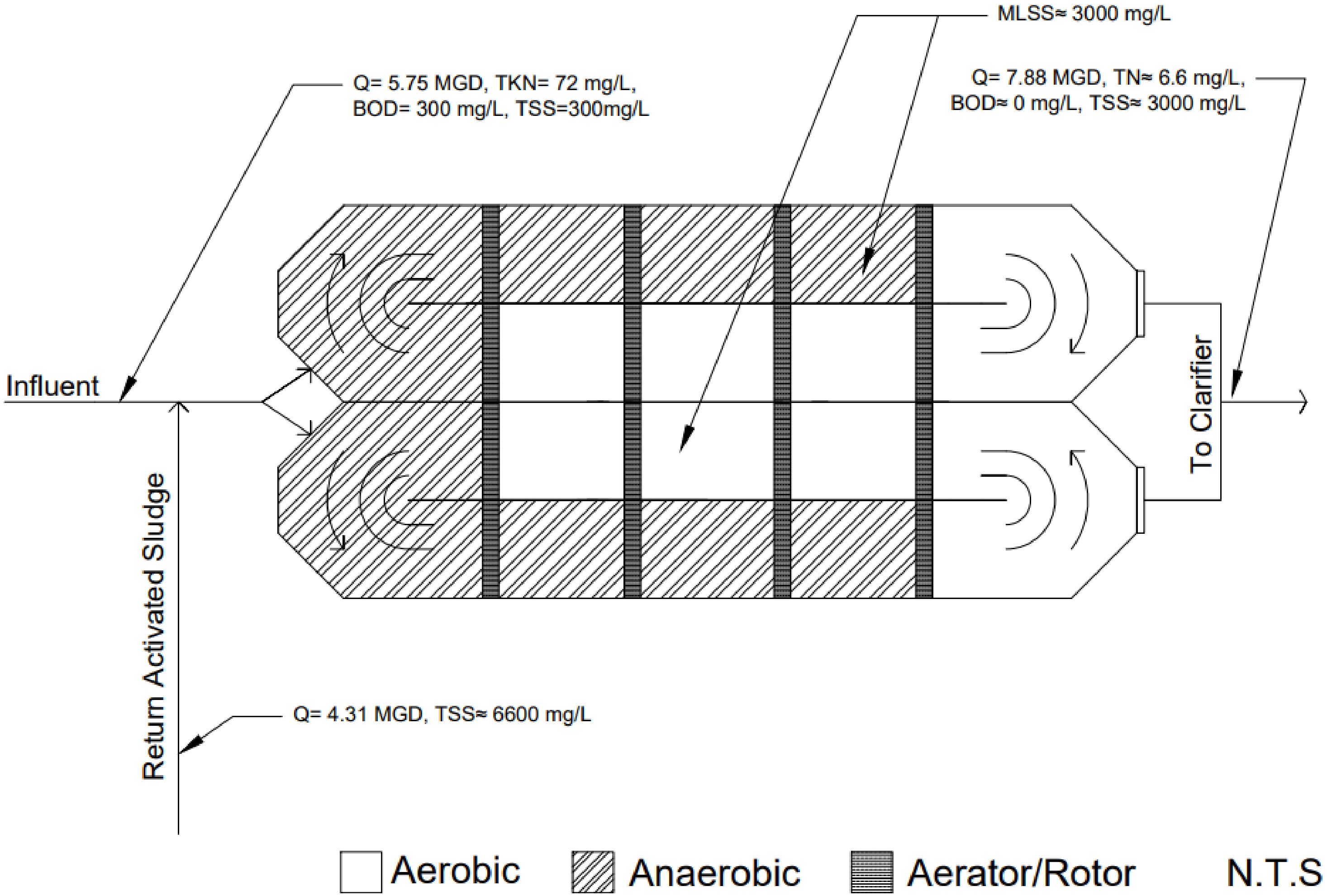

Figure 20: Oxidation Ditch Process Sketch

SECONDARY CLARIFIER DESIGN

- Verification of proper conveyance through secondary clarifiers of plants 4 and 5
  - Overflow rate (v_0) is overloaded
  - High hydraulic retention time (HRT)
  - Resulting in reduced TSS removal
- No changes to the clarifiers are recommended
  - Delegate more stress on disk filters
  - Increased disk filter maintenance rates
  - Permit TSS limit: 10 mg/L

