TABLE 8-3.
BASE CASE/EXISTING SYSTEM FOR MBR PLANT

Biowin Input Flow	1.0 mgd
Temperature	10 ºC
Aeration Tank	
Tank Volume	0.36 MG
HRT	8.64 hours
MLSS Concentration	5,073 mg/L
DO Concentration	2 mg/L
Aeration Tank Airflow Rate	697 cfm
SRT	23.01 days
RAS Recycle Rate	1.5 Q
Pre-Anoxic Tank	
Tank Volume	0.12 MG
HRT	2.88 hours
Internal Recycle Rate	4Q
Post-Anoxic Tank	
Tank Volume	0.12 MG
HRT	2.88 hours
Membrane Bioreactor	
Tank Volume	0.06 MG
No. of Cassettes	4.0
Area of each Cassette	16,320 ft^2
HRT	1.44 hours
MLSS Concentration	8,433 mg/L
DO Concentration	6.0 mg/L
Air Supply Rate	941 cfm
Membrane Flux	15.31 gpd/ft^2
Sludge Production	
Daily Sludge Production	930 ppd
Effluent	
BOD	0.87 mg/L
TSS	0.0 mg/L
Phosphorus	4.31 mg/L
Ammonia N	0.58 mg/L
TIN	1.71 mg/L (assumed to be <8 mg/L, to be conservative)
pH	6.53

8.2.2 Objective B

Process Description

The upgrade evaluated for achieving Objective B (TIN <3 mg/L) is to add methanol to the post-anoxic tank to drive the denitrification process. Figure 8-2 shows the upgraded process flow schematic. Except for the methanol storage tanks, the required facilities are same as the existing system.

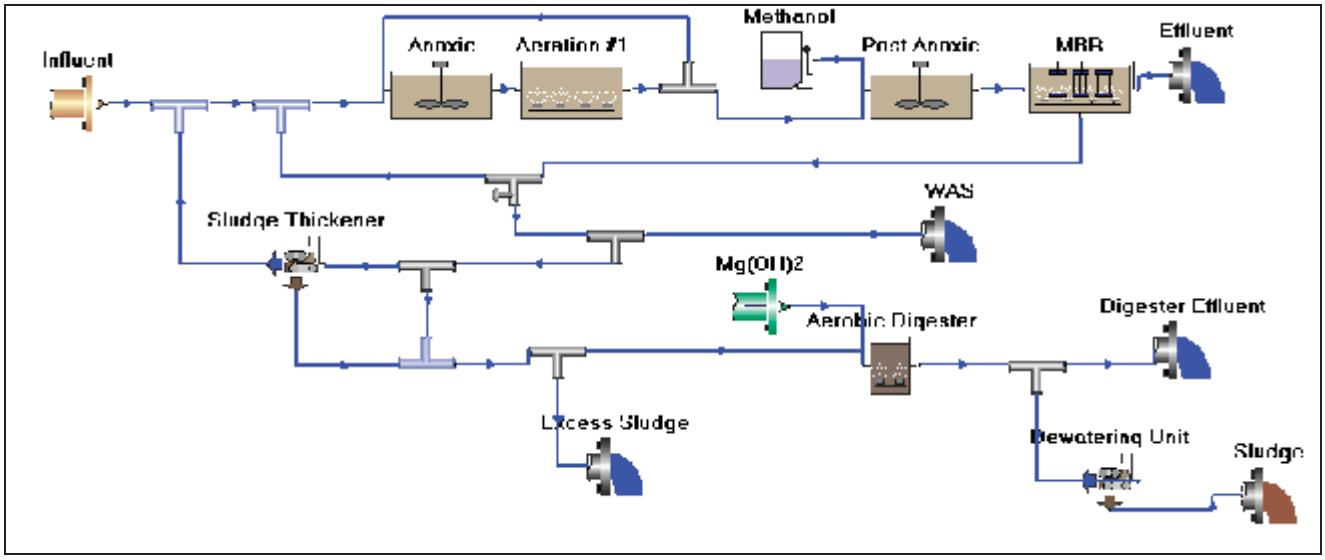

Figure 8-2. Process Schematic of MBR Plant Upgraded for Objective B Year-Round

The methanol dosage required to reduce TIN from 8 mg/L to 3 mg/L was calculated according to the dosage calculations described for extended aeration plants in Section 4.2.2. Methanol storage tanks were sized based on the methanol dosage required for the MMWWF. Table 8-4 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. The upgrades to achieve Objective B year-round will not change the estimated recycle loads.

Sludge Production

Based on modeling for Objective B upgrades to CAS and extended aeration systems, it is assumed that adding methanol will not change the sludge production compared to the existing plant.

Energy Consumption

Upgrading the MBR plant to achieve Objective B year-round would not change the plant energy requirements, as shown in Table 8-5.

TABLE 8-5.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective B Year-Round	1,213,800 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	0 kW-hours/year
Percent	0%
Increase per Volume of Plant Flow	0 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective B year-round would require 4,563 gallons of methanol per year for carbon supplementation to drive the denitrification process, or 20 gallons of methanol per million gallons of wastewater treated.

Footprint Requirements

Table 8-6 presents the additional site area that would be required for the three generic plant capacities. The additional footprint required for plant upgrades to achieve Objective B would be for a new methanol containment tank. Refer to detailed storage tank calculations in Appendix B.

TABLE 8-6.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING MBR PLANTS TO ACHIEVE OBJECTIVE B YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
1	600
10	1,000
100	3,300

8.2.3 Objective C

Process Description

The upgrade evaluated to achieve Objective C (TP <1 mg/L) is to provide addition of alum and magnesium hydroxide to the influent. Except for the addition of chemicals, the processes are the same as for the existing plant. Alum and magnesium hydroxide storage tanks were sized for the dosage required for MMWWF. Figure 8-3 depicts the upgraded process flow schematic. Table 8-4 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

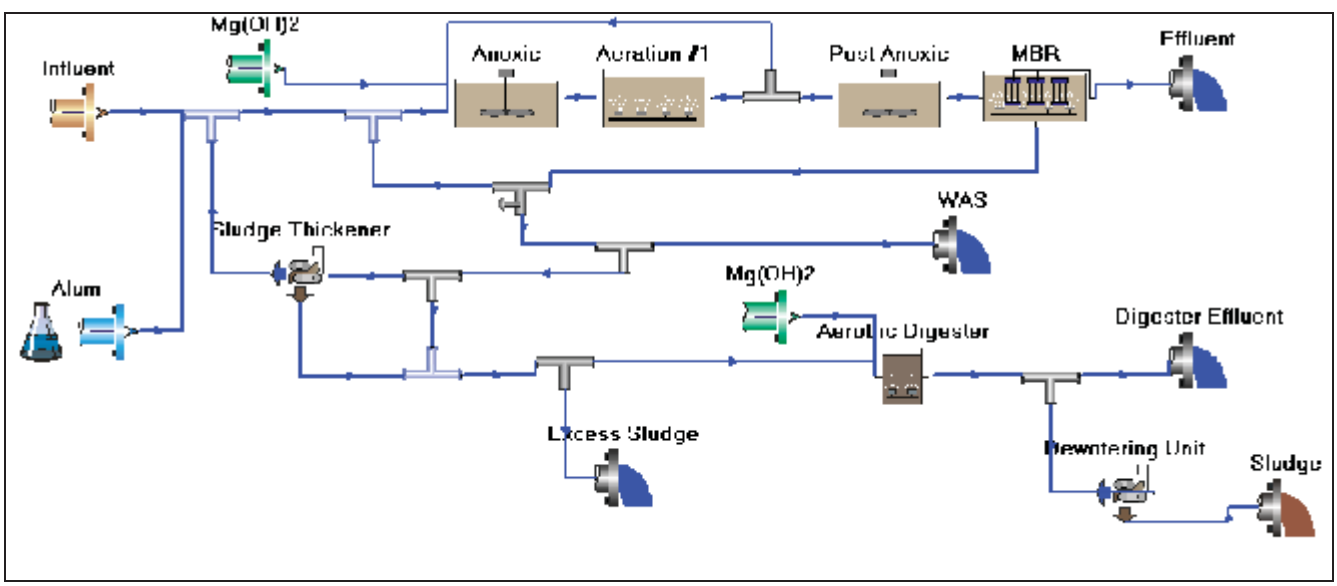

Figure 8-3. Process Schematic of MBR Plant Upgraded for Objective C Year-Round

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-7 summarizes the results.

TABLE 8-7.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE C YEAR-ROUND NUTRIENT REMOVAL

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Existing Plant	15.0%	14.2%	29.7%	39.1%
Objective C Year-Round	16.3%	15.4%	47.3%	52.0%

Sludge Production

The average sludge produced with the Objective C upgrades would be 1,160 ppd (212 dry tons per year), 23 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the MBR plant to achieve Objective C year-round would increase the plant energy requirements by 6,500 kW-hours/year, or about 0.5 percent, as shown in Table 8-8. There would be a net energy savings of 7,500 kW-hours/year associated with liquids treatment process and an additional energy requirement for the operation of solids processes of 14,000 kW-hours/year. The net increase amounts to about 29 kW-hours per million gallons of influent wastewater treated.

TABLE 8-8.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective C Year-Round	1,220,800 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	6,500 kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	29 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective C year-round would require approximately 36,500 gallons of alum per year to precipitate phosphorus and approximately 7,300 gallons of magnesium hydroxide for pH control. These chemical usage rates equate to 159 gallons of alum per million gallons of wastewater treated and 32 gallons of magnesium hydroxide per million gallons of wastewater treated.

Footprint Requirements

Table 8-9 presents the additional site area that would be required for the three generic plant capacities. The additional footprint required for plant upgrades to achieve Objective C would be for containment tanks for alum and for magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 8-9.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING MBR PLANTS TO ACHIEVE OBJECTIVE C YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
1	500
10	2,000
100	11,000

8.2.4 Objective D

Process Description

The upgrade evaluated to achieve Objective D (TP <0.1 mg/L) is to provide addition of alum and magnesium hydroxide to the influent. Except for the addition of chemicals, the processes are the same as for the existing plant. Alum storage tanks were sized for the dosage required for ADWF and magnesium hydroxide storage tanks were sized for the dosage required for MMWWF. The process flow schematic is the same as for Objective C (Figure 8-3). Table 8-4 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-10 summarizes the results.

TABLE 8-10.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE D YEAR-ROUND NUTRIENT REMOVAL

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Existing Plant	15.0%	14.2%	29.7%	39.1%
Objective D	16.6%	15.5%	36.6%	48.2%

Sludge Production

The average sludge produced with the Objective D upgrades would be 1,240 ppd (226 dry tons per year), 32 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the MBR plant to achieve Objective D year-round would reduce the plant energy requirements by 1,000 kW-hours/year, or <1 percent, as shown in Table 8-11. There would be a net energy savings of 10,000 kW-hours/year associated with liquids treatment process and an additional energy requirement for the operation of solids processes of 9,000 kW-hours/year. The net decrease amounts to about 4 kW-hours per million gallons of influent wastewater treated.

TABLE 8-11.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective D Year-Round	1,212,800 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(1000) kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	(4) kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective D year-round would require approximately 54,750 gallons of alum per year to precipitate phosphorus and approximately 14,600 gallons of magnesium hydroxide for pH control. These chemical usage rates equate to 238 gallons of alum per million gallons of wastewater treated and 63 gallons of magnesium hydroxide per million gallons of wastewater treated.

Footprint Requirements

Table 8-12 presents the additional site area that would be required for the three generic plant capacities. The additional footprint required for plant upgrades to achieve Objective D would be for containment tanks for alum and for magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 8-12.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING MBR PLANTS TO ACHIEVE OBJECTIVE D YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
1	500
10	2,000
100	11,000

8.2.5 Objective E

Because the existing system already achieves the Objective E TIN target (<8 mg/L), year-round treatment to achieve Objective E requires upgrade only to achieve the TP target (<1 mg/L) and is the same as the upgrade for Objective C year-round treatment. The process flow schematic is the same as for Objective C (Figure 8-3). Table 8-4 summarizes the process design data. Detailed Biowin model reports are in

Appendix A. The process flow schematic, process design data, recycled loads, sludge production, energy consumption, chemical usage and footprint requirements are all the same as for the year-round Objective C upgrade, as described in Section 8.2.3.

8.2.6 Objective F

Process Description

Objective F (TIN <3 mg/L and TP <0.1 mg/L) can be achieved by adding methanol to reduce TIN and adding alum and magnesium hydroxide to reduce TP. The process flow schematic for this alternative is combination of the schematics for Objectives B and D. Table 8-4 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-13 summarizes the results.

TABLE 8-13.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE F YEAR-ROUND NUTRIENT REMOVAL

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Existing Plant	15.0%	14.2%	29.7%	39.1%
Objective F Year-Round	16.6%	15.5%	36.6%	48.2%

Sludge Production

The average sludge produced with the Objective F upgrades would be 1,240 ppd (226 dry tons per year), 32 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the MBR plant to achieve Objective F year-round would reduce the plant energy requirements by 1,000 kW-hours/year, or <1 percent, as shown in Table 8-11. There would be a net energy savings of 10,000 kW-hours/year associated with liquids treatment process and an additional energy requirement for the operation of solids processes of 9,000 kW-hours/year. The net decrease amounts to about 4 kW-hours per million gallons of influent wastewater treated.

Chemical Usage

The upgraded plant to achieve Objective F year-round would require about 54,750 gallons of alum per year to precipitate phosphorus, 14,600 gallons of magnesium hydroxide for pH control, and 4,562 gallons of methanol per year for nitrogen reduction. These chemical usage rates equate to 238 gallons of alum per million gallons of wastewater treated, 63 gallons of magnesium hydroxide per million gallons of wastewater treated, and 20 gallons of methanol per million gallons of wastewater treated.

TABLE 8-14.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective F Year-Round	1,212,800 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(1,000) kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	(4) kW-hours/MG

Footprint Requirements

Table 8-15 presents the additional site area that would be required for the three generic plant capacities. The additional footprint required for plant upgrades to achieve Objective F would be for containment tanks for alum, magnesium hydroxide and methanol. Refer to detailed storage tank calculations in Appendix B.

TABLE 8-15.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING MBR PLANTS TO ACHIEVE OBJECTIVE F YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
1	700
10	2,300
100	17,000

8.3 SEASONAL NUTRIENT REMOVAL

Improvements required to provide seasonal nutrient removal to achieve each treatment objective are described below. Process design data for all objectives are included in Table 8-16, which is attached at the end of this chapter.

8.3.1 Objective A

No upgrades are required to achieve Objective A (TIN <8 mg/L), as the existing system already meets the effluent target for TIN. Operational changes should be performed if required to improve existing plant performance. Because no upgrade is required, the process flow schematic, process design data, recycled loads, sludge production, energy consumption, chemical usage and footprint requirements are all the same as for the existing MBR plant.

8.3.2 Objective B

Process Description

The Objective B (TIN <3 mg/L) treatment processes for seasonal nutrient removal would be the same as for year-round Objective B nutrient removal (add methanol to the post-anoxic tank to drive the

denitrification process) except that the capital facilities would be designed based on MMDWF instead of MMWWF and O&M costs will be based on ADWF instead of AWWF. Refer to Section 8.2.2 for detailed process description. Process design data are included in Table 8-16.

Recycled Loads

Seasonal treatment to achieve Objective B would not cause any change in recycled loads for an MBR plant.

Sludge Production

Seasonal treatment to achieve Objective B would not cause any change in sludge production for an MBR plant.

Energy Consumption

Seasonal treatment to achieve Objective B would not cause any change in energy consumption for an MBR plant.

Chemical Usage

The upgraded plant to achieve Objective B year-round would require 3,650 gallons of methanol per year for carbon supplementation to drive the denitrification process, or 16 gallons of methanol per million gallons of wastewater treated.

Footprint Requirements

The additional footprint requirements for achieving Objective B seasonally would be the same as for achieving this objective year-round.

8.3.3 Objective C

Process Description

The Objective C (TP <1 mg/L) treatment processes for seasonal nutrient removal would be the same as for year-round Objective C nutrient removal (adding alum and magnesium hydroxide to reduce TP) except that the capital facilities would be designed based on MMDWF instead of MMWWF and O&M costs will be based on ADWF instead of AWWF. Refer to Section 8.2.3 for detailed process description. Process design data are included in Table 8-16.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-17 summarizes the results.

TABLE 8-17.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE C SEASONAL NUTRIENT REMOVAL

	% of TN Recycled (ADWF)	% of TP Recycled (ADWF)
Existing Plant	14.2%	39.1%
Objective C, Seasonal	15.4%	52.0%

Sludge Production

The average sludge produced with the Objective C seasonal upgrades would be 1,060 ppd (193 dry tons per year), 13 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the MBR plant to achieve Objective C seasonally would increase the plant energy requirements by 2,000 kW-hours/year, or about <1%, as shown in Table 8-18. The annual energy consumption for the upgraded plant would increase by about 9 kW-hours per million gallons of influent wastewater treated.

TABLE 8-18.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective C Seasonal	1,215,800 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	2,000 kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	9 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective C seasonally would require chemical dosages during the dry season of 115 gpd of alum to precipitate phosphorus and 20 gpd of magnesium hydroxide for pH control. These rates equate to 20,990 gallons per year (91 gallons per million gallons of wastewater treated) of alum and 3,650 gallons per year (16 gallons per million gallons of wastewater treated) of magnesium hydroxide.

Footprint Requirements

The additional footprint requirements for achieving Objective C seasonally would be the same as for achieving this objective year-round.

Objective D

Process Description

The Objective D (TP <0.1 mg/L) treatment processes for seasonal nutrient removal would be the same as for year-round Objective D nutrient removal (adding alum and magnesium hydroxide to reduce TP) except that the capital facilities would be designed based on MMDWF instead of MMWWF and O&M costs will be based on ADWF instead of AWWF. Refer to Section 8.2.4 for detailed process description. Process design data are included in Table 8-16.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-19 summarizes the results.

TABLE 8-19.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE D SEASONAL NUTRIENT REMOVAL

	% of TN Recycled (ADWF)	% of TP Recycled (ADWF)
Existing Plant	14.2%	39.1%
Objective D, Seasonal	15.5%	48.2%

Sludge Production

The average sludge produced with the Objective D seasonal upgrades would be 1,087 ppd (198 dry tons per year), 16 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the MBR plant to achieve Objective D seasonally would slightly decrease the plant energy requirements as shown in Table 8-20. Although there would be a net decrease in energy requirements for the plant as a whole, the energy requirements of the solids treatment process would increase 2,500 kW-hour/year. The annual energy consumption for the upgraded plant would decrease by about 7 kW-hours per million gallons of influent wastewater treated.

TABLE 8-20.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective D Seasonal	1,212,300 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(1,500) kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	(7) kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective D seasonally would require chemical dosages during the dry season of 150 gpd of alum to precipitate phosphorus and 30 gpd of magnesium hydroxide for pH control. These rates equate to 27,380 gallons per year (119 gallons per million gallons of wastewater treated) of alum and 5,475 gallons per year (24 gallons per million gallons of wastewater treated) of magnesium hydroxide.

Footprint Requirements

The additional footprint requirements for achieving Objective D seasonally would be the same as for achieving this objective year-round.

8.3.5 Objective E

Because the existing system already achieves the Objective E TIN target (<8 mg/L), seasonal treatment to achieve Objective E requires upgrade only to achieve the TP target (<1 mg/L) and is the same as the

upgrade for Objective C seasonal treatment. The process flow schematic, process design data, recycled loads, sludge production, energy consumption, chemical usage and footprint requirements are all the same as for the year-round Objective C upgrade, as described in Section 8.3.3. Process design data are included in Table 8-16.

8.3.6 Objective F

Process Description

The Objective F (TIN <3 mg/L and TP <0.1 mg/L) treatment processes for seasonal nutrient removal would be the same as for year-round Objective F nutrient removal (adding methanol to reduce TIN and adding alum and magnesium hydroxide to reduce TP) except that the capital facilities would be designed based on MMDWF instead of MMWWF and O&M costs would be based on ADWF instead of AWWF. Process design data are included in Table 8-16.

Recycled Loads

Waste sludge will be thickened in a sludge thickener and digested in an aerobic digester. The percentage of TN and TP returning from these sludge treatment processes was calculated using Biowin model outputs. Table 8-21 summarizes the results.

TABLE 8-21.
NUTRIENT RECYCLING COMPARISON FOR MEMBRANE BIOLOGICAL REACTOR SYSTEMS, OBJECTIVE F SEASONAL NUTRIENT REMOVAL

	% of TN Recycled (ADWF)	% of TP Recycled (ADWF)
Existing Plant	14.2%	39.1%
Objective F, Seasonal	15.5%	48.2%

Sludge Production

The average sludge produced with the Objective F seasonal upgrades would be 1,087 ppd (198 dry tons per year), 16 percent higher than the existing plant average of 940 ppd (172 dry tons per year).

Energy Consumption

Upgrading the 1-mgd modeled MBR plant to achieve Objective F year-round would reduce the plant energy requirements by 1,500 kW-hours/year, or <1 percent, as shown in Table 8-22. There would be a net energy savings of 4,000 kW-hours/year associated with liquids treatment process and an additional energy requirement for the operation of solids processes of 2,500 kW-hours/year. The annual energy consumption for the upgraded plant would decrease by about 7 kW-hours per million gallons of influent wastewater treated.

Chemical Usage

The upgraded plant to achieve Objective F seasonally would require chemical dosages during the dry season of 150 gpd of alum to precipitate phosphorus, 30 gpd of magnesium hydroxide for pH control and 10 gpd of methanol for nitrogen removal. These rates equate to 27,380 gallons per year (119 gallons per million gallons of wastewater treated) of alum, 5,475 gallons per year (24 gallons per million gallons of wastewater treated) of magnesium hydroxide, and 1,825 gallons per year (8 gallons per million gallons of wastewater treated) of methanol.

TABLE 8-22.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

Yearly Energy Required	
Existing MBR Plant	1,213,800 kW-hours/year
Objective F Seasonal	1,212,300 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(1,500) kW-hours/year
Percent	<1%
Increase per Volume of Plant Flow	(7) kW-hours/MG

Footprint Requirements

The additional footprint requirements for achieving Objective F seasonally would be the same as for achieving this objective year-round.

TABLE 8-4.
MEMBRANE BIOREACTOR PLANT BIOWIN RESULTS FOR YEAR-ROUND NUTRIENT REMOVAL

	PROCESS DESIGN - MMWW							WET SEASON - AWW FLOWS							DRY SEASON - ADW FLOWS						
		Upgraded Plant							Upgraded Plant							Upgraded Plant					
Description	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F
Nutrient Removal Goals																					
TIN (mg/L)		< 8	< 3			< 8	< 3		< 8	< 3			< 8	< 3		< 8	< 3			< 8	< 3
TP (mg/L)				< 1	< 0.1	< 1	< 0.1				< 1	< 0.1	< 1	< 0.1				< 1	< 0.1	< 1	< 0.1
Plant Size, Average Temperature																					
Influent Flow, mgd	1.0		1.0	1.0	1.0		1.0	0.75		0.75	0.75	0.75		0.75	0.50		0.50	0.50	0.50		0.50
Temp, ^{o}C	10		10	10	10		10	10		10	10	10		10	15		15	15	15		15
Influent																					
BOD	165		165	165	165		165	221		221	221	221		221	331		331	331	331		331
TSS	188		188	188	188		188	251		251	251	251		251	376		376	376	376		376
VSS	132		132	132	132		132	176		176	176	176		176	263		263	263	263		263
TKN	24		24	24	24		24	32		32	32	32		32	48		48	48	48		48
TP	5.7		5.7	5.7	5.7		5.7	7.6		7.6	7.6	7.6		7.6	11.4		11.4	11.4	11.4		11.4
Alkalinity	2.01		2.01	2.01	2.01		2.01	2.68		2.68	2.68	2.68		2.68	4		4	4	4		4
pH	6.8		6.8	6.8	6.8		6.8	6.8		6.8	6.8	6.8		6.8	7		7	7	7		7
Aeration Tank																					
Tank Volume, MG	0.36		0.36	0.36	0.36		0.36	0.36		0.36	0.36	0.36		0.36	0.36		0.36	0.36	0.36		0.36
HRT, hrs	8.64		8.64	8.64	8.64		8.64	11.52		11.52	11.52	11.52		11.52	17.28		17.28	17.28	17.28		17.28
MLSS Conc., mg/L	5,073		5,073	5,000	5,138		5,138	5,158		5,158	5,086	5,166		5,166	5,123		5,123	5,195	5,097		5,097
DO Concentration, mg/L	2		2	2	2		2	2		2	2	2		2	2		2	2	2		2
Aeration Tank Airflow rate ft3/min	697		697	670	654		654	708		708	681	668		668	769		769	748	746		746
BioWin SRT, days	23.01		23.01	19	18		18	23.01		23.01	19.01	18.01		18.01	23.01		23.01	19.02	18.02		18.02
RAS Recyle Rate	1.5 Q		1.5 Q	1.5 Q	1.5 Q		1.5 Q	1.5 Q		1.5 Q	1.5 Q	1.5 Q		1.5 Q	1.5 Q		1.5 Q	1.5 Q	1.5 Q		1.5 Q
Pre - Anoxic Tank																					
Tank Volume, MG	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12
HRT, hrs	2.88		2.88	2.88	2.88		2.88	3.84		3.84	3.84	3.84		3.84	5.76		5.76	5.76	5.76		5.76
Internal Recycle Rate	4Q		4Q	4Q	4Q		4Q	4Q		4Q	4Q	4Q		4Q	4Q		4Q	4Q	4Q		4Q
Post - Anoxic Tank																					
Tank Volume, MG	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12
HRT, hrs	2.88		2.88	2.88	2.88		2.88	3.84		3.84	3.84	3.84		3.84	5.76		5.76	5.76	5.76		5.76
Methanol, gpd			20				20			15				15			10				10
Membrane Bioreactor																					
Tank Volume, MG	0.06		0.06	0.06	0.06		0.06	0.06		0.06	0.06	0.06		0.06	0.06		0.06	0.06	0.06		0.06
No. of Cassettes	4.0		4.0	4.0	4.0		4.0	4.0		4.0	4.0	4.0		4.0	4.0		4.0	4.0	4.0		4.0
Area of each Cassette, ft^2	16,320		16,320	16,320	16,320		16,320	16,320		16,320	16,320	16,320		16,320	16,320		16,320	16,320	16,320		16,320
HRT, hrs	1.44		1.44	1.44	1.44		1.44	1.92		1.92	1.92	1.92		1.92	2.88		2.88	2.88	2.88		2.88
MLSS Conc., mg/L	8,433		8,433	8,313	8,534		8,534	8,568		8,568	8,449	8,585		8,585	8,499		8,499	8,620	8,458		8,458
DO Concentration, mg/L	6		6	6	6		6	6		6	6	6		6	6		6	6	6		6
Air Supply Rate, ft^3/min	941		941	933	942		942	853		853	854	876		876	839		839	832	874		874
Membrane Flux, gpd/ft2	15.31		15.31	15.31	15.31		15.31	11.48		11.48	11.48	11.48		11.48	7.65		7.65	7.65	7.65		7.65

TABLE 8-4.
MEMBRANE BIOREACTOR PLANT BIOWIN RESULTS FOR YEAR-ROUND NUTRIENT REMOVAL

	PROCESS DESIGN - MMWW							WET SEASON - AWW FLOWS							DRY SEASON - ADW FLOWS						
		Upgraded Plant							Upgraded Plant							Upgraded Plant					
Description	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F
Chemical Addition																					
Alum Dosage, gpd				80	150		150				85	150		150				115	150		150
Magnesium Hydroxide Dosage, gpd				25	50		50				20	50		50				20	30		30
Magnesium Hydroxide Conc., meq/L				14,500	14,500		14,500				14,500	14,500		14,500				14,500	14,500		14,500
Aerobic Digester																					
Solids % from Clarifier	0.80%		0.80%	0.83%	0.85%		0.85%	0.85%		0.85%	0.84%	0.85%		0.85%	0.84%		0.84%	0.86%	0.84%		0.84%
Solids % from Thickener	6.00%		6.00%	5.90%	6.10%		6.10%	6.10%		6.10%	6.00%	6.10%		6.10%	6.00%		6.00%	6.10%	6.00%		6.00%
Combined Solids % to Aerobic Digester	3.90%		3.90%	3.90%	4.00%		4.00%	4.00%		4.00%	3.90%	4.00%		4.00%	3.90%		3.90%	4.02%	3.90%		3.90%
VSS loading to Digester,ppd	693		693	722	729		729	695		695	722	728		728	677		677	702	699		699
Total loading to Digester, ppd	1,282		1,282	1,529	1,659		1,659	1,303		1,303	1,555	1,668		1,668	1,293		1,293	1,587	1,645		1,645
Volume, MG	0.25		0.25	0.25	0.25		0.25	0.25		0.25	0.25	0.25		0.25	0.25		0.25	0.25	0.25		0.25
Hydraulic Residence Time, hrs	1,532		1,532	1,266	1,200		1,200	1,531		1,531	1,266	1,200		1,200	1,530		1,530	1,265	1,198		1,198
Digester Sludge Age, days	63.83		63.83	52.75	50.00		50.00	63.79		63.79	52.75	50.00		50.00	63.75		63.75	52.71	49.92		49.92
Total Sludge Age, days	86.84		86.84	71.75	68.00		68.00	86.80		86.80	71.76	68.01		68.01	86.76		86.76	71.73	67.94		67.94
Digester Airflow rate ft3/min	116		116	116	142		142	116		116	116	116		116	101		101	119	123		123
VSS destruction %	24.69%		24.69%	27.00%	27.60%		27.60%	24.70%		24.70%	27.00%	27.72%		27.72%	22.74%		22.74%	24.98%	25.58%		25.58%
SOUR, mg/L of O_2/hr/g TSS (< = 1.5)	0.194		0.194	0.222	0.219		0.219	0.191		0.191	0.217	0.218		0.218	0.171		0.171	0.188	0.195		0.195
Methanol addition,gpd	20.0		20.0	20.0	20.0		20.0	20.0		20.0	20.0	20.0		20.0	20.0		20.0	20.0	20.0		20.0
Sludge Production																					
Daily Sludge Production,ppd	930		930	1,119	1,238		1,238	941		941	1,140	1,246		1,246	938		938	1,180	1,233		1,233
Effluent																					
BOD, mg/L	0.87		0.87	0.9	1.06		1.06	0.81		0.81	0.86	1.07		1.07	0.71		0.71	0.72	0.84		0.84
TSS, mg/L	0.0		0.0	0.0	0.0		0.0	0.0		0.0	0.0	0.0		0.0	0.0		0.0	0.0	0.0		0.0
Phosphorus, mg/L	4.31		4.31	0.81	0.01		0.01	5.64		5.64	0.75	0.01		0.01	8.22		8.22	0.86	0.05		0.05
Ammonia N, mg/L	0.58		0.58	0.71	0.99		0.99	0.5		0.5	0.62	0.86		0.86	0.23		0.23	0.27	0.32		0.32
TIN, mg/L	1.71		1.71	1.85	2.15		2.15	1.95		1.95	2.1	2.38		2.38	2.05		2.05	2.11	2.27		2.27
pH	6.53		6.53	6.53	6.51		6.51	6.65		6.65	6.61	6.63		6.63	6.85		6.85	6.71	6.68		6.68
Recycle Loads																					
TN in thickener SSM	230.12		230.12	232.52	233.47		233.47	230.32		230.32	232.87	233.58		233.58	228.72		228.72	231.08	231.31		231.31
TN in aerobic digester SSM	220.44		220.44	222.34	223		223	220.55		220.55	222.53	223.06		223.06	219.17		219.17	221	221.21		221.21
TN in Influent	200.29		200.29	200.29	200.29		200.29	200.29		200.29	200.29	200.29		200.29	200.29		200.29	200.29	200.29		200.29
TN recycled from thickener	9.68		9.68	10.18	10.47		10.47	9.77		9.77	10.34	10.52		10.52	9.55		9.55	10.08	10.1		10.1
TN recycled from Digester	20.15		20.15	22.05	22.71		22.71	20.26		20.26	22.24	22.77		22.77	18.88		18.88	20.71	20.92		20.92
Total TN recycled	14.9%		14.9%	16.1%	16.6%		16.6%	15.0%		15.0%	16.3%	16.6%		16.6%	14.2%		14.2%	15.4%	15.5%		15.5%
Phosphorus Recycle from Thickener, ppd	3.66		3.66	8.78	9.01		9.01	4.35		4.35	9.19	9.02		9.02	5.42		5.42	9.67	9.77		9.77
Phosphorus Recycle from Digester, ppd	7.39		7.39	12.7	8.38		8.38	9.78		9.78	13.3	8.39		8.39	13.19		13.19	15.08	13.16		13.16
Total Phosphorus Recycled, ppd	11.05		11.05	21.48	17.39		17.39	14.13		14.13	22.49	17.41		17.41	18.61		18.61	24.75	22.93		22.93
% TP Recycled	23.2%		23.2%	45.2%	36.6%		36.6%	29.7%		29.7%	47.3%	36.6%		36.6%	39.1%		39.1%	52.0%	48.2%		48.2%

TABLE 8-16.
MEMBRANE BIOREACTOR PLANT BIOWIN RESULTS FOR SEASONAL NUTRIENT REMOVAL

	PROCESS DESIGN - MMDW							DRY SEASON - ADW FLOWS						
		Upgraded Plant							Upgraded Plant					
Description	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F
Nutrient Removal Goals														
TIN (mg/L)		< 8	< 3			< 8	< 3		< 8	< 3			< 8	< 3
TP (mg/L)				< 1	< 0.1	< 1	< 0.1				< 1	< 0.1	< 1	< 0.1
Plant Size, Average Temperature														
Influent Flow, mgd	0.69		0.69	0.69	0.69		0.69	0.50		0.50	0.50	0.50		0.50
Temp, °C	10		10	10	10		10	15		15	15	15		15
Influent														
BOD	241		241	241	241		241	331		331	331	331		331
TSS	273		273	273	273		273	376		376	376	376		376
VSS	191		191	191	191		191	263		263	263	263		263
TKN	35		35	35	35		35	48		48	48	48		48
TP	8.3		8.3	8.3	8.3		8.3	11.4		11.4	11.4	11.4		11.4
Alkalinity	2.92		2.92	2.92	2.92		2.92	4		4	4	4		4
pH	7		7	7	7		7	7		7	7	7		7
Aeration Tank														
Tank Volume, MG	0.36		0.36	0.36	0.36		0.36	0.36		0.36	0.36	0.36		0.36
HRT, hrs	12.5		12.5	12.5	12.5		12.5	17.28		17.28	17.28	17.28		17.28
MLSS Conc., mg/L	5,064		5,064	5,161	5,064		5,064	5,123		5,123	5,195	5,097		5,097
DO Concentration, mg/L	2		2	2	2		2	2		2	2	2		2
Aeration Tank Airflow rate ft3/min	769		769	745	736		736	769		769	748	746		746
BioWin SRT, days	23.02		23.02	19	18		18	23.01		23.01	19.02	18.02		18.02
RAS Recyle Rate	1.5 Q		1.5 Q	1.5 Q	1.5 Q		1.5 Q	1.5 Q		1.5 Q	1.5 Q	1.5 Q		1.5 Q
Pre - Anoxic Tank														
Tank Volume, MG	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12
HRT, hrs	4		4	4	4		4	5.76		5.76	5.76	5.76		5.76
Internal Recycle Rate	4Q		4Q	4Q	4Q		4Q	4Q		4Q	4Q	4Q		4Q
Post - Anoxic Tank														
Tank Volume, MG	0.12		0.12	0.12	0.12		0.12	0.12		0.12	0.12	0.12		0.12
HRT, hrs	4		4	4	4		4	5.76		5.76	5.76	5.76		5.76
Methanol, gal/d			15				15			10				10
Membrane Bioreactor														
Tank Volume, MG	0.06		0.06	0.06	0.06		0.06	0.06		0.06	0.06	0.06		0.06
No. of Cassettes	4.0		4.0	4.0	4.0		4.0	4.0		4.0	4.0	4.0		4.0
Area of each Cassette, ft^2	16,320		16,320	16,320	16,320		16,320	16,320		16,320	16,320	16,320		16,320
HRT, hrs	2		2	2	2		2	2.88		2.88	2.88	2.88		2.88
MLSS Conc., mg/L	8400		8400	8572	8400		8400	8,499		8,499	8,620	8,458		8,458
DO Concentration, mg/L	6		6	6	6		6	6		6	6	6		6
Air Supply Rate, ft^3/min	943		943	940	970		970	839		839	832	874		874
Membrane Flux, gpd/ft^2	15.31		15.31	15.31	15.31		15.31	7.65		7.65	7.65	7.65		7.65
Chemical Addition														
Alum Dosage, gpd				115	150		150				115	150		150
Magnesium Hydroxide Dosage, gpd				20	30		30				20	30		30

TABLE 8-16.
MEMBRANE BIOREACTOR PLANT BIOWIN RESULTS FOR SEASONAL NUTRIENT REMOVAL

	PROCESS DESIGN - MMDW							DRY SEASON - ADW FLOWS						
		Upgraded Plant							Upgraded Plant					
Description	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F	Existing MBR Plant	Obj. A (same as existing)	Obj. B	Ojb. C	Obj. D	Obj. E (same as Obj. C)	Obj. F
Magnesium Hydroxide Conc., meq/L											14,500	14,500		14,500
Aerobic Digester														
Solids % from Clarifier	0.84%		0.84%	0.85%	0.85%		0.85%	0.84%		0.84%	0.86%	0.84%		0.84%
Solids % from Thickener	6.00%		6.00%	6.10%	6.00%		6.00%	6.00%		6.00%	6.10%	6.00%		6.00%
Combined Solids % to Aerobic Digester	3.90%		3.90%	4.00%	4.00%		4.00%	3.90%		3.90%	4.02%	3.90%		3.90%
VSS loading to Digester, ppd	676		676	701	706		706	677		677	702	699		699
Total loading to Digester, ppd	1,279		1,279	1,578	1,653		1,653	1,293		1,293	1,587	1,645		1,645
Volume, MG	0.25		0.25	0.25	0.25		0.25	0.25		0.25	0.25	0.25		0.25
Hydraulic Residence Time, hrs	1,531		1,531	1,266	1,200		1,200	1,530		1,530	1,265	1,198		1,198
Digester Sludge Age, days	63.79		63.79	52.75	50.00		50.00	63.75		63.75	52.71	49.92		49.92
Total Sludge Age, days	86.81		86.81	71.75	68.00		68.00	86.76		86.76	71.73	67.94		67.94
Digester Airflow rate ft3/min	102		102	120	125		125	101		101	119	123		123
VSS destruction %	22.73%		22.73%	22.73%	25.67%		25.67%	22.74%		22.74%	24.98%	25.58%		25.58%
SOUR, mg/L of O_2/hr/g TSS (< = 1.5)	0.172		0.172	0.190	0.197		0.197	0.171		0.171	0.188	0.195		0.195
Methanol addition, gpd	20.0		20.0	20.0	20.0		20.0	20.0		20.0	20.0	20.0		20.0
Sludge Production														
Daily Sludge production, ppd	936		936	1,177	1,238		1,238	938		938	1,180	1,233		1,233
Effluent														
BOD, mg/L	0.76		0.76	0.76	0.88		0.88	0.71		0.71	0.72	0.84		0.84
TSS, mg/L	0.0		0.0	0.0	0.0		0.0	0.0		0.0	0.0	0.0		0.0
Phosphorous, mg/L	6.18		6.18	0.82	0.06		0.06	8.22		8.22	0.86	0.05		0.05
Ammonia N, mg/L	0.26		0.26	0.26	0.36		0.36	0.23		0.23	0.27	0.32		0.32
TIN, mg/L	1.66		1.66	1.74	1.85		1.85	2.05		2.05	2.11	2.27		2.27
pH	6.72		6.72	6.72	6.54		6.54	6.85		6.85	6.71	6.68		6.68
Recycle Loads														
Total TN in thickener SSM	**229.79**		**229.79**	**231.54**	**232.78**		**232.78**	**228.72**		**228.72**	**231.08**	**231.31**		**231.31**
Total TN in aerobic digester SSM	220.35		220.35	221.72	222.69		222.69	219.17		219.17	221	221.21		221.21
TN in Influent	200.29		200.29	200.29	200.29		200.29	200.29		200.29	200.29	200.29		200.29
TN recycled from thickener	9.44		9.44	9.82	10.09		10.09	9.55		9.55	10.08	10.1		10.1
TN recycled from Digester	20.06		20.06	21.43	22.4		22.4	18.88		18.88	20.71	20.92		20.92
% TN Recycled	14.7%		14.7%	15.6%	16.2%		16.2%	14.2%		14.2%	15.4%	15.5%		15.5%
Phosphorus Recycle from Thickener, ppd	4.35		4.35	9.19	9.8		9.8	5.42		5.42	9.67	9.77		9.77
Phosphorus Recycle from Digester, ppd	9.38		9.38	13.06	13.24		13.24	13.19		13.19	15.08	13.16		13.16
Total Phosphorus Recycled, ppd	13.73		13.73	22.25	23.04		23.04	18.61		18.61	24.75	22.93		22.93
% TP Recycled	28.9%		28.9%	46.8%	48.4%		48.4%	39.1%		39.1%	52.0%	48.2%		48.2%

CHAPTER 9.
TECHNOLOGICAL EVALUATION FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE PLANTS

9.1 BASE CASE/EXISTING SYSTEM

As there are few high-purity oxygen activated sludge (HPO) treatment plants in Washington, a base case model was developed based on process design data for the West Point Treatment Plant, which has a MMWWF of 215 mgd. The plant has six treatment trains, with a total mixed liquor tankage volume of 14.1 MG. Each train has four mixed liquor tank; under normal operating conditions the plant is operated contact sludge reoxygenation process where three tanks are operated in series as an oxygenated plug flow contact reactor with the fourth tank used for re-oxygenation of return activated sludge. The design recycle ratio for the plant is 0.3Q.

