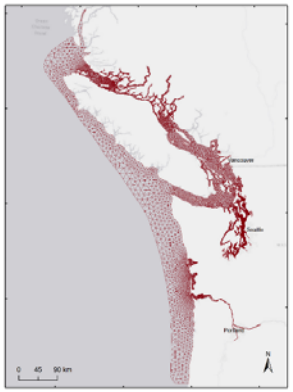
Economic Analysis for Nitrogen and Phosphorus Removal in Washington



ACWA Nutrients Permitting Workshop

June 5, 2018

Presented by: M. Eleanor Key, P.E., Permitting Policy Lead

How does the state continue to grow…



…and reduce nutrient impacts so that we

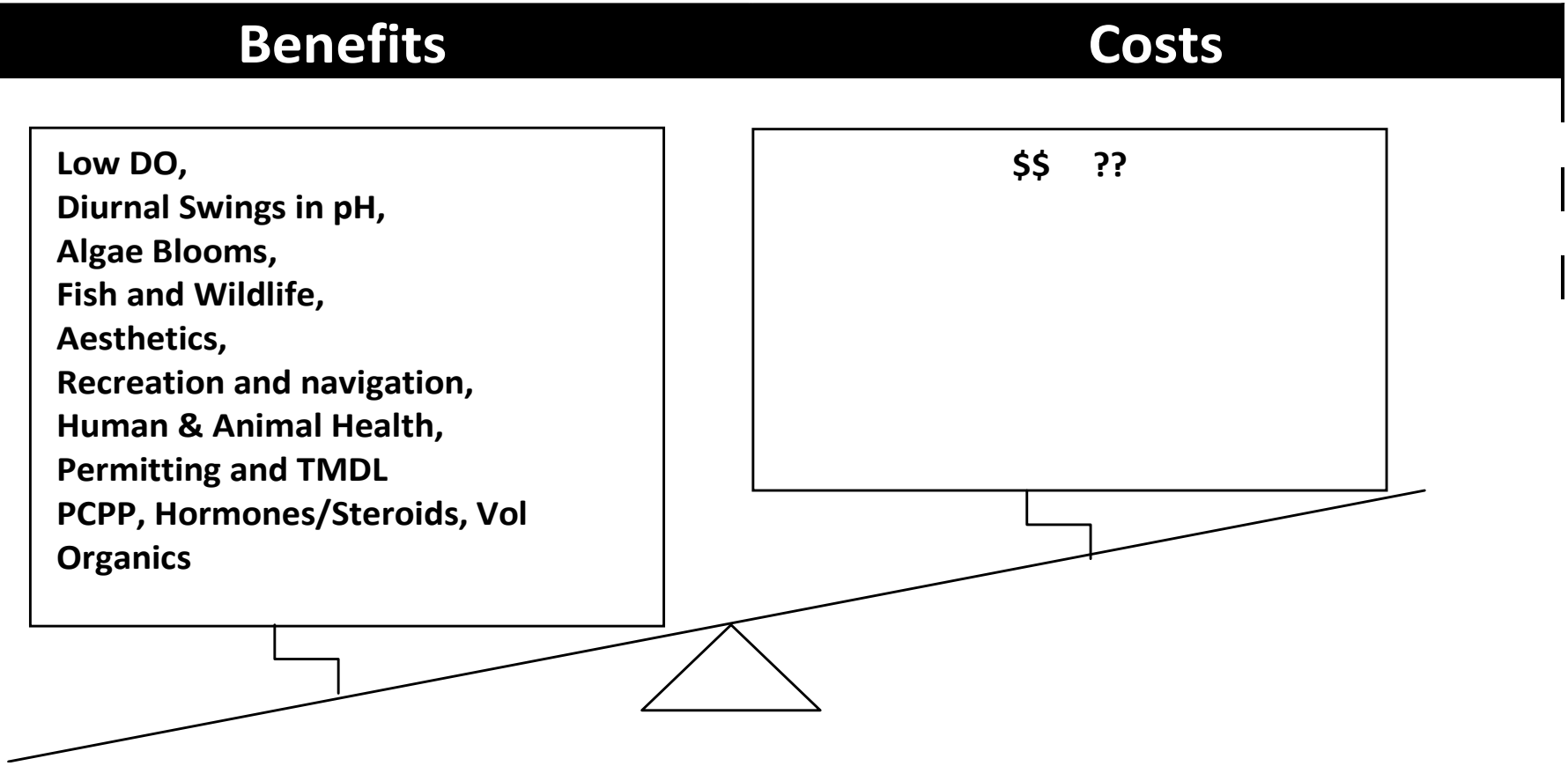
PROTECT THIS




Presentation Framework

- Why did we commission the study?
- Scope of the Study
- Evaluation Approach
- Modeling Overview
- Process Upgrade Examples
- Cost Evaluation
- Statewide Impacts

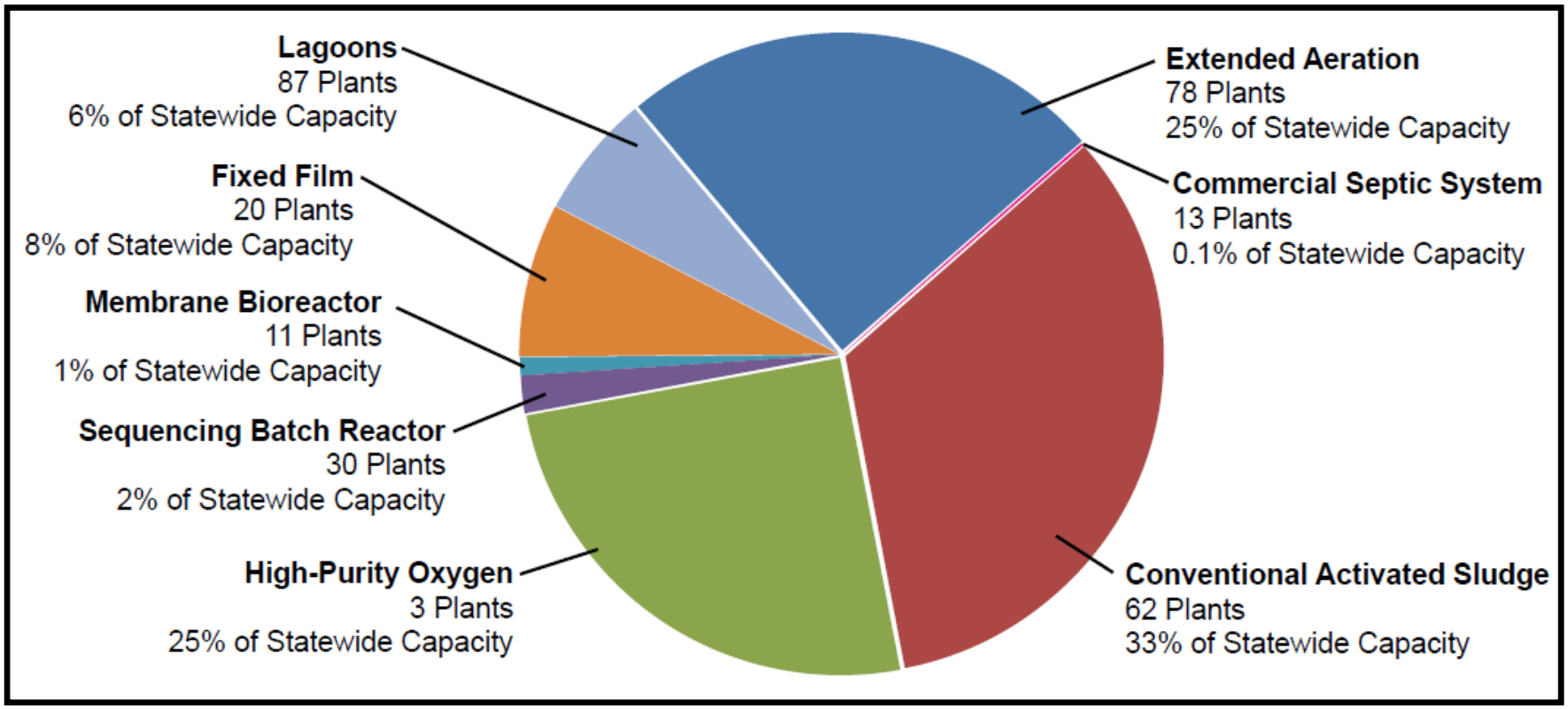
Why Did We Conduct the Study?



Study Scope

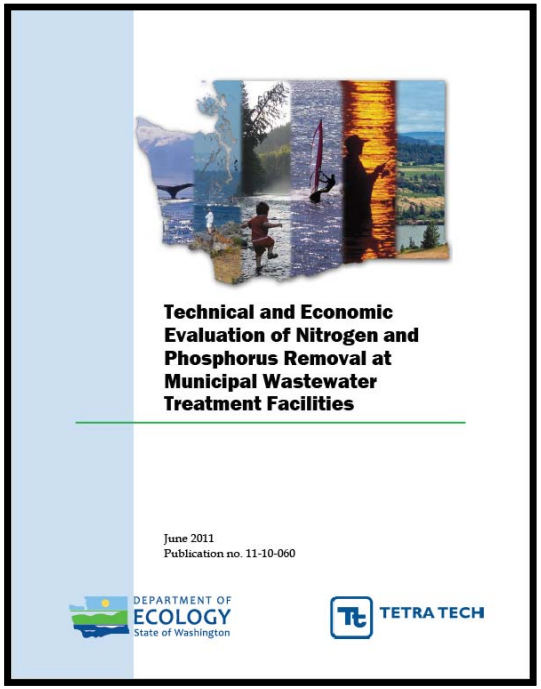
- Evaluate technologies for significant loading reductions of N and P
- Determine capital and O&M Costs
- Evaluate seasonal vs. year round nutrient removal
- Consider differences between marine and freshwater discharges
- Nexus of nutrient removal and reclaimed water generation
- Excludes some ancillary costs (land, biosolids disposal, etc.)