Table 6: Secondary Clarifier Limiting Parameters

Limiting Parameters of Plant 4 and 5 Secondary Clarifiers		
v_0 (m/h)	1.39	Overloaded
SOF (kg/m^2*h)	4.18	Underloaded
Peak v_0 (m/h)	3.48	Overloaded
Peak SOF (kg/m^2*h)	10.44	Underloaded
HRT (hr)	3.94	Too High

Equation 9: Overflow Rate [5]

$$v_0 = \frac{Q + Q_R}{A}$$

Equation 10: Solids Overflow Rate [5]

$$SOF = \frac{(Q + Q_{R)} * X}{A}$$

Equation 11: Hydraulic Retention Time [5]

$$HRT = \frac{V}{Q + Q_R}$$

ADVANCED TREATMENT SELECTION AND DESIGN

Table 7: Advanced Decision Matrix

Criterion	Weight	Alternative 1: No change to treatment technology	Alternative 2: Reincorporate antiquated sand filter system	Alternative 3: Install membrane filtration
Life Cycle Costs (Captial Cost and O&M)	40%	3	2	1
Water Quality	20%	1	1	5
Minimizing Construction Time	25%	5	3	2
Downstream Effects	15%	1	3	4
Total	100%	2.8	2.2	2.5

DISINFECTION SELECTION

Table 8: Disinfection Decision Matrix

Criterion	Weight	Alternative 1: No change to treatment technology	Alternative 2: Ultraviolet disinfection	Alternative 3: Ozone disinfection
Life Cycle Costs (Captial Cost and O&M)	40%	3	1	2
Ability to Meet Permit Limits	25%	1	2	2
Minimizing Construction Time	25%	5	2	4
Contact Time	10%	2	5	4
Total	100%	2.9	1.9	2.7

SOLIDS HANDLING SELECTION

Table 9: Solids Handling Decision Matrix

Criterion	Weight	Alternative 1: No change to treatment technology	Alternative 2: Retrofit antiquated aerobic digesters to anaerobic digesters
Capital Cost	20%	5	3
O&M and Lifetime Cycle Cost	25%	3	4
Ability to Meet Permit Limits	20%	1	3
Minimizing Construction Time	15%	5	2
Environmental and Societal Impacts	20%	1	4
Total	100%	2.9	3.3

SOLIDS HANDLING DESIGN

- Iterative process for calculating amount of influent sludge from known volume of the digesters

Equation 12: Volume Needed for Proper Digestion [5]

$$V_T = [(SRT * Q_w) + (Q_{BG} * 1day)] * SF$$

Where:
V_T= Total Volume for Digestion (m^3)
SRT= Solids Retention Time (day)
Q_w= Sludge to be Digested (m^3/d)
Q_{BG}= Total Biogas Production (m^3/d)
SF_{DIG}= Safety Factor of Digester (unitless)

Table 10: Solids Design Parameters

Digester Parameters	
Total Sludge Produced (m^3/d)	725.7
Heating Energy Required (MJ/day)	773.2
Mixing Rate (m^3/m^3*h)	0.28
Temperature of Sludge (C)	35
pH	7
SRT (day)	**20.4**
Q_W (m^3/d)	**225**
Q_{BG} (m^3/d)	**523**
Q_{CH4} (m^3/d)	**340**

Table 11: Sludge Digester Parameters

Dimensions of Digesters	
Height (m)	7.7
Width (m)	17.9
Length (m)	27.4
Total Volume per Digester (m^3)	3832
# of Digestors	2
V_T (m^3)	**7665**

SOLIDS HANDLING DESIGN

- Recommended Design
  - Divert 225 m^3/day of sludge to retrofitted anaerobic digesters
  - Divert 500 m^3/day of sludge to dewatering centrifuges
  - Sludge produced from anaerobic digesters and centrifuges will be dried on existing solar drying beds
  - Produce 340 m^3/day of biomethane
    - Annual profit of $157,523 for selling bio-methane produced [7] [8]