For a 1.0-mgd plant, the total mixed liquor tank volume would be 0.066 MG. Figure 9-1 depicts the process flow schematic for a 1.0-mgd HPO plant with anaerobic digestion for solids treatment. The system uses a series of well-mixed reactors employing concurrent gas-liquid contact in covered oxygenated mixed liquor tanks. Oxygenation Tanks 1, 2 and 3 operate in series (75 percent contact) as plug flow reactors and oxygenation Tank 4 is operated in line with the secondary clarifier. RAS from the clarifier is conveyed to sludge re-oxygenation tank(i.e. Tank 4) to partially stabilize the biological solids prior to combining the RAS with the primary clarifier effluent in oxygenation Tank 1. . The DO concentration in the mixed liquor oxygenation tanks is maintained at 7.0 mg/L. Table 9-1 summarizes the process design data for the 1.0-mgd base case HPO activated sludge treatment plant.

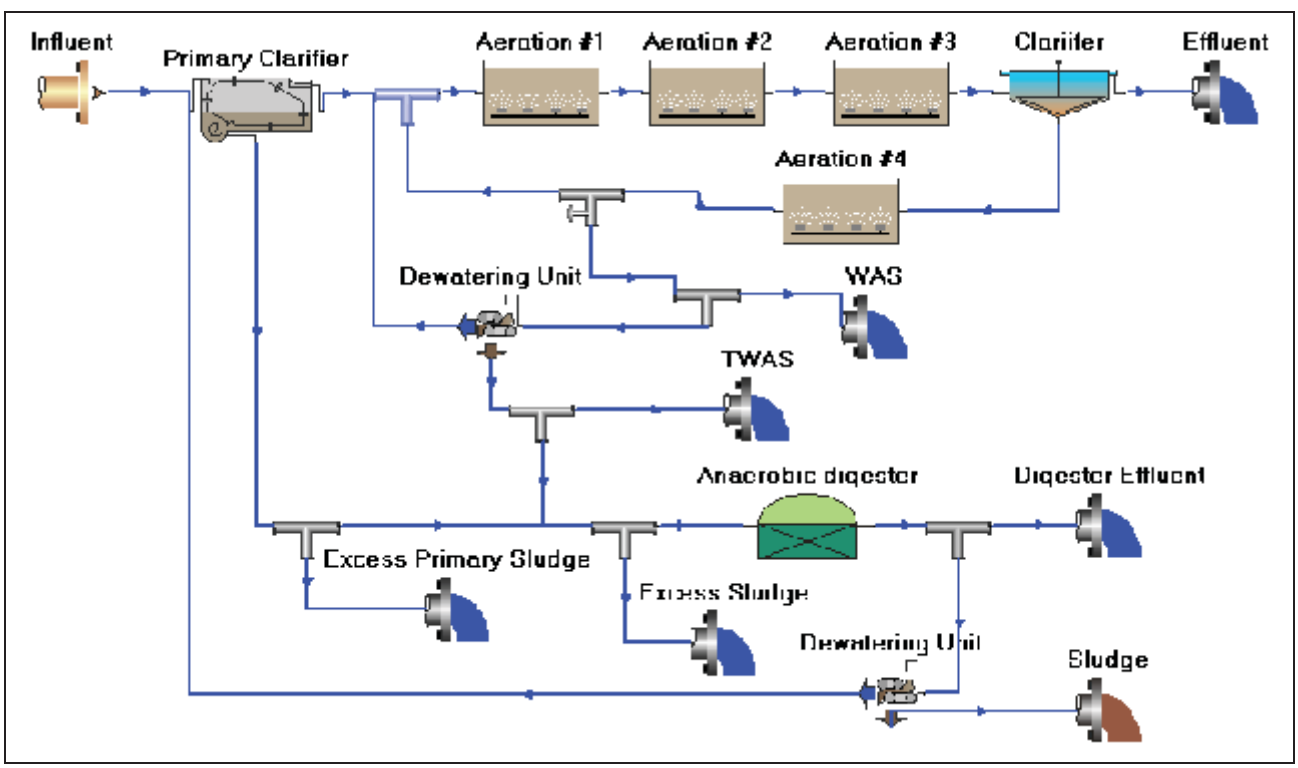

Figure 9-1. Process Flow Schematic for an Existing HPO Plant

TABLE 9-1. BASE CASE/EXISTING SYSTEM FOR HPO ACTIVATED SLUDGE PLANT	
Biowin Input Flow	1.0 mgd
Temperature	10ºC
Aeration Tank	
No of Stages	4
Mode of Operation	75%/25%
Total Oxygen Supply	52 cfm
SRT	1.5 days
RAS Recycle Rate	0.3Q
Stage #1	
Operation	ML Oxygenation
Volume	0.017 MG
HRT	0.40 hours
MLSS Concentration	1,142 mg/L
Oxygen Supply	16.1 cfm
Stage #2	
Operation	ML Oxygenation
Volume	0.017 MG
HRT	0.40 hours
MLSS Concentration	1,151 mg/L
Oxygen Supply	8.26 cfm
Stage #3	
Operation	ML Oxygenation
Volume	0.017 MG
HRT	0.40 hours
MLSS Concentration	1,153 mg/L
Oxygen Supply	6.5 cfm
Stage #4	
Operation	ML Oxygenation
Volume	0.017 MG
HRT	0.40 hours
MLSS Concentration	4,899 mg/L
Oxygen Supply	21 cfm
DO Concentration	7 mg/L
Sludge Production	
Total Sludge Produced	932 ppd
Effluent	
BOD	14.83 mg/L
TSS	18.8 mg/L
Phosphorous	4.26 mg/L
Ammonia N	15.95 mg/L
TIN	19.61 mg/L
pH	6.45

9.2 YEAR-ROUND NUTRIENT REMOVAL

Improvements required to provide year-round nutrient removal to achieve Objectives A and B are described below. The other treatment objectives were not evaluated for the HPO plant model. Process design data for year-round treatment to achieve these two objectives are included in Table 9-2, which is attached at the end of this chapter.

9.2.1 Objective A

Process Description

The upgrade evaluated for achieving Objective A (TIN <8 mg/L) included converting the existing HPO system to an oxygen activated MLE process coupled with a MBR (MLE-MBR). The upgraded system would consist of a 0.12-MG anoxic tank for denitrification, followed by three 0.04-MG aeration tanks in series for nitrification. The existing clarifier would be replaced with a 0.02-MG MBR tank. The existing mix liquor tank volume of 0.066 MG would be increased to 0.26 MG; this represents approximately a 300% increase in tankage that would need to be constructed.

The SRT of the upgraded system would be 16.3 days. Magnesium hydroxide would be added to the influent to maintain pH in the effluent at or above 6.5. Figure 9-2 shows the upgraded process flow schematic. Table 9-2 summarizes process design data. Detailed Biowin model reports are in Appendix A.

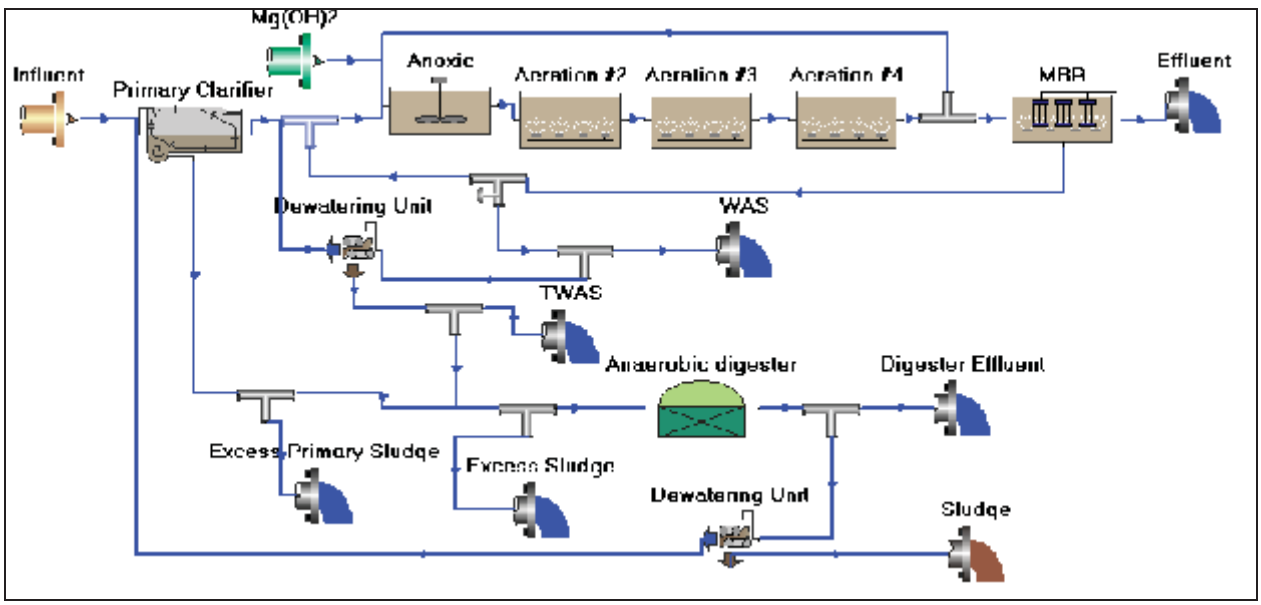

Figure 9-2. Process Schematic of HPO Plant Upgraded for Objective A Year-Round

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 9-3 summarizes the results.

TABLE 9-3. NUTRIENT RECYCLING COMPARISON FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE SYSTEMS, OBJECTIVE A YEAR-ROUND NUTRIENT REMOVAL				
	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Existing Plant	27.4%	28.1%	45.6%	50.2%
Objective A Year-Round	16.9%	16.1%	30.4%	31.1%

Sludge Production

The quantity sludge produced with the Objective A upgrades would be 938 ppd (171 dry tons per year), 1.6 percent higher than the existing plant average of 923 ppd (168 dry tons per year).

Energy Consumption

Upgrading a 20 mgd (MM) HPO plant to achieve Objective A year-round would increase the plant energy requirements by 2,726,991 kW-hours/year, or about 63 percent, as shown in Table 9-4. None of this increase in energy demand would be attributable to the operation of solids processes associated with achieving Objective A. The annual energy consumption for the upgraded plant would increase by about 598 kW-hours per million gallons of influent wastewater treated.

TABLE 9-4. ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND	
Yearly Energy Required	
Existing HPO Plant	5,080,000 kW-hours/year
Objective A Year-Round	7,807,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	2,727,000 kW-hours/year
Percent	54%
Increase per Volume of Plant Flow	598 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective A year-round would require approximately 18,250 gallons of magnesium hydroxide per year for pH control. This equates to 79 gallons of magnesium hydroxide per million gallons of wastewater treated.

Footprint Requirements

Table 9-5 presents the additional site area that would be required for the two generic plant capacities. The additional footprint required for plant upgrades to achieve Objective A would be for containment tanks for magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 9-5.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING HPO PLANTS TO ACHIEVE OBJECTIVE A YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
20	50,000
220	473,000

9.2.2 Objective B

Process Description

The upgrade evaluated for achieving Objective B (TIN <3 mg/L) is to convert the HPO system to a oxygen activated sludge system using a 4BDP-MBR process. The upgraded system would consist of a 0.12-MG anoxic tank for denitrification, followed by three 0.04-MG aeration tanks in series for nitrification and a 0.1-MG post-anoxic tank for post-denitrification. The existing clarifier would be replaced with a 0.02-MG MBR. The existing mixed liquor oxygenation tank volume of 0.066 MG would be increased to 0.36 MG; this represents approximately a 450% increase in the mixed-liquor tankage relative to the existing plant.

The SRT of the upgraded system would be 22.15 days. Magnesium hydroxide would be added to the influent to maintain pH in the effluent at or above 6.5. Methanol would be added to the post-anoxic tank to drive the denitrification process. Figure 9-3 shows the upgraded process flow schematic. Table 9-2 summarizes process design data. Detailed Biowin model reports are in Appendix A.

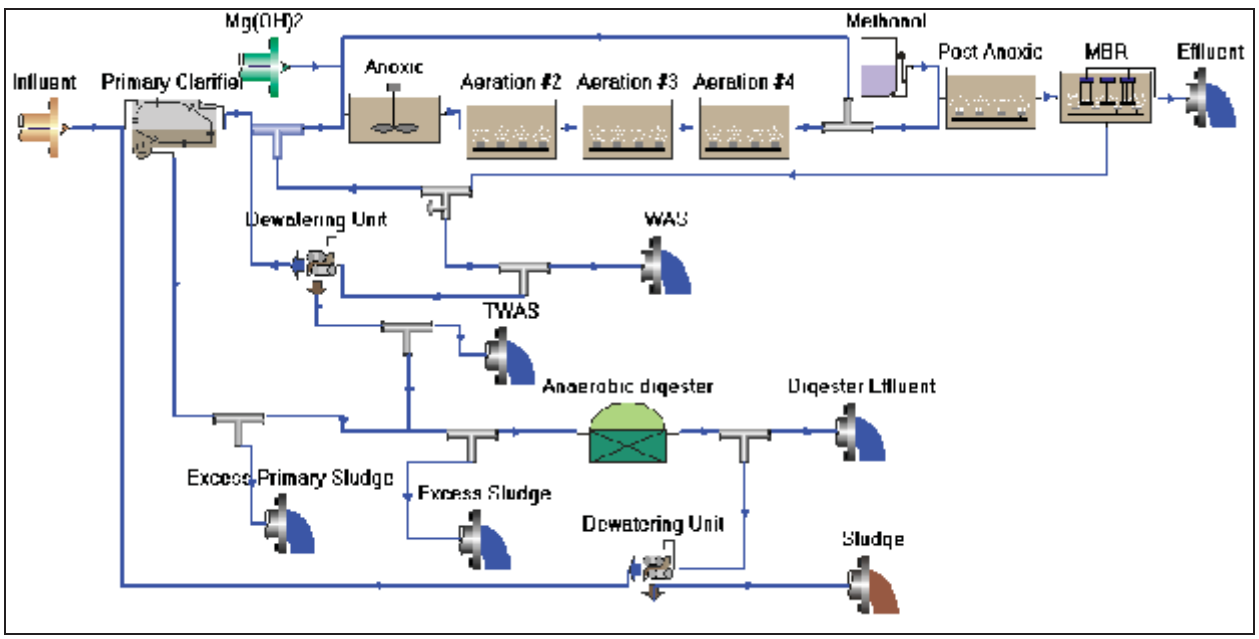

Figure 9-3. Process Schematic of HPO Plant Upgraded for Objective B Year-Round

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 9-6 summarizes the results.

TABLE 9-6.
NUTRIENT RECYCLING COMPARISON FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE SYSTEMS, OBJECTIVE B YEAR-ROUND NUTRIENT REMOVAL

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Existing Plant	27.4%	28.1%	45.6%	50.2%
Objective B Year-Round	16.3%	15.6%	51.6%	47.2%

Sludge Production

The average sludge produced with the Objective B upgrades would be 971 ppd (177 dry tons per year), 5.2 percent higher than the existing plant average of 923 ppd (168 dry tons per year).

Energy Consumption

Upgrading the HPO plant to achieve Objective B year-round would increase the 20 mgd-plant energy requirements by 6,637,000 kW-hours/year, or about 133 percent, as shown in Table 9-7. None of this increase in energy would be attributable to the operation of solids processes associated with achieving Objective B. The annual energy consumption for the upgraded plant would increase by about 1,455 kW-hours per million gallons of influent wastewater treated.

TABLE 9-7.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

Yearly Energy Required	
Existing HPO Plant	5,080,000 kW-hours/year
Objective B Year-Round	11,717,000.kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	6,637,000 kW-hours/year
Percent	133%
Increase per Volume of Plant Flow	1,455 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective B year-round would require approximately 5,475 gallons of methanol per year for nitrogen removal and 14,600 gallons of magnesium hydroxide per year for pH control. This equates to 24 gallons of methanol and 63 gallons of magnesium hydroxide per million gallons of wastewater treated.

Footprint Requirements

Table 9-8 presents the additional site area that would be required for the two generic plant capacities. The additional footprint required for plant upgrades to achieve Objective B would be for containment tanks for methanol and magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 9-8.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING HPO PLANTS TO ACHIEVE OBJECTIVE B YEAR-ROUND

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
20	114,100
220	1,161,700

9.3 SEASONAL NUTRIENT REMOVAL

Improvements required to provide seasonal nutrient removal to achieve Objectives A and B are described below. Process design data for the two objectives are included in Table 9-9, which is attached at the end of this chapter.

9.3.1 Objective A

Process Description

The upgrade evaluated for achieving seasonal treatment for Objective A (TIN <8 mg/L) seasonally is to convert the HPO system to an oxygen activated sludge system using the MLE process using the existing clarifiers. The mix liquor tankage would be the same as that described for the year around system to achieve objective A. The SRT of the upgraded system would be 13.5 days. Magnesium hydroxide would be added to the influent to maintain the pH in the effluent at or above 6.5. Figure 9-4 shows the upgraded process flow schematic. Table 9-9 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 9-10 summarizes the results.

Sludge Production

The annual average sludge produced with the Objective A seasonal upgrades would be 912 ppd (166 dry tons per year), 1 percent less than the existing plant average of 922 ppd (168 dry tons per year).

Energy Consumption

Upgrading the HPO plant to achieve Objective A seasonally would increase the plant energy requirements by 210,000 kW-hours/year, or about 4 percent, as shown in Table 9-11. The annual energy consumption for the upgraded plant would increase only 46 kW-hours per million gallons of influent wastewater treated. By comparison the energy required to achieve Objective A on a seasonal basis would be about 8 percent of the incremental energy requirements to achieve Objective A year around.

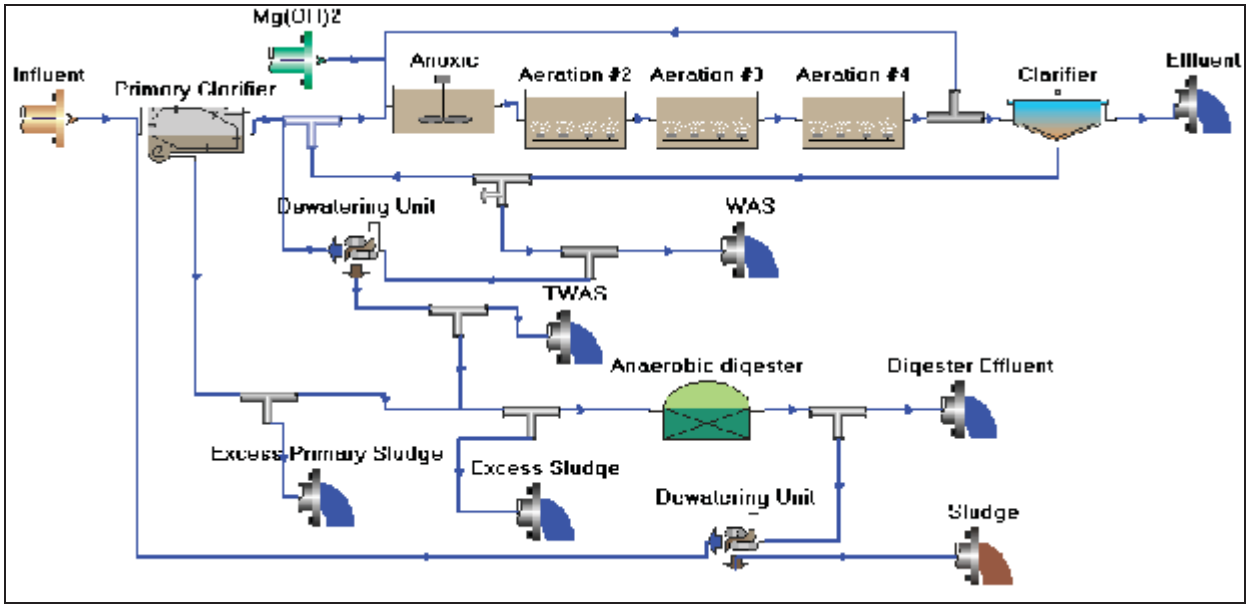

Figure 9-4. Process Schematic of HPO Plant Upgraded for Objective A Seasonal

TABLE 9-10.
NUTRIENT RECYCLING COMPARISON FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE SYSTEMS, OBJECTIVE A SEASONAL NUTRIENT REMOVAL

	% of TN Recycled	% of TP Recycled
	ADWF	ADWF
Existing Plant	28.1%	50.2%
Objective A, Seasonal	16.6%	38.4%

TABLE 9-11.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

Yearly Energy Required
- Existing HPO Plant..... 5,080,000 kW-hours/year
- Objective A Seasonal..... 5,290,000 kW-hours/year

Energy Increase for Upgrade
- Annual Quantity..... 210,000 kW-hours/year
- Percent 4%
- Increase per Volume of Plant Flow ..... 46 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective A seasonally would require chemical dosages during the dry season of 70 gpd of magnesium hydroxide for pH control. This equates to 12,775 gallons of magnesium hydroxide per year (56 gallons per million gallons of wastewater treated).

Footprint Requirements

Table 9-12 presents the additional site area that would be required for the two generic plant capacities. The additional footprint required for plant upgrades to achieve Objective A would be for containment tanks for magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 9-12.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING HPO PLANTS TO ACHIEVE OBJECTIVE A SEASONALLY

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
20	88,900
220	971,400

9.3.2 Objective B

Process Description

The upgrade evaluated for achieving seasonal treatment for Objective B (TIN <3 mg/L) seasonally is to convert the HPO system to an oxygen activated sludge system using 4BDP using the existing clarifiers. An additional 0.224 MG of mixed liquor tankage would need to be constructed per mgd of maximum month plant capacity. The SRT of the upgraded system would be 13.5 days. Magnesium hydroxide would be added to the influent to maintain the pH in the effluent at or above 6.5. Methanol would be added as a carbon source to the post-anoxic tank to drive the denitrification process. Figure 9-5 shows the upgraded process flow schematic. Table 9-9 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

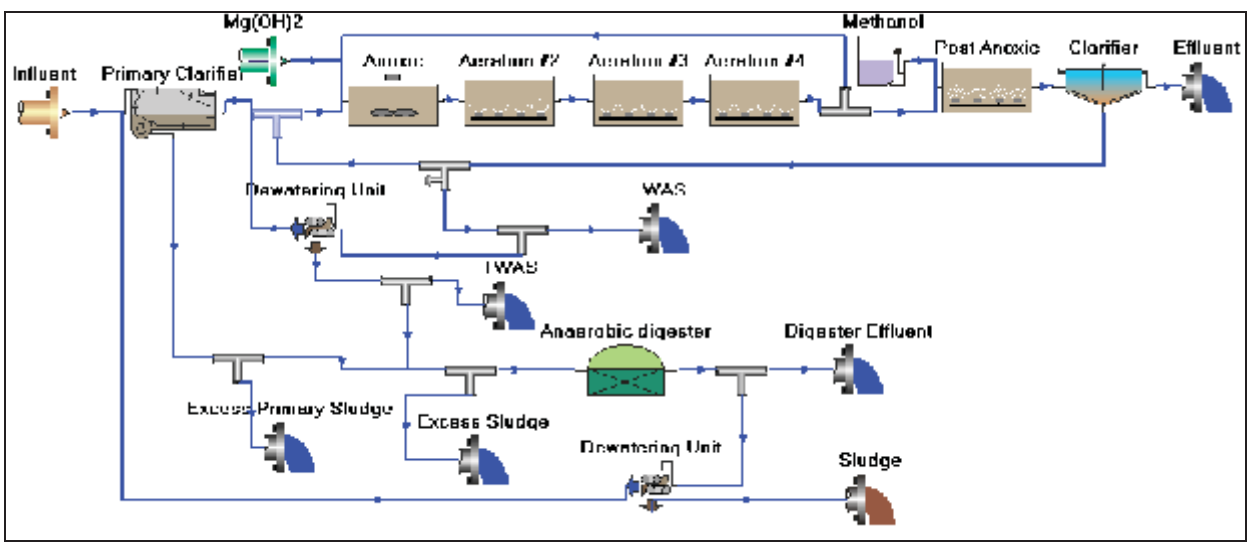

Figure 9-5. Process Schematic of HPO Plant Upgraded for Objective B Seasonal

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 9-13 summarizes the results.

TABLE 9-13. NUTRIENT RECYCLING COMPARISON FOR HIGH-PURITY OXYGEN ACTIVATED SLUDGE SYSTEMS, OBJECTIVE B SEASONAL NUTRIENT REMOVAL		
	% of TN Recycled	% of TP Recycled
	ADWF	ADWF
Existing Plant	28.1%	50.2%
Objective B	17.2%	50.1%

Sludge Production

The annual average sludge produced with the Objective B seasonal upgrades would be 918 ppd (168 dry tons per year), a negligible difference from the existing plant average of 922 ppd (168 dry tons per year).

Energy Consumption

Upgrading the HPO plant to achieve Objective B seasonally would increase the plant energy requirements by 1,425,000 kW-hours/year, or about 28 percent, as shown in Table 9-14. The annual energy consumption for the upgraded plant would increase by about 312 kW-hours per million gallons of influent wastewater treated. By comparison the energy required to achieve Objective B on a seasonal basis would be about 21 percent of the incremental energy requirements to achieve Objective B year around.

TABLE 9-14. ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B SEASONALLY	
Yearly Energy Required	
Existing HPO Plant	5.080,000 kW-hours/year
Objective B Seasonal	11,717,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	1,425,000 kW-hours/year
Percent	28%
Increase per Volume of Plant Flow	312 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective B seasonally would require chemical dosages during the dry season of 60 gpd of magnesium hydroxide for pH control and 10 gpd of methanol for nitrogen reduction. This equates to 10,950 gallons of magnesium hydroxide per year (48 gallons per million gallons of wastewater treated) and 1,825 gallons of methanol per year (8 gallons per million gallons of wastewater treated)

Footprint Requirements

Table 9-15 presents the additional site area that would be required for the two generic plant capacities. The additional footprint required for plant upgrades to achieve Objective B would be for containment tanks for methanol and magnesium hydroxide. Refer to detailed storage tank calculations in Appendix B.

TABLE 9-15.
ADDITIONAL FOOTPRINT REQUIRED FOR UPGRADING HPO PLANTS TO ACHIEVE OBJECTIVE B SEASONALLY

Plant Design Capacity (mgd)	Additional Area Required for Upgrade (square feet)
20	149,000
220	1,624,800

TABLE 9-2.
HIGH PURITY OXYGEN PLANTS BIOWIN RESULTS FOR YEAR-ROUND NUTRIENT REMOVAL

	PROCESS DESIGN - MMWW			WET SEASON - AWW FLOWS			DRY SEASON - ADW FLOWS		
	Existing	Upgraded Plant		Existing	Upgraded Plant		Existing	Upgraded Plant	
Description	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B
Nutrient Removal Goals									
TIN (mg/L)		< 8	< 3		< 8	< 3		< 8	< 3
TP (mg/L)		—	—		—	—		—	—
Plant Size, Average Temperature									
Influent Flow, mgd	1.0	1.0	1.0	0.75	0.75	0.75	0.5	0.5	0.75
Temp, °C	10	10	10	10	10	10	15	15	10
Influent									
BOD	165	165	165	221	221	221	331	331	331
TSS	188	188	188	251	251	251	376	376	376
VSS	132	132	132	176	176	176	263	263	263
TKN	24	24	24	32	32	32	48	48	48
TP	5.7	5.7	5.7	7.6	7.6	7.6	11.4	11.4	11.4
Alkalinity	2.01	2.01	2.01	2.68	2.68	2.68	4	4	4
pH	6.8	6.8	6.8	6.8	6.8	6.8	7	7	7
Aeration Tank									
No of Stages	4	4	4	4	4	4	4	4	4
Mode of Operation	75% / 25%	Complete Mix	Complete Mix	75% / 25%	Complete Mix	Complete Mix	75% / 25%	Complete Mix	Complete Mix
Stage #1									
Operation	Aeration	Anoxic	Anoxic	Aeration	Anoxic	Anoxic	Aeration	Anoxic	Anoxic
Volume	0.017	0.12	0.12	0.02	0.12	0.12	0.02	0.12	0.12
HRT	0.40	2.88	2.88	0.53	3.84	3.84	0.79	5.76	3.84
MLSS	1,142	4,216	4,539	1,262	4,254	4,413	1,301	4,093	4,193
Oxygen Supply, ft^3/min	16.1			16.1			21.9		
Stage #2									
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.40	0.96	0.96	0.53	1.28	1.28	0.79	1.92	1.28
MLSS	1,151	4,215	4,539	1,272	4,252	4,414	1,311	4,090	4,194
Oxygen Supply, ft^3/min	8.26	66.21	54.00	8.26	60.03	56.00	11.63	71.00	66.00
Stage #3									
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.40	0.96	0.96	0.53	1.28	1.28	0.79	1.92	1.28
MLSS	1,153	4,214	4,063	1,273	4,250	4,413	1,308	4,087	4,193
Oxygen Supply, ft^3/min	6.5	29.2	25.5	6.5	31.1	26.0	7.9	42.0	37.0
Stage #4									
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.40	0.96	0.96	0.53	1.28	1.28	0.79	1.92	1.28
MLSS	4,899	4,212	4,061	5,415	4,248	4,413	5,540	4,084	4,193
Oxygen Supply, ft^3/min	21	27.4	23.5	20.7	29.0	24.0	31.0	34.0	31.4
Total Oxygen Supply, ft^3/min	52	123	103	52	120	106	72	147	134
DO Concentration, mg/L	7	7	7	7	7	7	7	7	7
BioWin SRT, days	1.5	16.28	22.15	1.5	16.29	22.19	1.5	16.31	22.15
RAS Recyle Rate	0.3Q	1Q	1Q	0.3Q	1Q	1Q	0.3Q	1Q	1Q
Preanoxic Internal Recycle Rate		4Q	4Q		4Q	4Q		4Q	4Q
Post - Anoxic Tank									
Tank Volume, MG			0.10			0.10			0.10
HRT, hrs			2.40			3.20			3.20
Methanol, gpd			20			15			15

TABLE 9-2.
HIGH PURITY OXYGEN PLANTS BIOWIN RESULTS FOR YEAR-ROUND NUTRIENT REMOVAL

	PROCESS DESIGN - MMWW			WET SEASON - AWW FLOWS			DRY SEASON - ADW FLOWS		
	Existing	Upgraded Plant		Existing	Upgraded Plant		Existing	Upgraded Plant	
Description	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B
Clarifier									
Area, ft^2	1,000			1,000			1,000		
Surface Overflow Rate, gal/ft^2	1,000			750			500		
Membrane Bioreactor									
Tank Volume, MG		0.02	0.02		0.02	0.02		0.02	0.02
No. of Cassettes		4.0	4.0		4.0	4.0		4.0	4.0
Area of each Cassette, ft^2		16,320	16,320		16,320	16,320		16,320	16,320
HRT, hrs		0.48	0.48		0.64	0.64		0.96	0.64
MLSS Conc., mg/L		8,416	9,073		8,485	8,795		8,151	8,347
DO Concentration, mg/L		6	6		6	6		6	6
Air Supply Rate, ft^3/min		415	668		420	606		390	546
Membrane Flux, gpd/ft2		15.31	15.31		11.48	11.48		7.65	7.65
Tank Volumes									
Total Tankage Volume, MG	0.066	0.260	0.360	0.066	0.260	0.260	0.066	0.260	0.360
Total Additional Volume, MG		0.194	0.294		0.194	0.194		0.194	0.294
Available onsite volume, MG		0.130	0.130		0.130	0.130		0.130	0.130
Additional Volume needed, MG		0.064	0.164		0.064	0.064		0.064	0.164
Chemical Addition									
Magnesium Hydroxide Dosage, gpd		65	50		50	40			
Magnesium Hydroxide Conc., meq/L		14,500	14,500		14,500	14,500			
Anaerobic Digester									
TSS wasted from Aerobic Tank, ppd	765	597	643	845	602	624	865	578	580
Total loading to Digester, ppd	1,891	1,729	1,779	1,974	1,733	1,757	1,989	1,703	1,712
Volume, MG	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Hydraulic Residence Time, hrs	19.7	19.9	19.9	26.1	26.4	26.4	39.1	39.4	26.4
Sludge Production									
Total Sludge Produced, ppd	932	984	1,005	938	959	973	907	916	969
Effluent									
BOD, mg/L	14.83	0.86	0.87	10.13	0.86	0.83	6.23	0.86	0.75
TSS, mg/L	18.8	0.0	0.0	12.9	0.0	0.0	7.8	0.0	0.0
Phosphorous, mg/L	4.26	4.25	3.85	5.7	5.77	5.44	4.26	4.25	8.51
Ammonia N, mg/L	15.95	0.39	0.98	22.05	0.34	0.9	33.79	0.39	0.22
TIN, mg/L	15.95	6.59	2.49	22.05	6.29	2.87	33.84	6.59	1.97
pH	6.45	6.51	6.61	6.48	6.59	6.67	6.63	6.5	6.63
Recycle Loads									
TN in the influent	200.29	200.29	202.33	200.29	200.29	200.29	200.29	200.29	200.29
TN from Thickener and Digester	219.1	203.46	219.1	224.84	204.52	202.95	227.03	203.24	201.86
% TN Recycled to Aeration Tank	9%	2%	8%	12%	2%	1%	13%	1%	1%
TP from Thickener and Digester	53.55	48.23	62.66	56.24	49.06	58.93	58.51	49.51	56.98
TN from Thickener	10.57	6.1	6.12	12.58	6.13	5.99	14.97	5.79	5.61
TN from Digester	38.5	26.91	26.26	42.21	27.75	26.62	41.3	26.45	25.71
% TN Recycled	24.5%	16.5%	16.0%	27.4%	16.9%	16.3%	28.1%	16.1%	15.6%
Phosphorus Recycle from Thickener, ppd	3.11	2.22	4.85	3.68	2.35	4.12	4.37	2.5	3.82
Phosphorus Recycle from Digester, ppd	15.89	11.48	23.64	17.99	12.1	20.42	19.5	12.3	18.61
Total Phosphorus Recycled, ppd	19	13.7	28.49	21.67	14.45	24.54	23.87	14.8	22.43
% TP Recycled	39.9%	28.8%	59.9%	45.6%	30.4%	51.6%	50.2%	31.1%	47.2%

TABLE 9-9.
HIGH PURITY OXYGEN PLANTS BIOWIN RESULTS FOR SEASONAL NUTRIENT REMOVAL

	PROCESS DESIGN - MMDW			DRY SEASON - ADW FLOWS		
	Existing	Upgraded Plant		Existing	Upgraded Plant	
Description	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B
Nutrient Removal Goals						
TIN (mg/L)						
TP (mg/L)						
Plant Size, Average Temperature						
Influent Flow, mgd	0.7	0.7	0.7	0.5	0.5	0.5
Temp, ^{o}C	15	15	15	15	15	15
Influent						
BOD	241	241	241	331	331	331
TSS	273	273	273	376	376	376
VSS	191	191	191	263	263	263
TKN	35	35	35	48	48	48
TP	8.3	8.3	8.3	11.4	11.4	11.4
Alkalinity	2.92	2.92	2.92	4	4	4
pH	7	7	7	7	7	7
Aeration Tank						
No of Stages	4	4	4	4	4	4
Mode of Operation	75% / 25%	Complete Mix	Complete Mix	75% / 25%	Complete Mix	Complete Mix
Stage #1						
Operation	Aeration	Anoxic	Anoxic	Aeration	Anoxic	Anoxic
Volume	0.017	0.12	0.12	0.02	0.12	0.12
HRT	0.57	4.17	4.17	0.79	5.76	5.76
MLSS	1,259	3,588	3,030	1,301	3,880	3,597
Oxygen Supply, ft^3/min	22.0			21.9		
Stage #2						
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.57	1.39	1.39	0.79	1.92	1.92
MLSS	1,268	3,586	3,027	1,311	3,878	3,597
Oxygen Supply, ft^3/min	11.44	78.00	74.00	11.63	77.00	72.00
Stage #3						
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.57	1.39	1.39	0.79	1.92	1.92
MLSS	1,266	3,584	3,024	1,308	3,875	3,598
Oxygen Supply, ft^3/min	7.9	43.0	39.0	7.9	46.0	43.0
Stage #4						
Operation	Aeration	Aeration	Aeration	Aeration	Aeration	Aeration
Volume	0.017	0.04	0.04	0.017	0.04	0.04
HRT	0.57	1.39	1.39	0.79	1.92	1.92
MLSS	5,379	3,581	3,020	5,540	3,872	3,596
Oxygen Supply, ft^3/min	30.5	34.0	35.0	31.0	33.0	35.0
Total Oxygen Supply, ft^3/min	72	155	148	72	156	150
DO Concentration, mg/L	7	7	7	7	7	7
BioWin SRT, days	1.5	13.5	14.26	1.5	13.5	14.26
RAS Recyle Rate	0.3Q	0.5Q	0.5Q	0.3Q	0.5Q	0.5Q
Preanoxic Internal Recycle Rate		4Q	4Q		4Q	4Q
Post - Anoxic Tank						

TABLE 9-9.
HIGH PURITY OXYGEN PLANTS BIOWIN RESULTS FOR SEASONAL NUTRIENT REMOVAL

	PROCESS DESIGN - MMDW			DRY SEASON - ADW FLOWS		
	Existing	Upgraded Plant		Existing	Upgraded Plant	
Description	HPO Plant	Obj. A	Obj. B	HPO Plant	Obj. A	Obj. B
Tank Volume, MG			0.05			0.05
HRT, hrs			1.74			2.40
Methanol, gpd			15			10
Clarifier						
Area, ft^2	1,000	1,000	1,000	1,000	1,000	1,000
Surface Overflow Rate, gal/ft^2	690	690	690	500	500	500
Tank Volumes						
Total Tankage Volume, MG	0.066	0.240	0.290	0.066	0.240	0.290
Total Additional Volume, MG		0.174	0.224		0.174	0.224
Available Volume onsite, MG		0.0	0.0		0.0	0.0
Additional Volume needed, MG		0.174	0.224		0.174	0.224
Chemical Addition						
Magnesium Hydroxide Dosage, gpd		95	90		70	60
Magnesium Hydroxide Conc., meq/L		14,500	14,500		14,500	14,500
Anaerobic Digester						
TSS wasted from Aerobic Tank, ppd	839	576	582	865	576	610
Total loading to Digester, ppd	1,968	1,700	1,707	1,989	1,698	1,734
Volume, MG	0.15	0.15	0.15	0.15	0.15	0.15
Hydraulic Residence Time, hrs	28.3	28.8	28.7	39.1	39.4	39.4
Sludge Production						
Sludge Produced, ppd						
Effluent						
BOD, mg/L	8.29	5.28	8.29	6.23	3.55	4.37
TSS, mg/L	11.5	14.8	14.6	7.8	9.4	9.8
Phosphorous, mg/L	6.24	6.5	6.17	4.26	8.86	8.58
Ammonia N, mg/L	24.3	0.48	1.13	33.79	0.35	0.97
TIN, mg/L	24.33	5.07	1.38	33.84	6.85	2.01
pH	6.56	6.51	6.55	6.63	6.51	6.51
Recycle Loads						
Nitrogen Recycle from Thickener, ppd	13.2	5.51	5.87	14.97	5.79	6.11
Nitrogen Recycle from Digester, ppd	42.66	27.28	28.2	41.3	27.47	28.35
Total Nitrogen Recycled, ppd	55.86	32.79	34.07	56.27	33.26	34.46
% TN Recycled	27.9%	16.4%	17.0%	28.1%	16.6%	17.2%
Phosphorus Recycle from Thickener, ppd	3.86	2.06	3.71	4.37	2.83	3.86
Phosphorus Recycle from Digester, ppd	18.38	12.1	19.71	19.5	15.43	19.98
Total Phosphorus Recycled, ppd	22.24	14.16	23.42	23.87	18.26	23.84
% TP Recycled	46.8%	29.8%	49.2%	50.2%	38.4%	50.1%

CHAPTER 10.
TECHNOLOGICAL EVALUATION FOR AERATED OR FACULTATIVE LAGOON PLANTS

10.1 BASE CASE/EXISTING SYSTEM

Biowin cannot model lagoon plants, so CapdetWorks was used to develop the following lagoon models for base case cost estimating:

- A 1.0-mgd facultative lagoon system consisting of a bar screen for preliminary treatment followed by 68-acres facultative lagoons
- A 1.0-mgd aerated lagoon and facultative lagoon system consisting of a bar screen for preliminary treatment followed by 2-acres of complete mix aerated lagoon(s) and 34 acres of facultative lagoons.