Evaluation Approach



Treatment Objectives

- Effluent Total Inorganic Nitrogen (TIN) [$NH_4^+ + NO_3^- + NO_2^{-2}$]
  - Objective A: 8 mg/L as N
  - Objective B: 3 mg/L as N
- Effluent Total Phosphorus (TP)
  - Objective C: 1 mg/L as P
  - Objective D: 0.1 mg/L as P
- Effluent TIN and TP
  - Objective E: 8 mg/L as N & 1 mg/L as P
  - Objective F: 3 mg/L as N & 0.1 mg/L as P



Other Considerations

- Assumed representative wastewater characteristics and design criteria
- 3 sizes representing WA treatment plants
- Other factors:
  - Recycled Loads
  - Sludge Production
  - Energy Consumption
  - Chemical Usage
  - Footprint Requirements
- Reclaimed Water

Reclaimed Water Evaluation

- Costs evaluated for Class A production with groundwater recharge
  - Year round & Seasonally for existing plants at their capacity

- Assumed the following:
  - Meet Objective A
  - Upgrade/Replace Disinfection to UV process
  - Post-Chlorination sodium hypochlorite for minimum residual of 0.5 mg/L
  - New filtration process with coagulation/flocculation for plants w/o MBRs

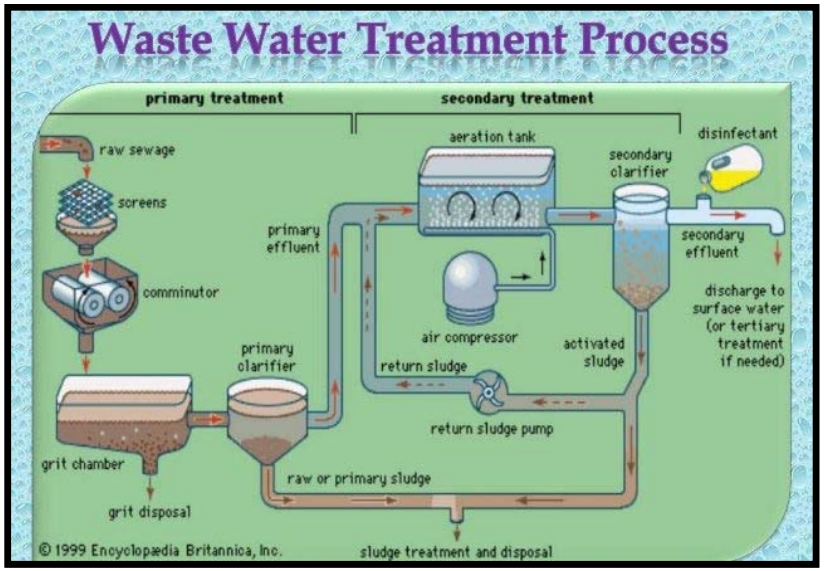
Design Assumptions

Constituent	Design Criteria
Annual Average Flow	100 gallons per capita per day (gpcd)
Average Wet-Weather Flow	120 gpcd
Maximum-Month Wet-Weather Flow	160 gpcd
Average Dry-Weather Flow	80 gpcd
Maximum-Month Dry-Weather Flow	110 gpcd
Peak-Day Flow	275 gpcd
BOD_5	0.22 pounds per capita per day (ppcd)[a]
TSS	0.25 ppcd[a]
Total Kjeldahl Nitrogen (TKN) as N	0.032 ppcd[a]
Organic Nitrogen as N	0.013 ppcd[a]
Ammonia as N	0.019 ppcd[a]
Total Phosphorus as P	0.0076 ppcd[a]
Organic Phosphorus as P	0.0028 ppcd[a]
Inorganic Phosphorus as P	0.0048 ppcd[a]

a. Values are from Table 3-12 Metcalf &Eddy 2003

Treatment Processes Evaluated

- Extended aeration (EA)
- Conventional activated sludge (CAS)
- Sequencing batch reactors (SBR)
- Fixed film systems (FF)
- Membrane biorectors (MBR)
- High-purity oxygen activated sludge (HPO)
- Lagoons
- Septic treatment (SPT)



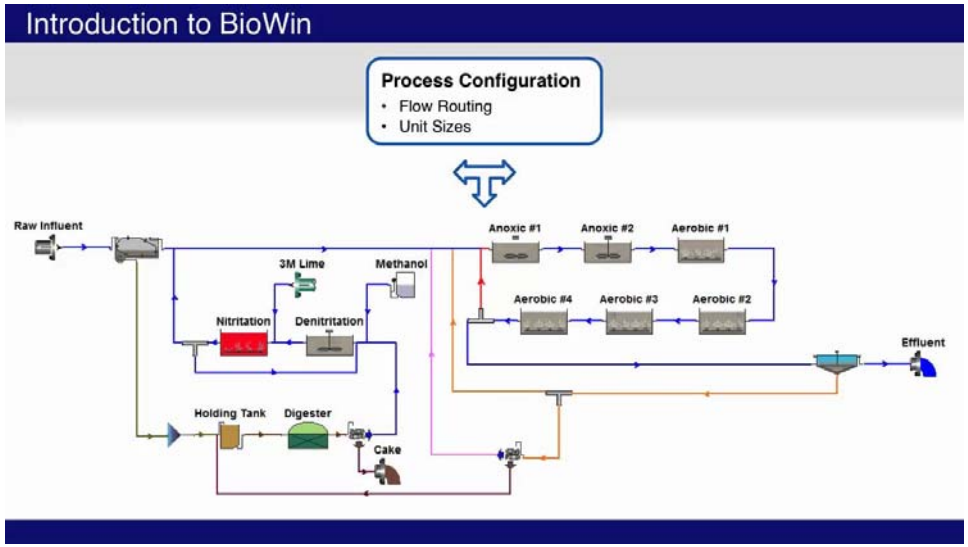
What was Investigated?

- Overall feasibility
- General nature and extent of necessary process modifications
- Capital and O&M costs associated with upgrades
- Year Round vs. Seasonal for all 6 Objectives

What about the Modeling?

- BioWin used in all evaluations
  - Established existing performance
  - Evaluated each nutrient objective
  - Generic, hypothetical WWTPs

- Modeling Assumptions
  - 1-MGD base case + upgrade scenarios
  - All size/process parameters from the “Orange Book”



1 MGD Design Criteria

		Annual Average	Max Month Wet Weather	Average Wet Weather	Max Month Dry Weather	Average Dry Weather	Peak Day
Flow (mgd)		0.63	1.00	0.75	0.69	0.50	1.72
pH (units)		7.0	6.8	6.8	7.0	7.0	7.0
	Loading Rate (lbs/day)	Concentration (mg/L)					
BOD_5	1,376	265	165	221	241	331	96
TSS	1,564	301	188	251	273	376	109
VSS[a]	1,095	210	132	175	191	263	77
TKN as N	200	38.5	24.1	32.1	35.0	48.1	14.0
Organic Nitrogen as N	81	15.6	9.8	13.0	14.2	19.5	5.7
Ammonia as N	119	22.9	14.3	19.1	20.8	28.6	8.3
Total Phosphorus as P	48	9.1	5.7	7.6	8.3	11.4	3.3
Organic Phosphorus as P	18	3.4	2.1	2.8	3.1	4.2	1.2
Inorganic Phosphorus as P	30	5.8	3.6	4.8	5.2	7.2	2.1
Alkalinity	835	161	100	134	146	200	58.4
Calcium	63	12.0	7.5	10.0	10.9	15.0	4.4
Magnesium	25	4.8	3.0	4.0	4.4	6.0	1.8

a. VSS = volatile suspended solids (assumed to equal 0.7 * TSS)

Cost Evaluation

- Cost curves generated for capital and O&M costs
  - Includes 3 treatment capacities for existing processes
  - Covers full range of existing plants utilizing that specific process

MAXIMUM-MONTH TREATMENT PLANT CAPACITIES EVALUATED FOR COST CURVES

Existing Treatment Process Type	Number of Capacities Evaluated	Maximum-Month Plant Capacity (mgd)		
		Low	Mid	High
Extended Aeration	3	1	10	100
Sequencing Batch Reactor	3	0.5	2	10
Conventional Activated Sludge	3	1.0	10	150
Fixed Film	3	1.0	10	150
Membrane Bioreactor	3	1.0	10	100
High-Purity-Oxygen Activated Sludge	2	20	NA	220
Lagoons	3	0.5	5.0	50

Cost Estimation Basis

- CapdetWorks 2.5 for capital and O&M estimation
  - ENR Cost Index – 8860 (January, 2010)
  - Marshall and Swift Index – 1448 (January, 2010)
  - Pipe Cost Index – 794.5 (January, 2010)
  - Capital Costs included the following adjustment:
    - 12% increase for instrumentation and controls
    - 7% increase for general site, structural, and electrical modifications
    - 10% increase of estimated unit construction costs for demolition
    - New processes (e.g., MBRs) used manufacturer and state supplied data
- Class 5 Planning Estimate -50% to 100% accurate

Unit Cost Examples

UNIT COSTS AND RATES	
Unit Costs	
Building Cost	$150/ft^2
Excavation	$8/cubic yard
Wall Concrete	$800/ cubic yard
Slab Concrete	$500/ cubic yard
Crane Rental	$200/hour
Canopy Roof	$16/ft^2
Electricity	$0.1/kW-hour
Hand Rail	$75/foot
Land Costs	$0/acre
Labor Rates	
Construction Labor Rate	$45/hour
Operator Labor Rate	$70/hour
Administration Labor Rate	$35/hour
Laboratory Labor Rate	$45/hour
Chemical Costs (all costs are per mass of the dry form)	
$AL_2(SO_4)_3$*14 H_2O as 42.8%	$0.06/lb
Magnesium hydroxide	$0.21/lb
Methanol	$3/gallon
Polymer	$4/lb
Citric Acid	$3/gallon
Sodium Hypochlorite	$0.80/gallon

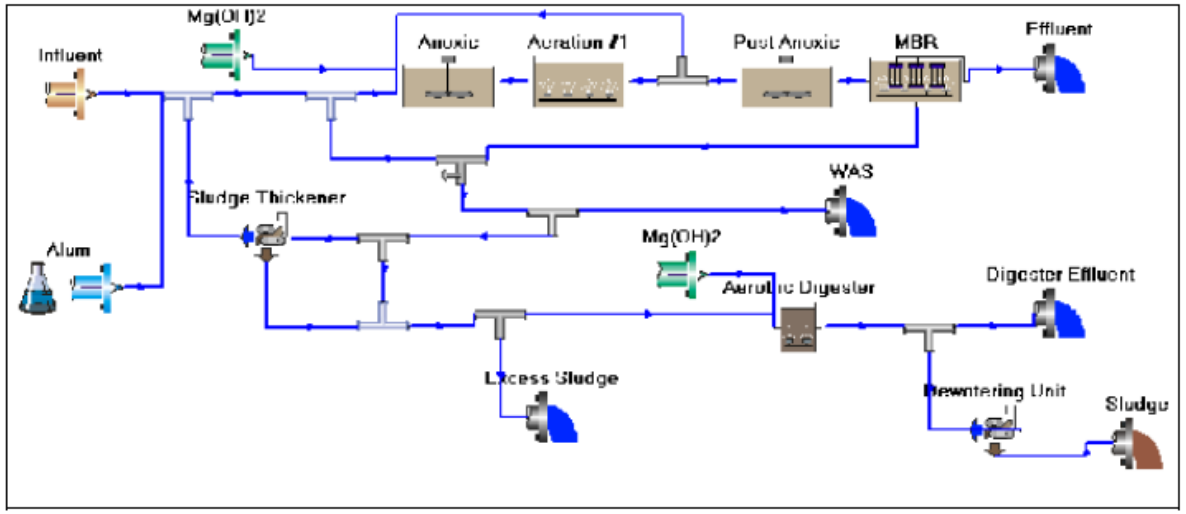
Financial	
Interest Rate	3%
Construction Period	3 years
Construction loan period	20 years
Operating Life of Plant	40 years
Other Costs	
Engineering Design Fee	15%
Miscellaneous	15%
Administration/Legal	2%
Inspection	8%
Contingency	30%
Technical	7%
Profit and Overhead	15%

Upgrades Evaluated – N Removal

- Modified Ludzack Ettinger for denitrification
- Membrane bioreactors for denitrification
- Sequencing batch reactors for denitrification
- Four Stage Bardenpho for denitrification
- Denitrification Filters
- Methanol addition for denitrification