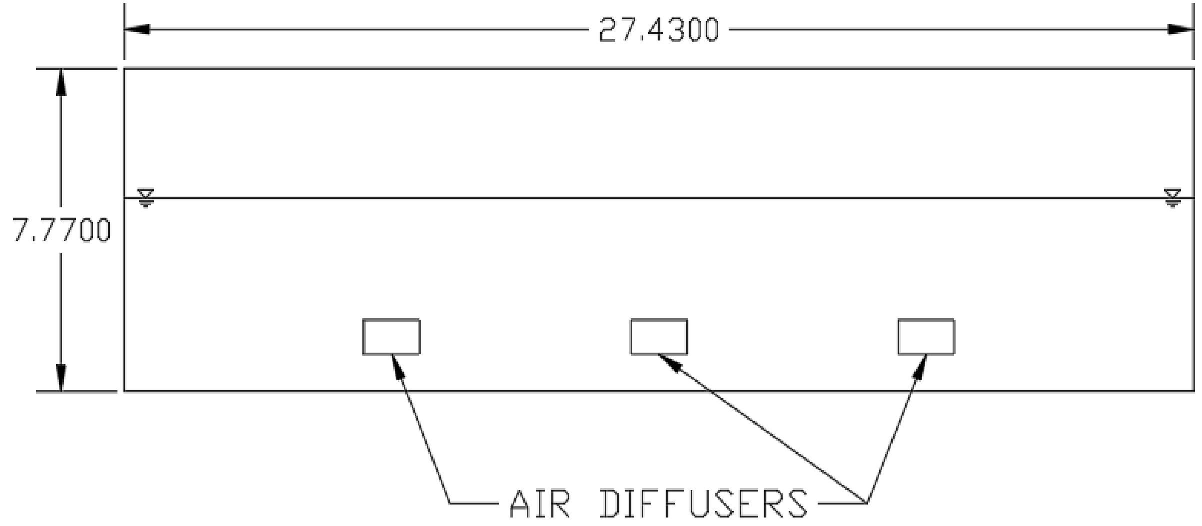

Figure 21: Anaerobic Digester Side View

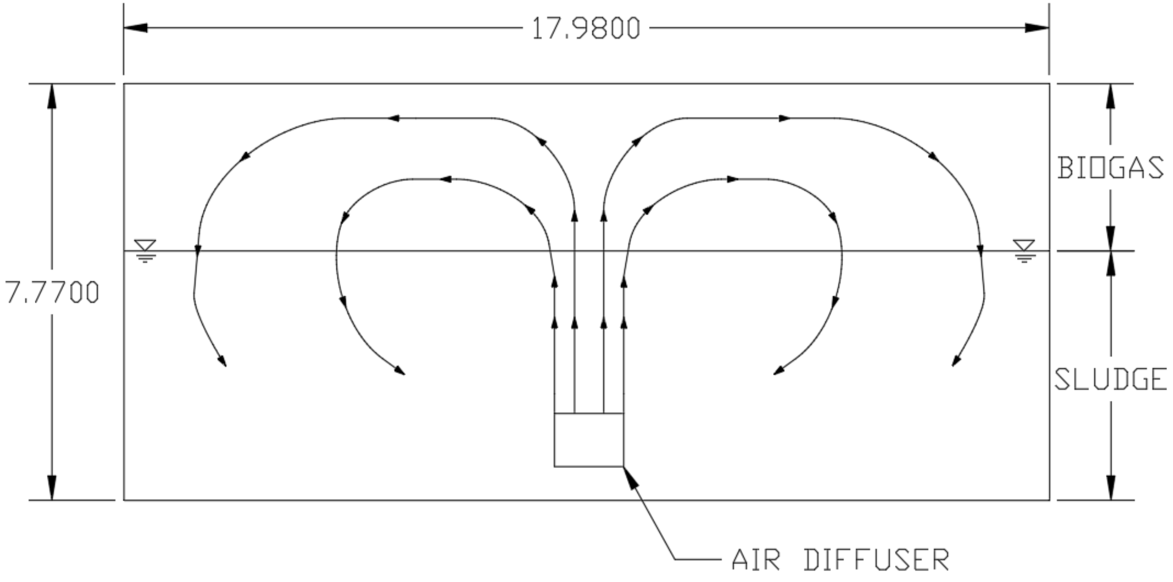

Figure 22: Anaerobic Digester Front View

HYDRAULIC ANALYSIS

Analysis to develop hydraulic profile:

- Excel's "goal seek" function to iterate to find depth of flow in open channel troughs
- Manning's equation (open channel head loss)
- Hazen-Williams equation (pipe head loss)

Table 12: Summary of Calculated Head Loss

Location	Head Loss (ft)
Preliminary Treatment	0.32
Open Channel Trough	0.39
Pump Station to Advanced Treatment	0.32
Advanced	1.5