Table 10-1 summarizes the concentrations assumed for the lagoon effluent.

TABLE 10-1.
LAGOON EFFLUENT CONCENTRATIONS

	AWWF	ADWF
BOD (mg/L)	30	30
TSS (mg/L)	30	45
VSS (mg/L)	21	32
TKN (mg/L)	13.3	20
TP (mg/L)	5.3	8
Alkalinity (meq/L)	3.35	5
pH	7	8.5

The evaluation assumed that aerated lagoons would be dredged every 10 years of operation and the facultative lagoons would be dredged every 20 years. The dredged solids from the lagoons was assumed to meet the Class B biosolids requirements. Sludge production for facultative lagoon treatment plants and treatment plants using aerated lagoons in conjunction with facultative lagoons were assumed to have a sludge production rate of 0.42 pounds of dry sludge solids per pound of BOD5 applied or 0.46 tons dry solids per million gallons of wastewater treated.

10.2 YEAR-ROUND NUTRIENT REMOVAL

To achieve year-round nitrogen-removal Objectives for A, B, E and F, the existing lagoon plant would need to be replaced with a new mechanical plant.. The elements included in the replacement plant would depend on the size of the original plant:

- For plants up to 5 mgd, the replacement plant would be the same as the upgraded plant for existing extended aeration treatment plants, as described in Chapter 4; process design data for these plants are presented in Table 4-2.

- For plants larger than 5 mgd, the proposed new plant is similar to, though not exactly the same as, the upgraded plant for existing CAS treatment plants, as described in Chapter 5. Process design data for these plants are presented in Table 10-2. In order to provide a consistent comparison with other upgrades discussed in this report, the modeled size of these plants is 1.0-mgd; tank sizes would be scaled linearly to obtain sizes for plants rated up to 50 mgd.

The phosphorus removal objectives associated with Objectives C and D can be achieved by upgrading the lagoon plant . Process design data for these plants are presented in Table 10-3.

10.2.1 Objective A

Process Description

To achieve Objective A (TIN <8 mg/L) year-round for lagoons rated up to 5.0 mgd, the existing lagoons would be decommissioned and new liquid and solids treatment facilities would be constructed on-site. The new plant would include the same process elements as the year-round Objective A upgrade for extended aeration plants. The process flow schematic for this new plant would be as shown in Figure 4-3. Table 4-2 summarizes the process design data.

To achieve Objective A year-round for lagoons rated greater than 5.0 mgd, the existing lagoons would be decommissioned and replace with new liquid and solids treatment facilities. The new treatment plant process elements would consist of the same process elements that are included in the upgraded conventional activated sludge plant upgrade to achieve this Objective on a dry season basis presented in Chapter 5. The new process elements would include, a new influent pump station, a headworks with a fine screen system, primary clarifiers a conventional MLE activated sludge process with secondary clarifiers,. The new plant would also include solids handling facility to thicken the waste activated sludge prior to digestion, an anaerobic digester, and digested solids dewatering system with a belt filter press. The process flow schematic for this objective is similar to the CAS seasonal process flow schematic shown in Figure 5-6. Table 10-2 summarizes the process design data; detailed Biowin model reports are in Appendix A.

Recycled Loads

Table 10-4 summarizes the recycled-load modeling results for the upgrades to achieve Objective A year-round at existing lagoon plants.

TABLE 10-4.
NUTRIENT RECYCLING ESTIMATES FOR LAGOON PLANTS UPGRADED TO ACHIEVE OBJECTIVE A YEAR-ROUND

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Plants Up to 5.0 mgd	16.3%	15.5%	48.7%	64.1%
Plants > 5.0 mgd	15.9%	15.5%	47.3%	42.4%

Sludge Production

The sludge produced from a 1-mgd plant with the Objective A year-round upgrades would be as follows:

- With upgrades proposed for plants up to 5.0 mgd:
  - Annual average of 939 ppd
  - 171 dry tons per year
  - 0.75 dry tons per million gallons of wastewater treated
  - This represents 63% increase in the quantity of biosolids by the plant
- With upgrades proposed for plants greater than 5.0 mgd
  - Annual average of 916 ppd
  - 167 dry tons per year
  - 0.73 dry tons per million gallons of wastewater treated
  - This represents a 59% increase in the quantity of biosolids generated by the plant

Energy Consumption

Upgrading an existing 1-mgd(MM) aerated or facultative lagoon plant to achieve Objective A year-round would change the plant energy requirements as shown in Table 10-5 or 10-6, respectively. These rates can be extrapolated and applied to plants up to a rated maximum month capacity of 5 mgd.

TABLE 10-5.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING A 1-MGD AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective A Year-Round	1,010,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	38,000 kW-hours/year
Percent	4%
Increase per Volume of Plant Flow	167 kW-hours/MG

TABLE 10-6.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING A 1- MGD FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective A Year-Round	1,010,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	874,000 kW-hours/year
Percent	642%
Increase per Volume of Plant Flow	3831 kW-hours/MG

Chemical Usage

For plants up to 5.0 mgd, the chemical usage for an upgraded plant to achieve Objective A year-round would be the same as for extended aeration plants upgraded to achieve Objective A year-round, as described in Section 4.2.1.

For plants larger than 5.0 mgd, no additional use of chemicals would be required the upgraded plant to achieve Objective A year-round.

Footprint Requirements

Table 10-7 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective A for the three generic plant capacities. For plants up to 5 mgd in capacity, the upgrade footprint includes preliminary treatment, an influent pump station, an aeration tank, an anoxic tank, secondary clarifiers, an aerobic digester and a belt filer press. For plants larger than 5 mgd, the upgrade footprint includes preliminary treatment, an influent pump station, primary clarifiers, an aeration tank, an anoxic tank, secondary clarifiers, an anaerobic digester and a belt filer press. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-7.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE A YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(304,900)	(348,500)
5	(6,708,200)	(7,143,800)
50	(72,004,700)	(76,360,700)

10.2.2 Objective B

Process Description

To achieve Objective B (TIN <3 mg/L) year-round for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the year-round Objective B upgrade for extended aeration plants. The process flow schematic for this upgrade is shown in Figure 4-4, and Table 4-2 summarizes the process design data.

To achieve Objective B year-round for lagoons rated greater than 5.0 mgd, the existing lagoons would be abandoned in place and new liquids and solids handling treatment facilities would be constructed. A new influent pump station, a headworks with a fine screen system and a new 1,020-square-foot primary clarifier should be constructed. The new liquids treatment system would use the 4-stage Bardenpho activated sludge process and secondary clarifiers, requiring the construction of a new 0.25-MG aeration tank, a 0.10-MG pre-anoxic tank, a 0.05-MG post-anoxic tank and a 2,200-square-foot secondary clarifier. Methanol would be added as an additional carbon source to the post-anoxic tank to increase the denitrification process, requiring a methanol storage and dosing system. The process flow schematic for this objective is similar to the CAS seasonal process flow schematic shown in Figure 5-7. Table 10-2 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Table 10-8 summarizes the recycled-load modeling results for the upgrades to achieve Objective B year-round at lagoon plants. For lagoon plants with capacities up to 5.0 mgd, the recycled loads are the same as those calculated for the year-round Objective B upgrade for extended aeration systems.

TABLE 10-8.
NUTRIENT RECYCLING ESTIMATES FOR LAGOON PLANTS UPGRADED TO ACHIEVE OBJECTIVE B YEAR-ROUND

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Plants Up to 5.0 mgd	17.2%	15.9%	55.7%	61.7%
Plants > 5.0 mgd	14.5%	15.5%	33.5%	29.7%

Sludge Production

The sludge produced from a 1-mgd plant with the Objective B year-round upgrades would be as follows:

- With upgrades proposed for plants up to 5.0 mgd:
  - Annual average of 951 ppd
  - 174 dry tons per year
  - 0.75 dry tons per million gallons of wastewater treated
  - This represents 63% increase in the quantity of biosolids by the plant
- With upgrades proposed for plants greater than 5.0 mgd
  - Annual average of 924 ppd
  - 169 dry tons per year
  - 0.73 dry tons per million gallons of wastewater treated
  - This represents 59% increase in the quantity of biosolids by the plant

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective B year-round would change the plant energy requirements as shown in Table 10-9 or 10-10, respectively.

Chemical Usage

For plants up to 5.0 mgd, the chemical usage for an upgraded plant to achieve Objective B year-round would be the same as for extended aeration plants upgraded to achieve Objective B year-round, as described in Section 4.2.2.

For plants larger than 5.0 mgd, the upgraded plant to achieve Objective B year-round would require 4,563 gallons of methanol per year for carbon supplementation to drive the denitrification process, or 20 gallons of methanol per million gallons of wastewater treated.

TABLE 10-9.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective B Year-Round	1,292,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	320,000 kW-hours/year
Percent	33%
Increase per Volume of Plant Flow	1403 kW-hours/MG

TABLE 10-10.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective B Year-Round	1,292,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	1,156,000 kW-hours/year
Percent	850%
Increase per Volume of Plant Flow	5068 kW-hours/MG

Footprint Requirements

Table 10-11 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective B for the three generic plant capacities. For plants up to 5 mgd in capacity, the upgrade footprint includes preliminary treatment, an influent pump station, an aeration tank, pre- and post-anoxic tanks, methanol containment, secondary clarifiers, an aerobic digester and a belt filer press. For plants larger than 5 mgd, the upgrade footprint includes preliminary treatment, an influent pump station, primary clarifiers, an aeration tank, pre- and post-anoxic tanks, methanol containment, secondary clarifiers, an anaerobic digester and a belt filer press. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-11.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE B YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(304,900)	(348,500)
5	(6,708,200)	(7,143,800)
50	(72,004,700)	(76,360,700)

10.2.3 Objective C

Process Description

Objective C (TP <1.0 mg/L) can be achieved year-round by adding a new chemical clarifier to the existing lagoon system. The effluent from the lagoon would be sent to the clarifier, where alum would be added for precipitation of phosphorus. The clarifier would be designed for an overflow rate of 500 gpd/ft^2, so the required clarifier area for a MMWWF of 1.0 mgd would be 2,000 square feet. A simple Biowin model was developed consisting of an influent equal to the lagoon effluent and a chemical clarifier as shown in Figure 10-1. Table 10-3 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

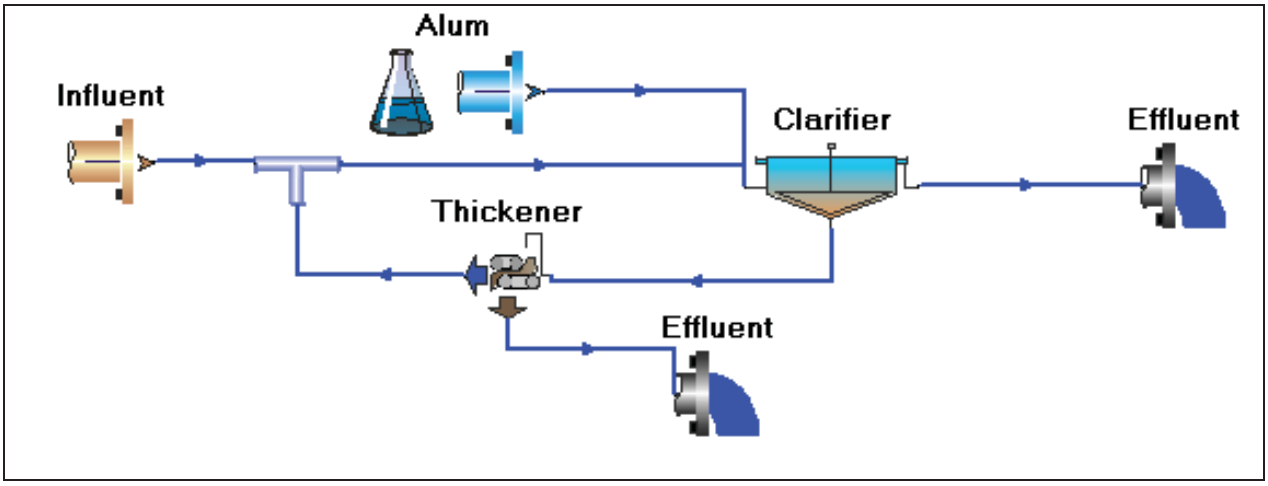

Figure 10-1. Process Schematic of Clarifier Used to Upgrade Lagoon Plant for Objective C Year-Round

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 10-12 summarizes the results.

TABLE 10-12.
NUTRIENT RECYCLING FOR AERATED OR FACULTATIVE LAGOON SYSTEMS, OBJECTIVE C YEAR-ROUND NUTRIENT REMOVAL

	AWWF	ADWF
% of TN Recycled	4.4%	4.4%
% of TP Recycled	1.1%	1.3%

Sludge Production

Addition of alum will result in higher sludge production rates which will increase the quantity of sludge that would need to be dredged from the lagoons. The additional sludge produced would be equivalent to 0.15 tons per million gallons of wastewater treated.. This represent approximately a 33% increase in the sludge production by the treatment plant.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective C year-round would change the plant energy requirements as shown in Table 10-13 or 10-14, respectively.

TABLE 10-13.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective C Year-Round	1,038,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	66,000 kW-hours/year
Percent	7%
Increase per Volume of Plant Flow	105,600 kW-hours/MG

TABLE 10-14.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective C Year-Round	202,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	66,000 kW-hours/year
Percent	49%
Increase per Volume of Plant Flow	105,600 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective C year-round would require 22,995 gallons of alum per year for phosphorus removal, or 100 gallons of alum per million gallons of wastewater treated.

Footprint Requirements

Table 10-15 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective C for the three generic plant capacities. The upgraded footprint area includes a new chemical clarifier, a chemical containment tank and a pump station. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-15.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE C YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	3,900	3,900
5	30,000	30,000
50	233,000	233,000

10.2.4 Objective D

Process Description

Objective D (TP <0.1 mg/L) can be achieved year-round by adding a new chemical clarifier and tertiary filters to the existing lagoon system. The effluent from the lagoon would be sent to the clarifier, where alum would be added for precipitation of phosphorus. The clarifier would be designed for an overflow rate of 500 gpd/ft^2, so the required clarifier area for an MMWWF of 1.0 mgd would be 2,000 square feet. A process schematic for this upgrade is shown in Figure 10-2. Table 10-3 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

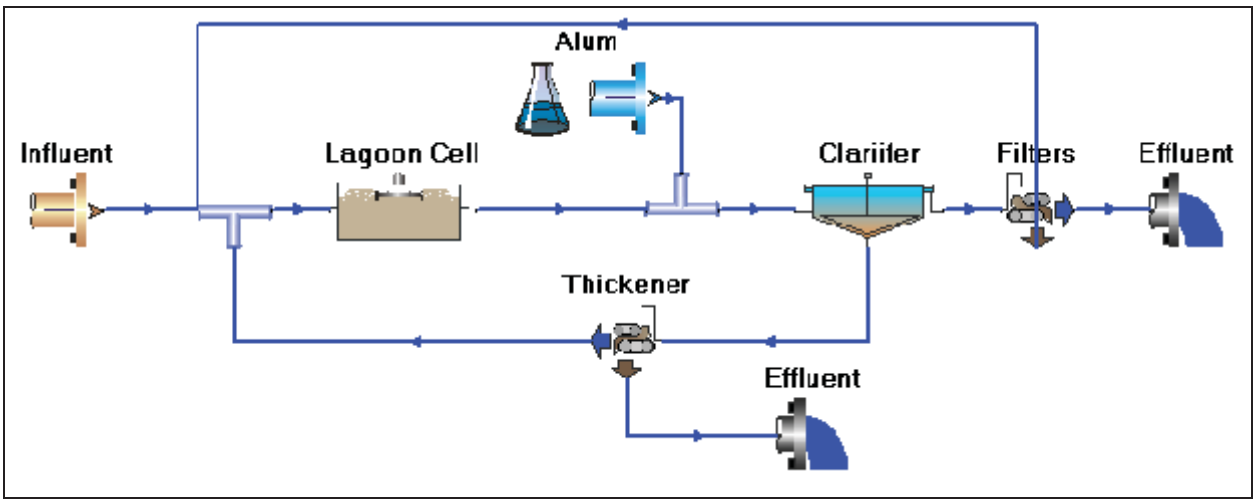

Figure 10-2. Process Schematic of Upgraded Lagoon Plant for Objective D Year-Round

The sludge produced from the chemical clarifier and the backwash from the filters would be sent back to the existing lagoon. Part of the lagoon would be partitioned to store the sludge from the chemical clarifier by constructing a 10-foot earthen berm with 3:1 side slopes. The size of this lagoon cell is assumed to be 1.0 acre for a 1.0-mgd lagoon plant. Sludge from the chemical clarifier will be accumulated in this lagoon cell and decanted. The accumulated sludge will be dredged out every 5 to 7 years. A new pump station should be constructed to transfer the lagoon effluent to the physical/chemical treatment process.

Recycled Loads

The percentage of TN and TP returning from the sludge treatment processes was calculated using Biowin model outputs. Table 10-16 summarizes the results.

TABLE 10-16.
NUTRIENT RECYCLING FOR AERATED OR FACULTATIVE LAGOON SYSTEMS, OBJECTIVE D YEAR-ROUND NUTRIENT REMOVAL

	AWWF	ADWF
% of TN Recycled	9.5%	8.7%
% of TP Recycled	5.9%	3.4%

Sludge Production

Addition of alum will result in higher sludge production rates which will increase the quantity of sludge that would need to be dredged from the lagoons. The additional sludge produced would be equivalent to 0.19 tons per million gallons of wastewater treated.. This represent approximately a 41% increase in the sludge production by the treatment plant.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective D year-round would change the plant energy requirements as shown in Table 10-17 or 10-18, respectively.

Chemical Usage

The upgraded plant to achieve Objective D year-round would require 51,100 gallons of alum per year for phosphorus removal, or 222 gallons of alum per million gallons of wastewater treated.

Footprint Requirements

Table 10-19 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective D for the three generic plant capacities. The upgraded footprint area includes a new chemical clarifier, a chemical containment tank, tertiary filters, and a pump station. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-17.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective D Year-Round	1,042,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity.....	71,000 kW-hours/year
Percent	7%
Increase per Volume of Plant Flow.....	113,600 kW-hours/MG

TABLE 10-18.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective D Year-Round	207,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	71,000 kW-hours/year
Percent	52%
Increase per Volume of Plant Flow	113,600 kW-hours/MG

TABLE 10-19.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE D YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	4,800	4,800
5	37,000	37,000
50	285,800	285,800

10.2.5 Objective E

Process Description

To achieve Objective E (TIN <8 mg/L and TP <1.0 mg/L) year-round for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the year-round Objective E upgrade for extended aeration plants. Table 4-2 summarizes the process design data.

To achieve Objective E year-round for lagoons rated greater than 5.0 mgd, the existing lagoon plant would be upgraded as described for Objective A, with the additional upgrades of constructing an alum tank for precipitation of phosphorus and a magnesium hydroxide tank for pH control. Tanks would be sized based on maximum chemical usage during MMWWF, AWWF or ADWF (whichever is higher). The process flow schematics are similar to those for Objective A, with the addition of alum and magnesium hydroxide to the secondary process. A mechanical dewatering system would be constructed to concentrate biosolids to a minimum of 16 percent dry solids content. Table 10-2 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Table 10-20 summarizes the recycled-load modeling results for the upgrades to achieve Objective E year-round at lagoon plants. For lagoon plants with capacities up to 5.0 mgd, the recycled loads are the same as those calculated for the year-round Objective E upgrade for extended aeration systems.

TABLE 10-20.
NUTRIENT RECYCLING ESTIMATES FOR LAGOON PLANTS UPGRADED TO ACHIEVE OBJECTIVE E YEAR-ROUND

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Plants Up to 5.0 mgd	18.0%	15.2%	35.9%	50.4%
Plants > 5.0 mgd	2.2%	15.4%	45.5%	46.4%

Sludge Production

The sludge produced from a 1-mgd plant with the Objective E year-round upgrades would be as follows:

- With upgrades proposed for plants up to 5.0 mgd:
  - Annual average of 1,177 ppd
  - 214 dry tons per year
  - 0.93 dry tons per million gallons of wastewater treated
  - Sludge production would therefore increase 102%
- With upgrades proposed for plants greater than 5.0 mgd
  - Annual average of 1,175 ppd
  - 214 dry tons per year
  - 0.93 dry tons per million gallons of wastewater treated
  - Sludge production would therefore increase 102%

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective E year-round would change the plant energy requirements as shown in Table 10-21 or 10-22, respectively.

TABLE 10-21.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective E Year-Round.....	1,022,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity.....	50,000 kW-hours/year
Percent	5%
Increase per Volume of Plant Flow.....	219 kW-hours/MG

TABLE 10-22.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective E Year-Round	1,022,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	886,000 kW-hours/year
Percent	651%
Increase per Volume of Plant Flow	3883 kW-hours/MG

Chemical Usage

For plants up to 5.0 mgd, the chemical usage for an upgraded plant to achieve Objective E year-round would be the same as for extended aeration plants upgraded to achieve Objective E year-round, as described in Section 4.2.5.

For plants larger than 5.0 mgd, the upgraded plant to achieve Objective E year-round would require 44,530 gallons of alum per year (194 gallons per million gallons of wastewater treated) for phosphorus reduction and 32,850 gallons of magnesium hydroxide per year (143 gallons per million gallons of wastewater treated) for pH control.

Footprint Requirements

Table 10-23 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective E for the three generic plant capacities. For plants up to 5 mgd in capacity, the upgrade footprint includes preliminary treatment, an influent pump station, an aeration tank, an anoxic tank, alum and magnesium hydroxide containment, secondary clarifiers, an aerobic digester and a belt filer press. For plants larger than 5 mgd, the upgrade footprint includes preliminary treatment, an influent pump station, primary clarifiers, an aeration tank, an anoxic tank, alum and magnesium hydroxide containment, secondary clarifiers, an anaerobic digester and a belt filer press. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-23.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE E YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(304,900)	(348,500)
5	(6,708,200)	(7,143,800)
50	(72,004,700)	(76,360,700)

10.2.6 Objective F

Process Description

To achieve Objective F (TIN <3 mg/L and TP <0.1 mg/L) year-round for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the year-round Objective F upgrade for extended aeration plants. Table 4-2 summarizes the process design data.

To achieve Objective F year-round for lagoons rated greater than 5.0 mgd, the existing lagoon plant would be upgraded as described for Objective B, with the additional upgrades of constructing an alum tank for precipitation of phosphorus, a magnesium hydroxide tank for pH control, and new conventional gravity filters. Tanks would be sized based on maximum chemical usage during MMWWF, AWWF or ADWF (whichever is higher). The process flow schematics are similar to those for Objective B, with the addition of alum and magnesium hydroxide to the secondary process. A mechanical dewatering system would be constructed to concentrate biosolids to a minimum of 16 percent dry solids content. Table 10-2 summarizes the process design data. Detailed Biowin model reports are in Appendix A.

Recycled Loads

Table 10-24 summarizes the recycled-load modeling results for the upgrades to achieve Objective F year-round at lagoon plants. For lagoon plants with capacities up to 5.0 mgd, the recycled loads are the same as those calculated for the year-round Objective F upgrade for extended aeration systems.

TABLE 10-24.
NUTRIENT RECYCLING ESTIMATES FOR LAGOON PLANTS UPGRADED TO ACHIEVE OBJECTIVE F YEAR-ROUND

	% of TN Recycled		% of TP Recycled	
	AWWF	ADWF	AWWF	ADWF
Plants Up to 5.0 mgd	16.5%	15.3%	36.5%	36.6%
Plants > 5.0 mgd	16.1%	15.5%	24.5%	24.7%

Sludge Production

The sludge produced from a 1-mgd plant with the Objective F year-round upgrades would be as follows:

- With upgrades proposed for plants up to 5.0 mgd:
  - Annual average of 1,228 ppd
  - 224 dry tons per year
  - 0.97 dry tons per million gallons of wastewater treated
  - Sludge production would therefore increase 111%
- With upgrades proposed for plants greater than 5.0 mgd
  - Annual average of 1,264 ppd
  - 231 dry tons per year
  - 1.00 dry tons per million gallons of wastewater treated

– Sludge production would therefore increase 117%

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective F year-round would change the plant energy requirements as shown in Table 10-25 or 10-26, respectively.

TABLE 10-25.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective F Year-Round	1,317,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	345,500 kW-hours/year
Percent	35.5%
Increase per Volume of Plant Flow	1515 kW-hours/MG

TABLE 10-26.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F YEAR-ROUND

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective F Year-Round	1,317,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	1,181,500 kW-hours/year
Percent	869%
Increase per Volume of Plant Flow	5179 kW-hours/MG

Chemical Usage

For plants up to 5.0 mgd, the chemical usage for an upgraded plant to achieve Objective F year-round would be the same as for extended aeration plants upgraded to achieve Objective F year-round, as described in Section 4.2.6.

For plants larger than 5.0 mgd, the upgraded plant to achieve Objective F year-round would require 63,875 gallons of alum per year (278 gallons per million gallons of wastewater treated) for phosphorus reduction, 43,800 gallons of magnesium hydroxide per year (190 gallons per million gallons of wastewater treated) for pH control, and 5,475 gallons of methanol per year (24 gallons per million gallons of wastewater treated) for nitrogen removal.

Footprint Requirements

Table 10-27 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective F for the three generic plant capacities. For plants up to 5 mgd in capacity, the upgrade footprint includes preliminary treatment; an influent pump station; an aeration tank; pre- and post-anoxic tanks; alum, magnesium hydroxide and methanol containment; tertiary filters; secondary clarifiers; an

aerobic digester; and a belt filer press. For plants larger than 5 mgd, the upgrade footprint includes preliminary treatment; an influent pump station; primary clarifiers; an aeration tank; pre- and post-anoxic tanks; alum, magnesium hydroxide and methanol containment; tertiary filters; secondary clarifiers; an anaerobic digester; and a belt filer press. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-27.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE F YEAR-ROUND

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(304,900)	(348,500)
5	(6,708,200)	(7,143,800)
50	(72,004,700)	(76,360,700)

10.3 SEASONAL NUTRIENT REMOVAL

To achieve seasonal nitrogen-removal objectives (A, B, E and F) a lagoon plant would need to be abandoned and a new plant constructed in its place. The elements included in the replacement plant would depend on the size of the original plant:

- For plants up to 5 mgd, the replacement plant would be the same as the upgraded plant for existing extended aeration treatment plants, as described in Chapter 4; process design data for these plants are presented in Table 4-31.
- For plants larger than 5 mgd, the proposed new plant is the same as the upgraded plant for existing CAS treatment plants, as described in Chapter 5. Process design data for these plants are presented in Table 5-21. In order to provide a consistent comparison with other upgrades discussed in this report, the modeled size of these plants is 1.0-mgd; tank sizes would be scaled linearly to obtain sizes for plants rated up to 50 mgd.

To achieve objectives to remove only phosphorus seasonally (Objectives C and D), a lagoon plant could be upgraded rather than abandoned and replaced. Process design data for these plants are presented in Table 10-3.

10.3.1 Objective A

Process Description

To achieve Objective A seasonally for lagoons rated up to 5.0 mgd, the existing lagoons would be replaced by a new mechanical liquid and solids treatment plant. The new plant would be feature the same processes as described for the upgraded extended aeration plant to achieve Objective A seasonally. Table 4-31 summarizes the process design data.

For existing lagoon plants greater than 5 mgd would require construction of a new mechanical liquid and solids treatment plant conforming with the processes described for upgraded CAS plants that are to achieve Objective A during the dry weather season. The process flow schematic for this upgrade is shown in Figure 5-6, and Table 5-21 summarizes the process design data.

Recycled Loads

For plants rated up to 5.0 mgd, recycled loads for upgrades to achieve Objective A seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.1. For plants rated greater than 5.0 mgd, recycled loads would be the same as given for upgraded CAS plants in Section 5.3.1.

Sludge Production

For plants rated up to 5.0 mgd, sludge production for upgrades to achieve Objective A seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.1. For plants rated greater than 5.0 mgd, sludge production would be the same as given for upgraded CAS plants in Section 5.3.1.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective A seasonally would change the plant energy requirements as shown in Table 10-28 or 10-29, respectively.

TABLE 10-28.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING 1 MGD AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective A, Seasonal	938,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(33,500), kW-hours/year
Percent	(3%)%
Increase per Volume of Plant Flow	(147) kW-hours/MG

TABLE 10-29.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING 1 MGD FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective A, Seasonal	938,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	802,500 kW-hours/year
Percent	590%
Increase per Volume of Plant Flow	3,518 kW-hours/MG

Chemical Usage

For plants rated up to 5.0 mgd, chemical usage for upgrades to achieve Objective A seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.1. For plants rated greater than 5.0 mgd, chemical usage would be the same as given for upgraded CAS plants in Section 5.3.1.

Footprint Requirements

Table 10-30 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective A seasonally for the three generic plant capacities.

TABLE 10-30.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE A SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(348,500)	(392,000)
5	(6,795,400)	(7,231,000)
50	(72,440,300)	(76,796,300)

10.3.2 Objective B

Process Description

To achieve Objective B seasonally for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective B upgrade for extended aeration plants. Table 4-31 summarizes the process design data.

To achieve Objective B seasonally for lagoons rated greater than 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective B upgrade for CAS plants. The process flow schematic for this upgrade is shown in Figure 5-7, and Table 5-21 summarizes the process design data.

Recycled Loads

For plants rated up to 5.0 mgd, recycled loads for upgrades to achieve Objective B seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.2. For plants rated greater than 5.0 mgd, recycled loads would be the same as given for upgraded CAS plants in Section 5.3.2.

Sludge Production

For plants rated up to 5.0 mgd, sludge production for upgrades to achieve Objective B seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.2. For plants rated greater than 5.0 mgd, sludge production would be the same as given for upgraded CAS plants in Section 5.3.2.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective B seasonally would change the plant energy requirements as shown in Table 10-31 or 10-32, respectively.

TABLE 10-31.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

Yearly Energy Required
- Existing Aerated Lagoon Plant..... 972,000 kW-hours/year
- Objective B, Seasonal..... 1,042,500 kW-hours/year

Energy Increase for Upgrade
- Annual Quantity ..... 70,500 kW-hours/year
- Percent..... 7%
- Increase per Volume of Plant Flow ..... 309 kW-hours/MG

TABLE 10-32.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

Yearly Energy Required
- Existing Facultative Lagoon Plant ..... 136,000 kW-hours/year
- Objective B, Seasonal ..... 1,042,500 kW-hours/year

Energy Increase for Upgrade
- Annual Quantity..... 906,500 kW-hours/year
- Percent..... 767%
- Increase per Volume of Plant Flow..... 3,974 kW-hours/MG

Chemical Usage

For plants rated up to 5.0 mgd, chemical usage for upgrades to achieve Objective B seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.2. For plants rated greater than 5.0 mgd, chemical usage would be the same as given for upgraded CAS plants in Section 5.3.2.

Footprint Requirements

Table 10-33 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective B seasonally for the three generic plant capacities.

TABLE 10-33.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE B SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(348,500)	(392,000)
5	(6,795,400)	(7,231,000)
50	(72,440,300)	(76,796,300)

10.3.3 Objective C

Process Description

Objective C can be achieved seasonally with the same upgrades as described for the year-round Objective C upgrade. Table 10-3 summarizes the process design data.

Recycled Loads

Average dry-weather recycled load percentages for upgrades to achieve Objective C seasonally would be the same as for upgrades to achieve Objective C year-round.

Sludge Production

Addition of alum will result in higher sludge production rates which will increase the quantity of sludge that would need to be dredged from the lagoons. The additional sludge produced would be equivalent to 0.084 tons per million gallons of wastewater treated.. This represent approximately a 18% increase in the sludge production by the treatment plant.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective C seasonally would change the plant energy requirements as shown in Table 10-34 or 10-35, respectively.

TABLE 10-34.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective C, Seasonal	853,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	118,500 kW-hours/year
Percent	12%
Increase per Volume of Plant Flow	519 kW-hours/MG

TABLE 10-35.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective C, Seasonal	254,500 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	118,500 kW-hours/year
Percent	87%
Increase per Volume of Plant Flow	3,145 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective C seasonally would require 12,775 gallons of alum per year for phosphorus removal, or 56 gallons of alum per million gallons of wastewater treated.

Footprint Requirements

Table 10-36 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective C seasonally for the three generic plant capacities. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-36.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE C SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	4,400	4,400
5	30,500	30,500
50	230,900	230,900

10.3.4 Objective D

Process Description

Objective D can be achieved seasonally with the same upgrades as described for the year-round Objective D upgrade. Table 10-3 summarizes the process design data.

Recycled Loads

Average dry-weather recycled load percentages for upgrades to achieve Objective D seasonally would be the same as for upgrades to achieve Objective D year-round.

Sludge Production

Addition of alum will result in higher sludge production rates which will increase the quantity of sludge that would need to be dredged from the lagoons. The additional sludge produced would be equivalent to 0.095 tons per million gallons of wastewater treated.. This represent approximately a 21% increase in the sludge production by the treatment plant.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective D seasonally would change the plant energy requirements as shown in Table 10-37 or 10-38, respectively.

TABLE 10-37.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective D, Seasonal	870,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(102,000) kW-hours/year
Percent	(10)%
Increase per Volume of Plant Flow	(447) kW-hours/MG

TABLE 10-38.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D SEASONALLY

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective D, Seasonal	870,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	734,000 kW-hours/year
Percent	539%
Increase per Volume of Plant Flow	3,217 kW-hours/MG

Chemical Usage

The upgraded plant to achieve Objective D year-round would require 25,550 gallons of alum per year for phosphorus removal, or 111 gallons of alum per million gallons of wastewater treated.

Footprint Requirements

Table 10-39 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective D seasonally for the three generic plant capacities. Refer to Appendix C for detailed footprint areas of the existing system and the proposed system.

TABLE 10-39.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE D SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	4,400	4,400
5	39,200	39,200
50	270,100	270,100

10.3.5 Objective E

Process Description

To achieve Objective E seasonally for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective E upgrade for extended aeration plants. Table 4-31 summarizes the process design data.

To achieve Objective E seasonally for lagoons rated greater than 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective E upgrade for CAS plants. Table 5-21 summarizes the process design data.

Recycled Loads

For plants rated up to 5.0 mgd, recycled loads for upgrades to achieve Objective E seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.5. For plants rated greater than 5.0 mgd, recycled loads would be the same as given for upgraded CAS plants in Section 5.3.5.

Sludge Production

For plants rated up to 5.0 mgd, sludge production for upgrades to achieve Objective E seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.5. For plants rated greater than 5.0 mgd, sludge production would be the same as given for upgraded CAS plants in Section 5.3.5.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective E seasonally would change the plant energy requirements as shown in Table 10-40 or 10-41, respectively.