Upgrades Evaluated – P Removal

- **Chemical addition: alum for P removal, $Mg(OH)_2$ for pH control**
- **Tertiary Filters**
- **Operational changes only (both N and P)**



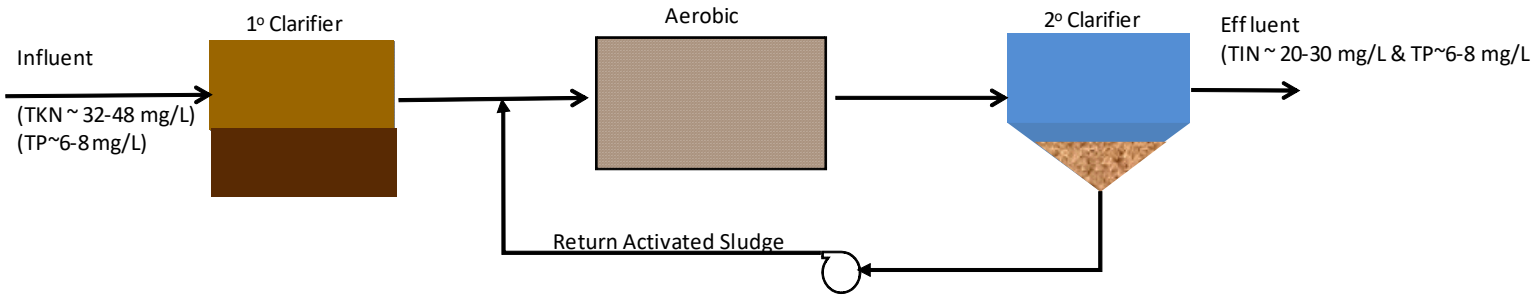
TREATMENT PROCESS UPGRADES EVALUATED TO ACHIEVE NUTRIENT-REMOVAL OBJECTIVES

	Objective A	Objective B	Objective C	Objective D	Objective E	Objective F
Definition of Objective						
Effluent TIN	< 8 mg/L	< 3 mg/L	—	—	< 8 mg/L	< 3 mg/L
Effluent TP	—	—	< 1 mg/L	< 0.1 mg/L	< 1 mg/L	< 0.1 mg/L
Treatment Processes to Achieve Objective						
Existing Extended Aeration Plant						
Year-Round	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F
Seasonal	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F
Existing Conventional Activated Sludge Plant						
Year-Round	MLE+MBR	4BDP+MBR+M	C	C+F	MLE+MBR+C	4BDP+MBR+M+C
Seasonal	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F
Existing Sequencing Batch Reactor Plant						
Year-Round	SBR	SBR+DNF+M	SBR+C	SBR+C+F	SBR+C	SBR+DNF+C+F+M
Seasonal	SBR	SBR+DNF+M	SBR+C	SBR+C+F	SBR+C	SBR+DNF+C+F+M
Existing Trickling Filter, Trickling Filter/Solids Contact, or Rotating Biological Contactor Plant						
Year-Round	MLE+MBR	4BDP+MBR+M	C	C+F	MLE+MBR+C	4BDP+MBR+M+C
Seasonal	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F
Existing Membrane Bioreactor Plant						
Year-Round	OC	M	C	C	C	C+M
Seasonal	OC	M	C	C	C	C+M
Existing High-Purity Oxygen Activated Sludge Plant						
Year-Round	MLE+MBR	4BDP+MBR	—	—	—	—
Seasonal	MLE	4BDP+M	—	—	—	—
Existing Aerated Lagoon or Facultative Lagoon Plant						
Year-Round	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F
Seasonal	MLE	4BDP+M	C	C+F	MLE+C	4BDP+M+C+F

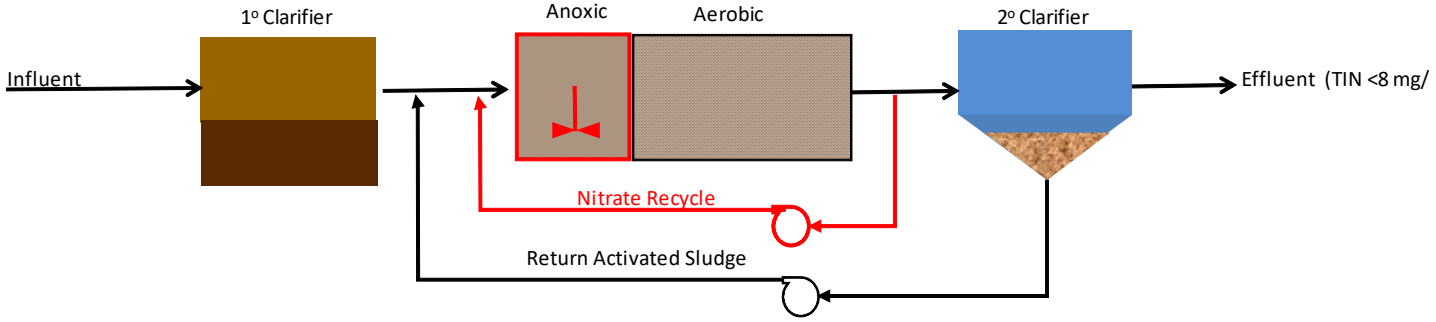
4BDP = Four-stage Bardenpho system for denitrification
C = Chemical addition: alum for phosphorous removal, magnesium hydroxide for pH control
DNF = Denitrification filters
F = Tertiary filters for phosphorus removal
M = Methanol addition for denitrification
MBR = Membrane bioreactors for denitrification
MLE = Modified Ludzack Ettinger process for denitrification
OC = Operational changes only
SBR = Sequencing batch reactor (capacity increased for denitrification)

Process Upgrade Examples

Typical CAS Process

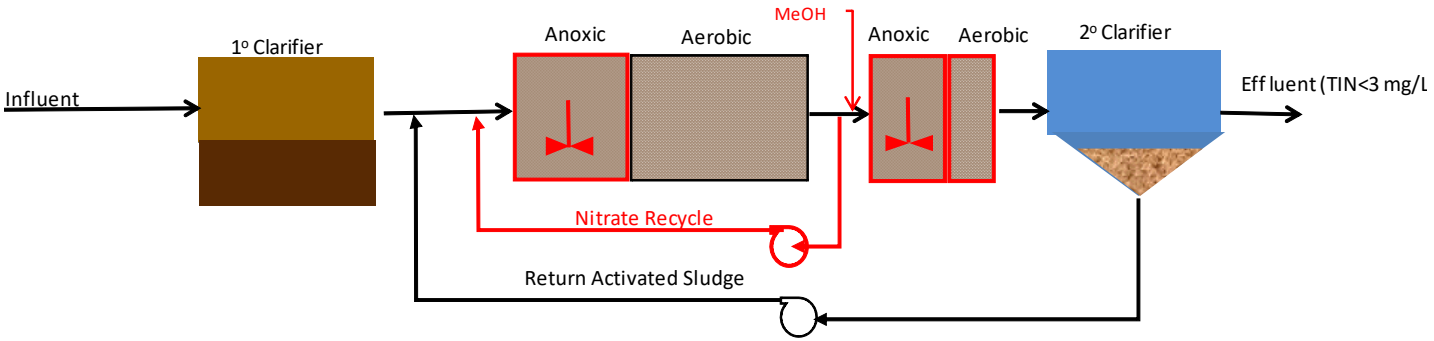


Typical Modified Ludzack-Ettinger (MLE) Process (Upgrade for TIN < 8 mg/L)

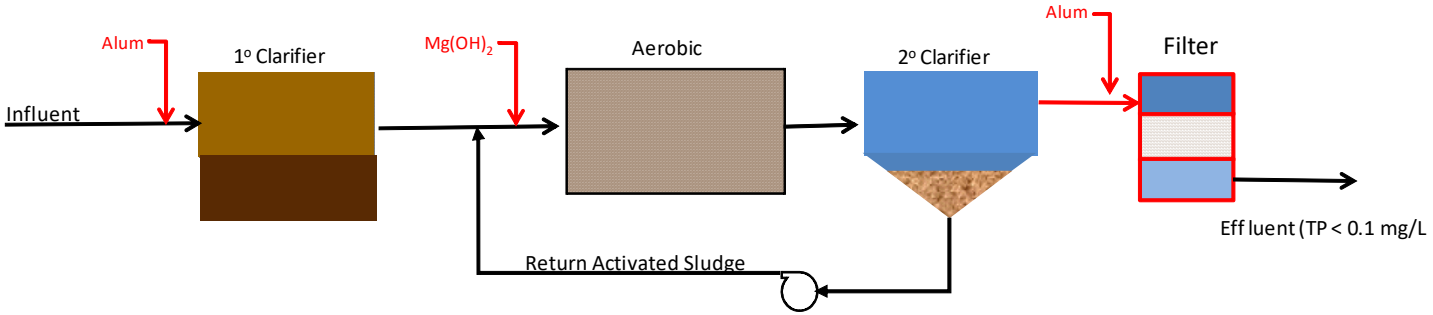


Process Upgrade Examples

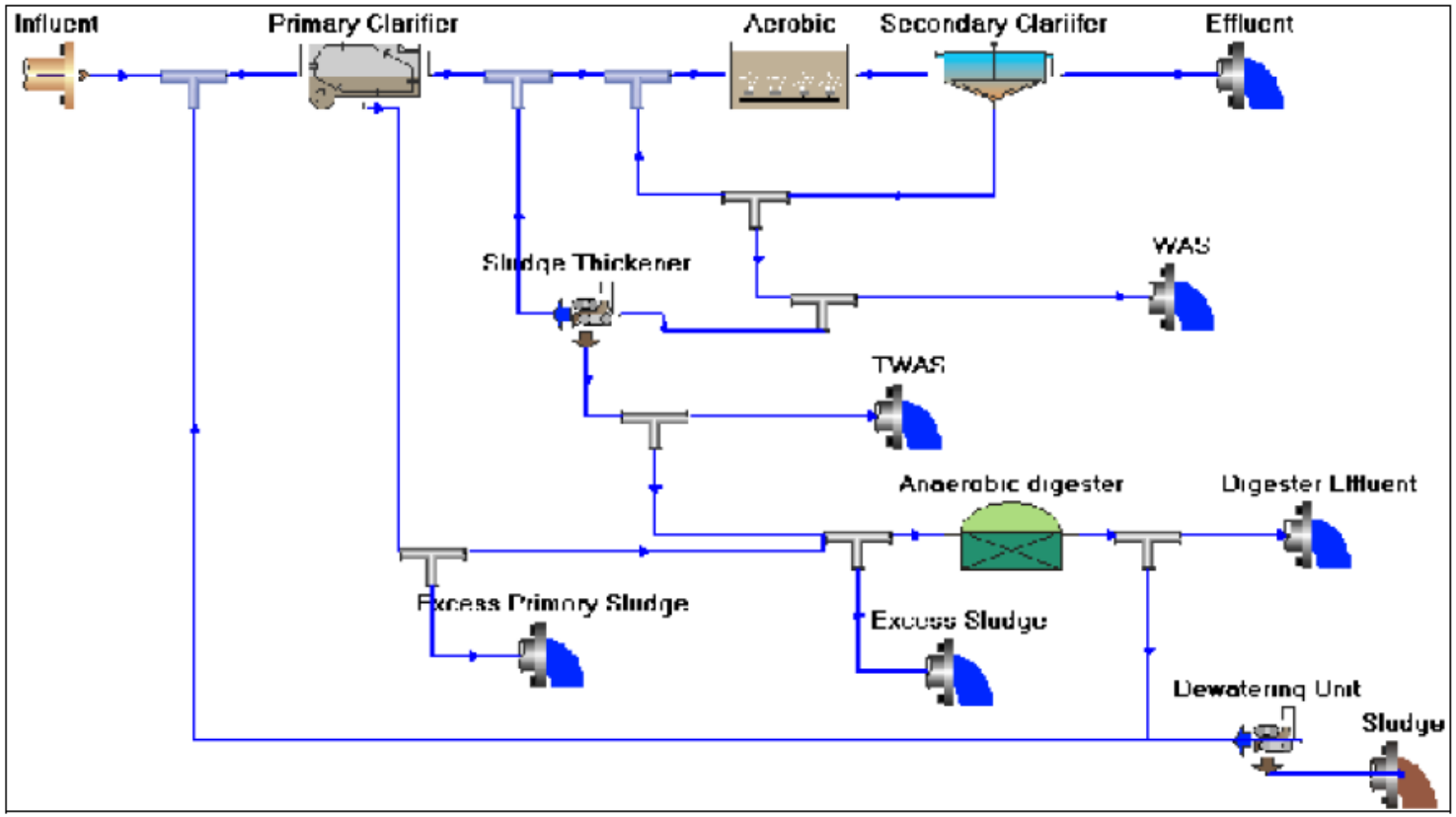
4-Stage Bardenpho Process (4-BDP) Upgrade for TIN < 3 mg/L