Equation 13: Manning's Equation

$$S = \left(\frac{Q \times n}{1.49 \times A \times R^{\frac{2}{3}}} \right)^2$$

Equation 14: Hazen-Williams Equation

$$S = \frac{h_{L,f}}{L} = \left(\frac{Q}{A \times k \times C \times {R_H}^{0.63}} \right)^{\frac{1}{0.54}}$$

HYDRAULIC ANALYSIS CONTINUED

Analysis of:

- Plants 4 and 5 RAS pumps
- Plants 4 and 5 RAS pipes
- Pipes conveying flow downstream of secondary treatment
  - Maximum velocity of 10 ft/s in pipes [8]

Equation 15: Volumetric Flow Rate

$$Q = VA$$

Table 13: Water Surface Elevations

Location	WSE (ft)	
	Average Flow	Peak Flow
Screening Influent Box	1144.17	1144.26
Screening Effluent Box	1143.97	1144.06
Trough to Oxidation Ditches	1141.86	1143.00
Parshall Flume	1140.61	1140.75
Selector Basins	1140.42	1140.56
Oxidation Ditches	1139.75	1139.83
Mixed Liquor Flow Splitter Box	1136.39	1136.84
Secondary Clarifier	1136.25	1136.30
Entering Disk Filters	1136.12	1136.17
Exiting Disk Filters	1134.62	1134.67
Disinfection Basin	1119.50	1120.50