Chemical Usage

For plants rated up to 5.0 mgd, chemical usage for upgrades to achieve Objective E seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.5. For plants rated greater than 5.0 mgd, chemical usage would be the same as given for upgraded CAS plants in Section 5.3.5.

Footprint Requirements

Table 10-42 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective E seasonally for the three generic plant capacities.

TABLE 10-40.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective E, Seasonal	940,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	(32,000) kW-hours/year
Percent	(3)%
Increase per Volume of Plant Flow	(140) kW-hours/MG

TABLE 10-41.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE E SEASONALLY

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective E, Seasonal	940,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	804,000 kW-hours/year
Percent	591%
Increase per Volume of Plant Flow	3,524 kW-hours/MG

TABLE 10-42.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE E SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(348,500)	(392,000)
5	(6,791,000)	(7,226,600)
50	(72,435,900)	(76,791,900)

10.3.6 Objective F

Process Description

To achieve Objective F seasonally for lagoons rated up to 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective F upgrade for extended aeration plants. Table 4-31 summarizes the process design data.

To achieve Objective F seasonally for lagoons rated greater than 5.0 mgd, the existing lagoons would be abandoned in place and new liquid and solids treatment facilities would be constructed the same as for the seasonal Objective F upgrade for CAS plants. Table 5-21 summarizes the process design data.

Recycled Loads

For plants rated up to 5.0 mgd, recycled loads for upgrades to achieve Objective F seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.6. For plants rated greater than 5.0 mgd, recycled loads would be the same as given for upgraded CAS plants in Section 5.3.6.

Sludge Production

For plants rated up to 5.0 mgd, sludge production for upgrades to achieve Objective F seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.6. For plants rated greater than 5.0 mgd, sludge production would be the same as given for upgraded CAS plants in Section 5.3.6.

Energy Consumption

Upgrading an aerated or facultative lagoon plant to achieve Objective B seasonally would change the plant energy requirements as shown in Table 10-43 or 10-44, respectively.

TABLE 10-43.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

Yearly Energy Required	
Existing Aerated Lagoon Plant	972,000 kW-hours/year
Objective F, Seasonal	1,045,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	73,000 kW-hours/year
Percent	8%
Increase per Volume of Plant Flow	320 kW-hours/MG

TABLE 10-44.
ADDITIONAL ENERGY CONSUMPTION FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE F SEASONALLY

Yearly Energy Required	
Existing Facultative Lagoon Plant	136,000 kW-hours/year
Objective F, Seasonal	1,045,000 kW-hours/year
Energy Increase for Upgrade	
Annual Quantity	909,000 kW-hours/year
Percent	668%
Increase per Volume of Plant Flow	3,984 kW-hours/MG

Chemical Usage

For plants rated up to 5.0 mgd, chemical usage for upgrades to achieve Objective F seasonally would be the same as given for upgraded extended aeration plants in Section 4.3.6. For plants rated greater than 5.0 mgd, chemical usage would be the same as given for upgraded CAS plants in Section 5.3.6.

Footprint Requirements

Table 10-45 compares the additional footprint area for upgrading existing lagoon plants to achieve Objective B seasonally for the three generic plant capacities.

TABLE 10-45.
ADDITIONAL FOOTPRINT REQUIREMENTS FOR UPGRADING AERATED LAGOON AND FACULTATIVE LAGOON PLANTS TO ACHIEVE OBJECTIVE F SEASONALLY

	Additional Area Required for Upgrade (square feet)	
Plant Design Capacity (mgd)	Aerated Lagoon Plants	Facultative Lagoon Plants
0.5	(348,500)	(392,000)
5	(6,786,600)	(7,222,200)
50	(72,435,000)	(76,791,000)

TABLE 10-2.
BIOWIN RESULTS FOR AERATED OR FACULTATIVE LAGOONS > 5.0 MGD, FOR OBJECTIVES A, B, E AND F YEAR-ROUND

Description	PROCESS DESIGN - MMWW				AWW				ADW			
	Obj. A	Obj. B	Obj. E	Obj. F	Obj. A	Obj. B	Obj. E	Obj. F	Obj. A	Obj. B	Obj. E	Obj. F
Nutrient Removal Goals												
TIN (mg/L)	< 8	< 3	< 8	< 3	< 8	< 3	< 8	< 3	< 8	< 3	< 8	< 3
TP (mg/L)			< 1	< 0.1			< 1	< 0.1			< 1	< 0.1
Plant Size, Average Temperature												
Influent Flow, mgd	1.0	1.0	1.0	1.0	0.75	0.75	0.75	0.75	0.50	0.50	0.50	0.50
Temp, ^{o}C	10	10	10	10	10	10	10	10	15	15	15	15
Influent												
BOD	165	165	165	165	221	221	221	221	331	331	331	331
TSS	188	188	188	188	251	251	251	251	376	376	376	376
VSS	132	132	132	132	176	176	176	176	263	263	263	263
TKN	24	24	24	24	32	32	32	32	48	48	48	48
TP	5.7	5.7	5.7	5.7	7.6	7.6	7.6	7.6	11.4	11.4	11.4	11.4
Alkalinity	2.01	2.01	2.01	2.01	2.68	2.68	2.68	2.68	4	4	4	4
pH	6.8	6.8	6.8	6.8	6.8	6.8	6.8	6.8	7	7	7	7
Aerobic Tank												
Tank Volume, MG	0.25	0.2	0.25	0.2	0.25	0.2	0.25	0.2	0.25	0.2	0.25	0.2
HRT, hrs	6.0	4.8	6.0	4.8	8.0	6.4	8.0	6.4	12	9.6	12	9.6
MLSS Conc., mg/L	3,182	3,372	3,602	3,989	3,334	3,372	3,869	3,339	3,264	3,334	3,889	4,117
DO Concentration, mg/L	2, 0.5	2, 0.5, 2	2, 0.5	2, 0.5, 2	2, 0.5	2, 0.5, 2	2, 0.5	2, 0.5, 2	2, 0.5	2, 0.5, 2	2, 0.5	2, 0.5, 2
Air Supply Rate, ft^3/min	592	672	617	684	618	672	628	724	680	720	689	733
BioWin SRT, days	18.45	20.14	17.6	19.13	18.45	20.14	18.45	15.32	18.47	20.19	18.81	19.16
RAS Recyle Rate	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q	0.5Q
Pre - Anoxic Tank												
Tank Volume, MG	0.15	0.1	0.15	0.1	0.15	0.1	0.15	0.1	0.15	0.1	0.15	0.1
HRT, hrs	3.6	2.4	3.6	2.4	4.8	3.2	4.8	3.2	7.2	4.8	7.2	4.8
Internal Recycle Rate	5Q	5Q	5Q	5Q	5Q	5Q	5Q	5Q	5Q	5Q	5Q	5Q
Post - Anoxic Tank												
Tank Volume, MG		0.05		0.05		0.05		0.05		0.05		0.05
HRT, hrs		1.2		1.2		1.6		1.6		2.4		2.4
Methanol, gpd		15		15		15		15		10		15
Clarifier												
Area, ft^2	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200	2,200
Surface Overflow Rate, gal/ft^2	454	454	454	454	341	341	341	357	227	227	227	227

TABLE 10-2.
BIOWIN RESULTS FOR AERATED OR FACULTATIVE LAGOONS > 5.0 MGD, FOR OBJECTIVES A, B, E AND F YEAR-ROUND

	PROCESS DESIGN - MMWW				AWW				ADW			
Description	Obj. A	Obj. B	Obj. E	Obj. F	Obj. A	Obj. B	Obj. E	Obj. F	Obj. A	Obj. B	Obj. E	Obj. F
Tertiary Filters												
Filter Area (ft2)				552				552				552
Chemical Addition												
Alum Dosage, gpd			90	200			105	175			130	175
Magnesium Hydroxide Dosage, gpd			100	170			120	120			60	120
Magnesium Hydroxide Conc., meq/L											14,500	14,500
Anaerobic Digester												
TSS wasted from Aerobic Tank, ppd	540	536	612	682	567	536	658	698	555	557	661	687
Total loading to Digester, ppd	1,668	1,663	1,898	2,073	1,695	1,663	1,972	2,082	1,678	1,682	1,990	2,054
Volume, MG	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Hydraulic Residence Time, hrs	19.8	19.8	19.8	19.8	26.5	26.5	26.5	26.5	39.5	39.5	39.5	37.5
Sludge Production												
Sludge Production, ppd	934	937	1,137	1,325	931	937	1,176	1,282	902	911	1,173	1,246
Effluent												
BOD, mg/L	2.96	3	2.78	1.53	2.31	3	2.13	1.36	1.66	1.61	1.57	1.12
TSS, mg/L	8.0	8.1	8.2	4.5	5.7	8.1	5.8	4.4	3.6	3,6	3.6	5.5
Phosphorous, mg/L	4.11	4.27	0.48	0.06	5.6	4.27	0.68	0.05	8.7	8.8	0.45	0.03
Ammonia N, mg/L	1.41	0.54	0.86	0.64	1.26	0.54	0.9	0.17	0.34	0.09	0.37	0.09
TIN, mg/L	4.06	2.08	5.51	2.17	5.03	2.08	4.68	2.09	6.4	1.44	4.8	1.4
pH	6.31	6.33	6.58	6.52	6.27	6.33	6.6	6.54	6.4	6.53	6.55	6.57
Recycle Loads												
Nitrogen Recycle from Thickener, ppd	5.29	5.35	5.36	5.57	5.54	5.35	5.51	6.04	5.35	5.51	5.39	5.73
Nitrogen Recycle from Digester, ppd	23.7	23.73	23.77	25.39	26.33	23.7	23.79	26.22	25.66	25.51	25.35	25.35
Total Nitrogen Recycled, ppd	28.99	29.08	29.13	30.96	31.87	29.05	4.33	32.26	31.01	31.02	30.74	31.08
Phosphorus Recycle from Thickener, ppd	3.06	2.45	4.14	3.18	3	2.45	3.52	3.32	2.67	2.24	4.25	3.39
Phosphorus Recycle from Digester, ppd	19.78	13.5	17.48	8.13	19.49	13.5	18.13	8.34	17.5	11.9	17.84	8.37
Total Phosphorus Recycled, ppd	22.84	15.95	21.62	11.31	22.49	15.95	21.65	11.66	20.17	14.14	22.09	11.76
% TN Recycled	14.5%	14.5%	14.6%	15.5%	15.9%	14.5%	2.2%	16.1%	15.5%	15.5%	15.4%	15.5%
% TP Recycled	48.0%	33.5%	45.4%	23.8%	47.3%	33.5%	45.5%	24.5%	42.4%	29.7%	46.4%	24.7%

TABLE 10-3.
BIOWIN RESULTS FOR AERATED OR FACULTATIVE LAGOONS FOR OBJECTIVES C AND D

	Year-Round Nutrient Removal						Seasonal Nutrient Removal			
	MMWW		AWW		ADW		MMDW		ADW	
Description	Obj. C	Obj. D	Obj. C	Obj. D	Obj. C	Obj. D	Obj. C	Obj. D	Obj. C	Obj. D
Nutrient Removal Goals										
TIN (mg/L)	—	—	—	—	—	—	—	—	—	—
TP (mg/L)	< 1	< 0.1	< 1	< 0.1	< 1	< 0.1	< 1	< 0.1	< 1	< 0.1
Plant Size, Average Temperature										
Influent Flow, mgd	1.00	1.00	0.75	0.75	0.50	0.50	0.69	0.69	0.50	0.50
Temp, ^{o}C	10	10	10	10	15	15	15	15	15	15
Influent										
BOD	22.5	22.5	30	30	45	45	32.6	32.6	45	45
TSS	22.5	22.5	30	30	45	45	32.6	32.6	45	45
VSS	16	16	21	21	32	32	23	23	32	32
TKN	10	10	13.3	13.3	20	20	14.5	14.5	20	20
TP	4	4	5.3	5.3	8	8	5.8	5.8	8	8
Alkalinity	2.5	2.5	3.35	3.35	5	5	3.6	3.6	5	5
pH	7	7	7	7	8.5	8.5	8.5	8.5	8.5	8.5
Existing Lagoon Partition										
Area of the partition		43,560		43,560		43,560		43,560		43,560
Volume		1.3		1.3		1.3		1.3		1.3
Clarifier										
Area, ft^2	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Surface Overflow Rate, gal/ft^2	525	525	375	375	250	250	345	345	250	250
Thickener / Dewatering Unit										
% Removal Efficiency	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
Tertiary Filters										
Filter Area (ft2)		555		555		555		380		380
Chemical Addition										
Alum Dosage, gpd	55	160	55	140	70	140	70	140	70	140
Effluent										
BOD, mg/L	13.47	9.07	17.43	4.16	25.24	2.38	18.58	3.11	25.24	2.38
TSS, mg/L	5.1	1.2	4.0	0.9	2.8	0.6	3.8	0.9	2.8	0.6
Phosphorous, mg/L	0.63	0.09	0.52	0.07	0.67	0.05	0.65	0.07	0.67	0.05
Ammonia N, mg/L	6.6	6.34	8.78	8.48	13.2	12.34	9.57	9.16	13.2	12.34
TIN, mg/L	6.6	6.35	8.78	8.48	13.2	13.08	9.57	13.08	13.2	13.08
pH	6.81	6.66	6.81	6.78	7.29	6.79	7.29	6.79	7.29	6.79
TN returned from thickener, ppd	87.04	91.2	86.83	91.1	87.05	90.62	87.09	91.08	87.05	90.62
TP Returned from Thickener, ppd	33.71	36.48	33.51	35.12	33.78	34.48	33.78	35.13	33.78	34.48
% TN Recycled	4.36%	9.35%	4.37%	9.51%	4.38%	8.66%	4.37%	9.15%	4.38%	8.66%
% TP Recycled	1.05%	9.35%	1.08%	5.94%	1.26%	3.36%	1.21%	5.25%	1.26%	3.36%

CHAPTER 11.
COST EVALUATION, OBJECTIVE A

11.1 YEAR-ROUND NUTRIENT REMOVAL

11.1.1 Extended Aeration Plants

Table 11-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for an extended aeration plant using mechanical aeration. Figures 11-1 and 11-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-2 and Figures 11-3 and 11-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 11-3 and 11-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 11-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.78	$2.26	$2.20
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.21	$0.01	($0.02)

TABLE 11-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.07	$0.75	$0.31
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.02	($0.05)	($0.05)

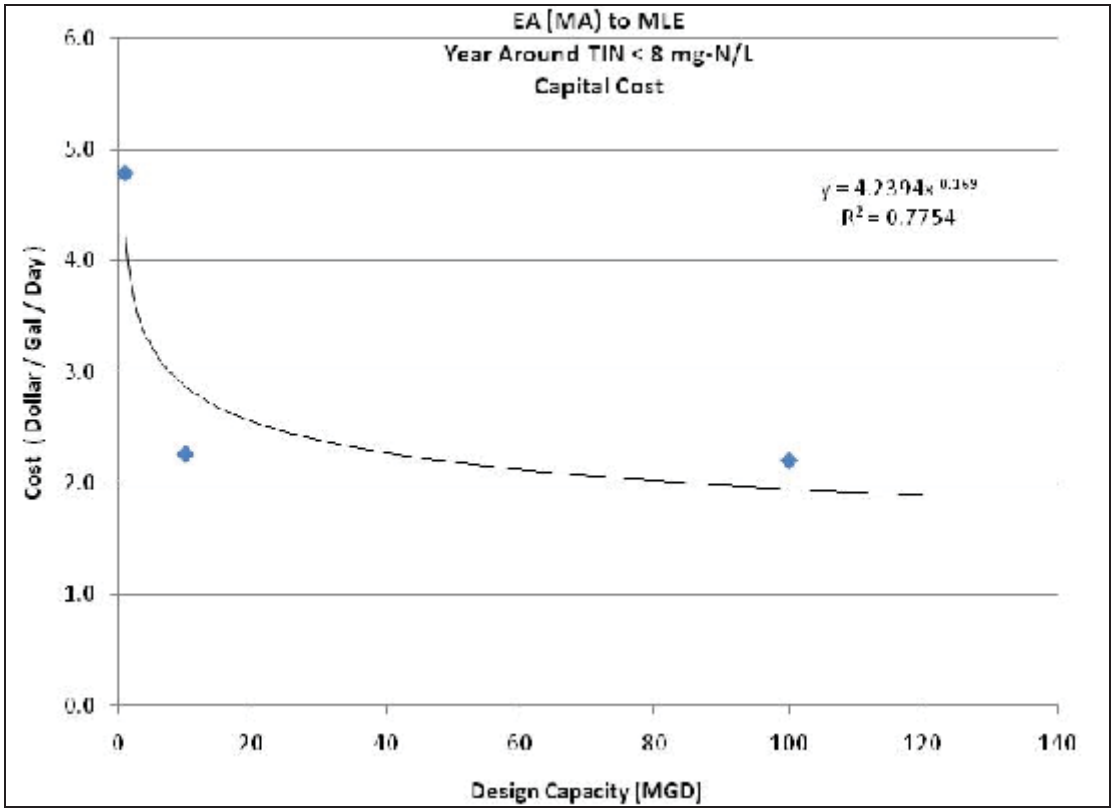

Figure 11-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective A Year-Round

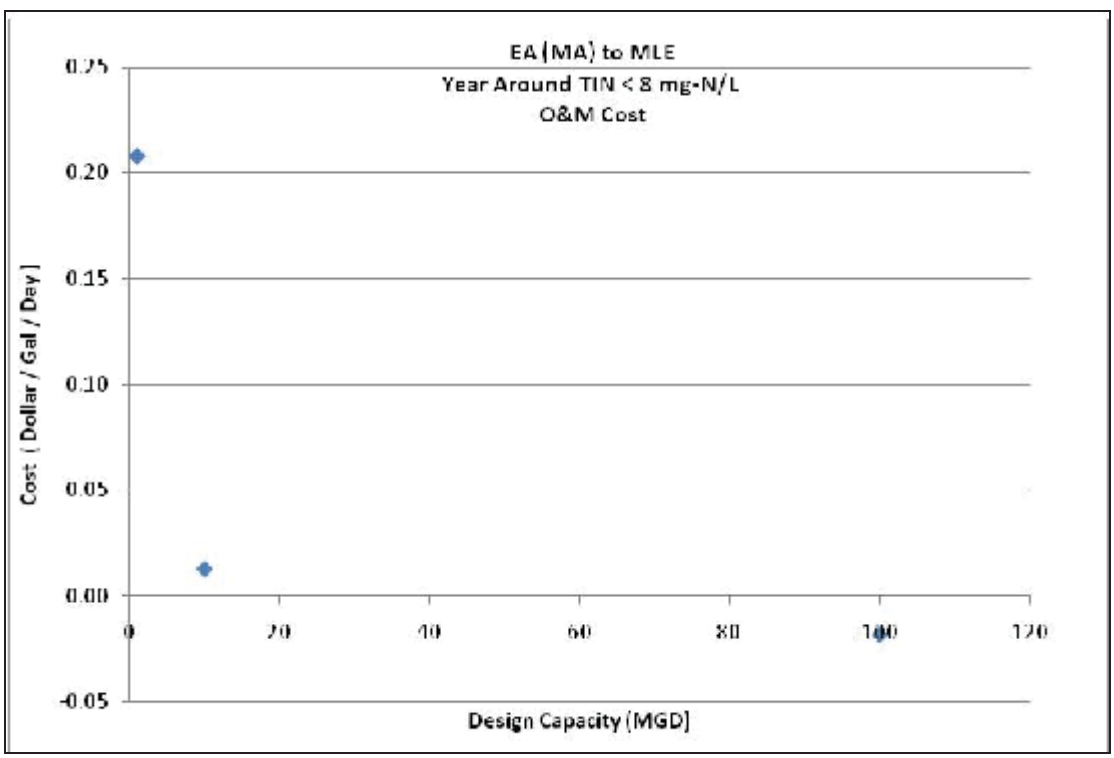

Figure 11-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective A Year-Round

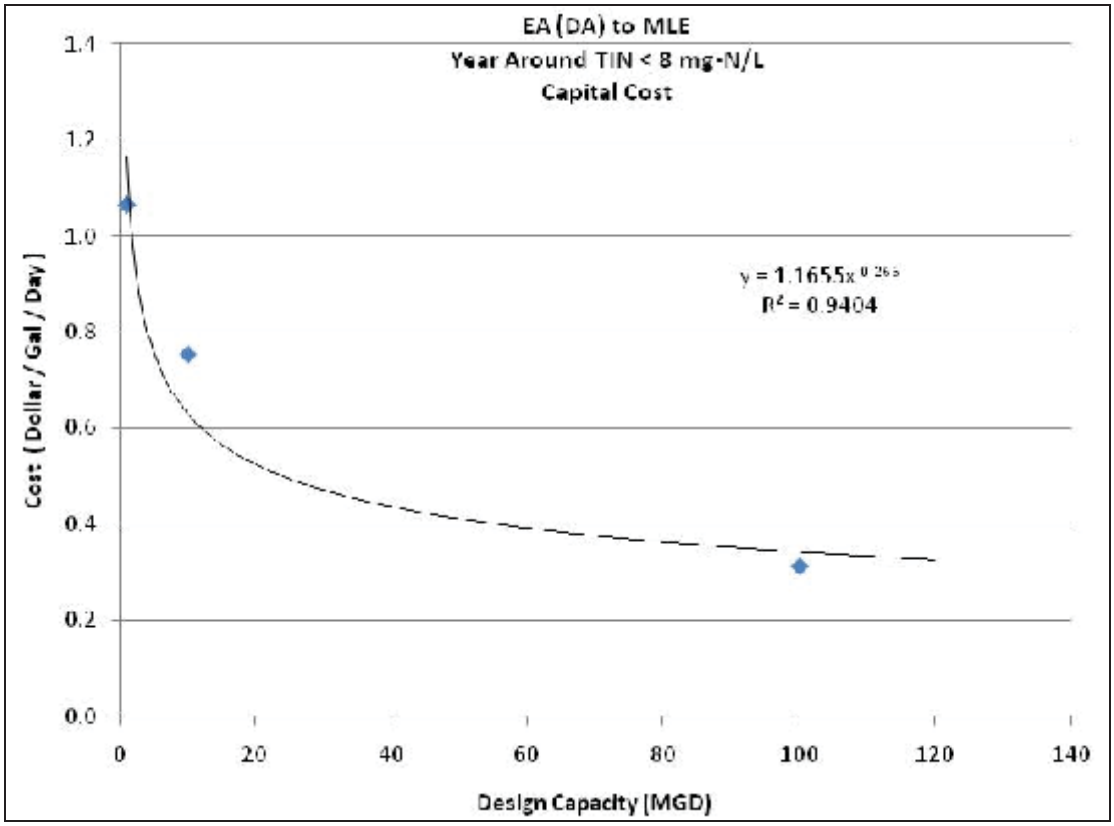

Figure 11-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective A Year-Round

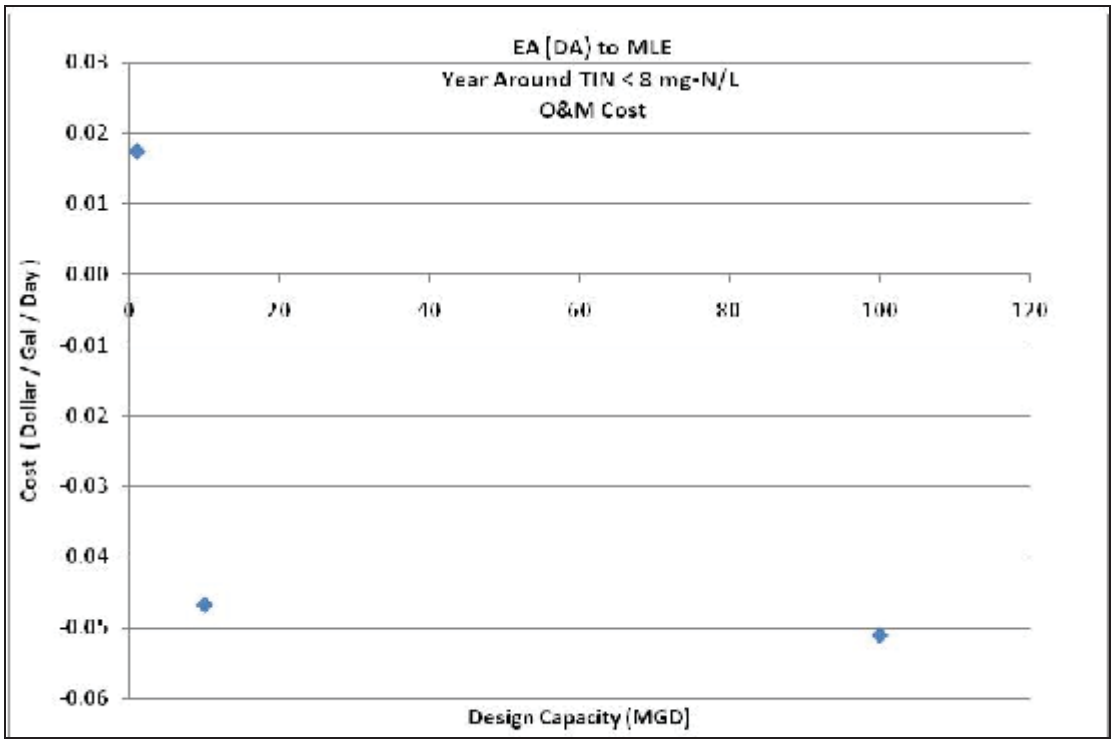

Figure 11-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective A Year-Round

TABLE 11-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$351,414	$1,656,556	$16,134,708
2014 Incremental O&M Cost	$234,218	$142,715	-$2,068,685
Total Annual Cost	**$585,632**	**$1,799,270**	**$14,066,023**
Annual TIN Load Reduction (lb/yr)	35,259	352,590	3,525,900
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$16.61	$5.10	$3.99

Equation:[a] ..... $y = 363.87x^{-0.31}$
R-Square Value: 0.8746

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$78,303	$554,242	$2,298,201
2014 Incremental O&M Cost	$19,584	-$526,175	-$5,747,411
Total Annual Cost	**$97,887**	**$28,066**	**-$3,449,210**
Annual TIN Load Reduction (lb/yr)	35,223	352,225	3,522,250
Estimated Cost for TIN Reduction ($/lb TIN removed)	$2.78	$0.08	-$0.98
Equation and R-Square Value[a]		—	

a. Equation and R-square value not determined because annual cost estimates are below the level of precision that can be achieved using the CapdetWorks cost model.

11.1.2 Conventional Activated Sludge Plants

Table 11-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for a conventional activated sludge plant. Figures 11-5 and 11-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.63	$4.55	$3.32
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.23	$0.13	$0.08

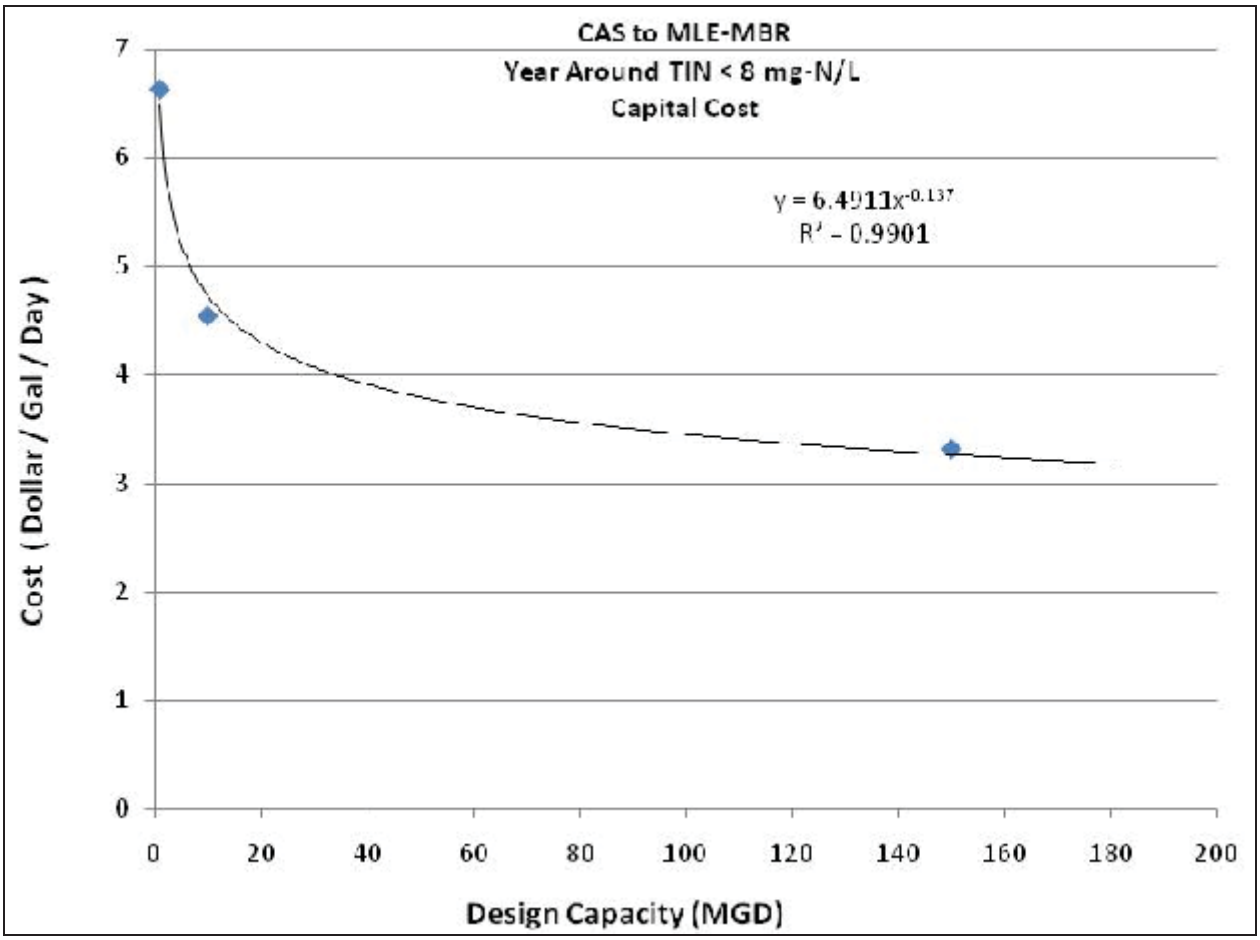

Figure 11-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective A Year-Round

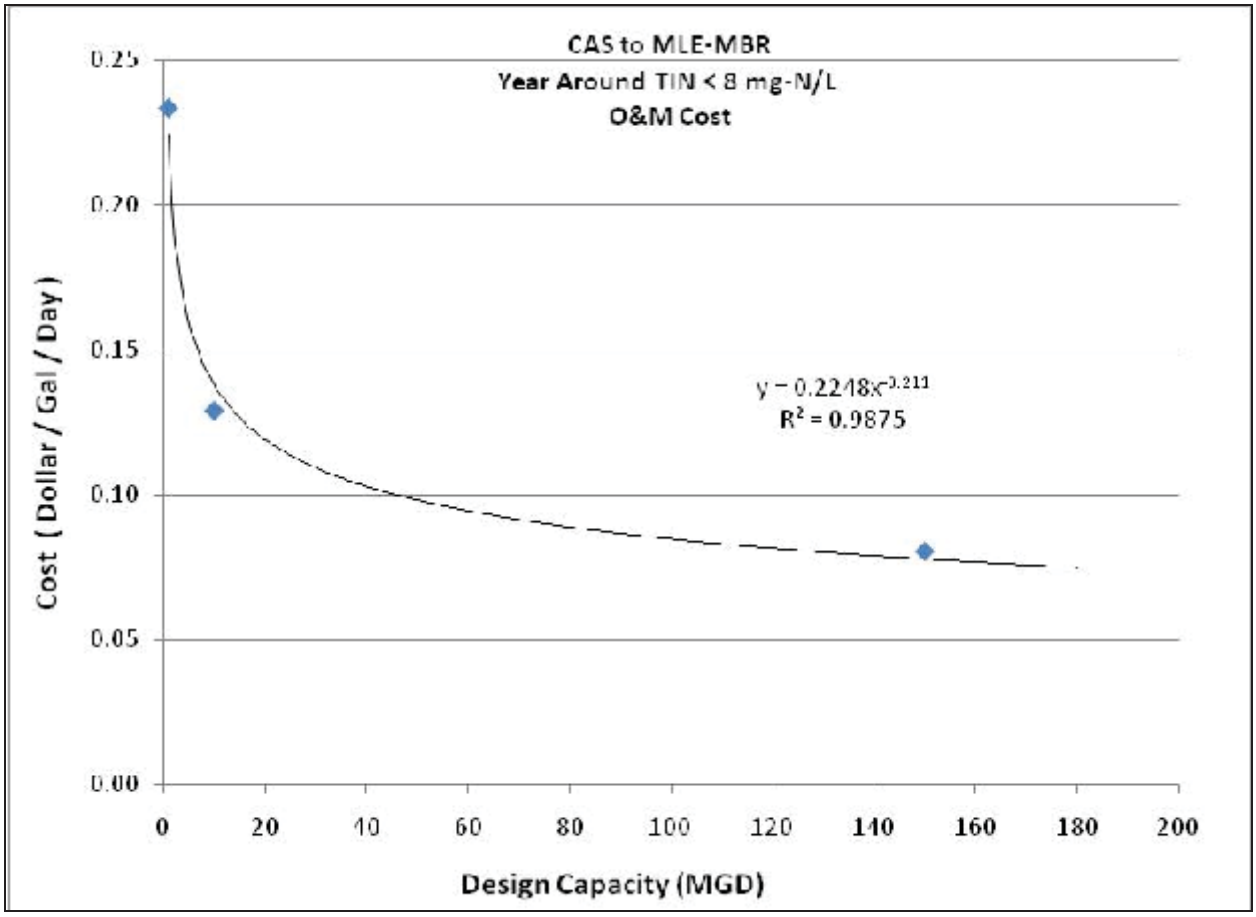

Figure 11-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective A Year-Round

TABLE 11-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$487,073	$3,341,694	$36,630,838
2014 O&M Cost	$262,642	$1,451,579	$13,597.004
Total Annual Cost	**$749,715**	**$4,793,273**	**$50,209,841**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$21.09	$13.48	$9.42
Equation:[a]			$y = 109.71x^{-0.16}$
R-Square Value:			$R^2 = 0.9878$

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.1.3 Sequencing Batch Reactor Plants

Table 11-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for an SBR plant. Figures 11-7 and 11-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.45	$0.24	$0.18
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.01	$0.01	$0.004

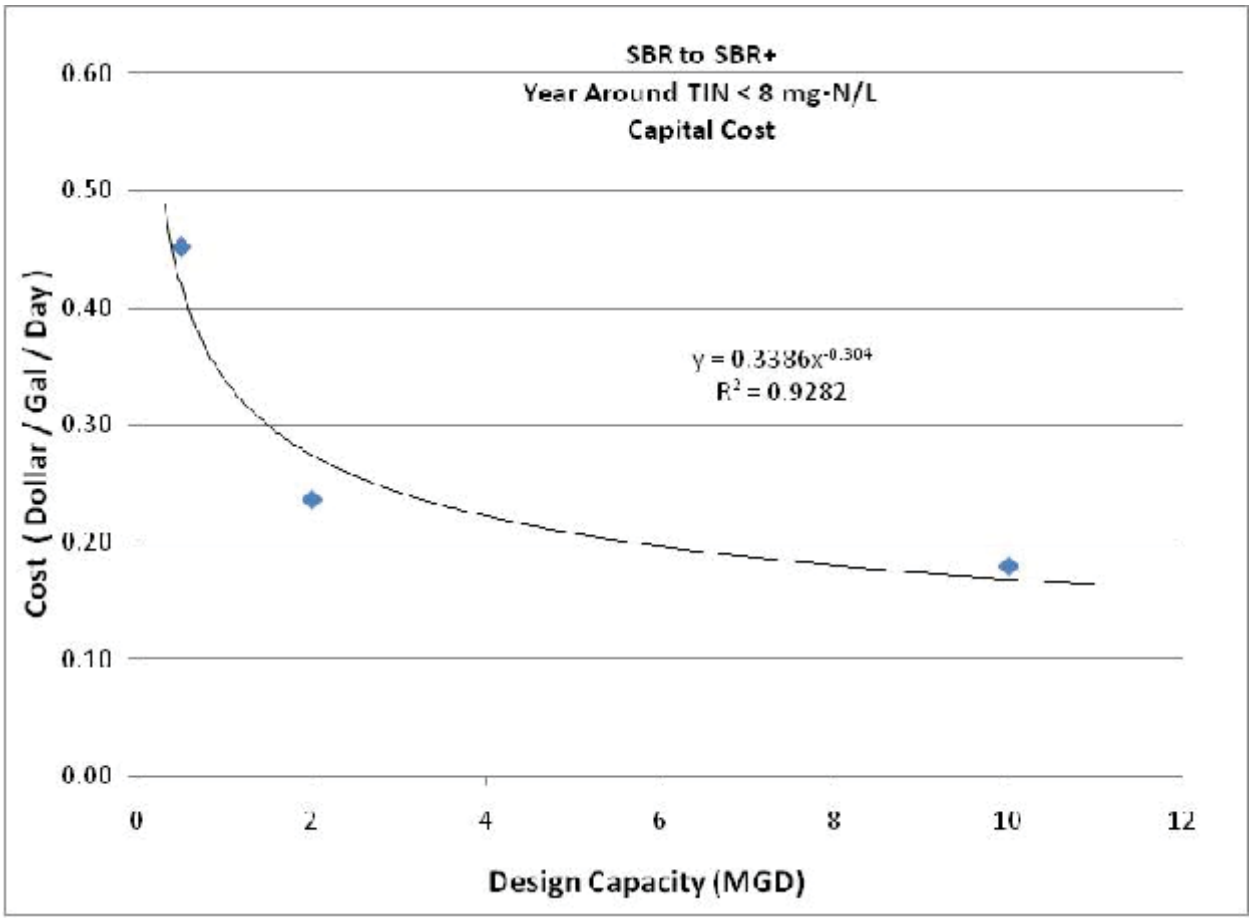

Figure 11-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective A Year-Round