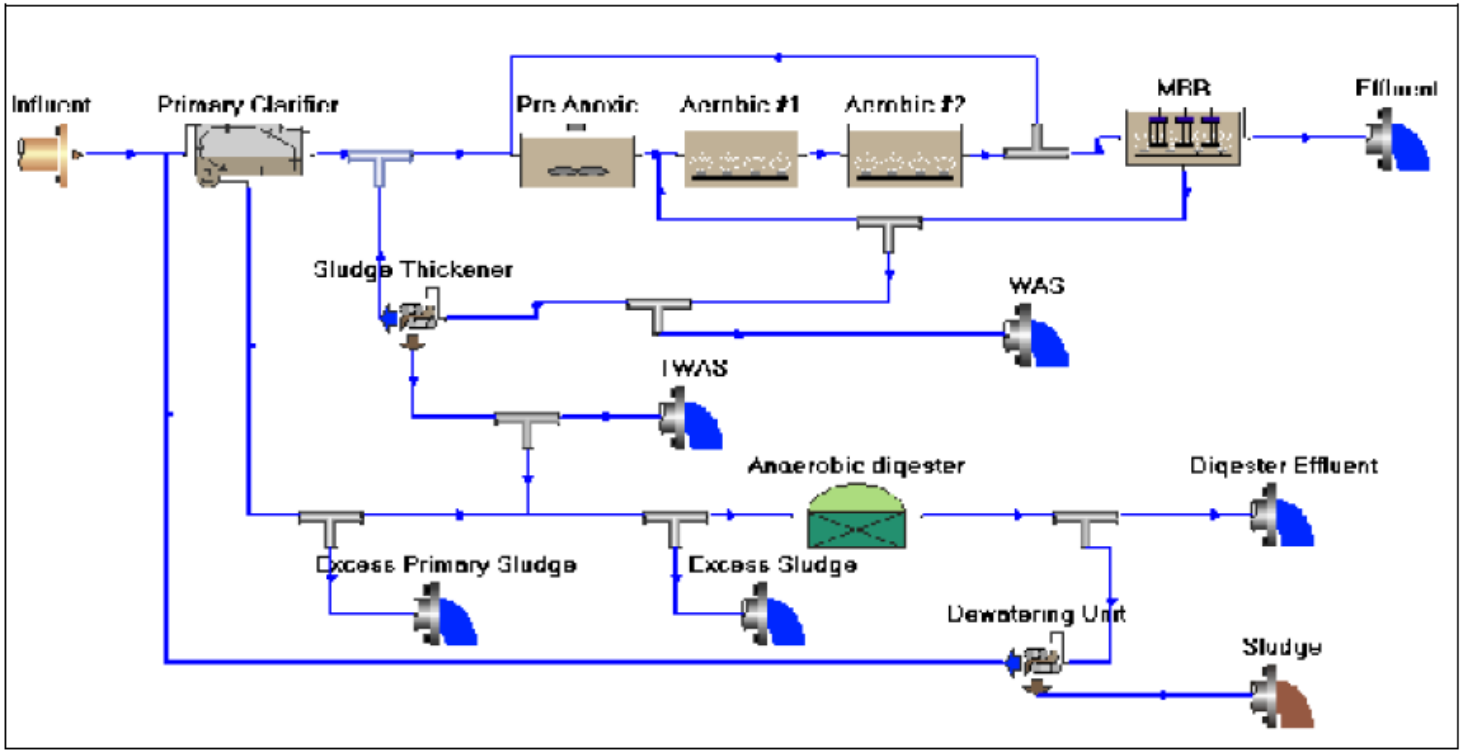
CAS Process Upgrade for TP < 0.1 by Chemical Precipitation and Filtration



Existing CAS Evaluation



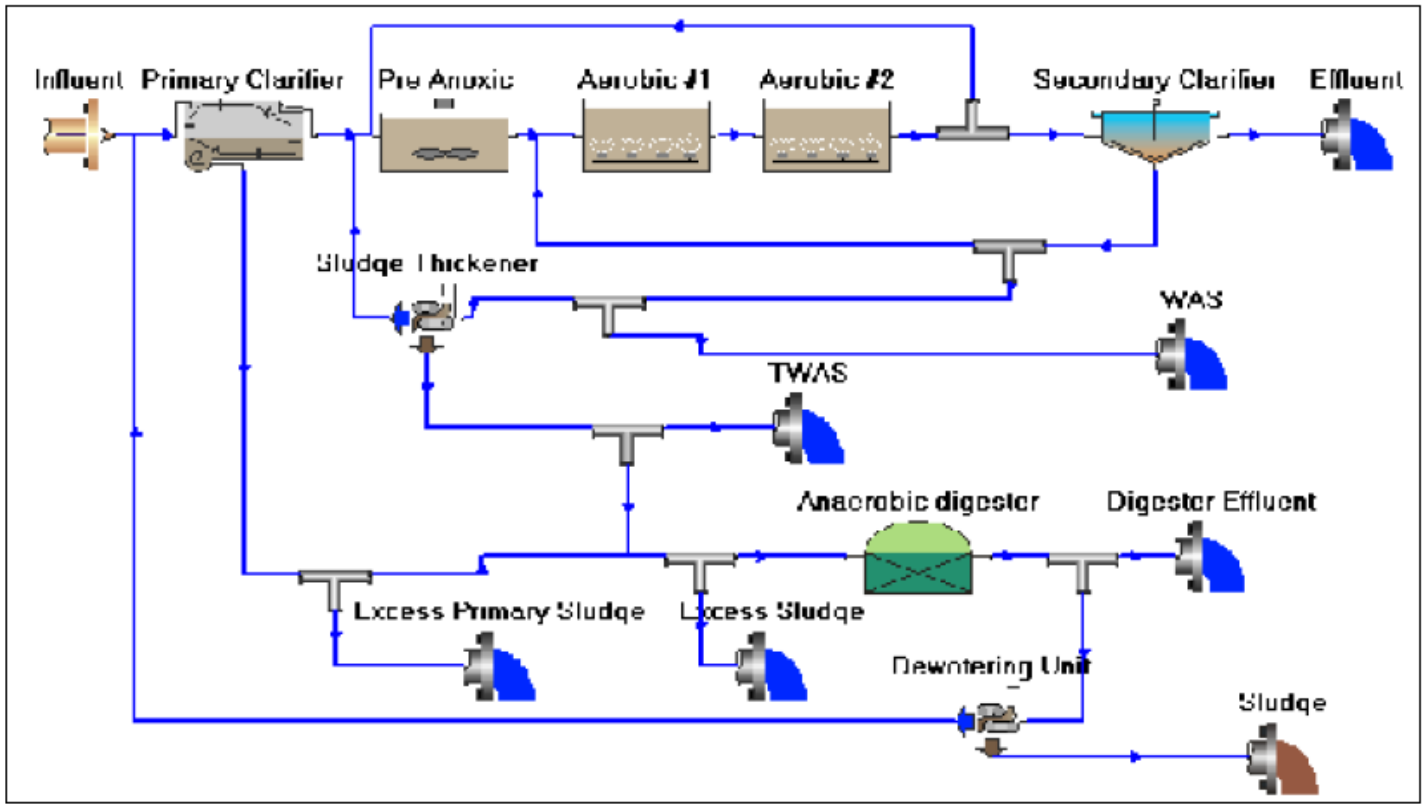
CAS Upgrade for Obj. A - YR



Other Design Considerations

- **Recycled Loads**
  - **Decrease TN ~33% in recycle; Decrease TP ~28%**
- **Sludge Production**
  - **168 ton/year (0.74 dry tons/ MG) – Existing**
  - **174 ton/year (0.76 dry tons/MG) – Upgrade**
- **Energy Consumption**
  - **150% increase process air; 2,088 kW-hour/ MG increase overall**
- **Chemical Usage**
  - **Minimal, for MBR maintenance**
- **Footprint Requirements**
  - **Need 2,000 SF**