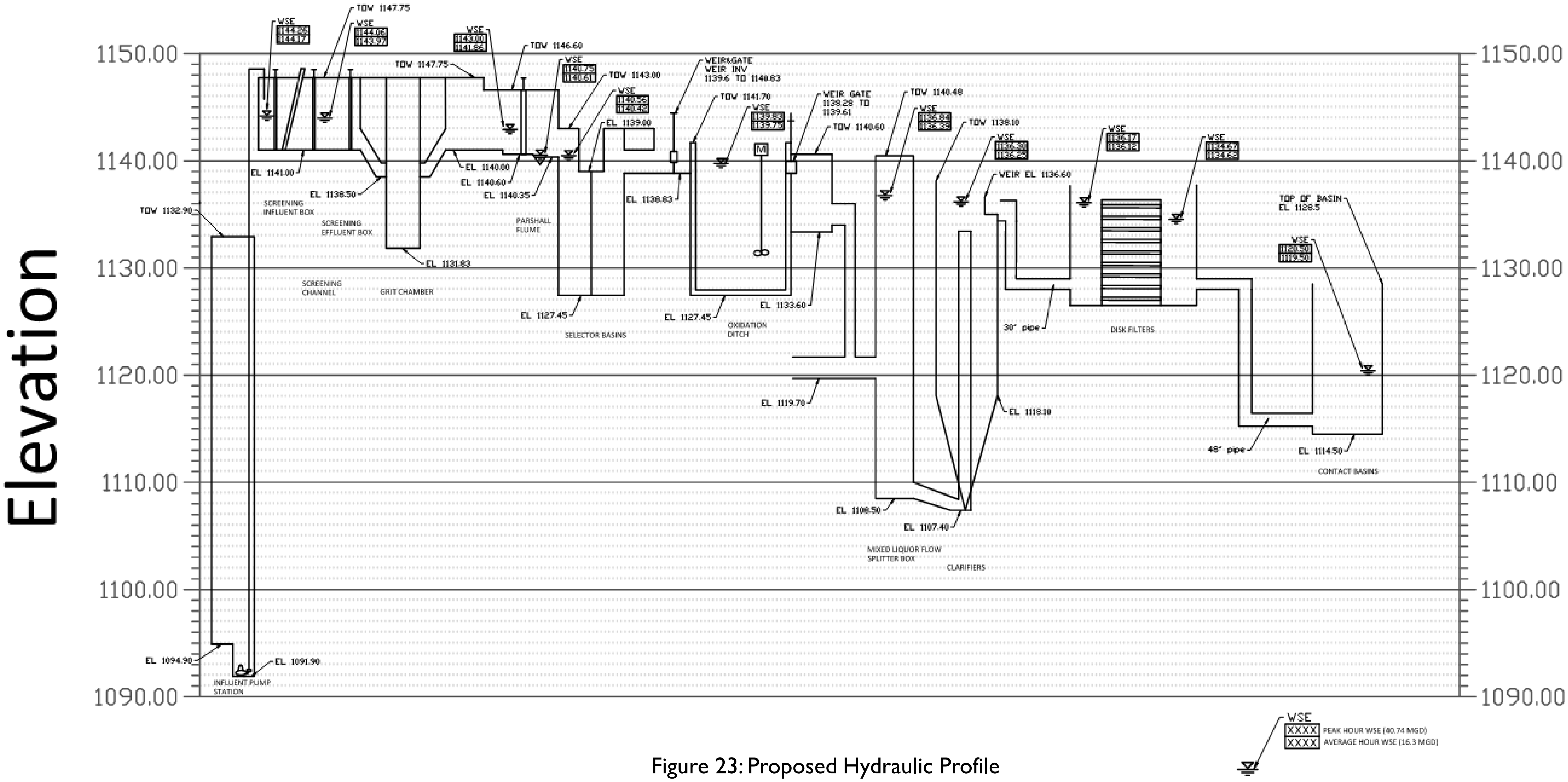

Figure 23: Proposed Hydraulic Profile

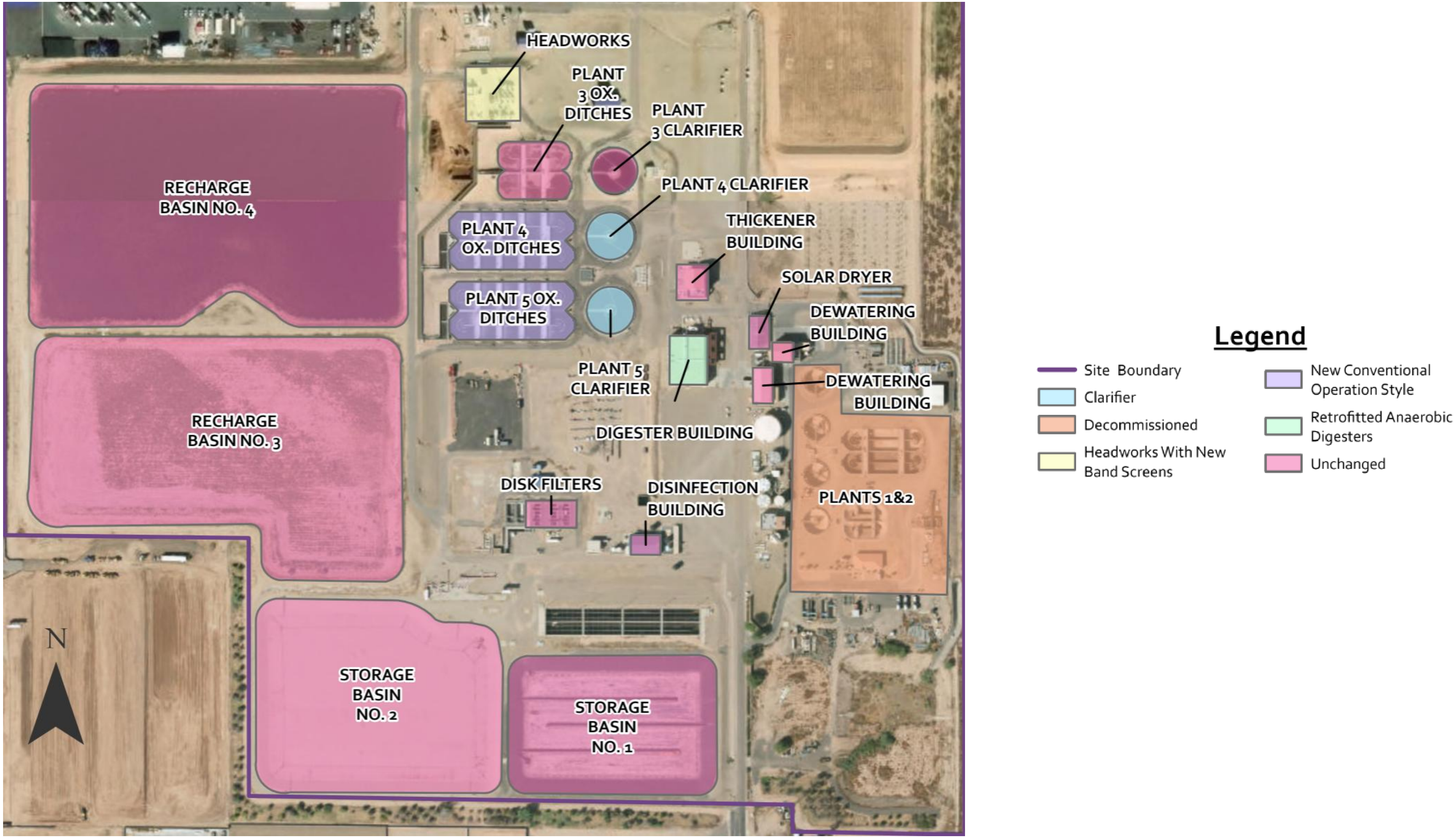

Figure 24: Proposed Site Layout

CONSTRUCTION PHASING

- Preliminary: Changes of fine screens to band screens
  - Changed out one by one, non-peak hours
- Secondary: Change from BioDenitro mode to conventional operation style
  - Batching will occur to adjust microbiome, non-peak hours
  - Aeration style changed via digital controls
  - Increasing the recycle rate to 75% of the influent flow rate
  - Further RAS/WAS adjustments by licensed operators
- Solids Handling: Convert existing aerobic digestors to anaerobic digestors
  - Pipes and aerobic digestors will be refurbished (1-2 years)
  - Existing equipment will be utilized until construction completed

CAPITAL COST

Table 14: Capital Cost

Process	Description	Quantity	Unit	Unit Price	Amount
Preliminary	Band screens, 3mm perforations	3	EA	$150,000	$450,000
Secondary	Convert to conventional treatment style	1	LS	$5,000	$5,000
Solids Handling	Convert to aerobic with heat exchanger, gas collection, and air scrubber	1	LS	$1,000,000	$1,000,000
				Total	**$1,455,000**

Table 15: Operation and Maintenance Cost

	Description	Quantity	Unit	Unit Price	Amount
Preliminary	Annual Energy	22,251	kWh	$0.15	$3,378
	Annual Inspection and Maintenance Cost	208	h	$25.00	$5200
Secondary	Annual Energy	4,992,882	kWh	$0.15	$1,179,650
	Brush Aerators	16	aerators/yr	$60,000.00	$960,000
Advanced	Annual Operational Cost	1	LS	$31,362.00	$31,362
	Replacement of Filters	1	LS	$6,694.00	$6,694
Disinfection	Annual Operational Cost	1	LS	$63,280.00	$63,280
Solids Handling	Cost of Operation	1	LS	$80,000.00	$80,000
	Potential Savings	1	LS	$157,000.00	-$157,000
Hydraulics	Annual Energy Cost of RAS/WAS Pumps	1,911,000	kWh	$0.15	$286,650