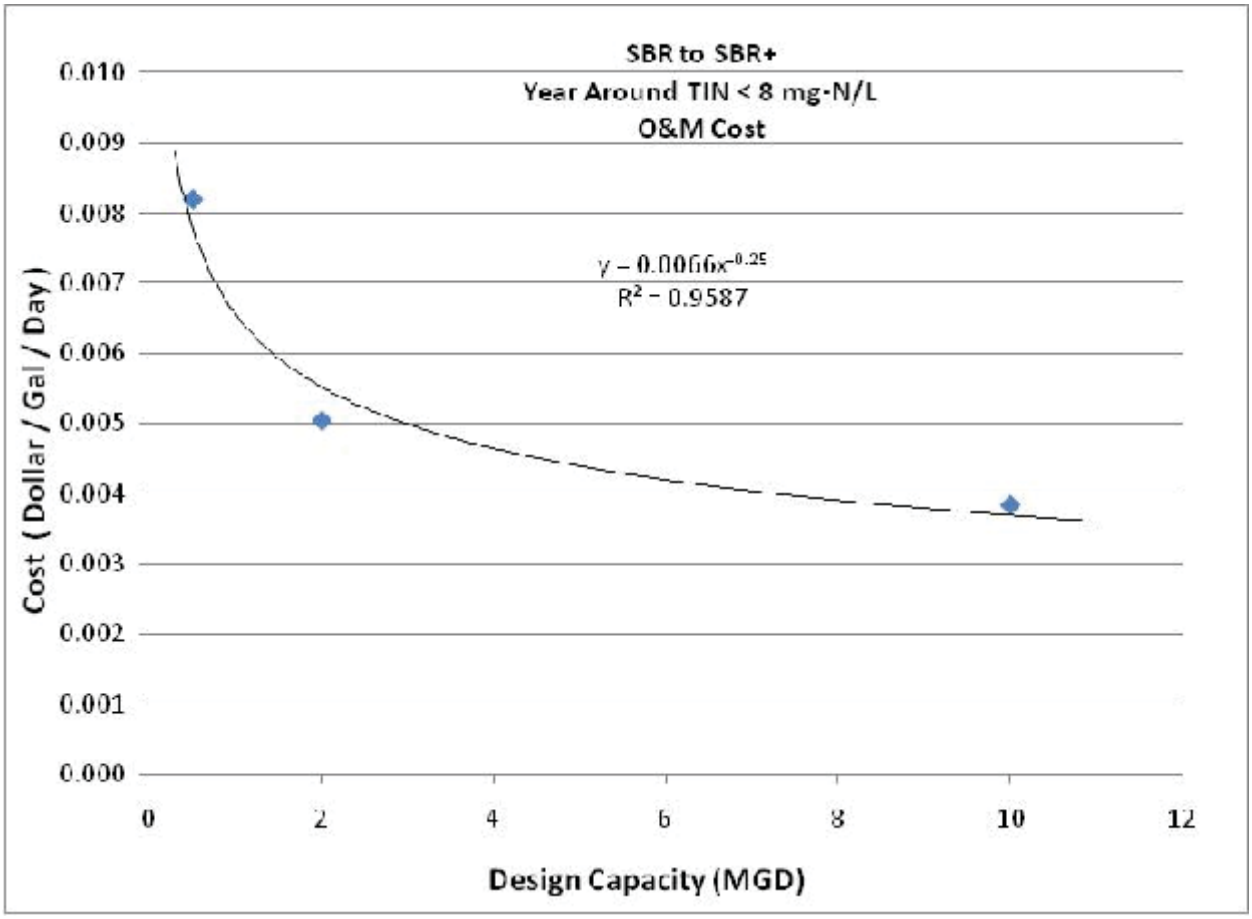

Figure 11-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective A Year-Round

TABLE 11-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$16,607	$34,807	$132,134
2014 O&M Cost	$4,615	$11,368	$43,332
Total Annual Cost	**$21,221**	**$46,175**	**$175,466**
Annual TIN Load Reduction (lb/yr)	2,245	8,979	44,895
Estimated Cost for TIN Reduction ($/lb TIN removed)	$9.45	$5.14	$3.91
Equation:[a]			$y = 83.25x^{-0.291}$
R-Square Value:			$R^2 = 0.9344$

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 11-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for a trickling filter plant. Figures 11-9 and 11-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-10 and Figures 11-11 and 11-12 summarize these costs for a trickling filter/solids contact plant. Table 11-11 and Figures 11-13 and 11-14 summarize these costs for an RBC plant. Tables 11-12, 11-13 and 11-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 11-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$8.19	$5.83	$3.82
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.29	$0.15	$0.08

TABLE 11-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.91	$5.27	$3.50
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.18	$0.13	$0.07

TABLE 11-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$8.19	$5.85	$3.87
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.35	$0.16	$0.09

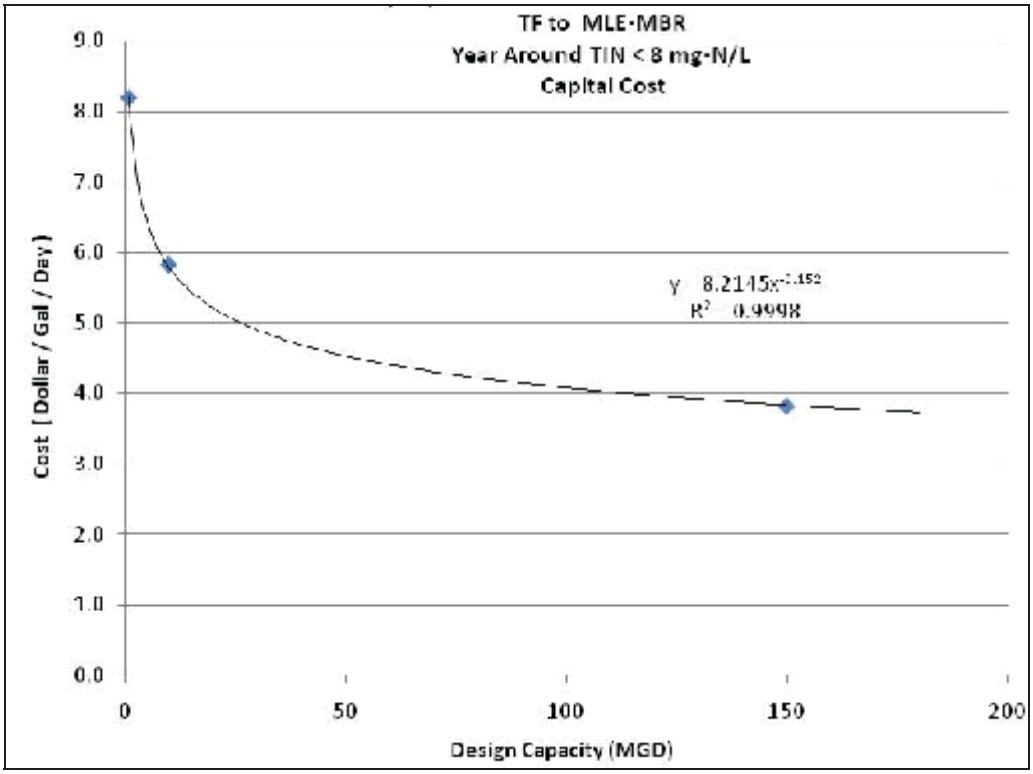

Figure 11-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective A Year-Round

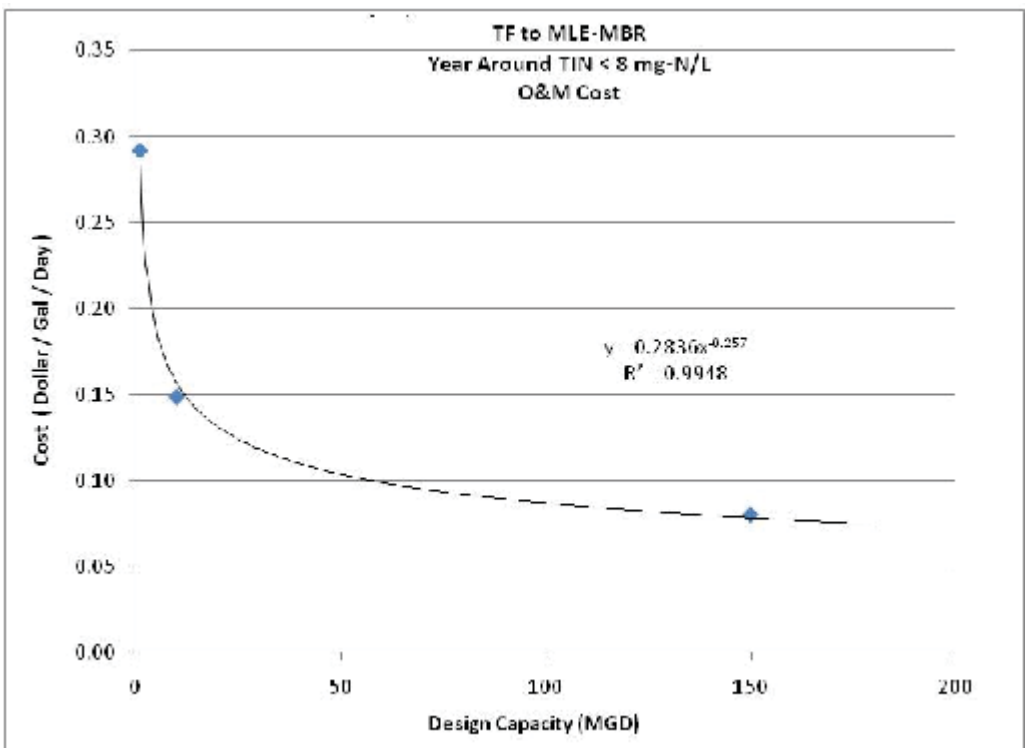

Figure 11-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective A Year-Round

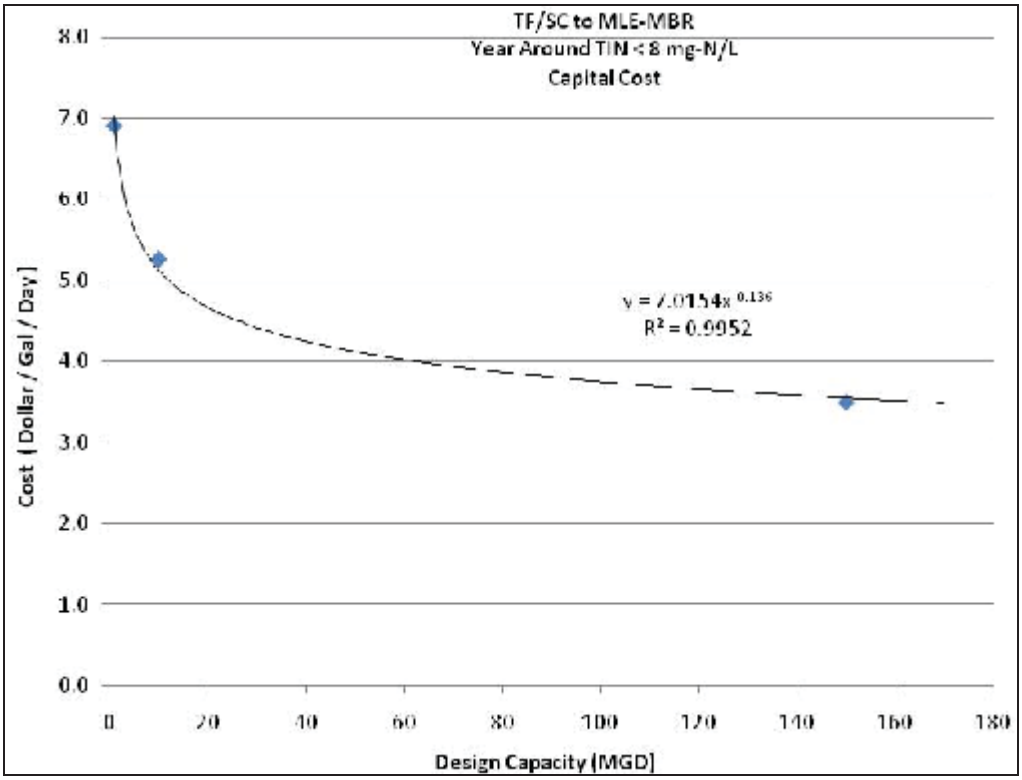

Figure 11-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective A Year-Round

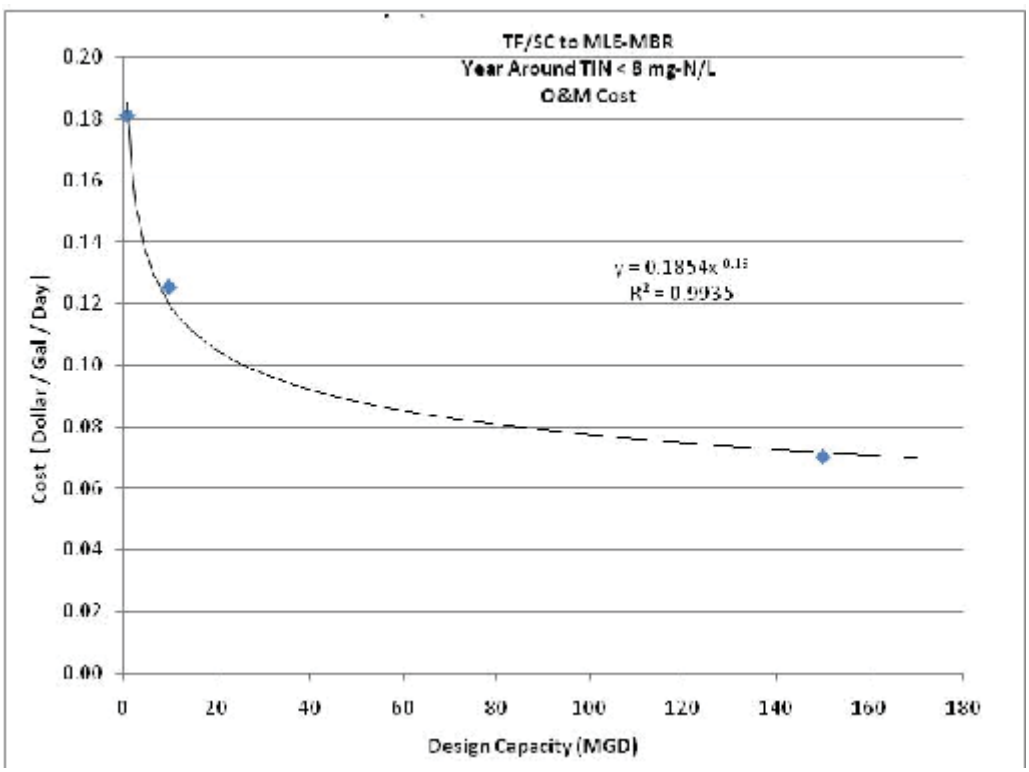

Figure 11-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective A Year-Round

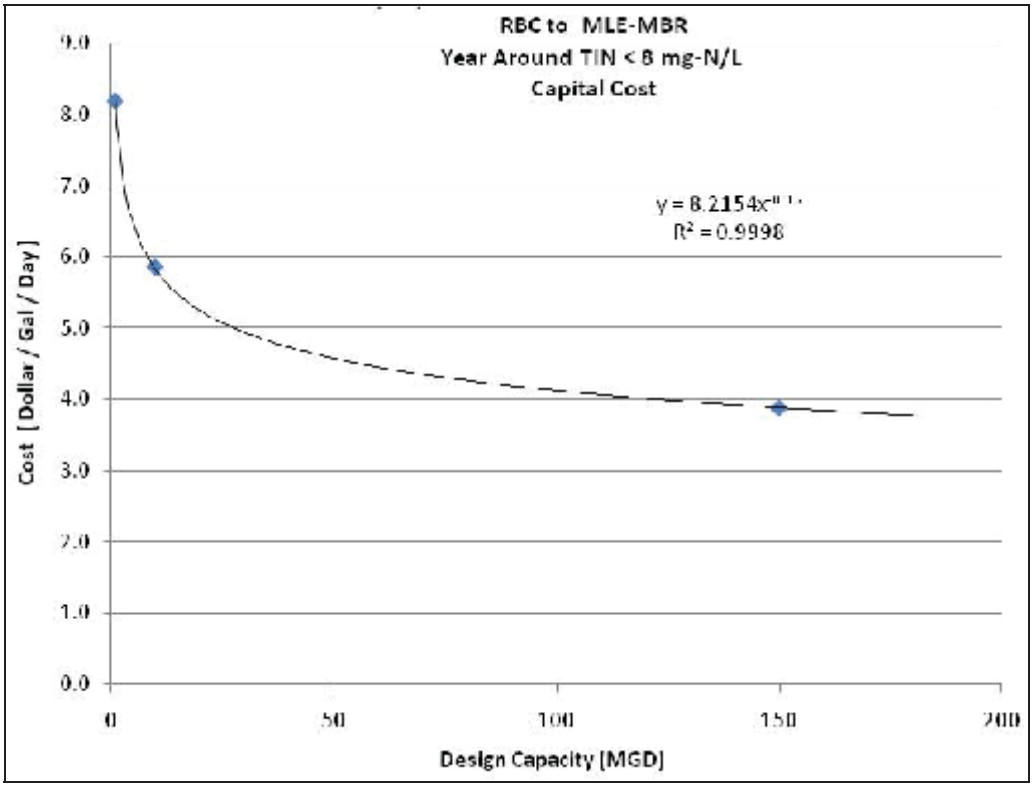

Figure 11-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective A Year-Round

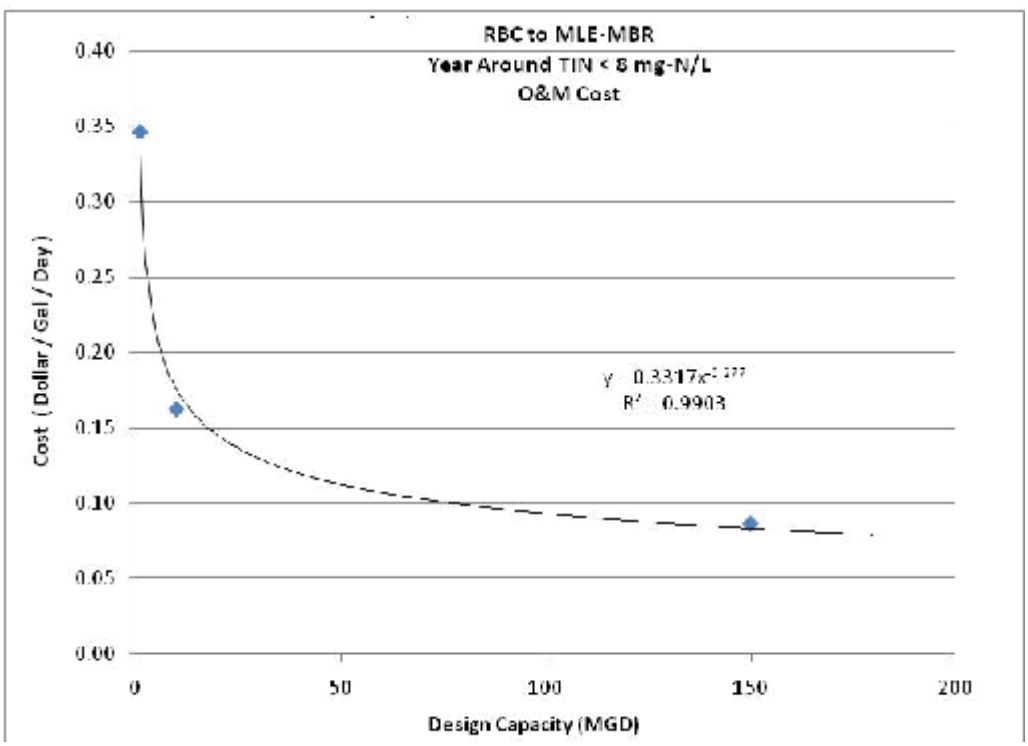

Figure 11-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective A Year-Round

TABLE 11-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$601,194	$4,278,563	$42,098,874
2014 O&M Cost	$328,594	$1,672,797	$13,518,789
Total Annual Cost	**$929,791**	**$5,951,361**	**$55,617,663**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$26.15	$16.74	$10.43

Equation:[a] ..... $y = 176.78x^{-0.183}$
R-Square Value: 0.9991

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$507,744	$3,870,296	$38,592,858
2014 O&M Cost	$203,721	$1,409,147	$11,856,412
Total Annual Cost	**$711,465**	**$5,279,443**	**$50,449,270**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$20.01	$14.85	$9.46

Equation:[a] ..... $y = 97.972x^{-0.15}$
R-Square Value: 0.995

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$601,523	$4,298,964	$42,622,884
2014 O&M Cost	$389,616	$1,824,178	$14,526,119
Total Annual Cost	**$991,139**	**$6,123,143**	**$57,149,004**
Annual TIN Load Reduction (lb/yr)	35,551	355,510	5,332,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$27.88	$17.22	$10.72

Equation:[a] ..... $y = 201.67x^{-0.19}$
R-Square Value: 0.9974

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.1.5 Membrane Biological Reactor Plants

No new facilities or activities are required to achieve Objective A for MBR plants, so there are no associated capital or O&M costs.

11.1.6 High-Purity Oxygen Activated Sludge Plants

Table 11-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for an HPO activated sludge plant. Figures 11-15 and 11-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	20-mgd Plant	220-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.91	$3.03
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.14

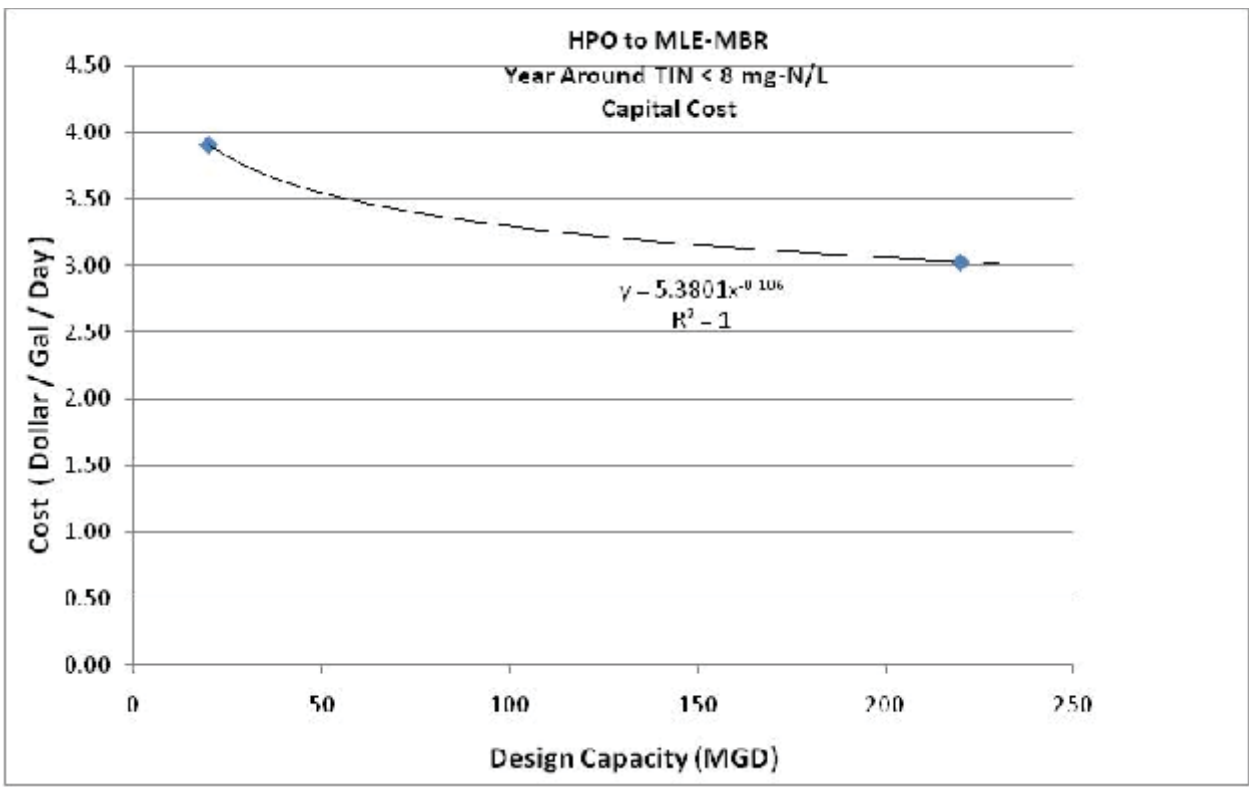

Figure 11-15. Capital Cost per Plant Capacity for HPO Plant Upgraded for Objective A Year-Round

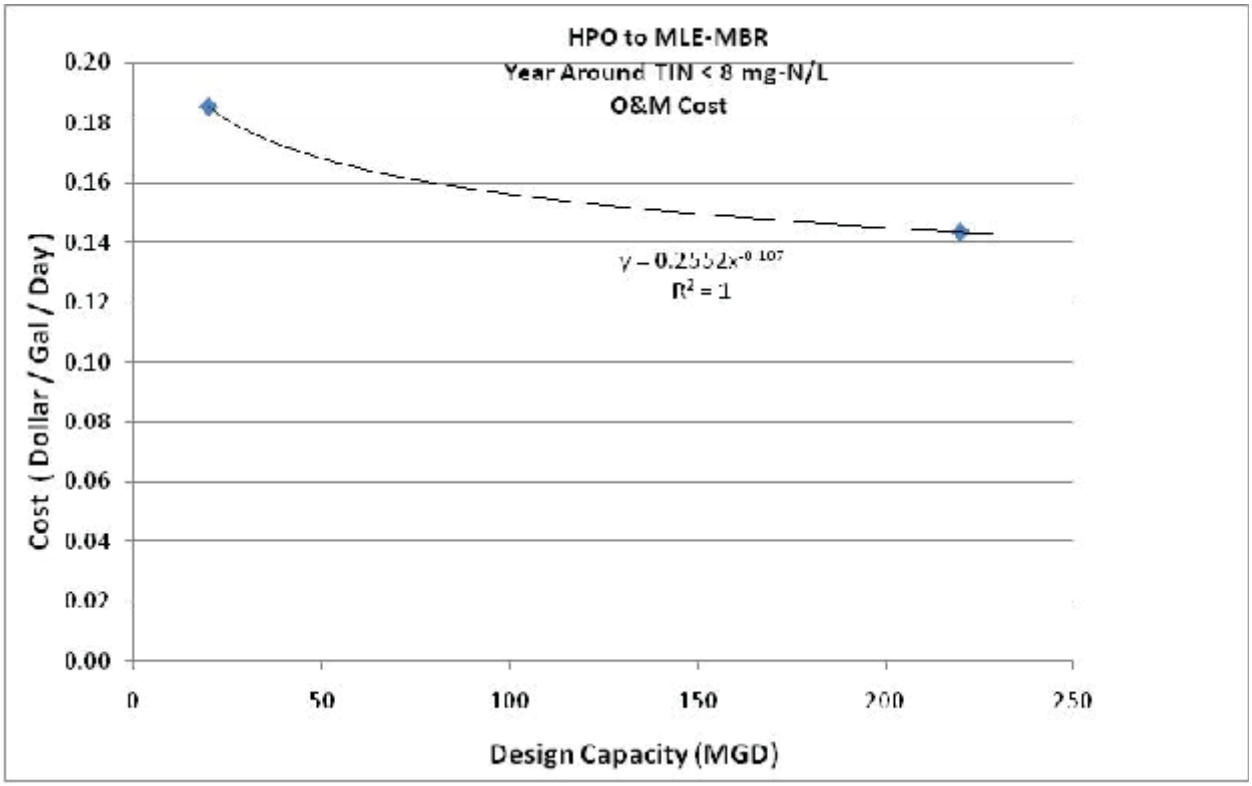

Figure 11-16. O&M Cost per Plant Capacity for HPO Plant Upgraded for Objective A Year-Round

TABLE 11-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	20-mgd Plant	220-mgd Plant
Annualized Capital Cost	$5,745,000	$48,960,000
2014 O&M Cost	$4,172,000	$35,520,000
Total Annual Cost	**$9,917,000**	**$87,480,000**
Annual TIN Load Reduction (lb/yr)	761,390	8,375,290
Estimated Cost for TIN Reduction ($/lb TIN removed)	$13.00	$10.10
Equation:[a]	$y = 54.946x^{-0.106}$	
R-Square Value:	1	

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.1.7 Aerated or Facultative Lagoon Plants

Table 11-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A year-round for an aerated lagoon plant. Figures 11-17 and 11-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-18 and Figures 11-19 and 11-20 summarize these costs for a facultative lagoon plant. Tables 11-19 and 11-20 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 11-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$22.33	$17.04	$11.18	$6.58
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.91	$0.53	$0.23	$0.11

TABLE 11-18.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$22.19	$16.92	$11.09	$6.53
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.18	$0.77	$0.40	$0.14

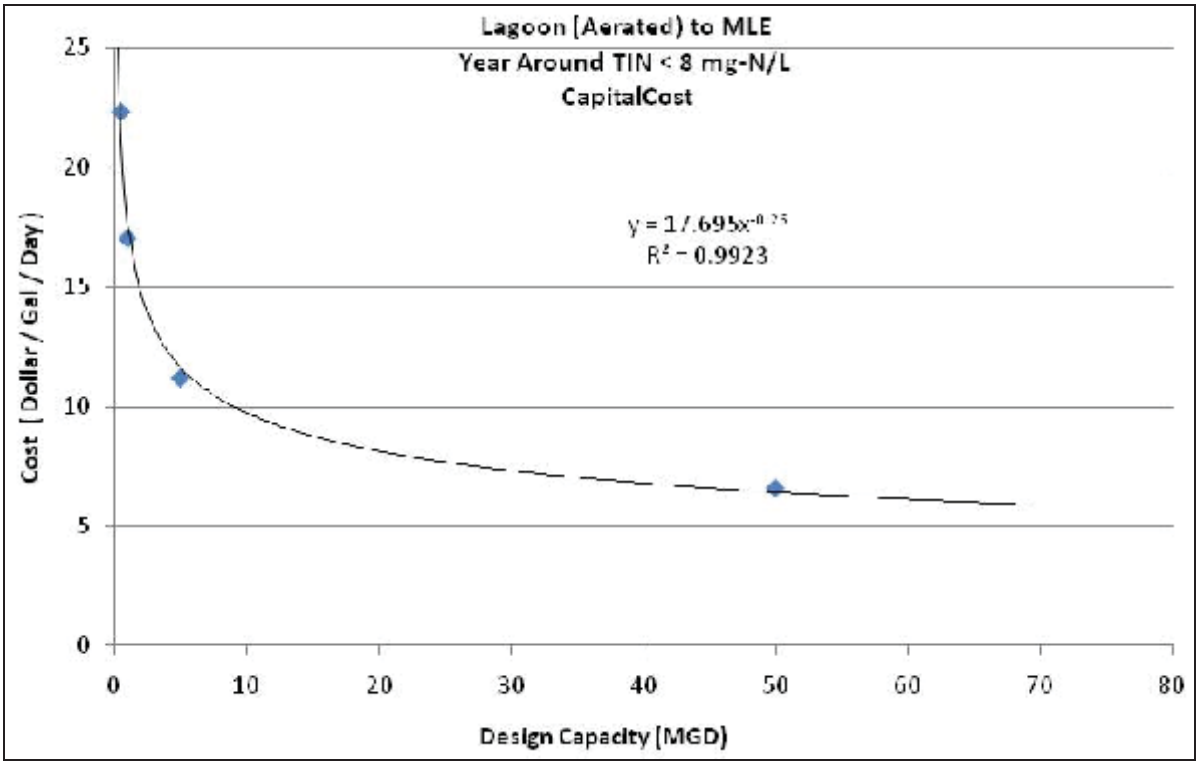

Figure 11-17. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective A Year-Round

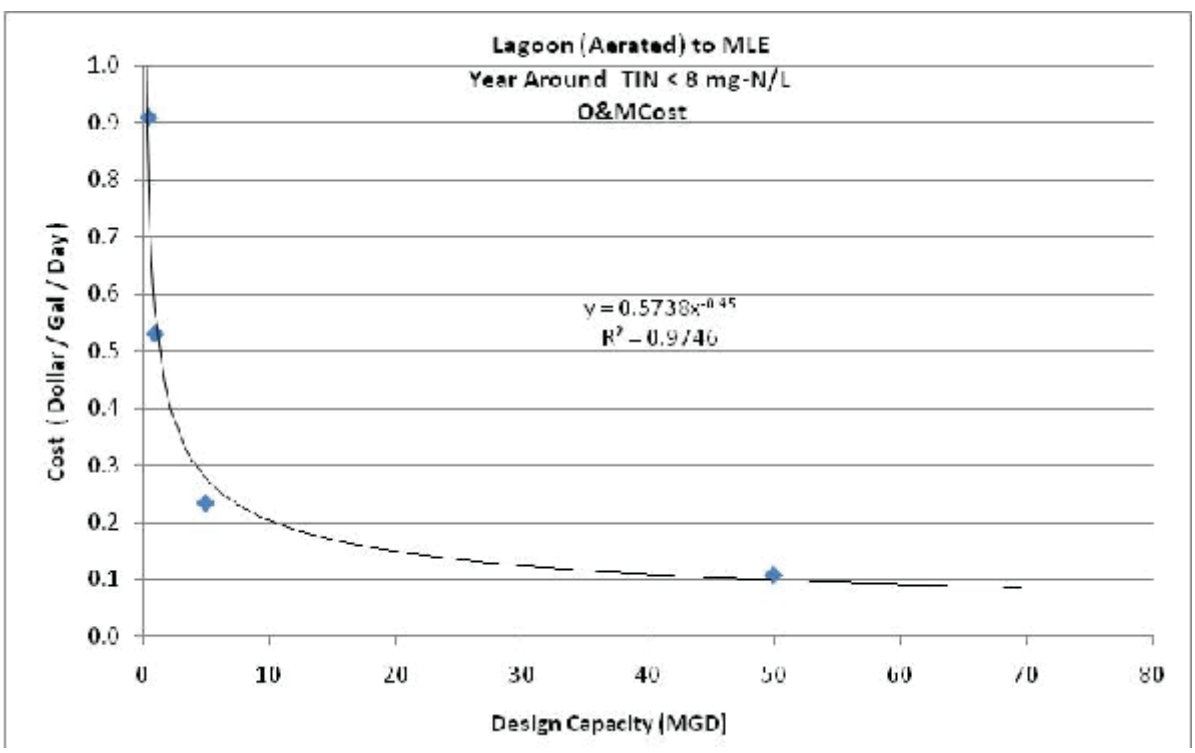

Figure 11-18. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective A Year-Round

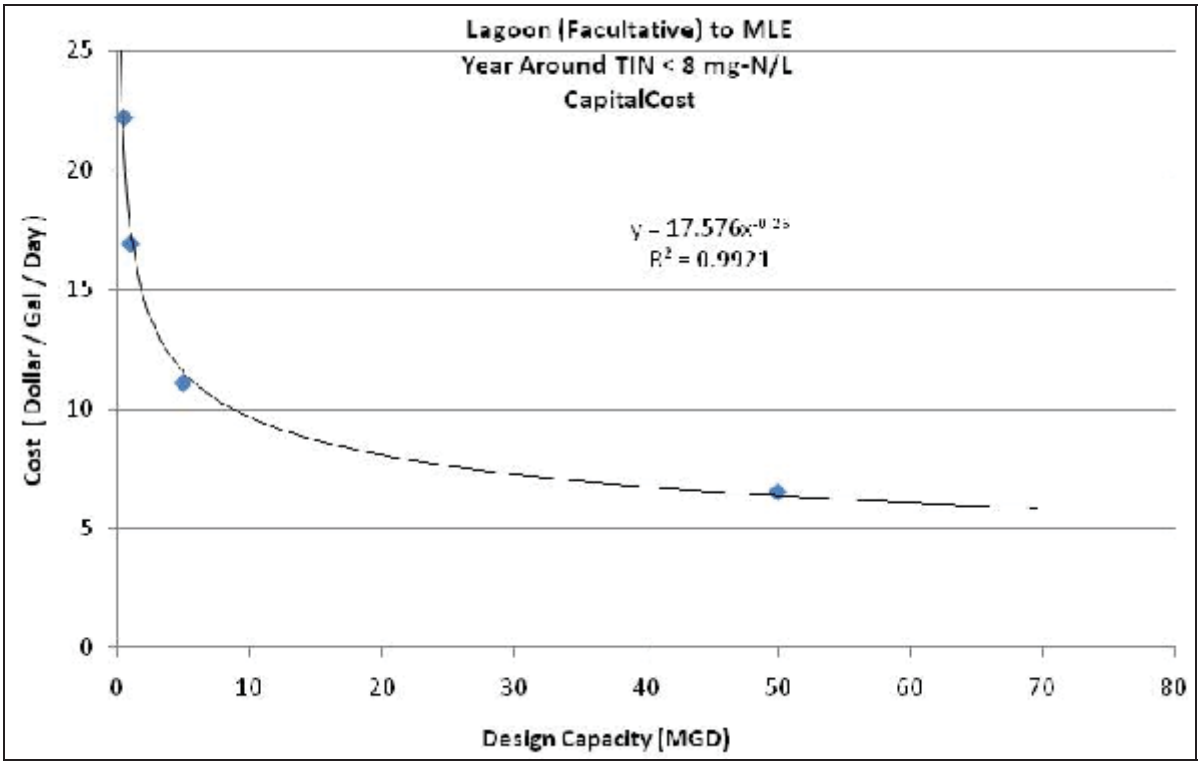

Figure 11-19. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective A Year-Round

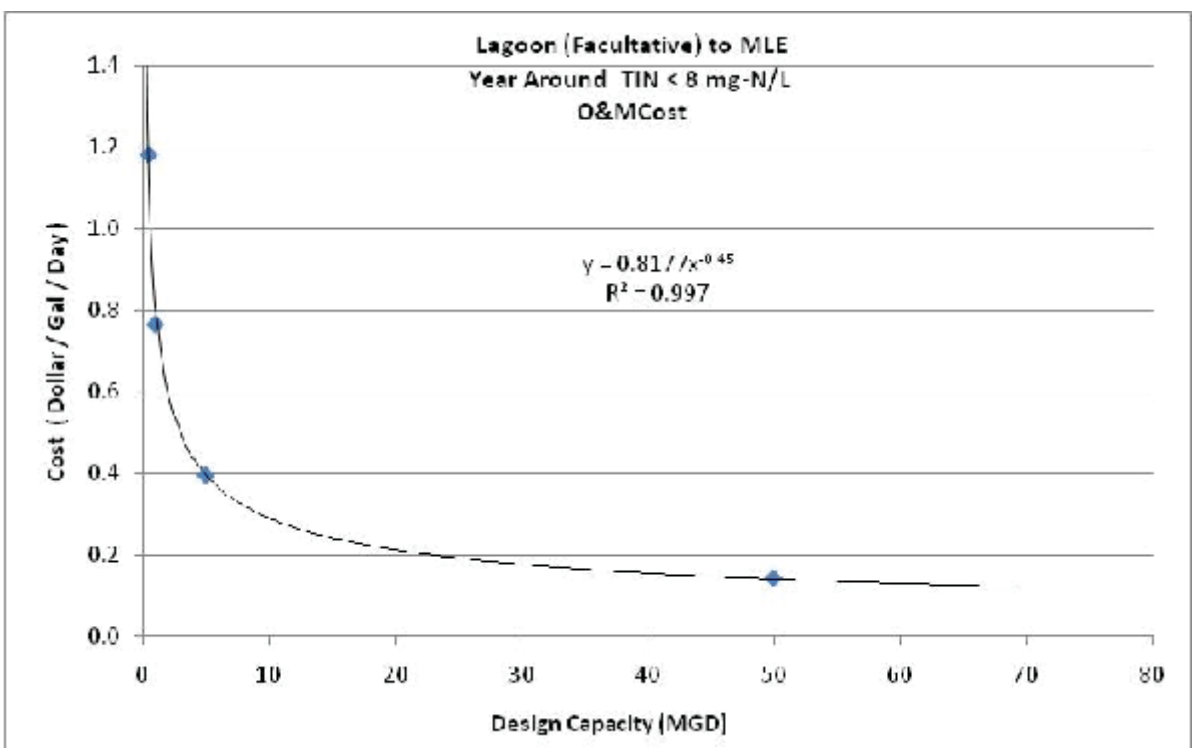

Figure 11-20. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective A Year-Round