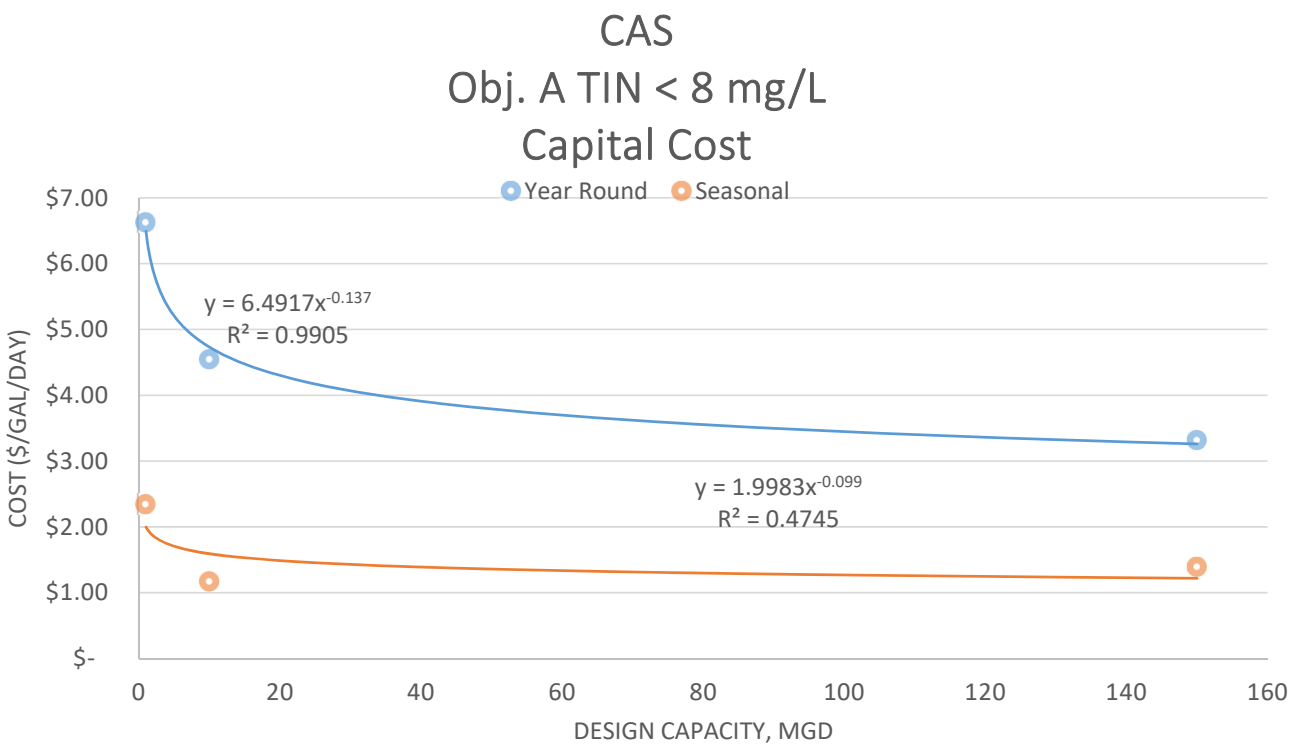
CAS Upgrade for Obj. A - Seasonal



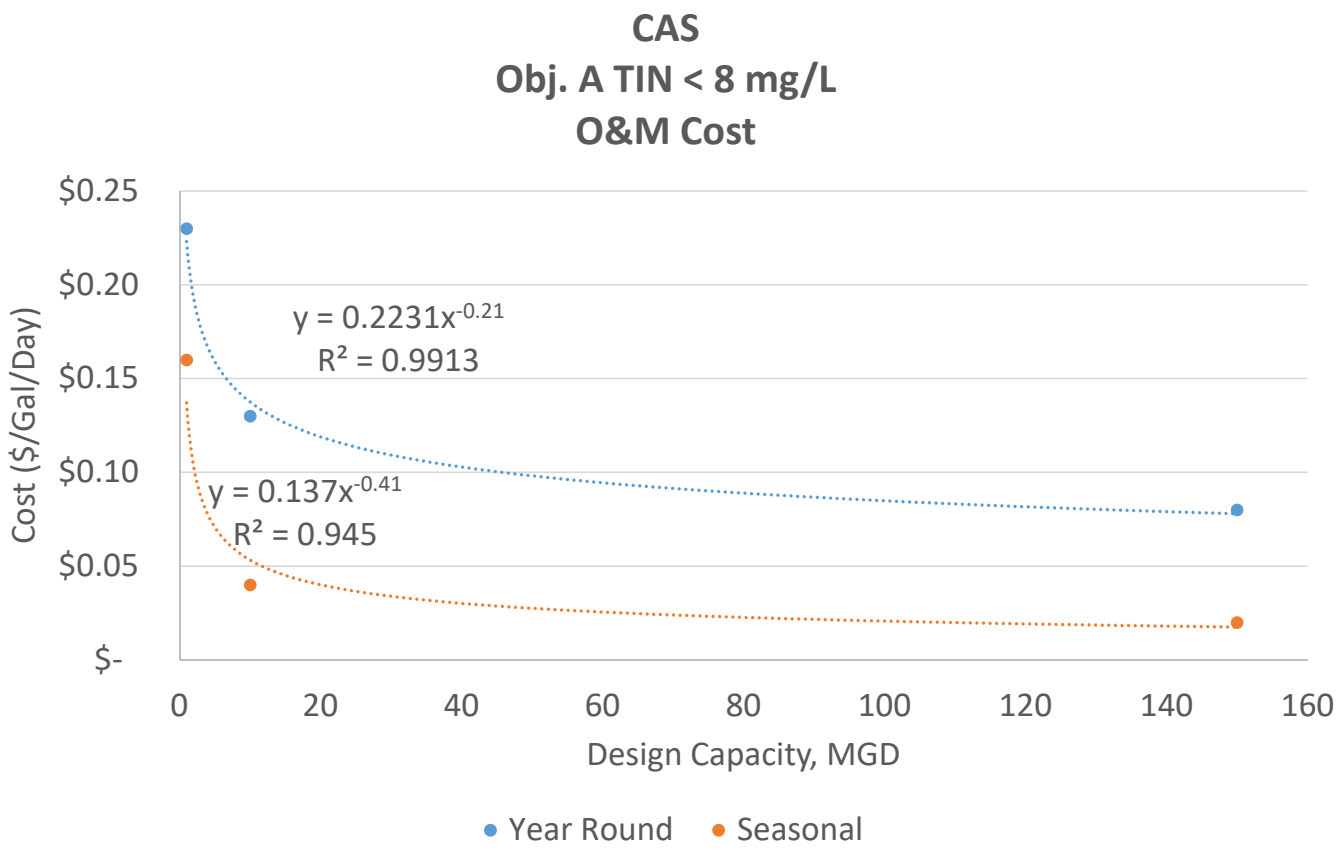
Other Design Considerations

- **Recycled Loads**
  - Decrease TN ~12% in recycle; Decrease TP ~4%
- **Sludge Production**
  - 168 ton/year (0.74 dry tons/ MG) – Existing
  - 167 ton/year (0.73 dry tons/MG) – Upgrade
- **Energy Consumption**
  - 17% increase process air; 754 kW-hour/ MG increase
- **Chemical Usage**
  - None
- **Footprint Requirements**
  - Need 1,000 SF