	Annual Cost of Influent Pumps	1	LS	$300,000.00	$300,000
Additional	Operator 1	3	operators	$52,000.00	$156,000
	Operator 2	3	operators	$62,400.00	$187,200
	Operator 3	2	operators	$72,800.00	$145,600
				Total	**$3,102,685**

LIFE CYCLE COST ANALYSIS

Table 16: Capital and O&M Costs

Process	Capital Cost	Existing O&M Cost	Proposed O&M Cost
Preliminary	$450,000	$8,578	$8,578
Primary	N/A	N/A	N/A
Secondary	$5,000	$3,099,650	$2,139,650
Advanced	N/A	$34,979	$38,326
Disinfection	N/A	$63,280	$63,280
Solids Management	$1,000,000	$80,000	-$77,000
Hydraulics	N/A	$586,650	$586,650
Operators	N/A	$343,200	$343,200
TOTAL	**$ 1,455,000**	**$4,219,685**	**$3,102,685**

PROJECT IMPACTS

Social:
- Accommodate population growth
- Create work in construction industry

Environmental
- Focusing on retrofitting/repurposing existing infrastructure

Economic
- Decrease yearly O&M for facility
- Focus on minimizing required capital cost
- Minimal affect to taxpayers

Figure 25: Triple Bottom Line [11]

CONCLUSION

Key Takeaways:

- Final capacity of SPA WRF increased to 16.3 MGD with secondary treatment being the limiting step
- Total construction time of 1-2 years, with the limiting step being solids handling
- Water master plan anticipates hitting 16.3 MGD after 2035
  - Design is cost effective to get to that point
- Placed 1st over University of Arizona at AZWA SDC

Figure 26: Pictures of the Winning Team

ACKNOWLEDGEMENTS

- Adias Fostino, WEF Student Design Competition Chair
- Kt Stowers, AZ Water Association Representative
- Sam Nieslanik, WEF Student Design Assistant Competition Chair
- Dr. Jeffrey Heiderscheidt, NAU Advisor
- Dr. Diana Calvo, NAU Faculty

Figure 27: AZ Water Association Logo

Figure 28: NAU Logo

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QUESTIONS?