TABLE 11-19.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$82,0052	$1,251,455	$4,106,942	$24,168,643
2014 O&M Cost	$512,439	$598,073	$1,321,179	$6,109,993
Total Annual Cost	**$1,332,490**	**$1,849,528**	**$5,428,120**	**$30,278,636**
Annual TIN Load Reduction (lb/yr)	17,593	35,186	175,930	1,755,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$75.74	$52.26	$30.85	$17.25
Equation:[a]				$y = 1458.7x^{-0.312}$
R-Square Value:				0.982

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-20.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$815,034	$1,242,982	$4,073,790	$23,994,247
2014 O&M Cost	$665,608	$861,751	$2,224,005	$7,997,263
Total Annual Cost	**$1,480,641**	**$2,104,734**	**$6,297,796**	**$31,991,510**
Annual TIN Load Reduction (lb/yr)	17,593	35,186	175,930	1,755,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$63.89	$44.77	$35.80	$18.22
Equation:[a]				$y = 725.24x^{-0.255}$
R-Square Value:				0.9728

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2 SEASONAL NUTRIENT REMOVAL

11.2.1 Extended Aeration Plants

Table 11-21 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for an extended aeration plant using mechanical aeration. Figures 11-21 and 11-22 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-22 and Figures 11-23 and 11-24 summarize these costs for an extended aeration plant using diffuser aeration. Tables 11-23 and 11-24 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 11-21.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.37	$2.28	$2.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.04	$0.01

TABLE 11-22.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.64	$0.79	$0.40
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.03	($0.02)	($0.02)

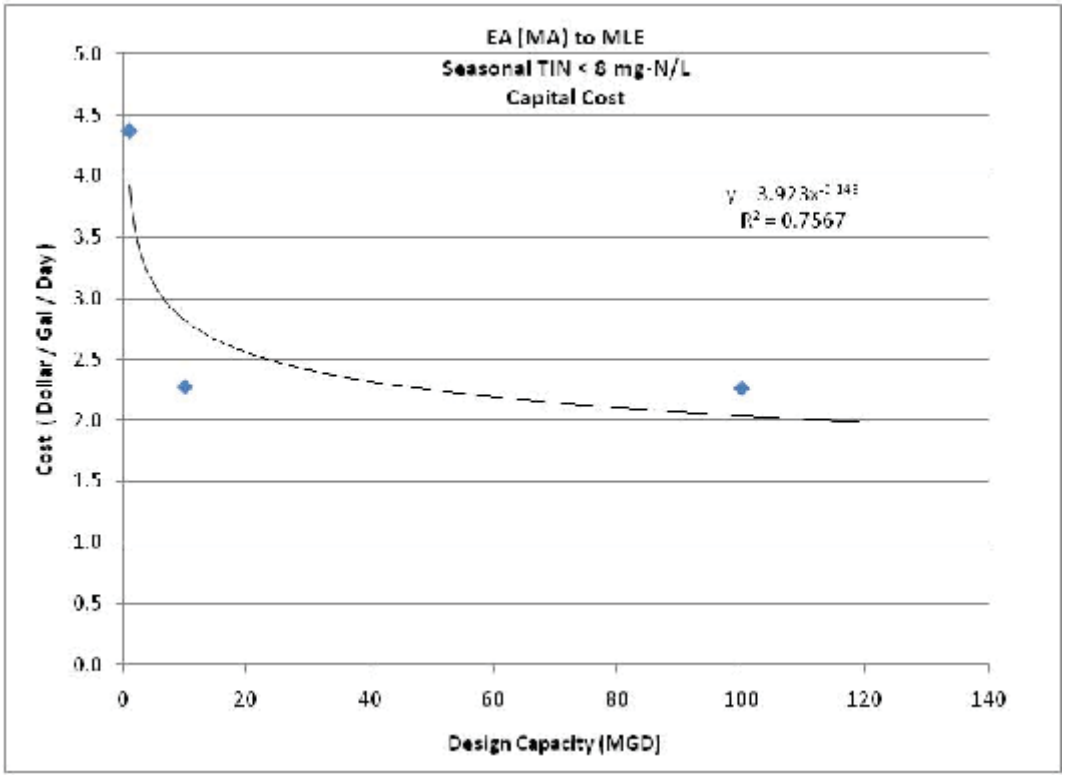

Figure 11-21. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective A Seasonally

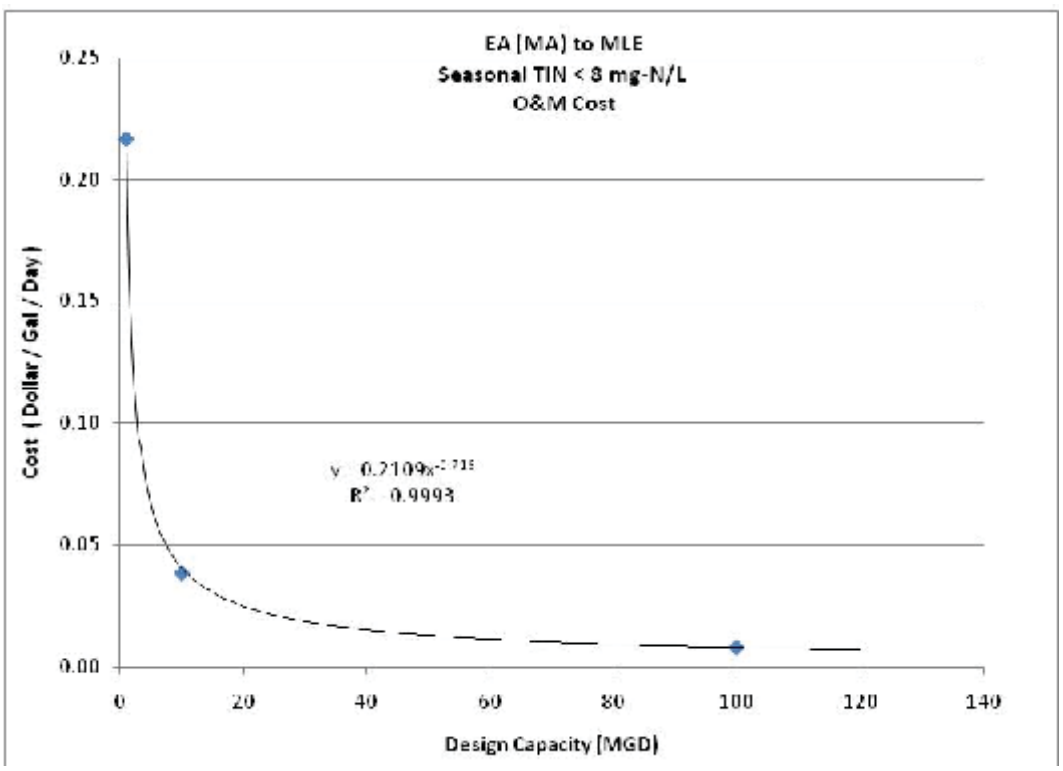

Figure 11-22. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective A Seasonal

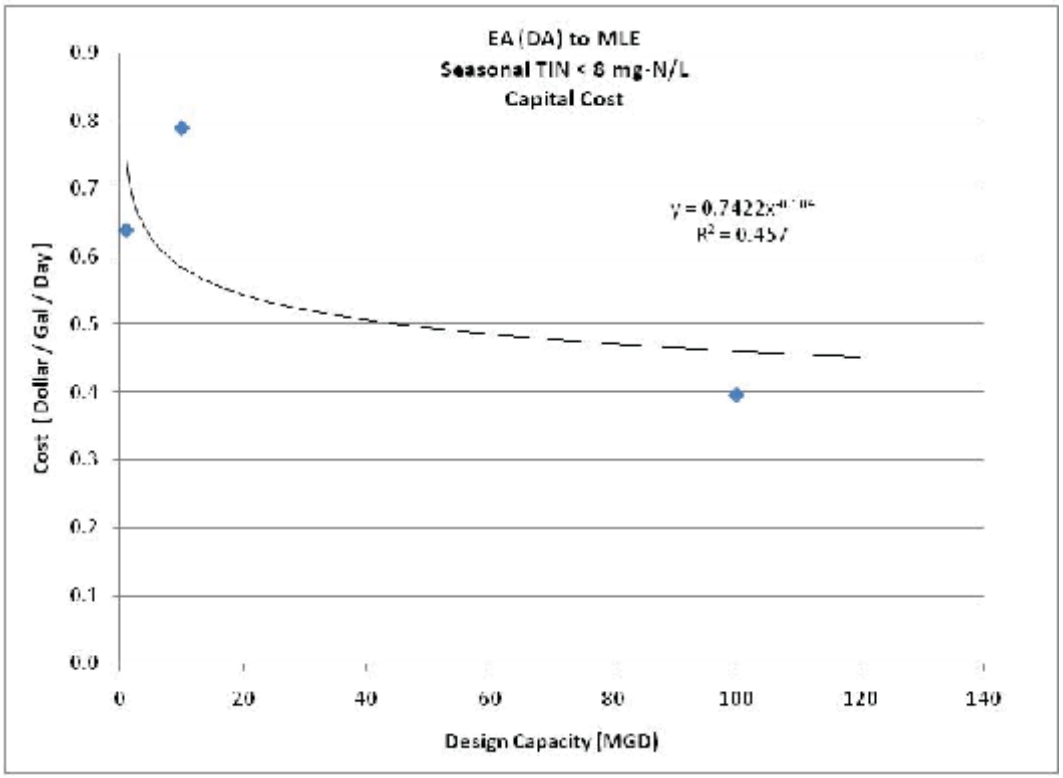

Figure 11-23. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective A Seasonally

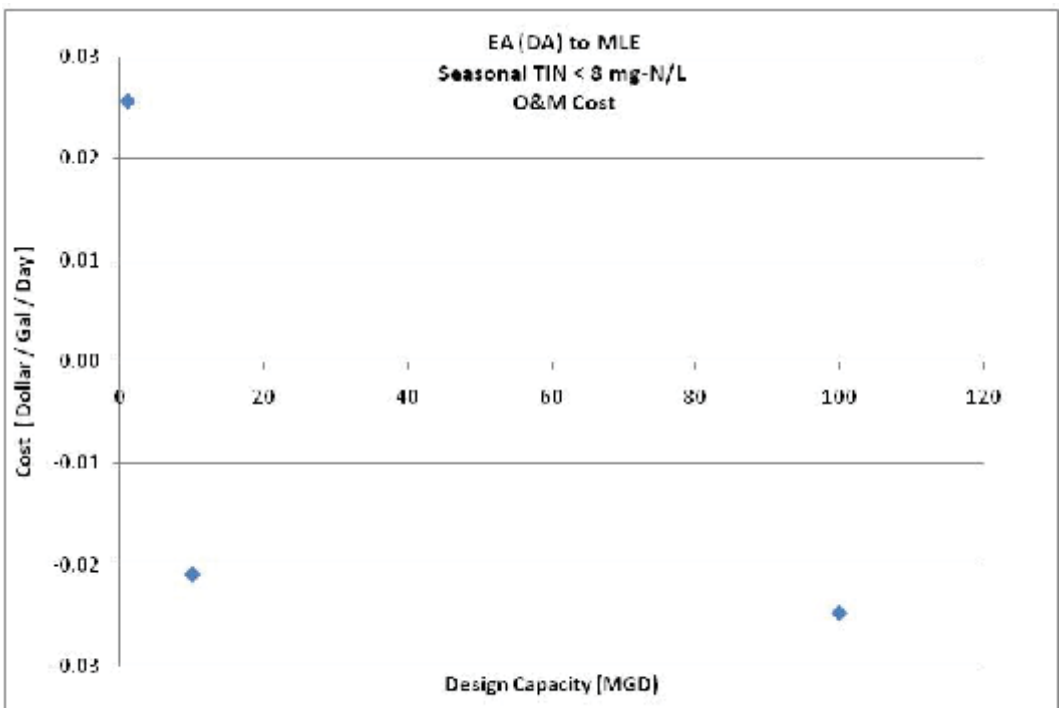

Figure 11-24. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective A Seasonal

TABLE 11-23.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$320,823	$1,674,036	$16,642,677
2014 O&M Cost	$243,560	$433,659	$901,533
Total Annual Cost	**$564,383**	**$2,107,695**	**$17,544,210**
Annual TIN Load Reduction (lb/yr)	19,418	194,180	1,941,800
Estimated Cost for TIN Reduction ($/lb TIN removed)	$29.06	$10.85	$9.04
Equation:[a]			$y = 310.83x^{-0.254}$
R-Square Value:			0.8639

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-24.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$46,889	$579,949	$2,904,885
2014 O&M Cost	$28,926	-$235,231	-$2,777,193
Total Annual Cost	**$75,815**	**$344,717**	**$127,692**
Annual TIN Load Reduction (lb/yr)	19,400	193,998	1,939,975
Estimated Cost for TIN Reduction ($/lb TIN removed)	$3.91	$1.78	$0.07
Equation:[a]			$y = 32735x^{-0.874}$
R-Square Value:			0.8901

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2.2 Conventional Activated Sludge Plants

Table 11-25 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for a conventional activated sludge plant. Figures 11-25 and 11-26 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-26 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-25.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.35	$1.18	$1.40
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.16	$0.04	$0.02

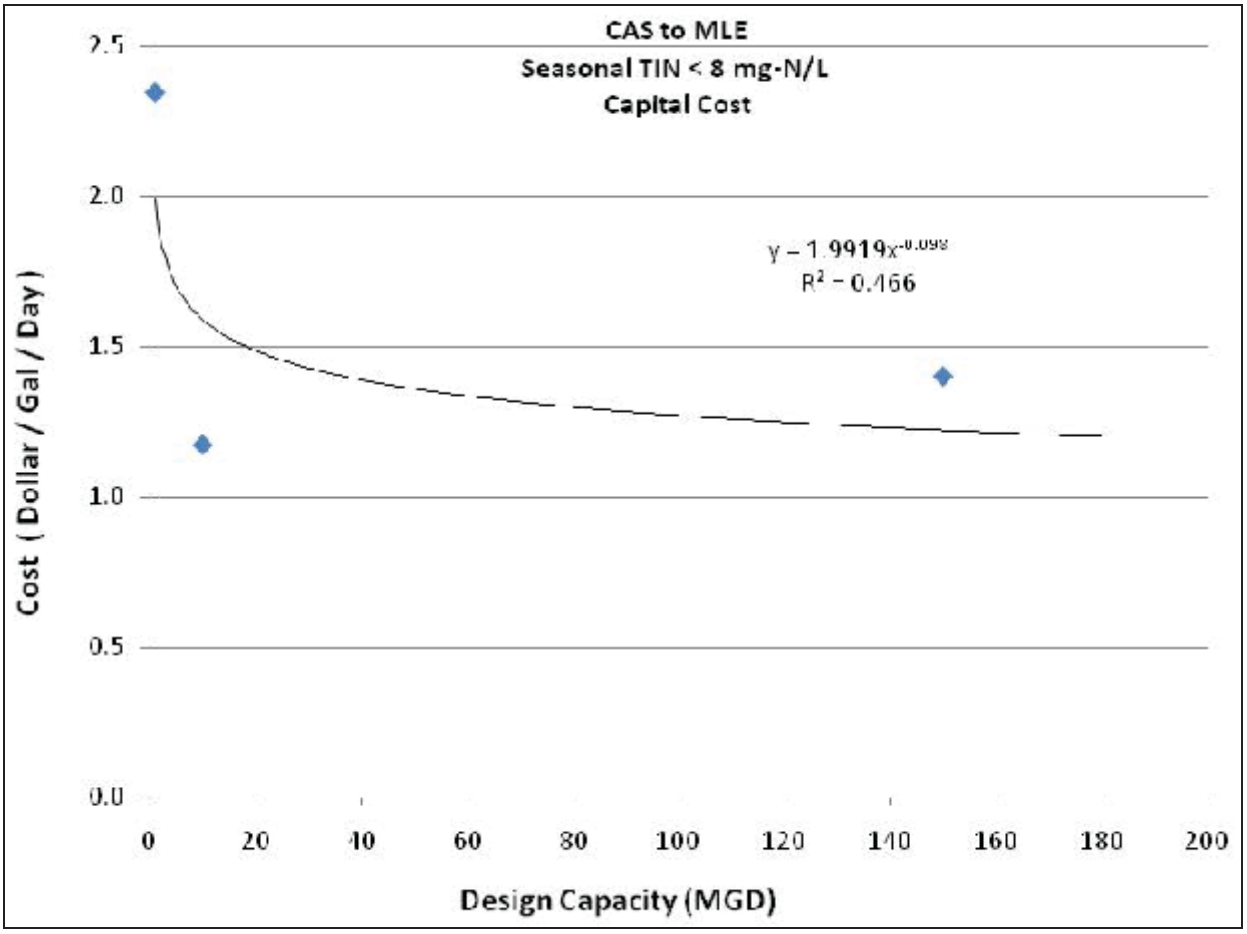

Figure 11-25. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective A Seasonally

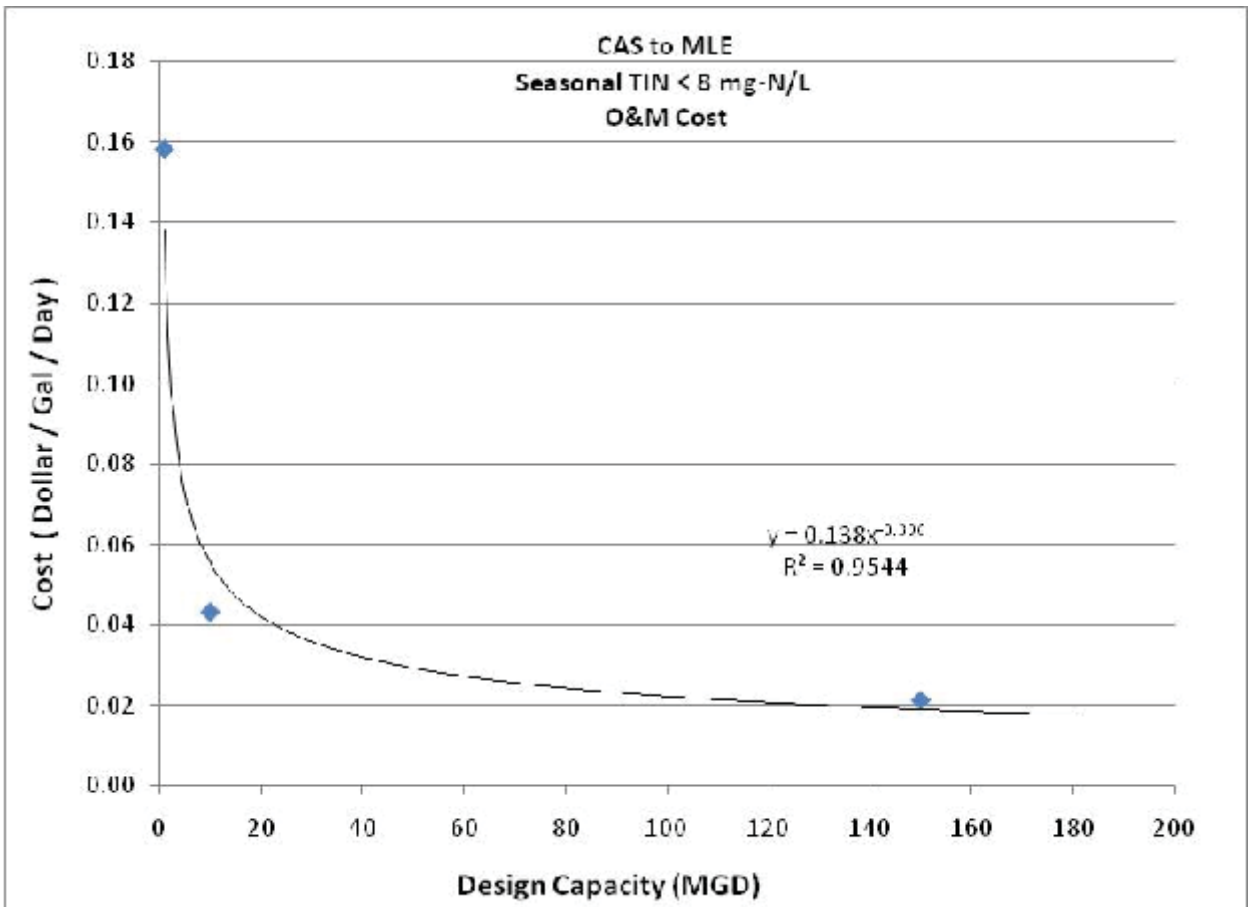

Figure 11-26. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective A Seasonal

TABLE 11-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$172,242	$864,178	$15,467,709
2014 O&M Cost	$177,887	$486,220	$3,598,252
Total Annual Cost	**$350,129**	**$1,350,397**	**$19,065,961**
Annual TIN Load Reduction (lb/yr)	19,455	194,545	2,918,175
Estimated Cost for TIN Reduction ($/lb TIN removed)	$18.00	$6.94	$6.53
Equation:[a]			$y = 105.86x^{-0.197}$
R-Square Value:			0.7559

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2.3 Sequencing Batch Reactor Plants

Table 11-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for an SBR plant. Figures 11-27 and 11-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.42	$0.22	$0.16
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.00	($0.00)	$0.0004

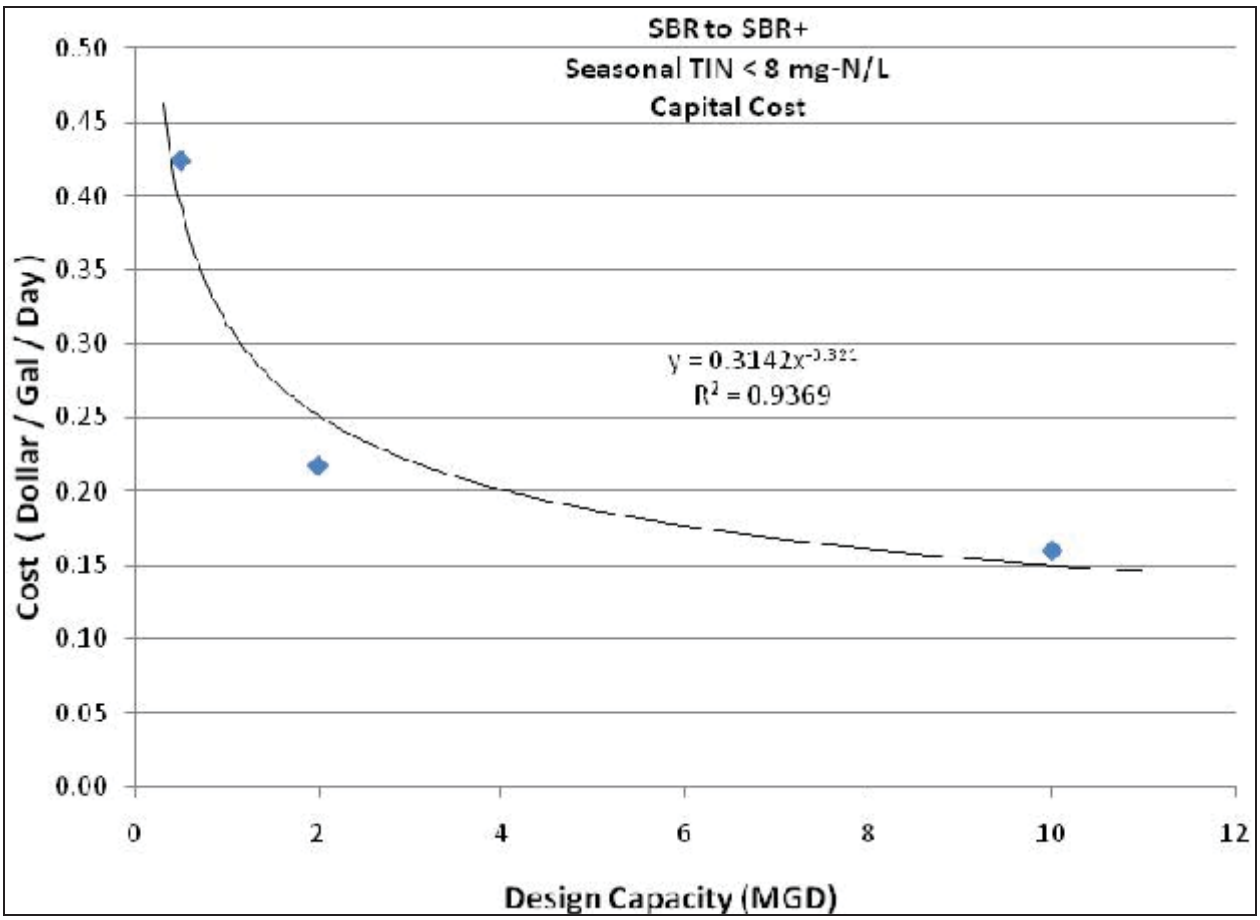

Figure 11-27. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective A Seasonally

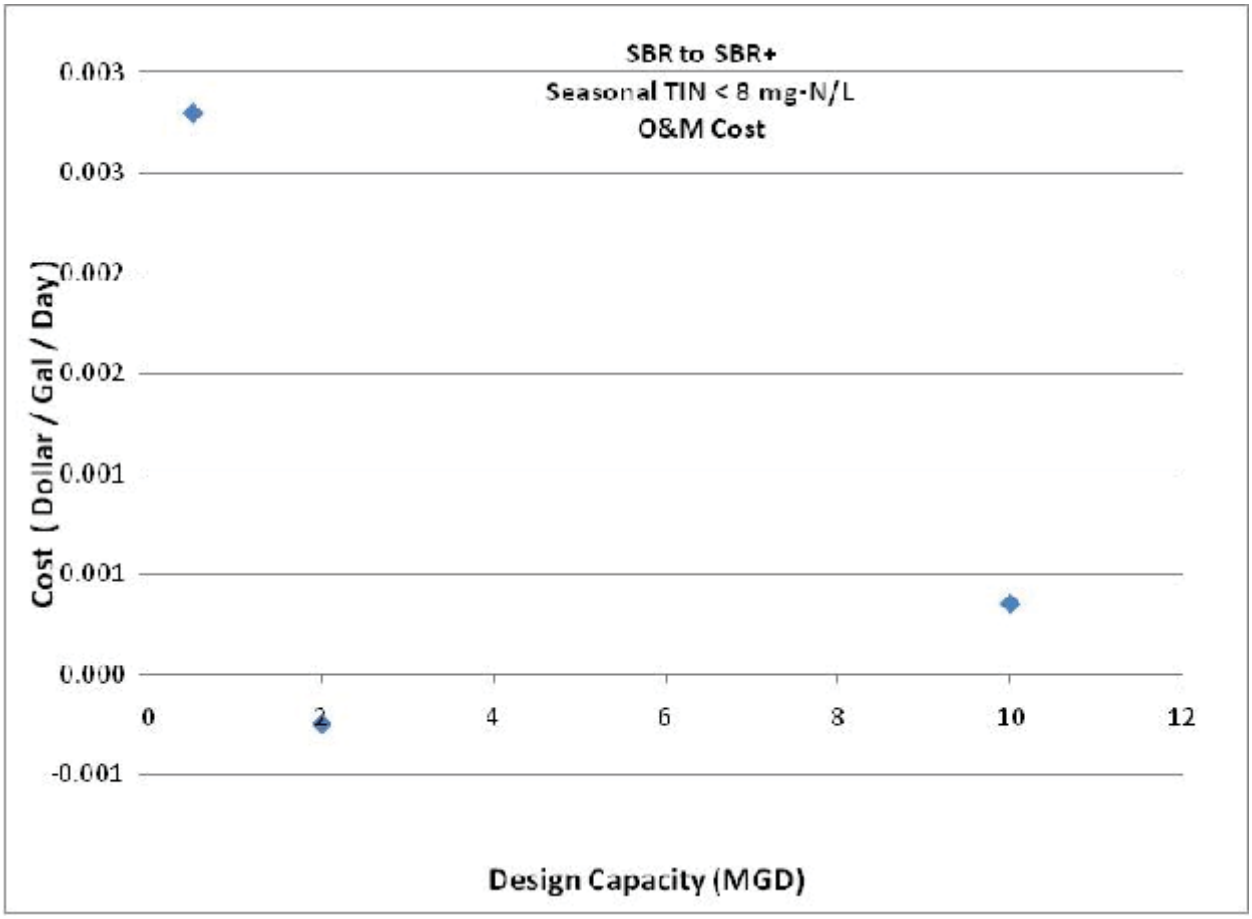

Figure 11-28. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective A Seasonal

TABLE 11-28.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$15,578	$31,979	$117,738
2014 O&M Cost	$1,576	-$563	$3,939
Total Annual Cost	**$17,154**	**$31,417**	**$121,677**
Annual TIN Load Reduction (lb/yr)	246	986	4,928
Estimated Cost for TIN Reduction ($/lb TIN removed)	$69.63	$31.88	$24.69

Equation:[a] ..... $y = 408.67x^{-0.341}$
R-Square Value: 0.8967

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 11-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for a trickling filter plant. Figures 11-29 and 11-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-30 and Figures 11-31 and 11-32 summarize these costs for a trickling filter/solids contact plant. Table 11-31 and Figures 11-33 and 11-34 summarize these costs for an RBC plant. Tables 11-32, 11-33 and 11-34 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 11-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.68	$2.80	$2.18
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.06	$0.02

TABLE 11-30.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.94	$2.11	$1.77
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.11	$0.04	$0.01

TABLE 11-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.71	$2.83	$2.22
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.27	$0.08	$0.03

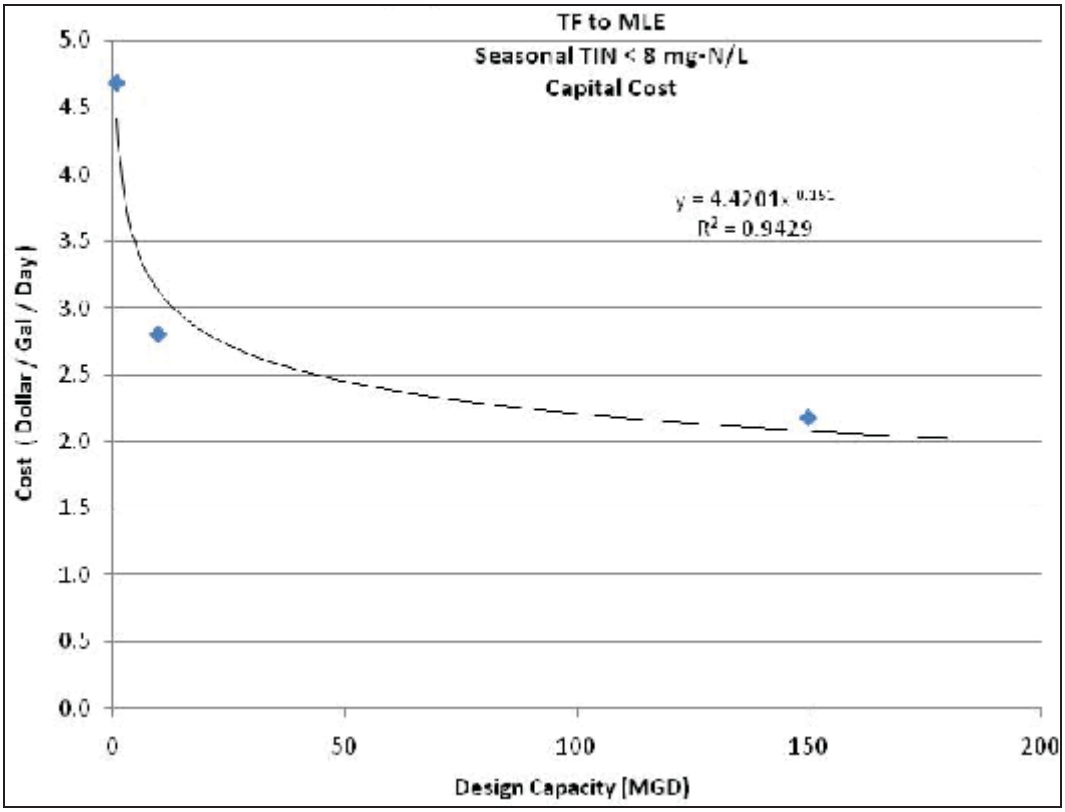

Figure 11-29. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective A Seasonally

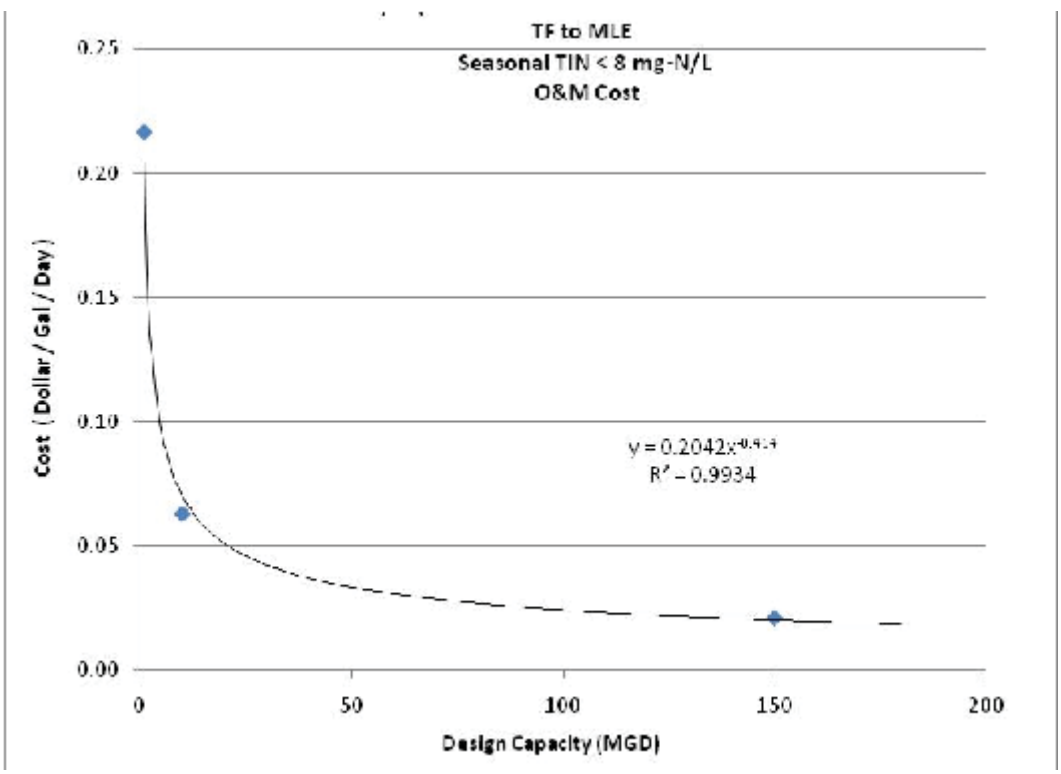

Figure 11-30. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective A Seasonal

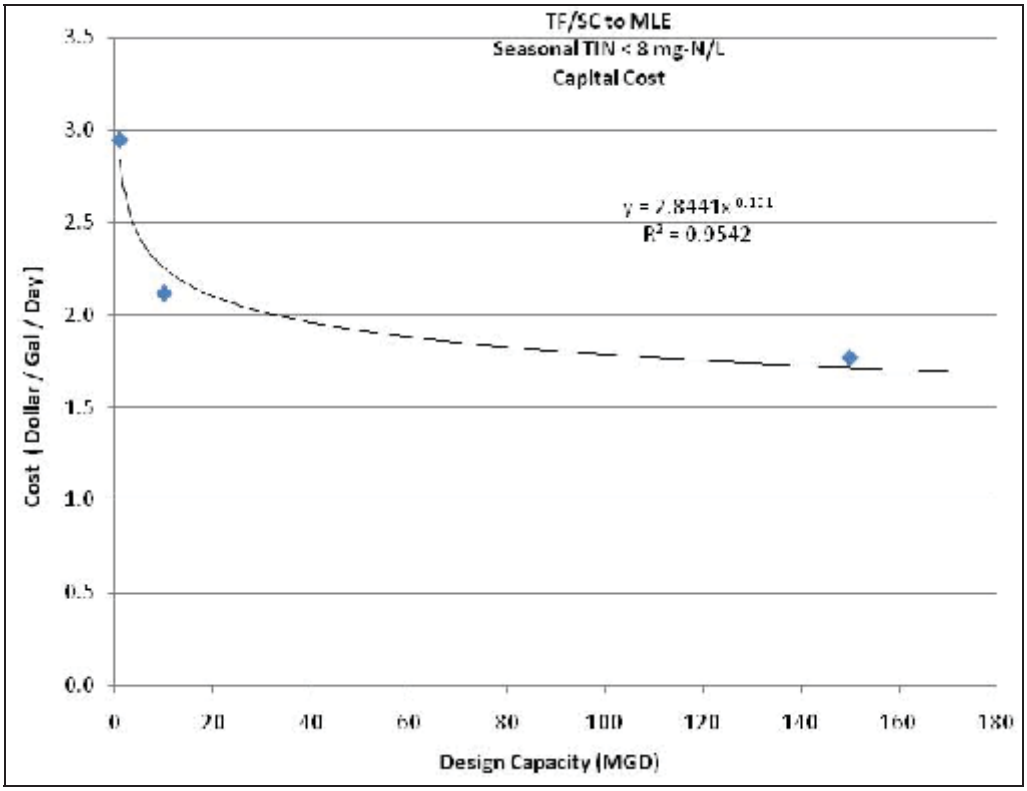

Figure 11-31. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective A Seasonally