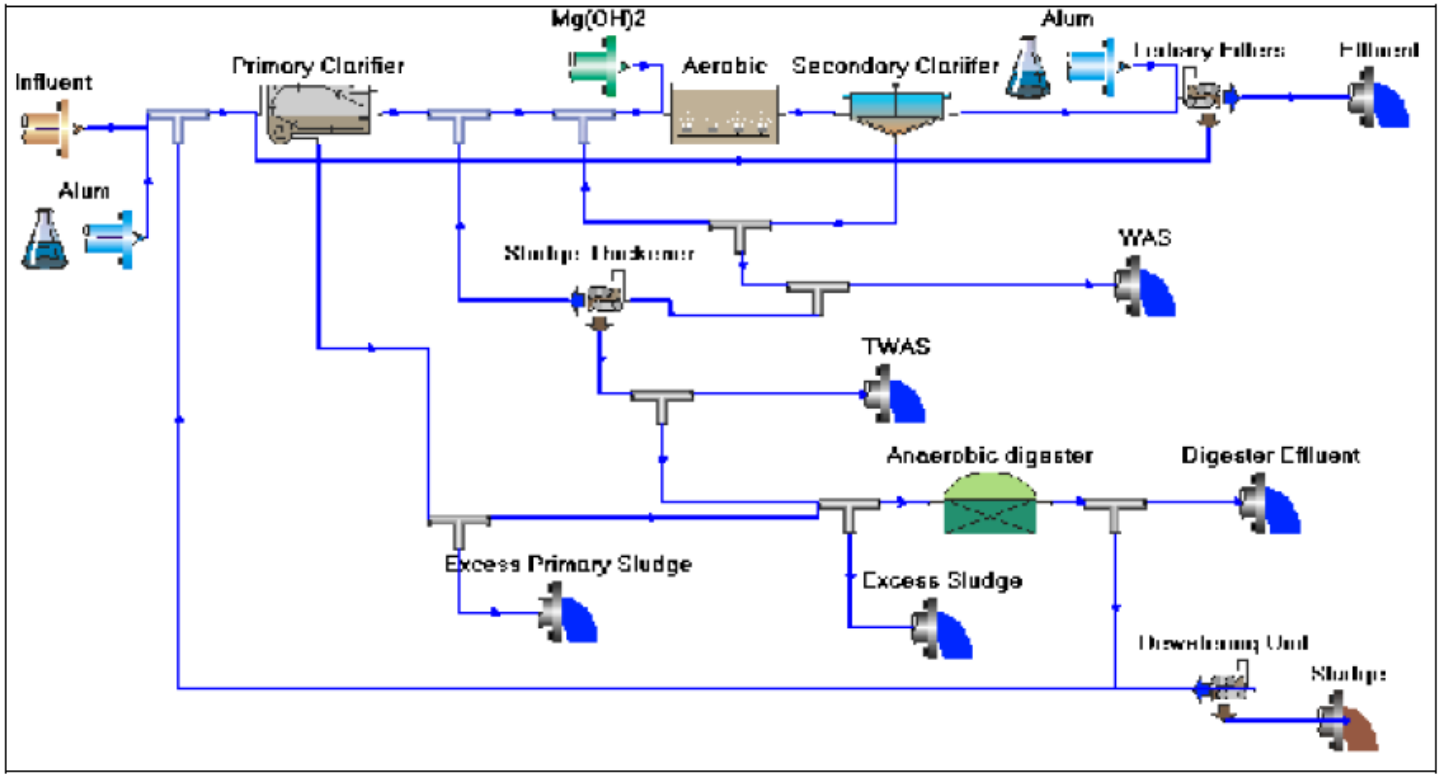
Capital Cost Curve



O&M Cost Curve

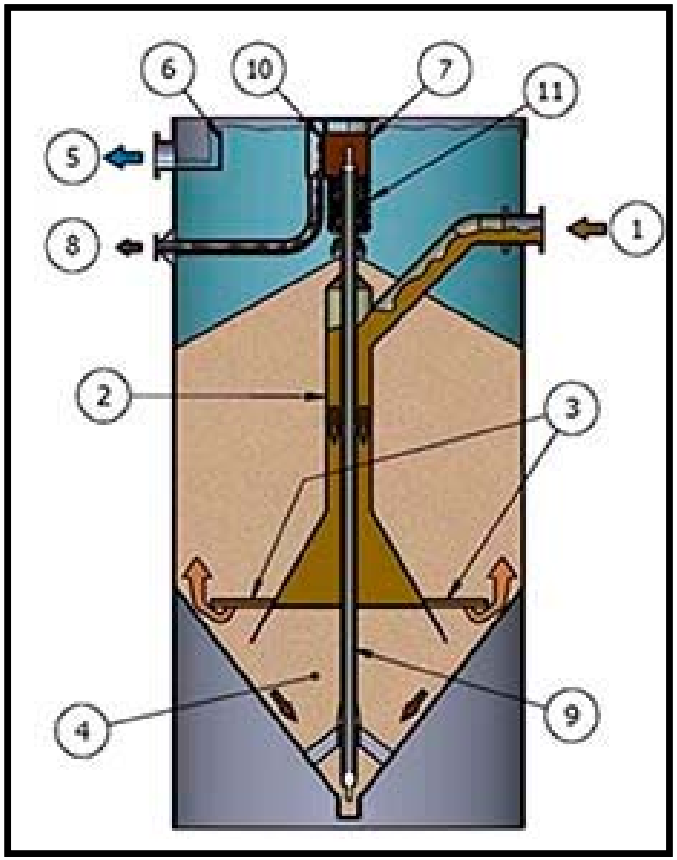


CAS Upgrade for Obj. D

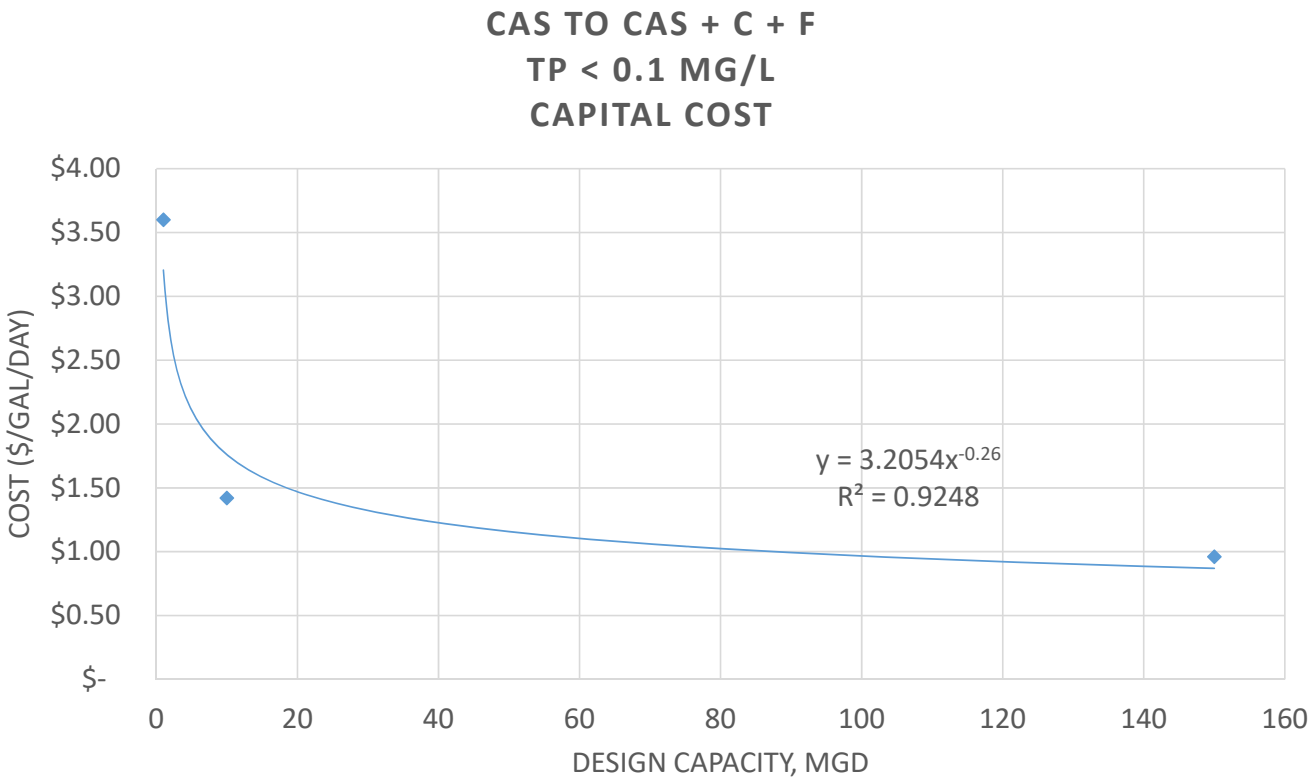


Other Design Considerations

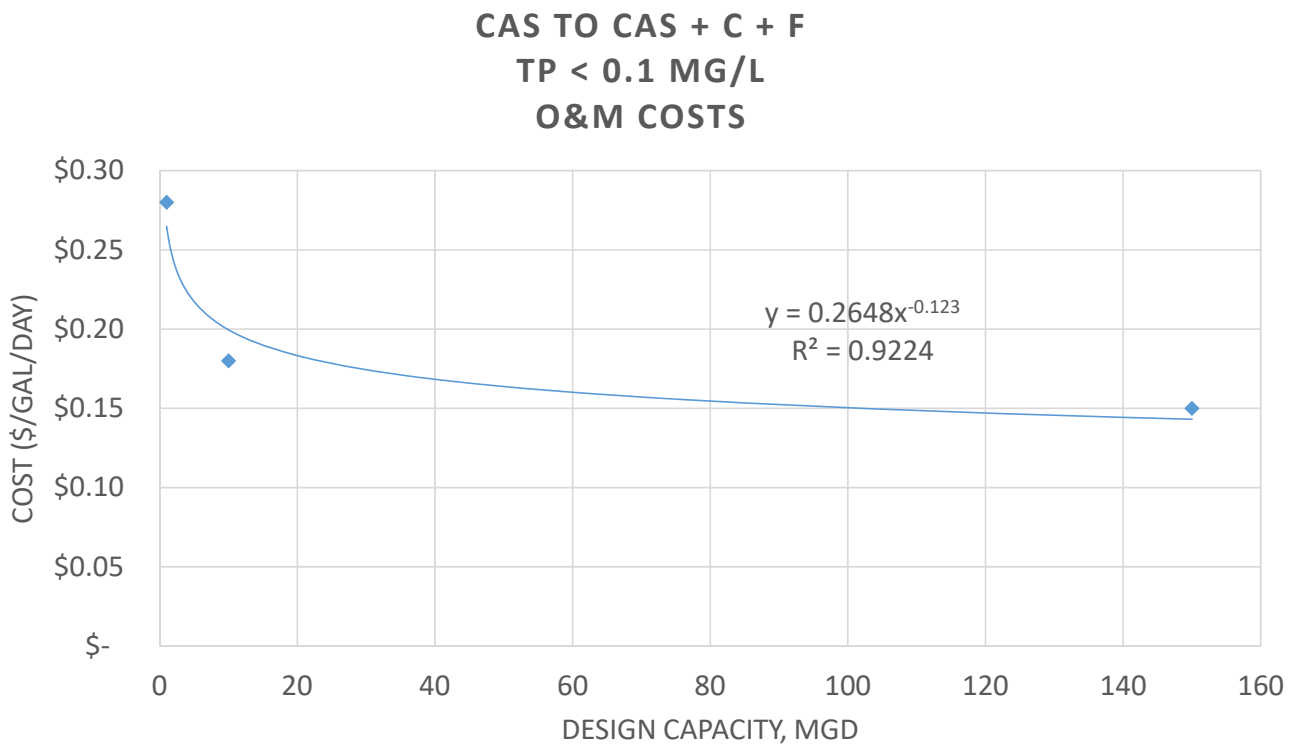
- **Recycled Loads**
  - No significant effect
- **Sludge Production**
  - 168 ton/year (0.74 dry tons/ MG) – Existing
  - 229 ton/year (1.0 dry tons/MG) – Upgrade
- **Energy Consumption**
  - 21% increase; 192 kW-hour/ MG increase
- **Chemical Usage**
  - 256 gal alum/MG ; 128 gal $Mg(OH)_2$ /MG
- **Footprint Requirements**
  - Need 1,200 SF



Capital Cost Curve



O & M Cost Curve



State Wide Cost Impacts

- **Cost models from each objective applied to all POTWs**
  - **Used treatment types, max month capacity with models for estimation of costs for specific plants**
- **All costs totaled by treatment type**
  - **Capital costs, Annual O&M and 20-year annualized total cost**
- **Includes estimating statewide rate impact**

State Wide Costs – Capital/Year Round

ESTIMATED CAPITAL COSTS FOR YEAR AROUND NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Capital Cost ($ millions, 2010)					
Year-Around Nutrient Removal						
Extended Aeration (Mechanical Aeration)	204	239	29	133	221	360
Extended Aeration (Diffused Aeration)	4	7	3	11	5	16
Extended Aeration (with Biological Nutrient Removal)	29	128	75	328	94	414
Conventional Activated Sludge	1625	1773	142	559	1725	2253
Sequencing Batch Reactor	7	28	18	54	18	76
Trickling Filter	177	195	15	58	186	246
Rotating Biological Contactor	140	155	13	47	148	197
Trickling Filter/Solids Contact	193	207	15	59	193	252
Membrane Bioreactor	0	0	11	10	11	11
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	170	182	40	62	184	218
High Purity Oxygen	942	1134	N/A	N/A	942(1)	1134(1)
Statewide Total	**$4,264**	**$4,844**	**$522**	**$1,555**	**$4,564**	**$6,107**

Note: (1) costs are for nitrogen removal only

State Wide Costs – Capital/Seasonal

ESTIMATED CAPITAL COSTS FOR YEAR AROUND NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Capital Cost ($ millions, 2010)					
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	192	217	28	84	227	308
Extended Aeration (Diffused Aeration)	2	5	3	7	6	11
Extended Aeration (with Biological Nutrient Removal)	38	76	76	252	66	272
Conventional Activated Sludge	564	629	185	429	660	1032
Sequencing Batch Reactor	6	25	18	46	18	66
Trickling Filter	96	105	18	42	102	138
Rotating Biological Contactor	76	84	15	33	82	111
Trickling Filter/Solids Contact	88	93	20	46	88	127
Membrane Bioreactor	0	0	10	10	10	10
Lagoons (Aerated)	773	797	163	234	836	931
Lagoons (Facultative)	164	168	35	50	177	197
High Purity Oxygen	363	477	N/A	N/A	363[1]	477[1]
Statewide Total	**$2,360**	**$2,674**	**$570**	**$1,233**	**$2,635**	**$3,680**

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State Wide Costs – O&M/ Year Round

ESTIMATED ANNUAL O&M COSTS FOR YEAR AROUND NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Annual O&M Cost ($ millions, 2010)					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	0	13	9	14	16	26
Extended Aeration (Diffused Aeration)	0	0	0	1	1	1
Extended Aeration (with Biological Nutrient Removal)	0	0	16	33	11	38
Conventional Activated Sludge	45	57	55	69	90	122
Sequencing Batch Reactor	0	9	1	3	0	12
Trickling Filter	5	7	4	6	9	12
Rotating Biological Contactor	5	6	4	4	8	11
Trickling Filter/Solids Contact	4	6	6	7	9	12
Membrane Bioreactor	0	0	1	2	1	2
Lagoons (Aerated)	24	28	10	12	31	37
Lagoons (Facultative)	7	8	2	2	10	12
High Purity Oxygen	44	53	N/A	N/A	44(1)	53(1)
Statewide Total	**$135**	**$187**	**$108**	**$152**	**$230**	**$338**

Note: (1) costs are for nitrogen removal only

Impact to Sewer Rates - YR

TABLE 17-4.
ESTIMATED MONTHLY HOUSEHOLD SEWER RATE INCREASE FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

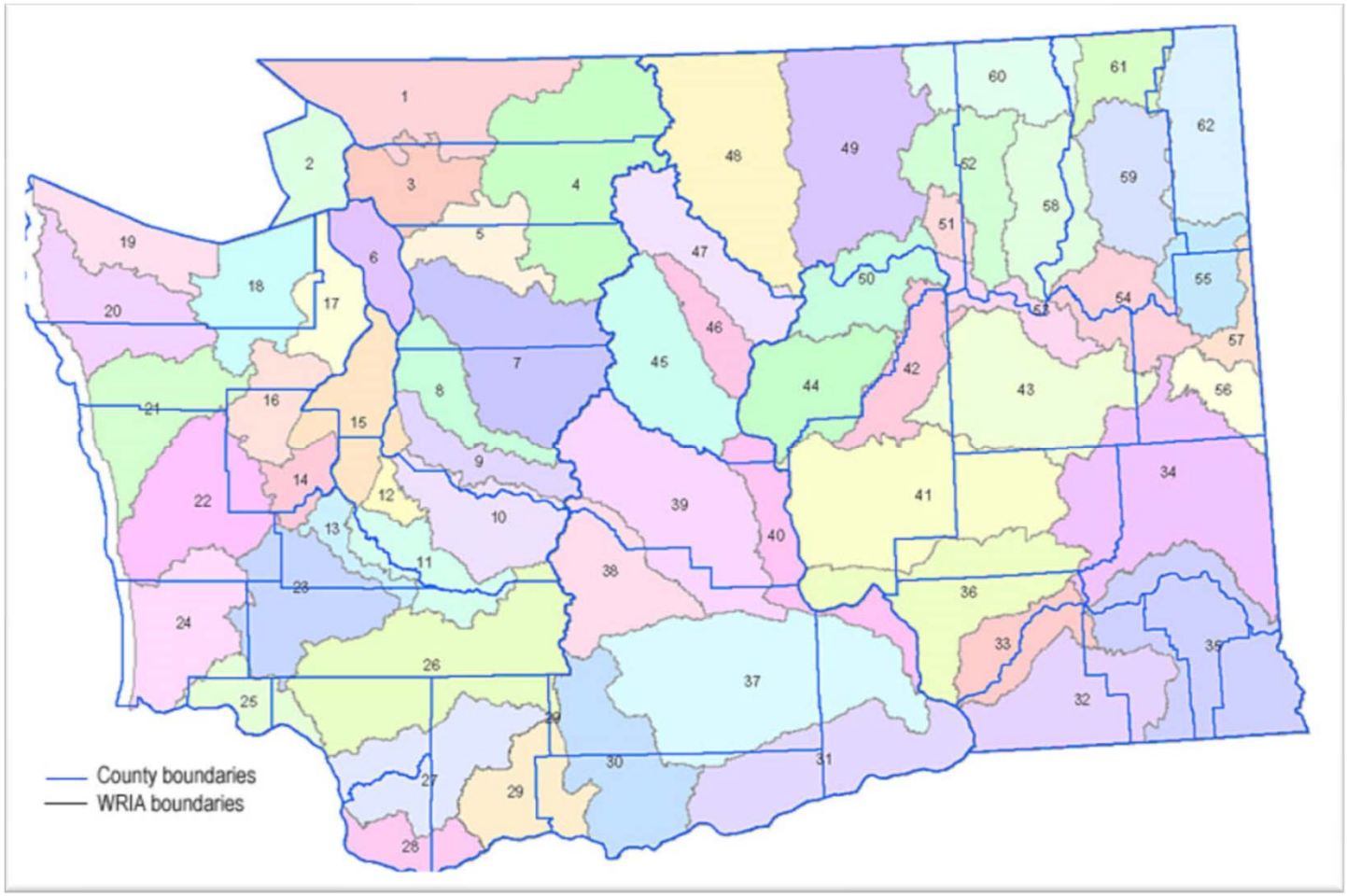
	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Monthly Household Sewer Rate Increase [1]					
Year-Round Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$11.29	$24.30	$9.26	$18.96	$25.20	$41.13
Extended Aeration (Diffused Aeration)	$4.09	$7.01	$9.91	$22.18	$15.29	$36.23
Extended Aeration (with Biological Nutrient Removal)	$0.37	$1.66	$4.07	$10.50	$3.31	$12.68
Conventional Activated Sludge	$17.48	$19.95	$7.25	$12.03	$23.33	$30.97
Sequencing Batch Reactor	$1.16	$22.37	$4.71	$13.09	$2.45	$33.21
Trickling Filter	$27.43	$31.48	$8.85	$15.26	$35.23	$46.42
Rotating Biological Contactor	$29.77	$34.14	$9.24	$15.92	$38.27	$49.99
Trickling Filter/Solids Contact	$17.79	$20.08	$6.86	$11.38	$22.33	$30.00
Membrane Bioreactor	$0.00	$0.81	$9.46	$10.67	$9.46	$11.46
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$66.89	$74.14	$16.43	$23.38	$78.62	$94.66
High Purity Oxygen	$16.24	$19.47	N/A	N/A	16.24	19.47
Weighted Average	**$16.00**	**$19.48**	**$7.29**	**$13.02**	**$20.40**	**$28.43**

Impact to Sewer Rates - Seasonal

ESTIMATED MONTHLY HOUSEHOLD SEWER RATE INCREASE FOR NUTRIENT REMOVAL UPGRADES OF ALL TREATMENT PLANTS IN WASHINGTON

	Obj. A	Obj. B	Obj. C	Obj. D	Obj. E	Obj. F
Effluent TIN Limit (mg/L):	<8	<3	—	—	<8	<3
Effluent TP Limit (mg/L):	—	—	<1	<0.1	<1	<0.1
Existing Plant Type	Estimated Monthly Household Sewer Rate Increase [1]					
Dry-Season-Only Nutrient Removal						
Extended Aeration (Mechanical Aeration)	$17.71	$22.12	$6.25	$11.73	$24.88	$34.67
Extended Aeration (Diffused Aeration)	$2.34	$4.73	$8.45	$14.66	$15.55	$28.56
Extended Aeration (with Biological Nutrient Removal)	$0.48	$0.98	$2.96	$6.98	$2.97	$8.99
Conventional Activated Sludge	$6.23	$7.46	$6.01	$8.78	$11.15	$16.02
Sequencing Batch Reactor	$0.83	$18.88	$4.54	$10.35	$4.68	$27.51
Trickling Filter	$14.74	$17.01	$7.69	$11.32	$21.47	$28.34
Rotating Biological Contactor	$16.93	$19.46	$8.06	$11.80	$24.21	$31.42
Trickling Filter/Solids Contact	$7.20	$8.19	$5.66	$8.37	$10.84	$15.53
Membrane Bioreactor	$0.00	$0.66	$8.60	$8.77	$8.60	$9.39
Lagoons (Aerated)	$57.67	$62.05	$15.87	$20.91	$66.71	$76.37
Lagoons (Facultative)	$64.37	$68.74	$14.66	$19.74	$73.51	$83.15
High Purity Oxygen	$7.68	$9.70	N/A	N/A	$7.69[2]	$9.70[2]
Weighted Average	**$9.43**	**$11.41**	**$6.08**	**$9.64**	**$13.05**	**$23.28**