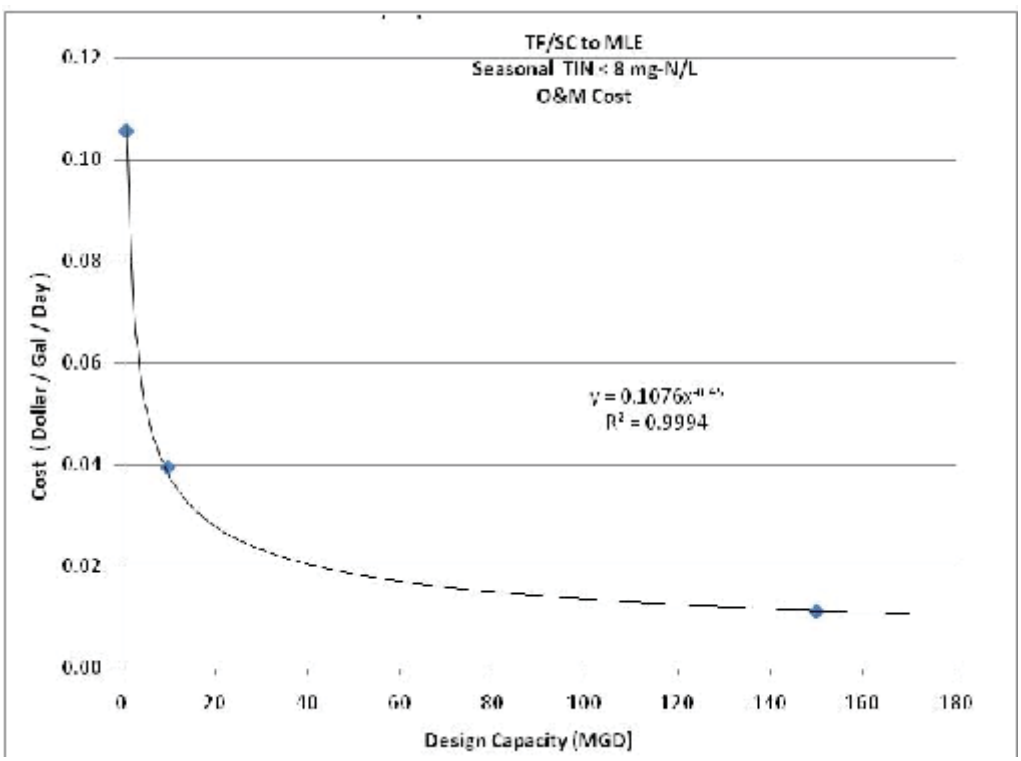

Figure 11-32. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective A Seasonal

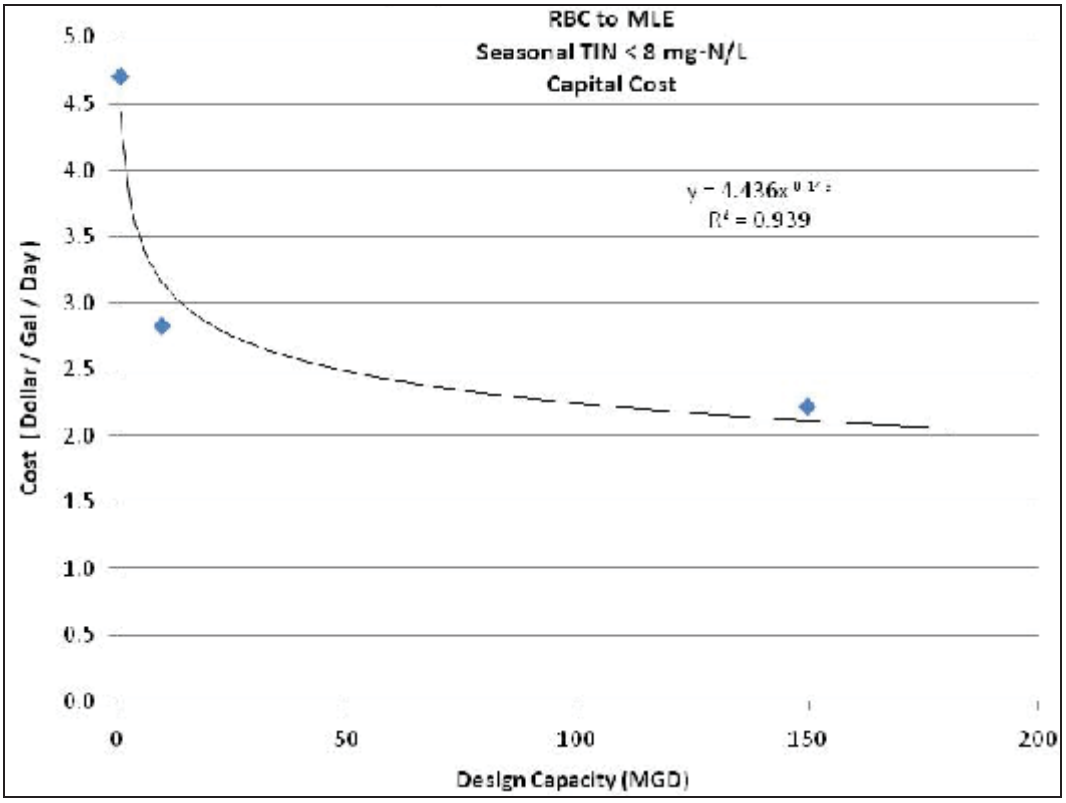

Figure 11-33. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective A Seasonally

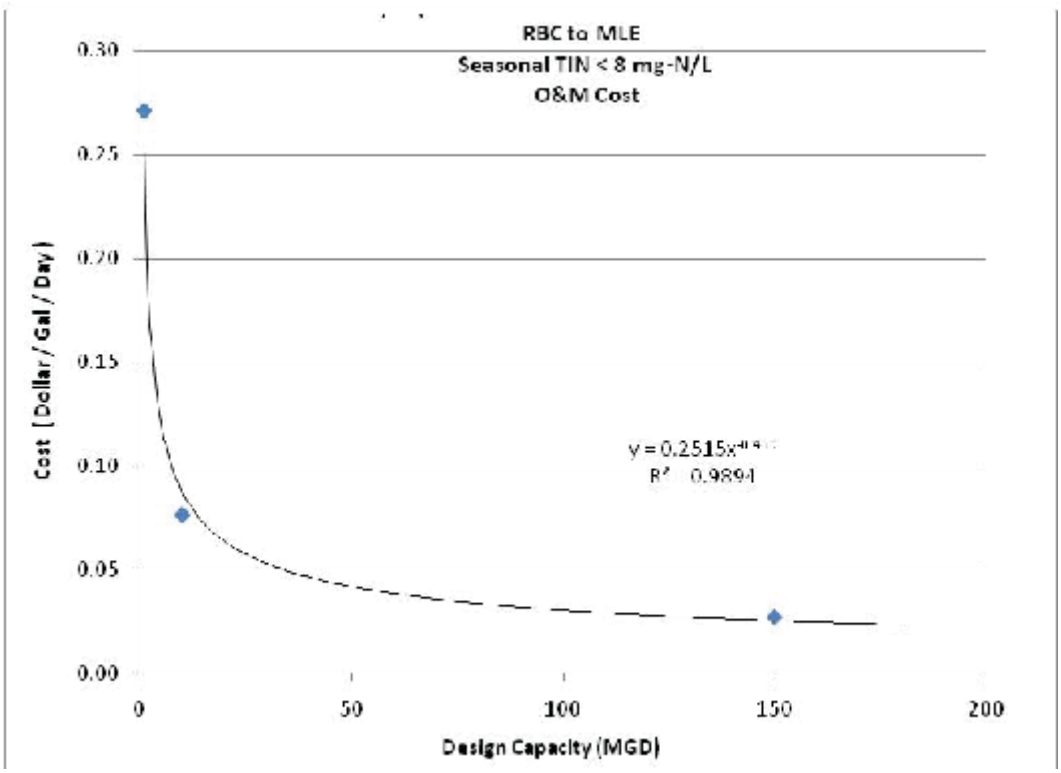

Figure 11-34. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective A Seasonal

TABLE 11-32.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$344,062	$2,059,887	$24,020,776
2014 O&M Cost	$243,841	$707,439	$3,538,037
Total Annual Cost	**$587,903**	**$2,767,326**	**$27,558,813**
Annual TIN Load Reduction (lb/yr)	19,455	194,545	2,918,175
Estimated Cost for TIN Reduction ($/lb TIN removed)	$30.22	$14.22	$9.44
Equation:[a]			$y = 270.37x^{-0.23}$
R-Square Value:			0.9541

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-33.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$216,251	$1,552,823	$19,453,578
2014 O&M Cost	$118,966	$443,788	$1,875,660
Total Annual Cost	**$335,217**	**$1,996,611**	**$21,329,238**
Annual TIN Load Reduction (lb/yr)	19,455	194,545	2,918,175
Estimated Cost for TIN Reduction ($/lb TIN removed)	$17.23	$10.26	$7.31
Equation:[a]			$y = 88.118x^{-0.17}$
R-Square Value:			0.9724

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$345,625	$2,077,327	$24,474,041
2014 O&M Cost	$304,861	$858,819	$4,545,367
Total Annual Cost	**$650,486**	**$2,936,146**	**$29,019,409**
Annual TIN Load Reduction (lb/yr)	19,455	194,545	2,918,175
Estimated Cost for TIN Reduction ($/lb TIN removed)	$33.44	$15.09	$9.94
Equation:[a]			$y = 327.02x^{-0.24}$
R-Square Value:			0.9503

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2.5 Membrane Biological Reactor Plants

No new facilities or activities are required to achieve Objective A for MBR plants, so there are no associated capital or O&M costs.

11.2.6 High-Purity Oxygen Activated Sludge Plants

Table 11-35 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for an HPO plant. Figures 11-35 and 11-36 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-36 presents the annualized unit costs for reducing nutrient loads.

TABLE 11-35.
ESTIMATED COST PER CAPACITY FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	20-mgd Plant	220-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$1.24
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.11	$0.09

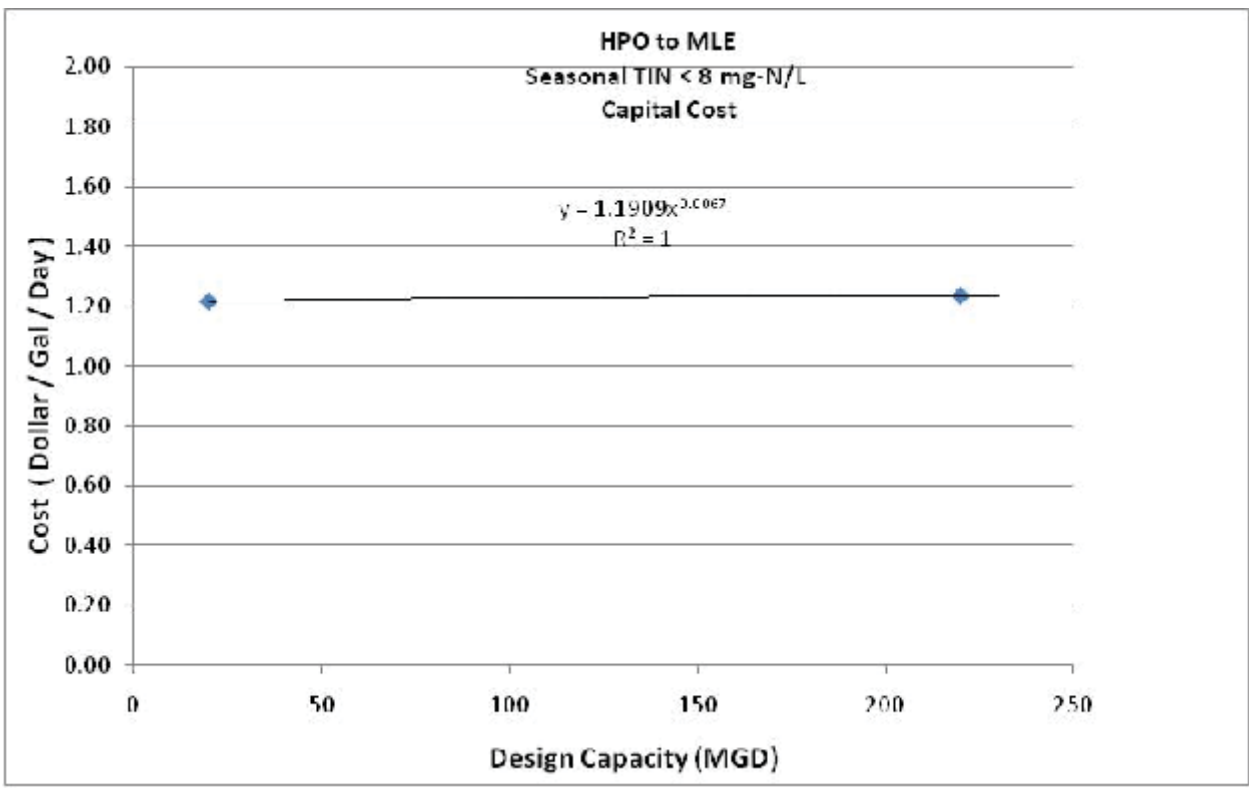

Figure 11-35. Capital Cost per Plant Capacity for HPO Plant Upgraded for Objective A Seasonal

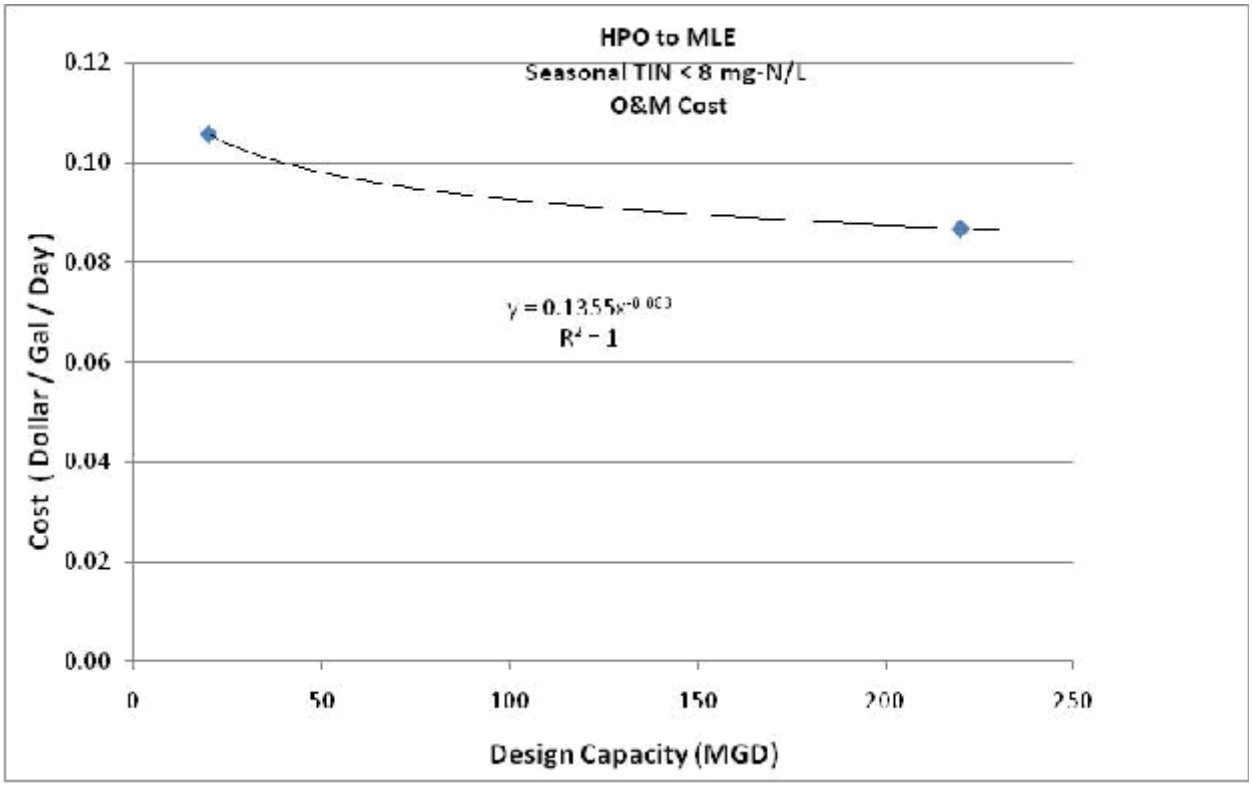

Figure 11-36. O&M Cost per Plant Capacity for HPO Plant Upgraded for Objective A Seasonal

TABLE 11-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	20-mgd Plant	220-mgd Plant
Annualized Capital Cost	$1,785,000	$19,957,000
2014 O&M Cost	$2,381,000	$21,479,000
Total Annual Cost	**$4,166,000**	**$41,436,000**
Annual TIN Load Reduction (lb/yr)	401,500	4,416,500
Estimated Cost for TIN Reduction ($/lb TIN removed)	$10.40	$9.40
Equation:[a]	$y = 17.903x^{-0.042}$	
R-Square Value:	1	

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

11.2.7 Aerated or Facultative Lagoon Plants

Table 11-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective A seasonally for an aerated lagoon plan. Figures 11-37 and 11-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 11-38 and Figures 11-39 and 11-40 summarize these costs for a facultative lagoon plant. Tables 11-39 and 11-40 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 11-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$21.49	$16.16	$10.54	$6.78
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.87	$0.51	$0.22	$0.08

TABLE 11-38.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$21.35	$16.04	$10.45	$6.74
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.14	$0.74	$0.38	$0.11

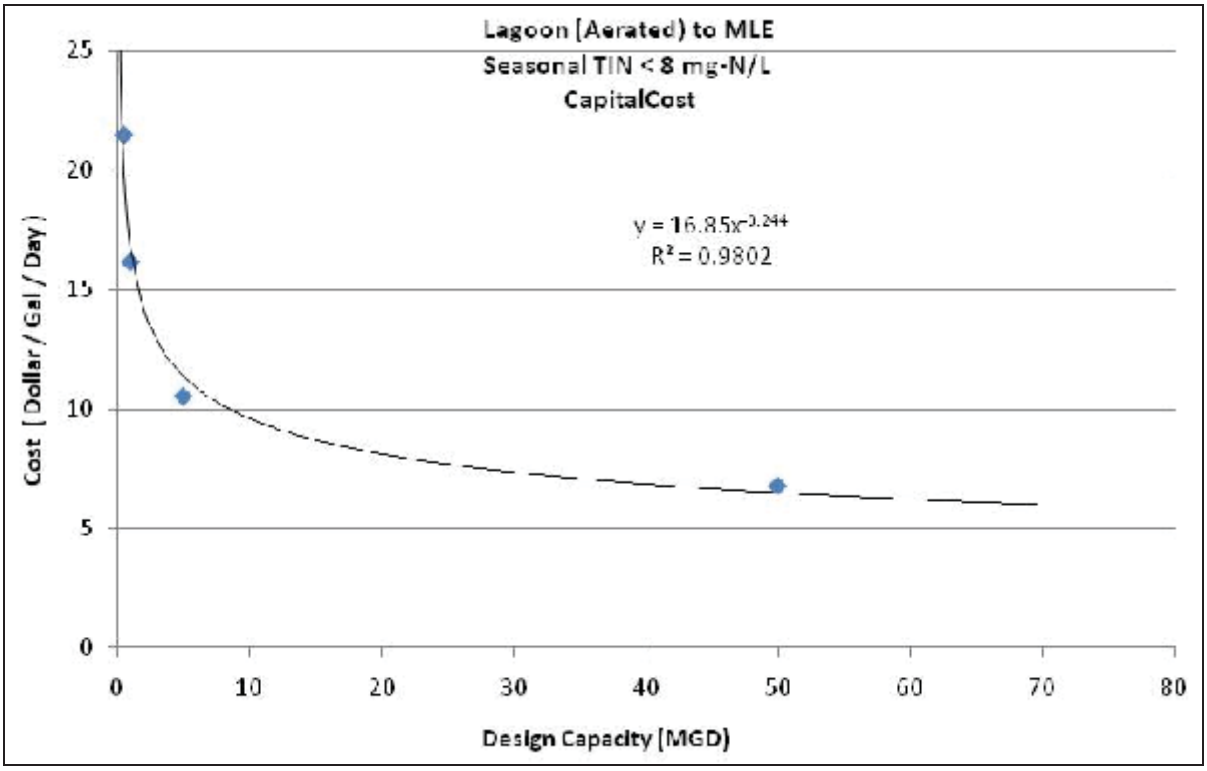

Figure 11-37. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective A Seasonally

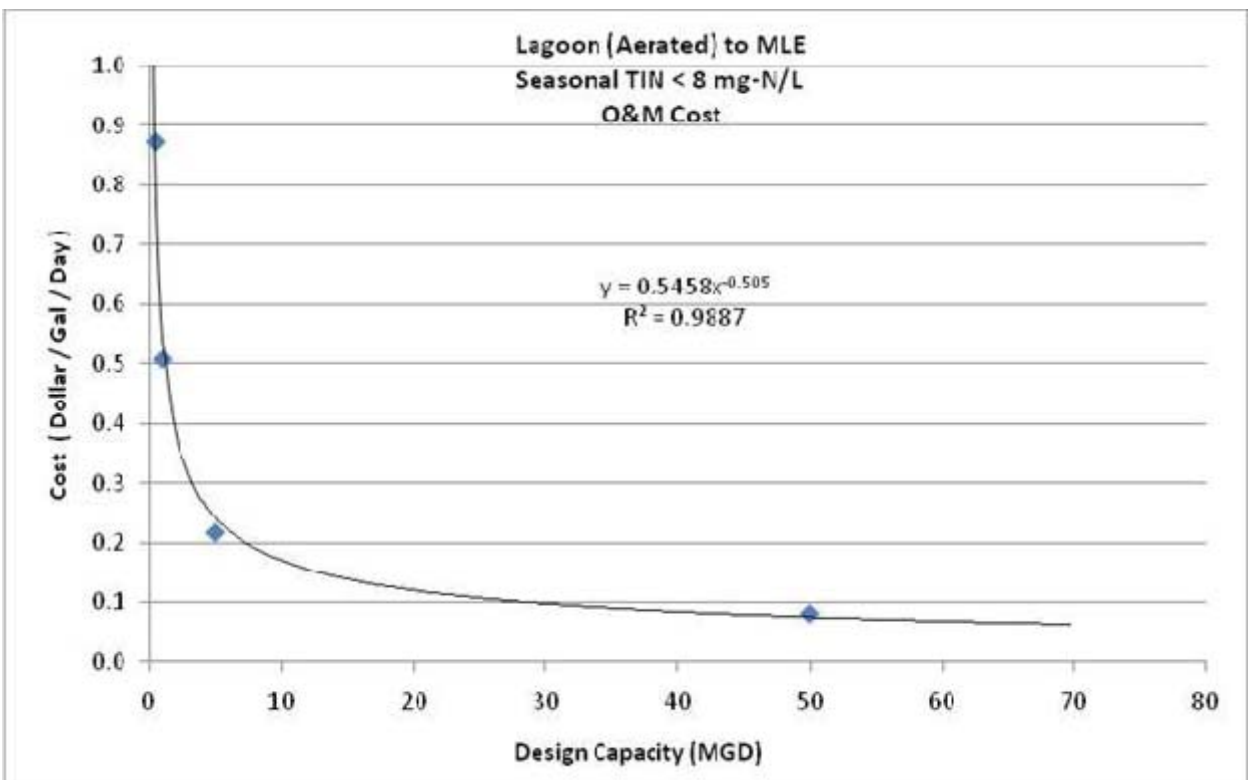

Figure 11-38. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective A Seasonal

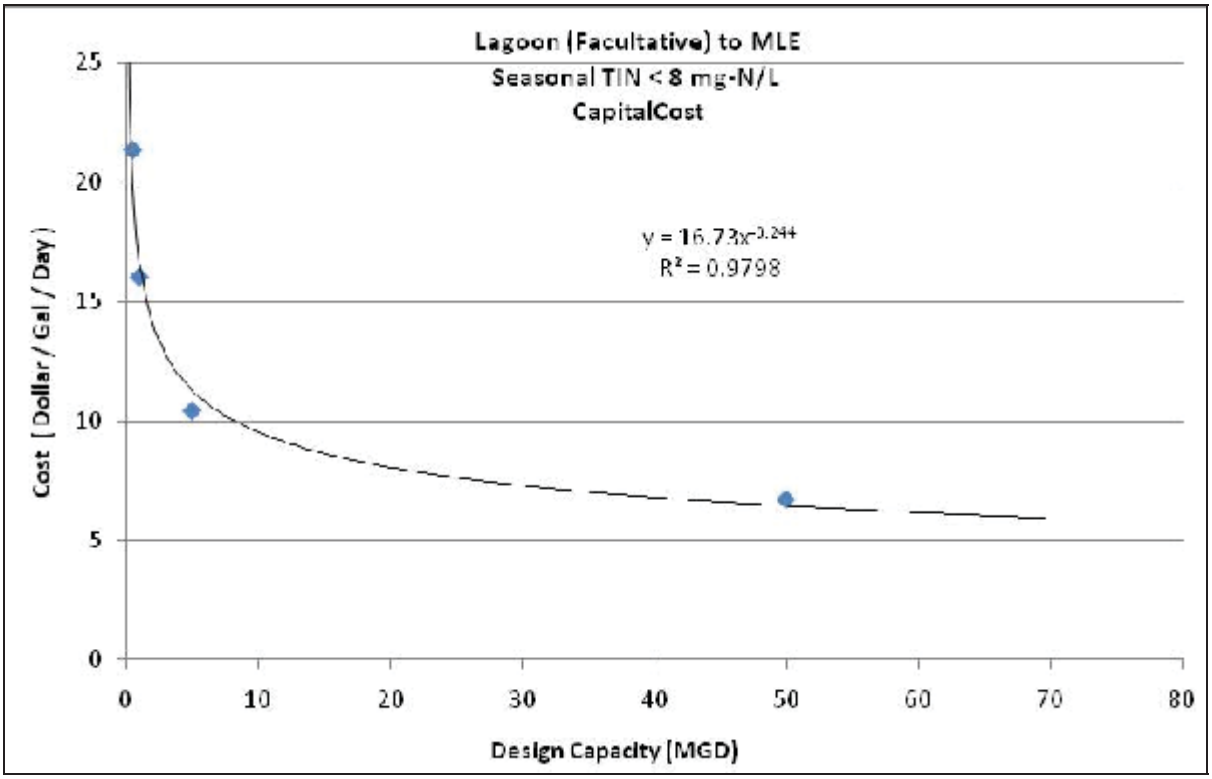

Figure 11-39. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective A Seasonally

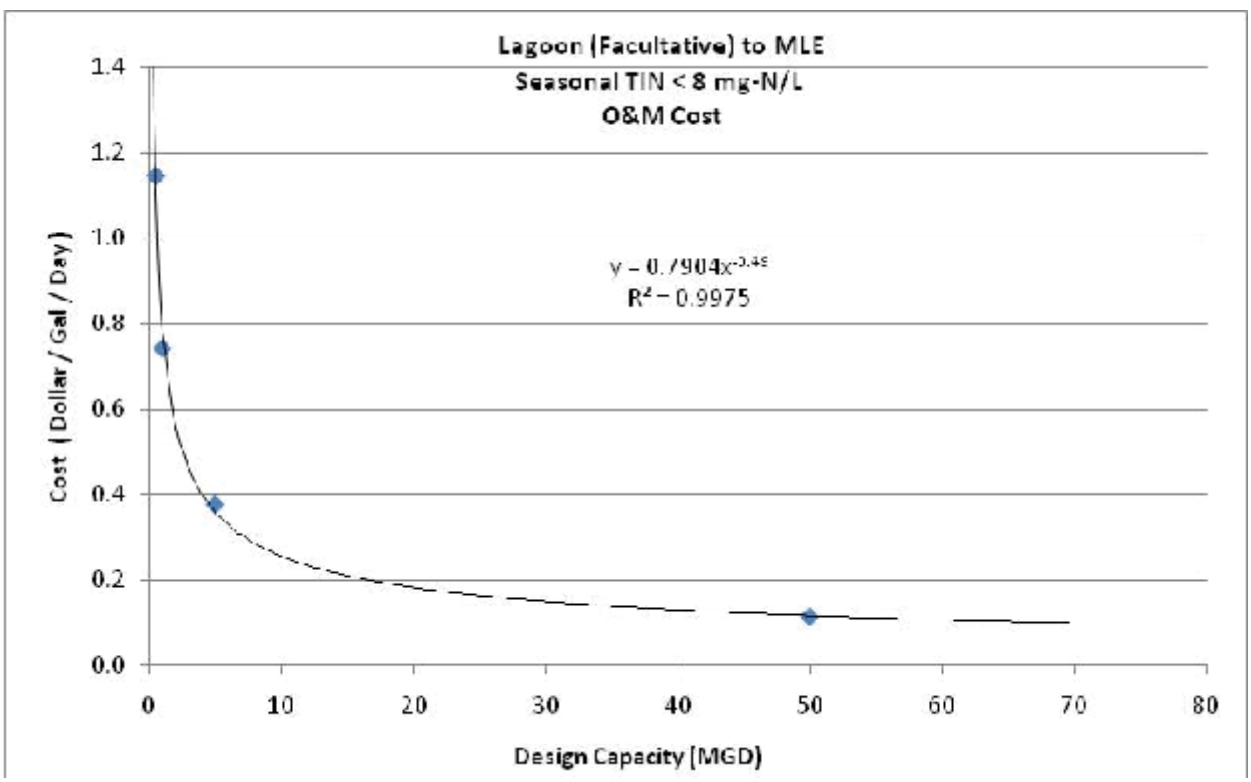

Figure 11-40. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective A Seasonal

TABLE 11-39.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$789,070	$1,186,818	$3,870,397	$24,915,789
2014 O&M Cost	$490,941	$570,779	$1,212,069	$4,519,475
Total Annual Cost	$1,280,011	$1,757,597	$5,087,466	$29,465,265
Annual TIN Load Reduction (lb/yr)	10,476	20,951	104,755	972,725
Estimated Cost for TIN Reduction ($/lb TIN removed)	$122.19	$83.89	$48.57	$30.29

Equation:[a] ..... $y = 1747.8x^{-0.299}$
R-Square Value: 0.9681

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 11-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE A SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$783,969	$1,178,345	$3,837,246	$24,741,394
2014 O&M Cost	$644,111	$834,458	$2,119,896	$6,436,745
Total Annual Cost	$1,428,080	$2,012,803	$5,957,141	$31,178,139
Annual TIN Load Reduction (lb/yr)	10,476	20,951	104,755	972,725
Estimated Cost for TIN Reduction ($/lb TIN removed)	$136.33	$96.07	$56.87	$32.05

Equation:[a] ..... $y = 2251.9x^{-0.312}$
R-Square Value: 0.9857

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

CHAPTER 12.
COST EVALUATION, OBJECTIVE B

12.1 YEAR-ROUND NUTRIENT REMOVAL

12.1.1 Extended Aeration Plants

Table 12-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for an extended aeration plant using mechanical aeration. Figures 12-1 and 12-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-2 and Figures 12-3 and 12-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 12-3 and 12-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 12-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.57	$2.65	$2.38
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.34	$0.07	$0.02

TABLE 12-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.85	$1.15	$0.49
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.15	$0.02	($0.01)

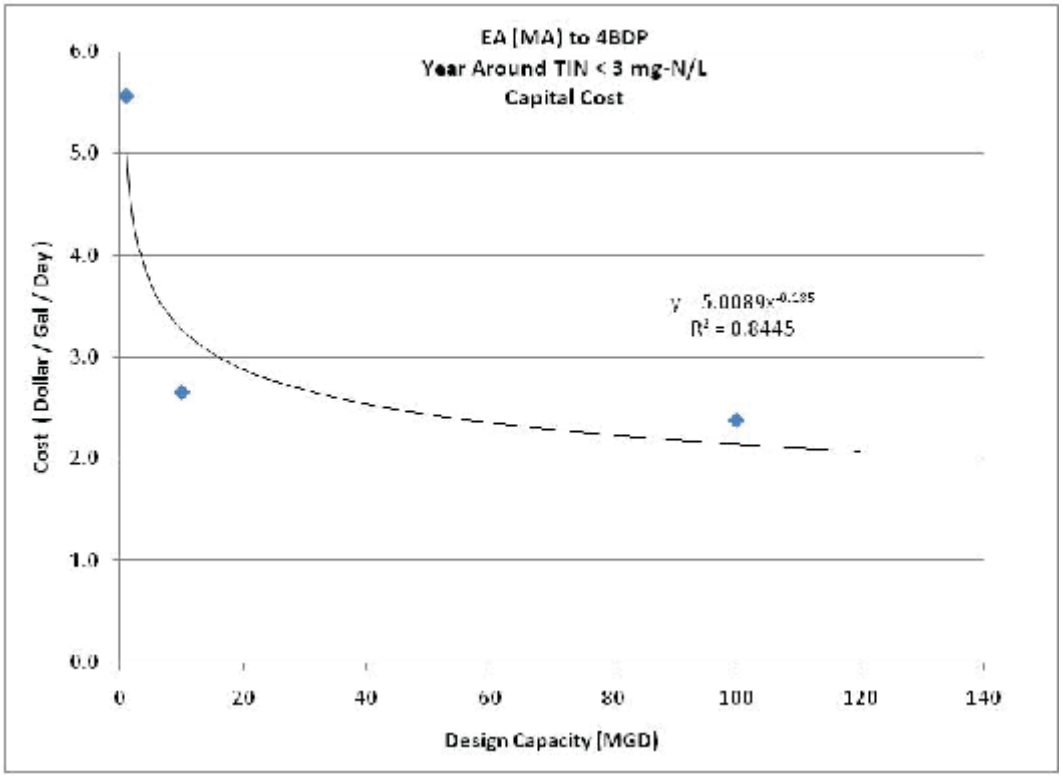

Figure 12-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective B Year-Round

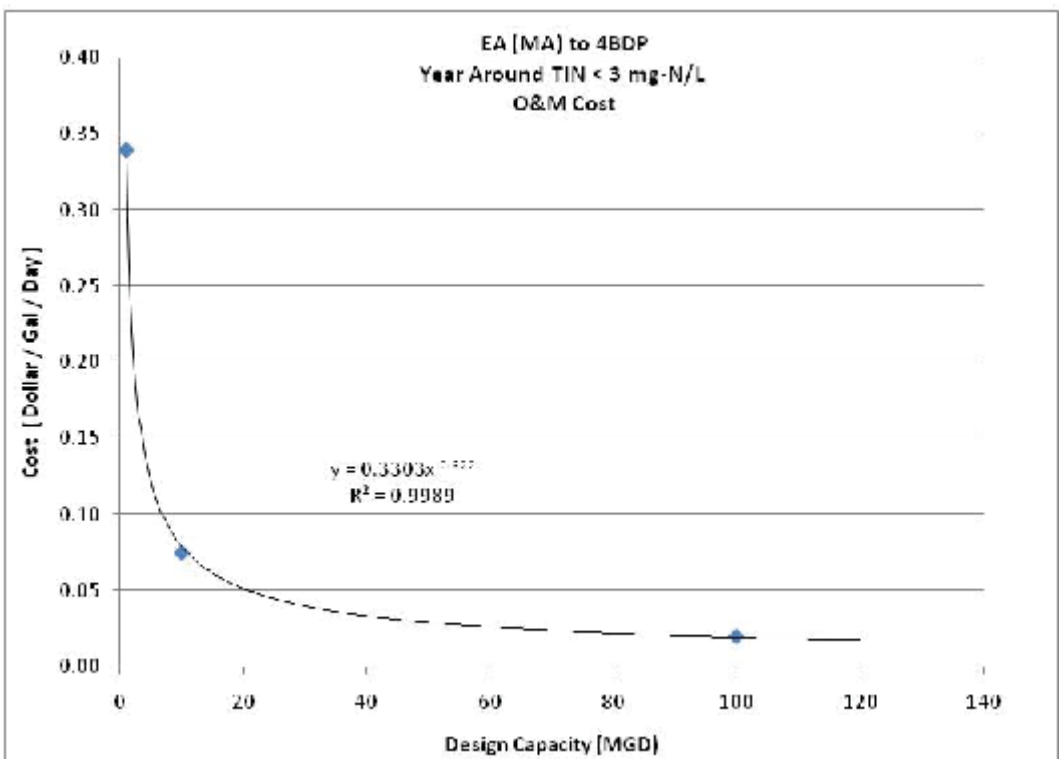

Figure 12-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective B Year-Round

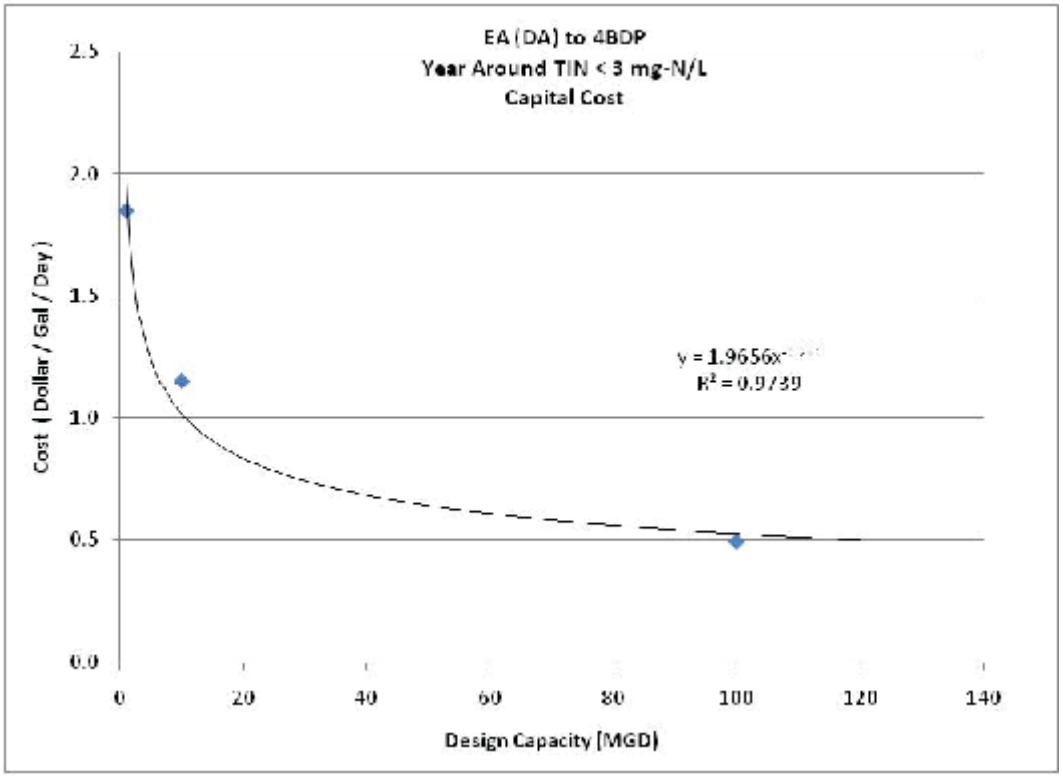

Figure 12-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective B Year-Round