Water Resource Inventory Area



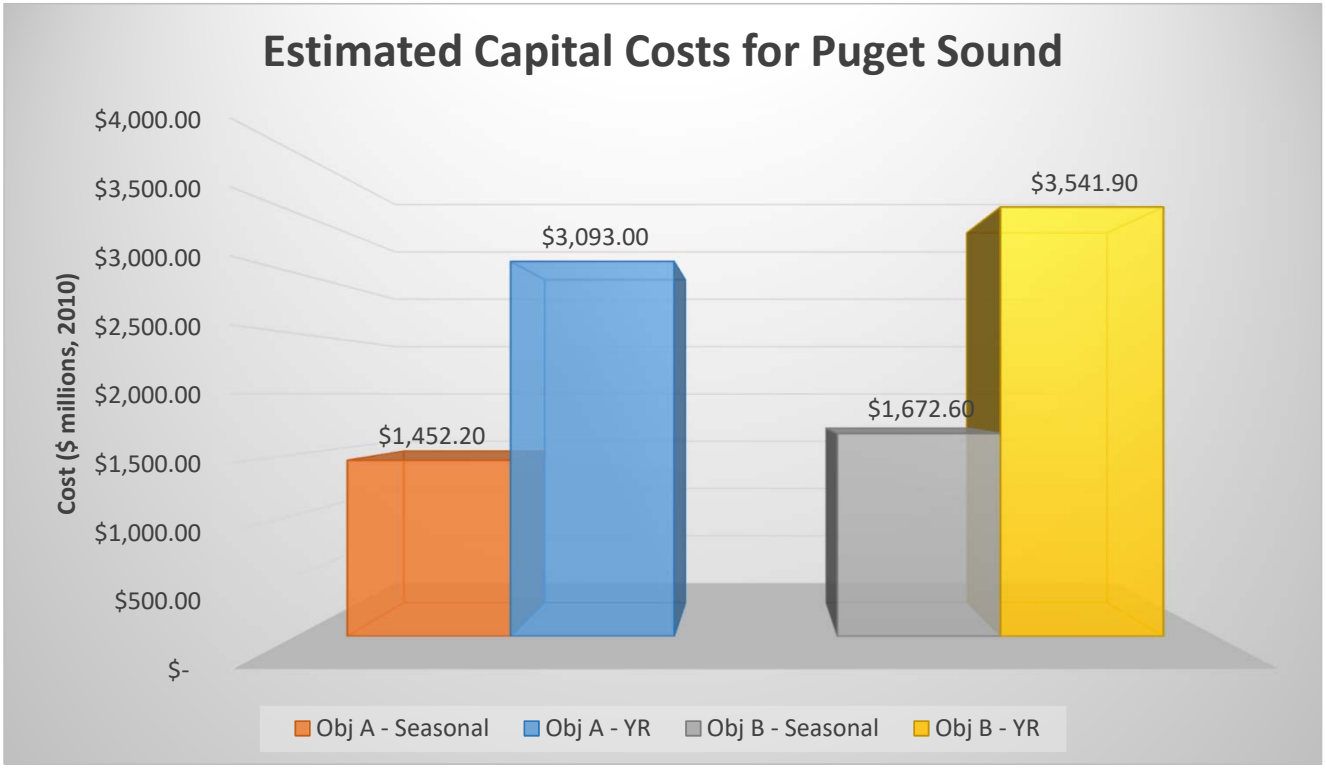
Year Round Capital and O&M Costs

	B	C	D	E	F	H	I	J	K	L	M	N	O	P	Q	R	S
1						YEAR ROUND REMOVAL (costs in million $)											
2	WRIA	Facility	Permit	Type	Max Month Flo	Obj. A Capita	Obj. A O&M	Obj. B Capita	Obj. B O&M	Obj. C Capita	Obj. C O&M	Obj. D Capita	Obj. D O&M	Obj. E Capita	Obj. E O&M	Obj. F Capita	Obj. F O&M
3																	
4	1	BELLINGHAM STP	WA0023744E	HPO	20.02	78.397	3.708	92.208	4.439					78.397	3.708	92.208	4.439
5	1	WHATCOM CNTY WATER DIST	ST0007367C	LAG-AIR	0.28	6.437	0.291	6.774	0.330	1.241	0.113	1.745	0.124	7.032	0.351	7.734	0.407
6	1	FERNDALE STP	WA0022454D	LAG-AIR	8	81.159	1.528	82.327	1.930	18.193	0.729	26.540	0.955	87.193	2.378	97.844	3.012
7	1	WA PARKS LARRABEE	WA0023787D	LAG-FAC	0.297	7.157	0.419	7.285	0.482	1.344	0.108	2.138	0.119	7.721	0.479	8.608	0.563
8	1	BLAINE STP	WA0022641D	RBC	2.4	17.291	0.625	19.262	0.770	1.650	0.436	6.128	0.540	18.522	1.059	24.842	1.348
9	1	BIRCH BAY STP	WA0029556D	CAS	3.3	18.188	0.577	20.647	0.759	2.065	0.595	7.754	0.751	20.124	1.099	27.949	1.475
10	1	EVERSON STP	WA0020435E	EA-MA	1.8	6.909	0.000	8.087	0.412	0.972	0.314	4.509	0.474	7.480	0.529	12.214	0.869
11	1	LYNDEN STP	WA0022578E	EA-MA	6.82	20.902	0.000	23.948	0.682	2.627	1.058	12.310	1.594	22.357	1.290	35.126	2.306
12					SUBTOTAL WRIA 1	236.4	7.1	260.5	9.8	28.1	3.4	61.1	4.6	248.8	10.9	306.5	14.4
13																	
14	2	ROSARIO WWTP	WA0029891D	LAG-AIR	0.187	4.744	0.238	5.015	0.267	0.898	0.090	1.257	0.097	5.193	0.278	5.697	0.320
15	2	FISHERMAN BAY STP	WA0030589E	LAG-AIR	0.034	1.307	0.102	1.408	0.109	0.229	0.035	0.315	0.035	1.443	0.105	1.568	0.116
16	2	FRIDAY HARBOR STP	WA0023582E	SBR	0.69	0.262	0.005	1.133	0.395	0.745	0.044	2.065	0.113	0.771	0.049	2.974	0.487
17	2	ROCHE HARBOR RESORT	WA0021822D	EA-DA	0.1296	0.260	0.000	0.457	0.000	0.214	0.023	0.698	0.038	0.354	0.043	1.046	0.081
18	2	EASTSOUND WATER DISTRICT	WA0030571D	EA-DA	0.186	0.339	0.000	0.591	0.000	0.279	0.031	0.915	0.052	0.461	0.056	1.361	0.107
19					SUBTOTAL WRIA 2	6.912	0.345	8.604	0.770	2.365	0.223	5.250	0.334	8.223	0.532	12.646	1.111

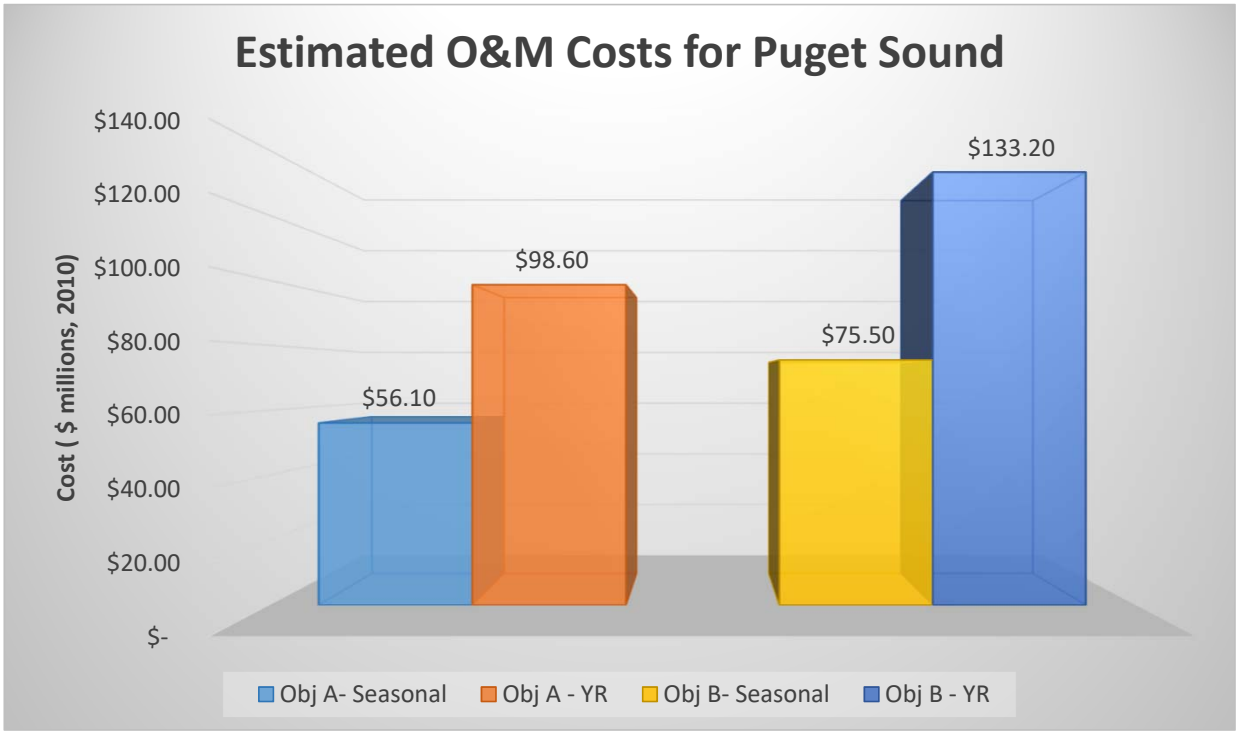
Critical Season Capital and O&M Costs

	B	C	D	E	F	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE
1						DRY SEASON REMOVAL (costs in million $)											
2	WRIA	Facility	Permit	Type	Max Month Flo	Obj. A Capita	Obj. A O&M	Obj. B Capita	Obj. B O&M	Obj. C Capita	Obj. C O&M	Obj. D Capita	Obj. D O&M	Obj. E Capita	Obj. E O&M	Obj. F Capita	Obj. F O&M
3																	
4	1	BELLINGHAM STP	WA0023744E	HPO	20.02	24.325	2.115	34.202	2.665					24.325	2.115	34.202	2.665
5	1	WHATCOM CNTY WATER DIST	ST0007367C	LAG-AIR	0.28	6.437	0.291	6.774	0.330	1.241	0.113	1.745	0.124	7.032	0.351	7.734	0.407
6	1	FERNDALE STP	WA0022454D	LAG-AIR	8	81.159	1.528	82.327	1.930	18.193	0.729	26.540	0.955	87.193	2.378	97.844	3.012
7	1	WA PARKS LARRABEE	WA0023787D	LAG-FAC	0.297	6.682	0.426	7.039	0.467	1.301	0.107	1.830	0.119	7.302	0.487	8.039	0.544
8	1	BLAINE STP	WA0022641D	RBC	2.4	9.353	0.404	10.465	0.496	1.856	0.360	4.230	0.424	10.309	0.790	14.006	0.982
9	1	BIRCH BAY STP	WA0029556D	CAS	3.3	5.847	0.284	7.239	0.395	2.384	0.489	5.446	0.580	7.560	0.740	12.394	0.983
10	1	EVERSON STP	WA0020435E	EA-MA	1.8	6.492	0.249	7.347	0.389	0.931	0.194	2.847	0.290	7.678	0.500	10.425	0.718
11	1	LYNDEN STP	WA0022578E	EA-MA	6.82	20.332	0.364	22.315	0.706	2.427	0.614	8.566	0.922	22.919	1.156	30.831	1.737
12					SUBTOTAL WRIA 1	160.626	5.660	177.708	7.378	28.333	2.607	51.204	3.415	174.318	8.516	215.474	11.050
13																	
14	2	ROSARIO WWTP	WA0029891D	LAG-AIR	0.187	4.744	0.238	5.015	0.267	0.898	0.090	1.257	0.097	5.193	0.278	5.697	0.320
15	2	FISHERMAN BAY STP	WA0030589E	LAG-AIR	0.034	1.307	0.102	1.408	0.109	0.229	0.035	0.315	0.035	1.443	0.105	1.568	0.116
16	2	FRIDAY HARBOR STP	WA0023582E	SBR	0.69	0.244	0.000	1.031	0.329	0.728	0.046	1.829	0.085	0.755	0.042	2.660	0.397
17	2	ROCHE HARBOR RESORT	WA0021822D	EA-DA	0.1296	0.119	0.000	0.286	0.000	0.216	0.019	0.389	0.029	0.373	0.046	0.712	0.077
18	2	EASTSOUND WATER DISTRICT	WA0030571D	EA-DA	0.186	0.164	0.000	0.378	0.000	0.281	0.026	0.522	0.039	0.486	0.058	0.938	0.098
19					SUBTOTAL WRIA 2	6.579	0.340	8.118	0.705	2.352	0.216	4.312	0.284	8.250	0.530	11.574	1.008

Puget Sound Area Example



Puget Sound Area Example



Reclaimed Water Needs

- **MBR Treatment Upgrades**
  - Need UV process to meet virus reduction and disinfection standards
  - Post chlorination systems for maintenance of residual in distribution system
- **Non-MBR**
  - Need UV process to meet virus reduction and disinfection standards
  - Post chlorination systems for maintenance of residual in distribution system
  - New filtration process with coagulation/flocculation

Reclaimed Water Costs – Non MBR

ESTIMATED CAPITAL COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Coagulation /Filtration	$4.10	$1.79	$1.02	$0.66
UV Disinfection	$5.29	$6.63	$4.56	$4.08
Post-Disinfection Chlorination	$1.67	$0.33	$0.16	$0.09
Total	**$11.06**	**$8.76**	**$5.71**	**$4.55**

ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR NON-MEMBRANE PLANTS

	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.74	$0.59	$0.38	$0.31
Annual O&M Cost	$0.99	$0.23	$0.15	$0.09
Total Annualized Cost	**$1.73**	**$0.82**	**$0.53**	**$0.38**

Reclaimed Water Costs –MBR

ESTIMATED CAPITAL COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS				
	Estimated Capital Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
UV Disinfection	$5.29	$6.63	$4.56	$4.08
Post-Disinfection Chlorination	$1.67	$0.33	$0.16	$0.09
Total	**$6.96**	**$6.96**	**$4.70**	**$4.02**

ESTIMATED ANNUALIZED CAPITAL AND O&M COSTS FOR YEAR-ROUND RECLAIMED WATER UPGRADES FOR MEMBRANE PLANTS				
	Estimated Cost per gpd of Maximum-Month Capacity			
	0.5 mgd Plant	5 mgd Plant	50 mgd Plant	220 mgd Plant
Annualized Capital Cost	$0.47	$0.47	$0.32	$0.27
Annual O&M Cost	$0.20	$0.14	$0.12	$0.11
Total Annualized Cost	**$0.67**	**$0.61**	**$0.44**	**$0.38**

Conclusions for Nitrogen Removal

- ✓Seasonal removal more cost effective (per lb. N removed)
  - ✓Year round – higher capital investment but removes 40% more/year
- ✓Reductions to 3mg/L produces additional sludge
- ✓8 mg/L uses 2-3x more electrical energy
  - ✓Energy recovery from methane gas production through digestion produces 5-10% less

Conclusions for TP Removal

- ✓Seasonal removal less cost effective (per lb. P removed)
- ✓Similar capital investments seasonal or year round
  - ✓Year round – removes 40% more/year
- ✓Chemical precipitation produces 20-35% more sludge
- ✓TP <1 mg/L increases energy consumption by 15-20% statewide

Questions?

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