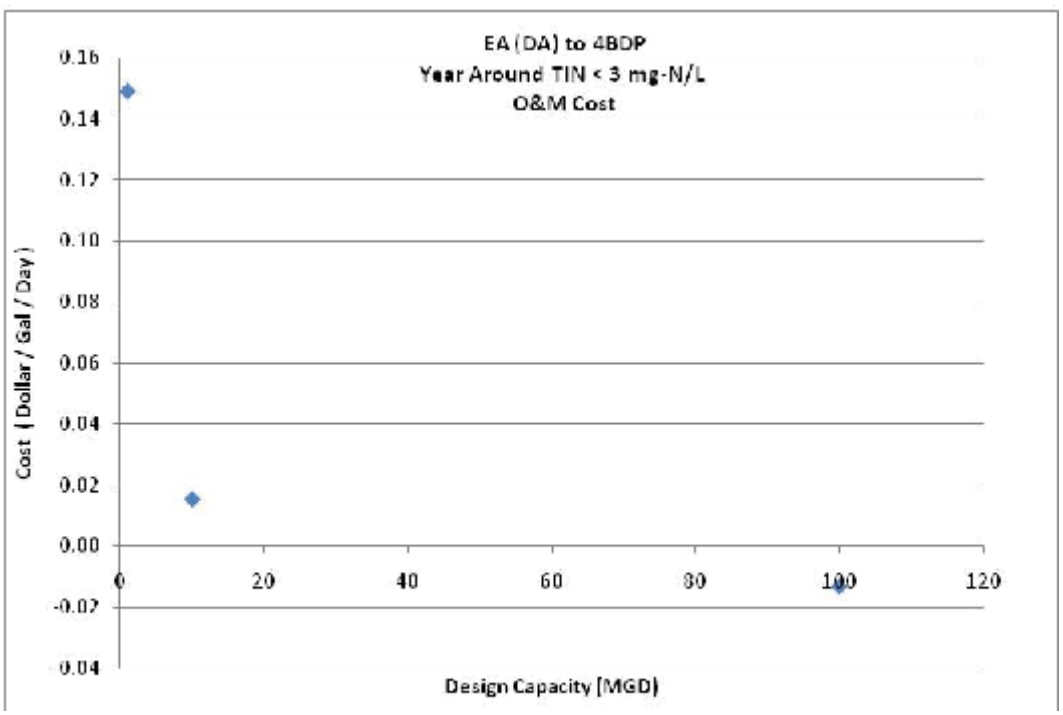

Figure 12-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective B Year-Round

TABLE 12-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$408,762	$1,947,903	$17,463,507
2014 Incremental O&M Cost	$382,230	$840,600	$2,183,065
Total Annual Cost	**$790,992**	**$2,788,504**	**$19,646,572**
Annual TIN Load Reduction (lb/yr)	44,932	449,315	4,493,150
Estimated Unit Cost for TIN Reduction ($/lb TIN removed)	$17.60	$6.21	$4.37

Equation:[a] ..... $y = 400.88x^{-0.303}$
R-Square Value: 0.9243

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$135,652	$845,590	$3,627,000
2014 Incremental O&M Cost	$167,595	$171,710	-$1,495,661
Total Annual Cost	**$303,247**	**$1,017,300**	**$2,131,340**
Annual TIN Load Reduction (lb/yr)	44,932	449,315	4,493,150
Estimated Cost for TIN Reduction ($/lb TIN removed)	$6.75	$2.26	$0.47

Equation:[a] ..... $y = 3595.5x^{-0.579}$
R-Square Value: 0.9895

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.2 Conventional Activated Sludge Plants

Table 12-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for a conventional activated sludge plant. Figures 12-5 and 12-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.63	$5.15	$3.44
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.32	$0.16	$0.10

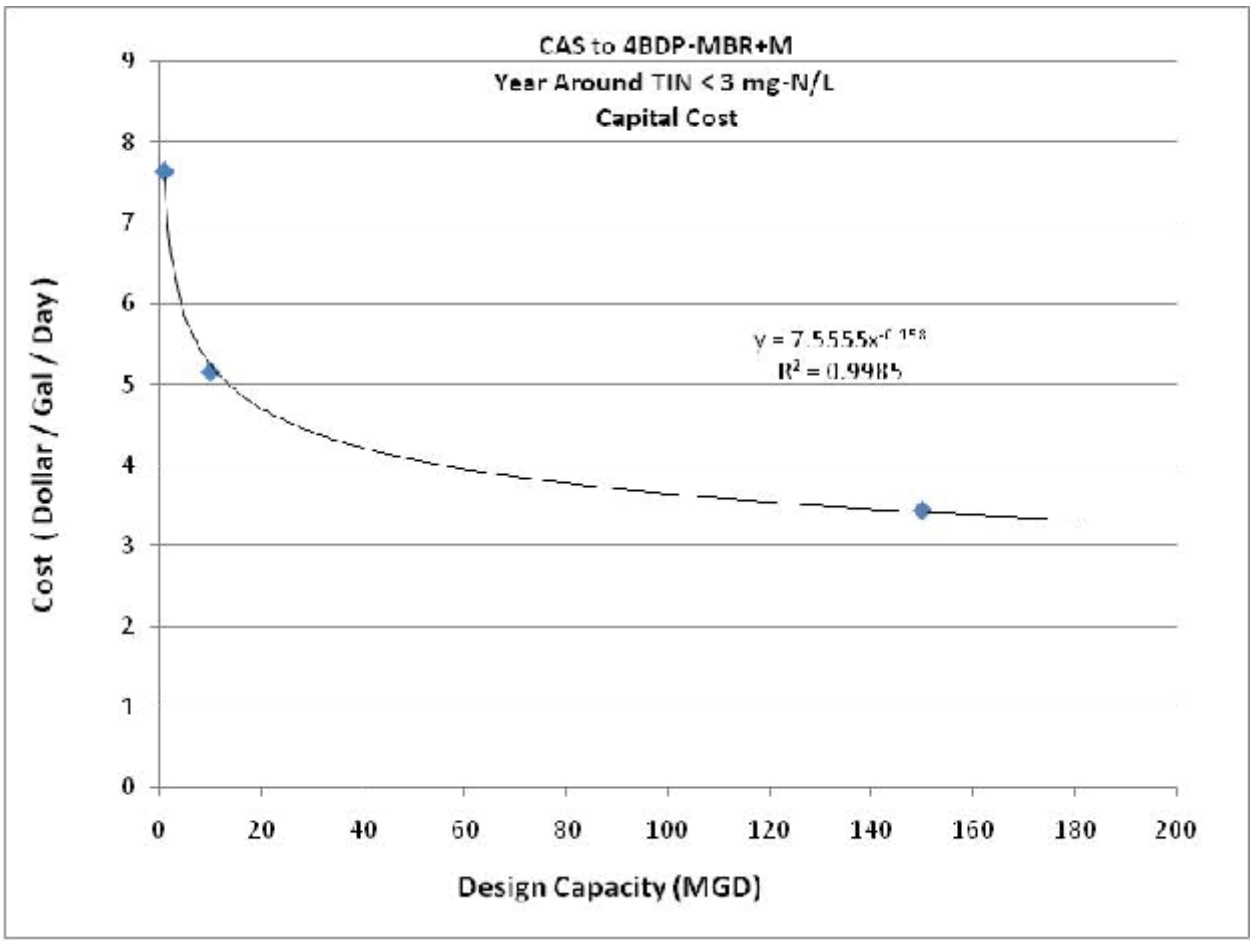

Figure 12-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective B Year-Round

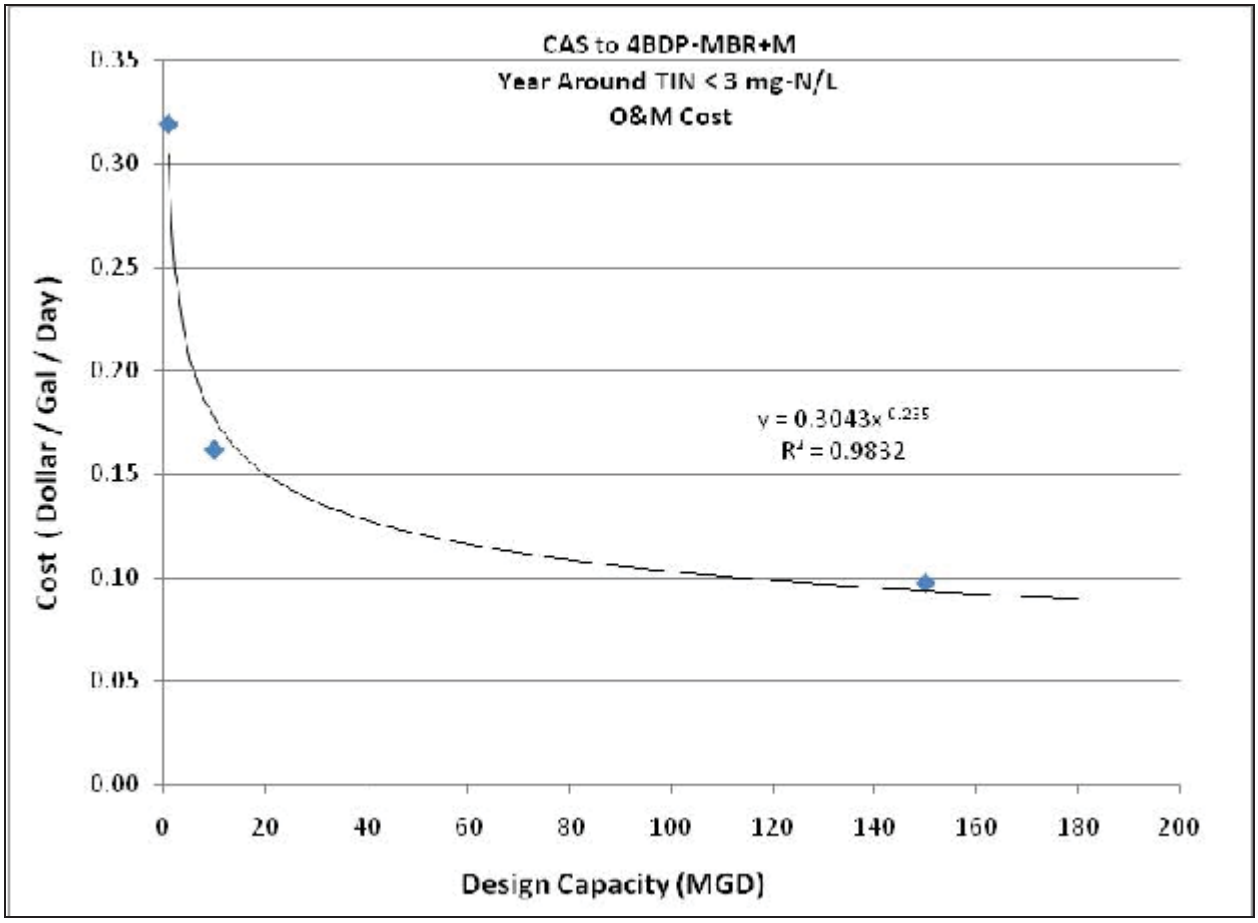

Figure 12-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective B Year-Round

TABLE 12-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$560,269	$3,785,071	$37,928,146
2014 O&M Cost	$359,351	$1,824,403	$16,486,747
Total Annual Cost	**$919,620**	**$5,6094,74**	**$54,414,620**
Annual TIN Load Reduction (lb/yr)	45,443	454,425	6,816,375
Estimated Cost for TIN Reduction ($/lb TIN removed)	$20.24	$12.34	$7.98

Equation:[a] ..... $y = 143.71x^{-0.185}$
R-Square Value: 0.9931

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.3 Sequencing Batch Reactor Plants

Table 12-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for an SBR plant. Figures 12-7 and 12-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.98	$0.96	$0.59
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.70	$0.31	$0.14

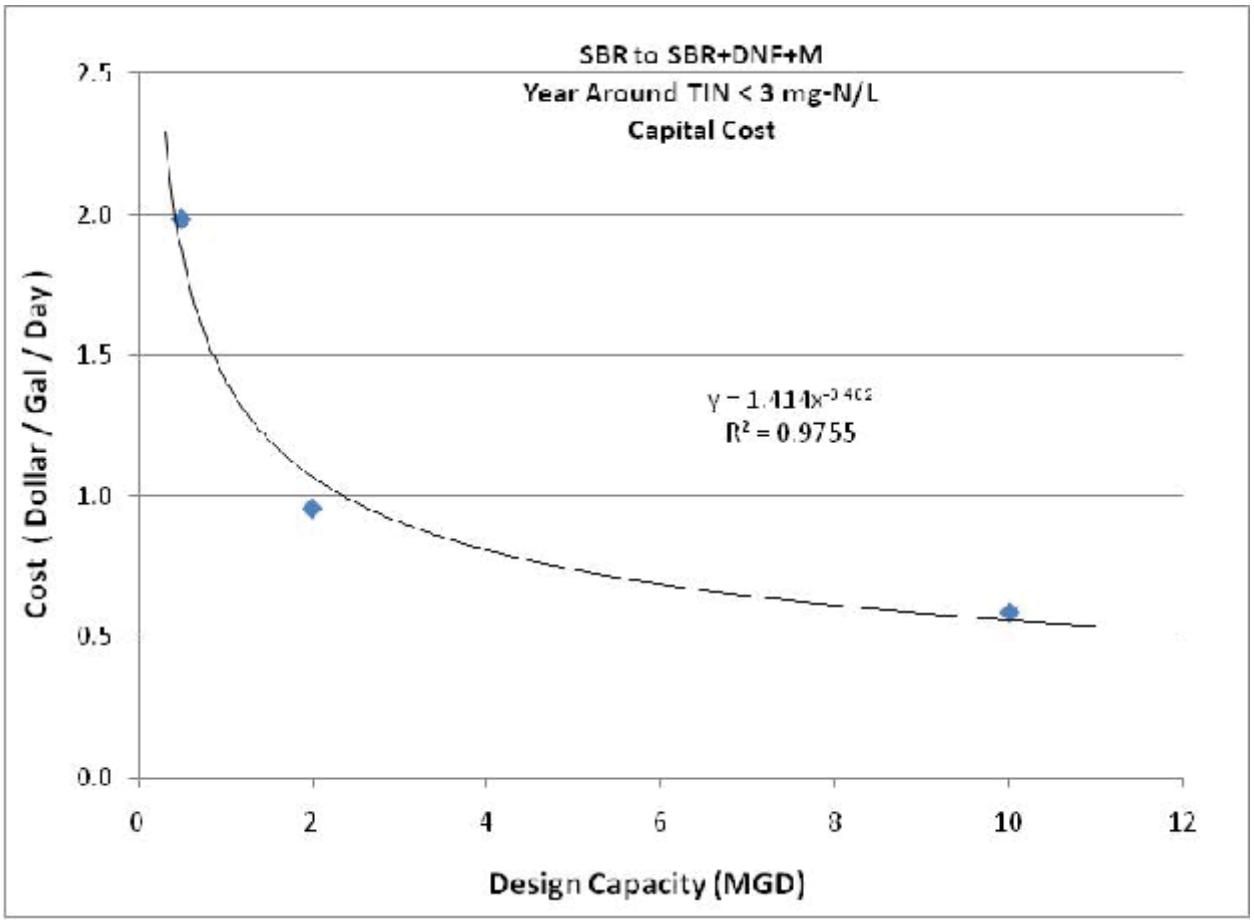

Figure 12-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective B Year-Round

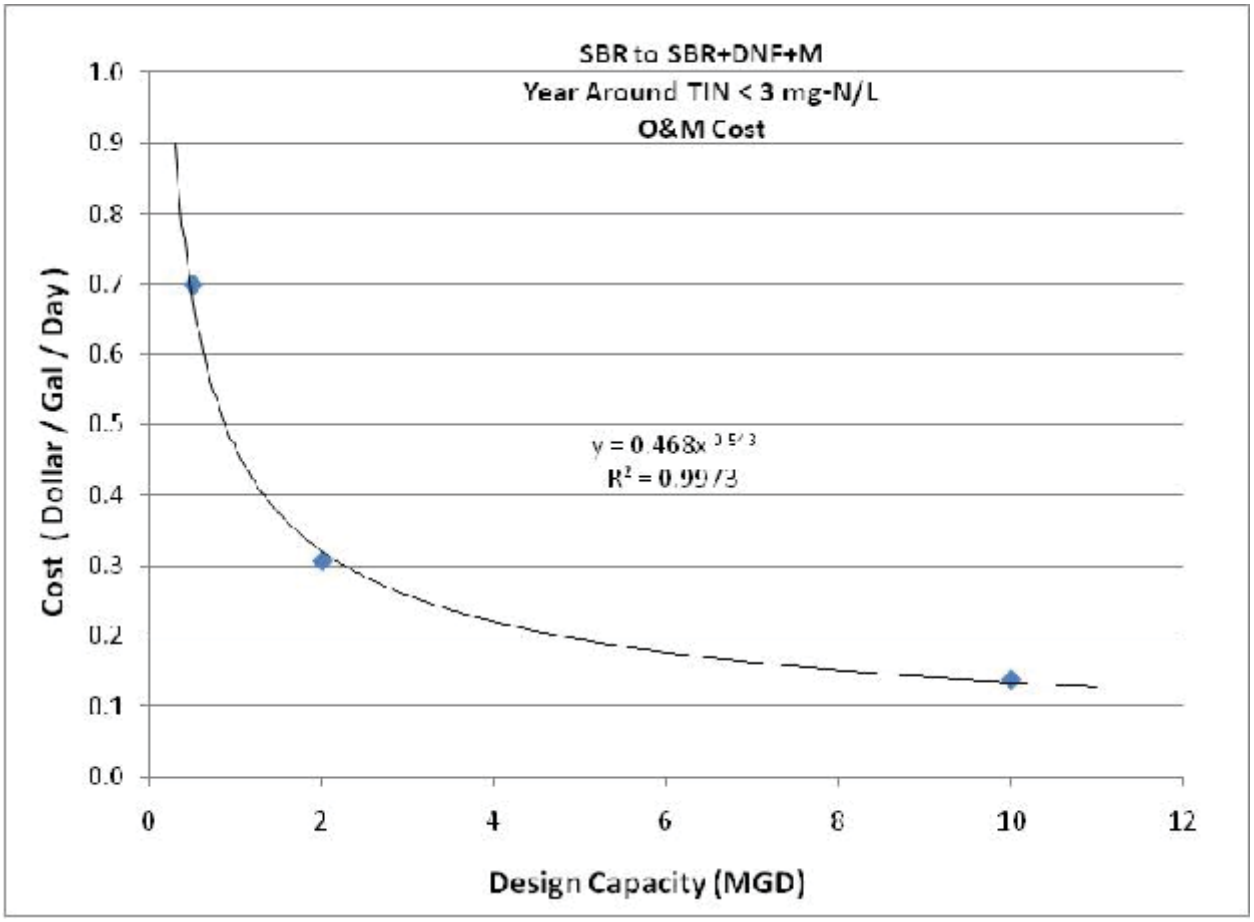

Figure 12-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective B Year-Round

TABLE 12-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$72,824	$140,735	$432,604
2014 O&M Cost	$393,776	$688,910	$1,543,846
Total Annual Cost	**$466,600**	**$829,644**	**$1,976,450**
Annual TIN Load Reduction (lb/yr)	2,537	10,147	50,735
Estimated Cost for TIN Reduction ($/lb TIN removed)	$183.94	$81.76	$38.96
Equation:[a]			$y = 10207x^{-0.517}$
R-Square Value:			$R^2 = 0.9953$

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 12-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for a trickling filter plant. Figures 12-9 and 12-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-10 and Figures 12-11 and 12-12 summarize these costs for a trickling filter/solids contact plant. Table 12-11 and Figures 12-13 and 12-14 summarize these costs for an RBC plant. Tables 12-12, 12-13 and 12-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 12-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$9.18	$6.43	$3.94
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.38	$0.18	$0.10

TABLE 12-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$7.91	$5.87	$3.62
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.27	$0.16	$0.09

TABLE 12-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$9.19	$6.46	$3.99
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.43	$0.20	$0.10

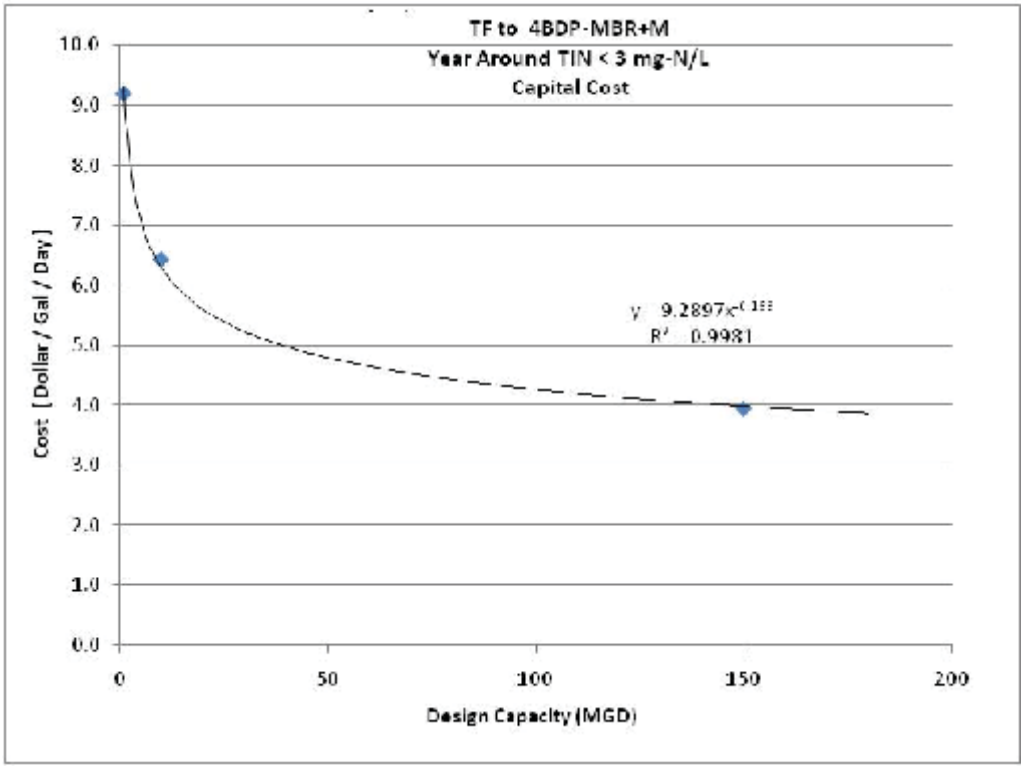

Figure 12-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective B Year-Round

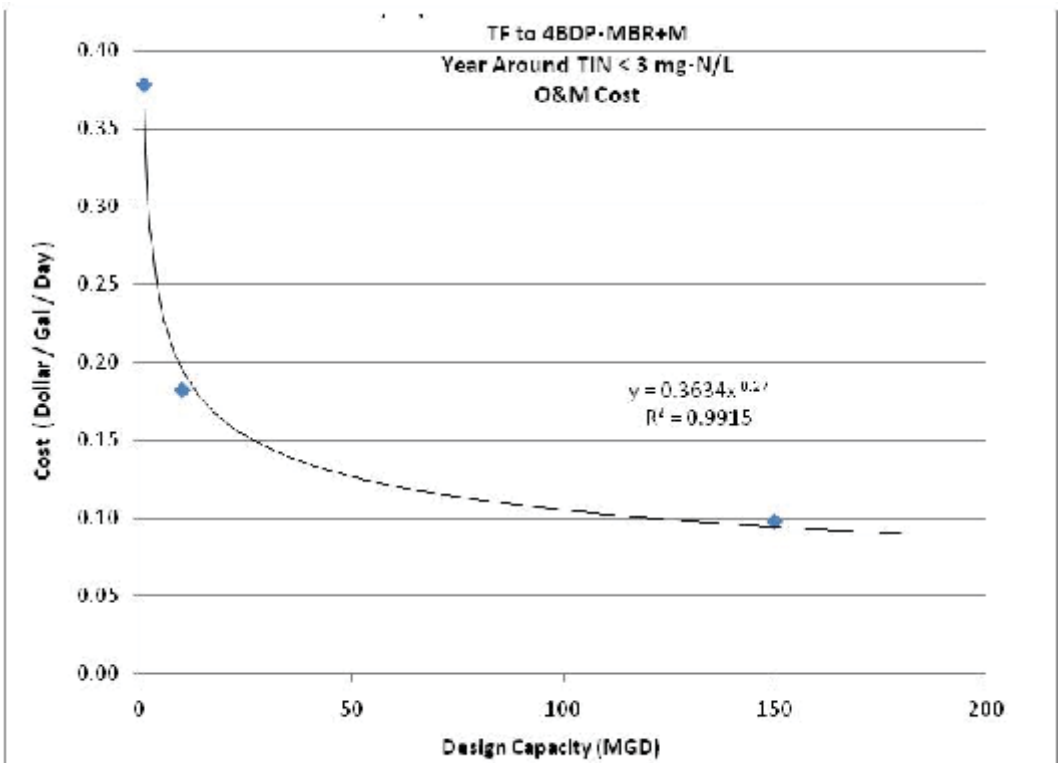

Figure 12-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective B Year-Round

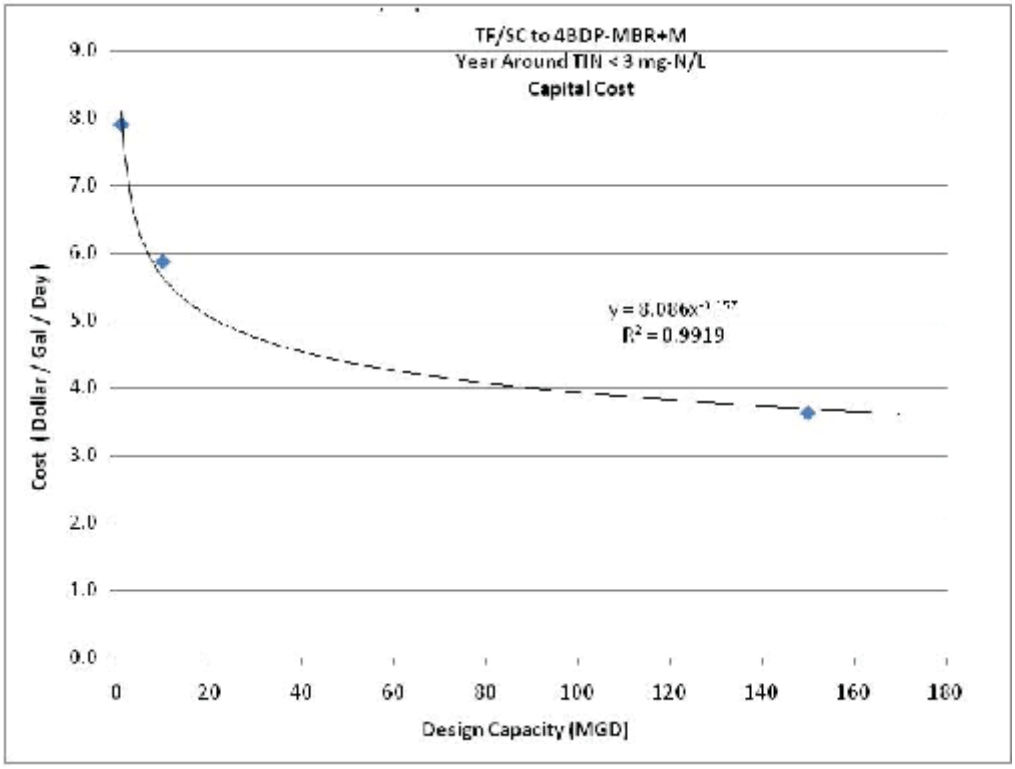

Figure 12-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective B Year-Round

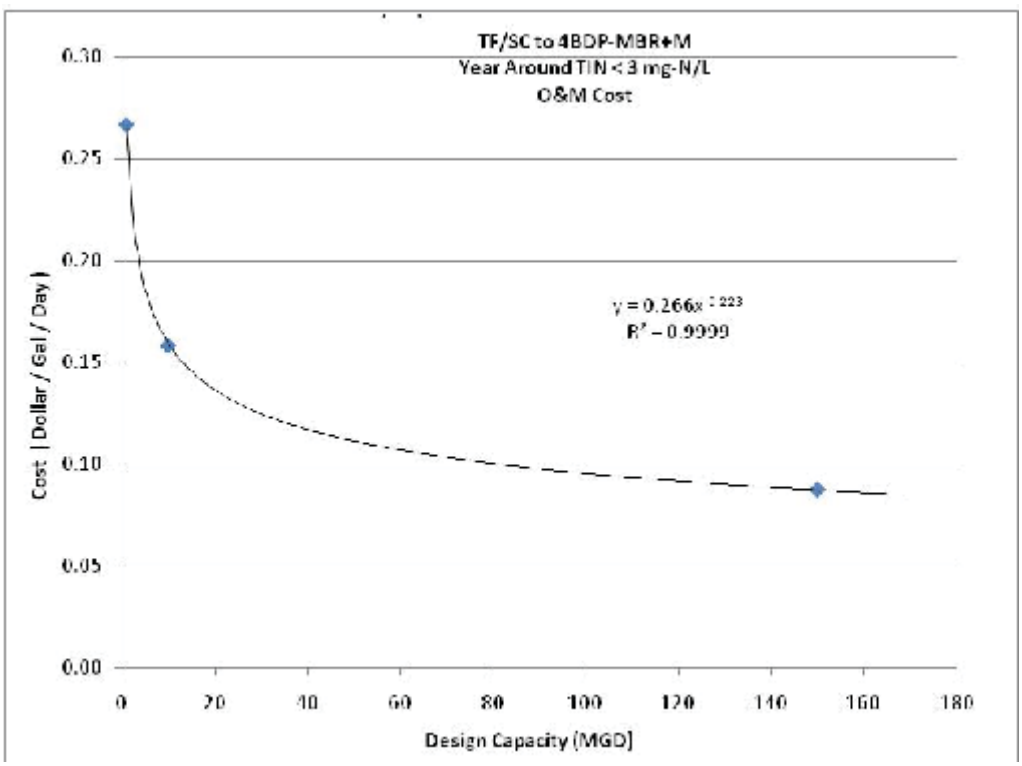

Figure 12-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective B Year-Round

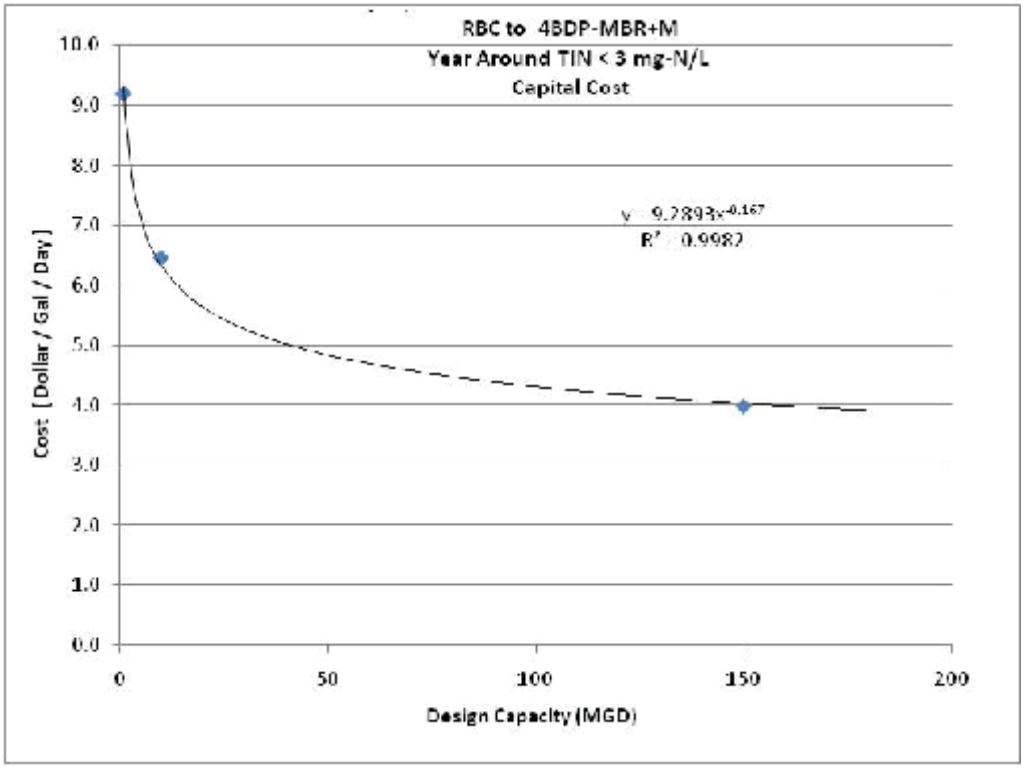

Figure 12-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective B Year-Round

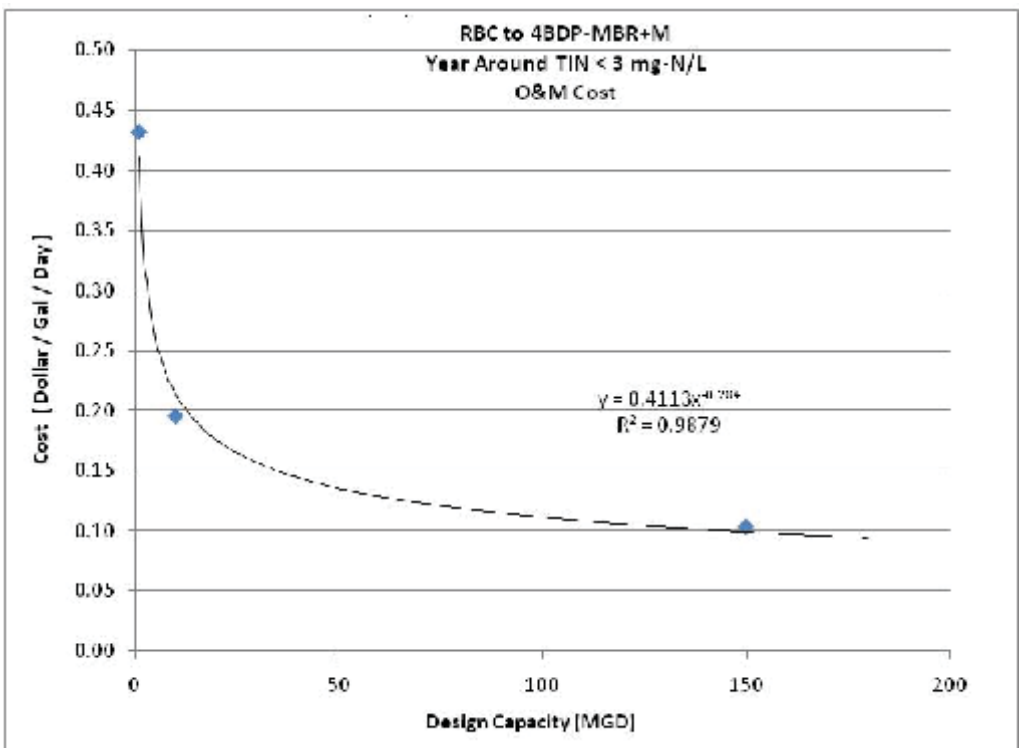

Figure 12-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective B Year-Round

TABLE 12-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$674,390	$4,721,940	$43,396,182
2014 O&M Cost	$425,306	$2,045,622	$16,426,259
Total Annual Cost	**$1,099,696**	**$6,767,562**	**$59,822,441**
Annual TIN Load Reduction (lb/yr)	45,443	454,425	6,816,375
Estimated Cost for TIN Reduction ($/lb TIN removed)	$24.20	$14.89	$8.78
Equation:[a]			$y = 209.97x^{-0.202}$
R-Square Value:			0.9995

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	580,940	4,313,673	39,890,166
2014 O&M Cost	300,431	1,781,972	14,763,883
Total Annual Cost	**881,371**	**6,095,644**	**54,654,049**
Annual TIN Load Reduction (lb/yr)	45,443	454,425	6,816,375
Estimated Cost for TIN Reduction ($/lb TIN removed)	19.40	13.41	8.02
Equation:[a]			$y = 130.75x^{-0.177}$
R-Square Value:			0.9977

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$674,719	$4,742,341	$43,920,192
2014 O&M Cost	$486,325	$2,197,003	$17,433,590
Total Annual Cost	**$1,161,044**	**$6,939,344**	**$61,353,782**
Annual TIN Load Reduction (lb/yr)	45,443	454,425	6,816,375
Estimated Cost for TIN Reduction ($/lb TIN removed)	$25.55	$15.27	$9.00
Equation:[a]			$y = 234.42x^{-0.208}$
R-Square Value:			0.9985

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.5 Membrane Biological Reactor Plants

Table 12-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for an MBR plant. Figures 12-15 and 12-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.031	$0.004	$0.002
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.016	$0.016	$0.016

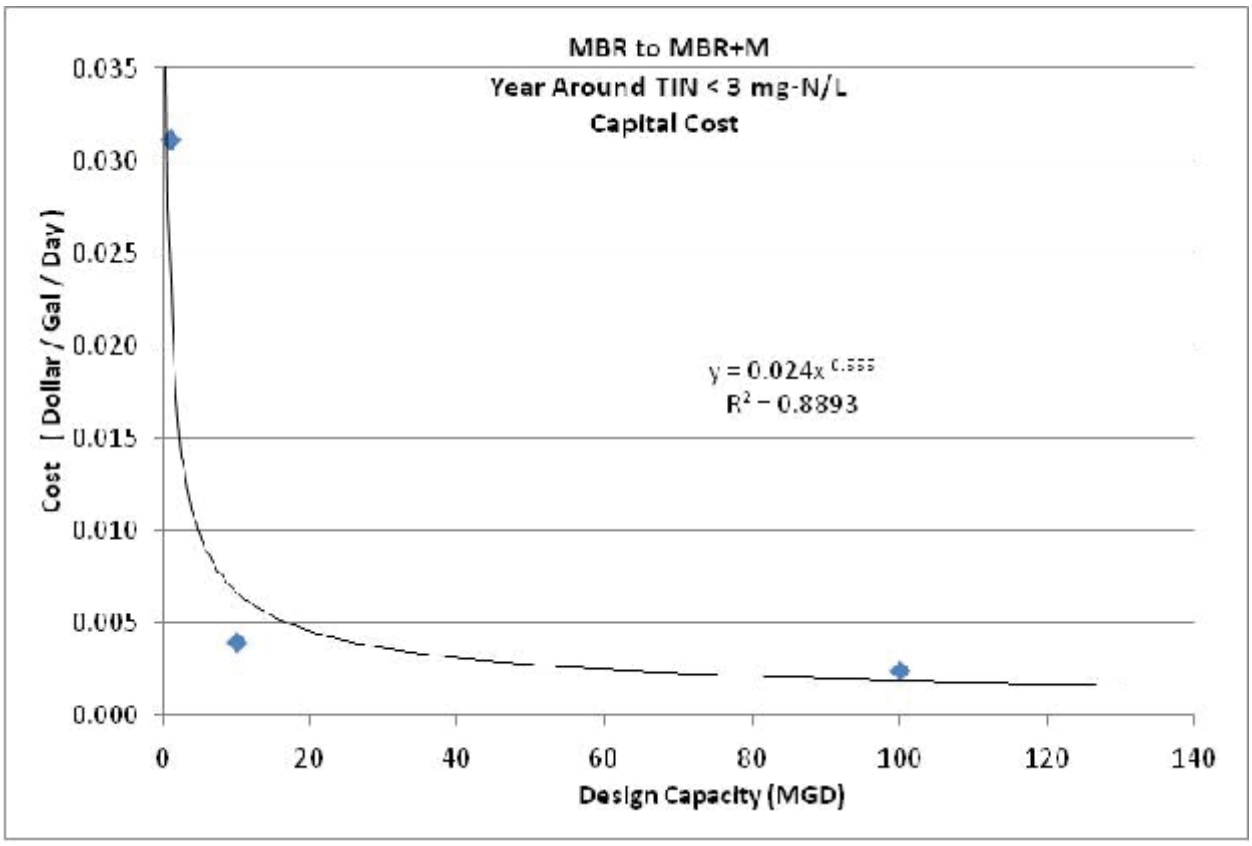

Figure 12-15. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective B Year-Round

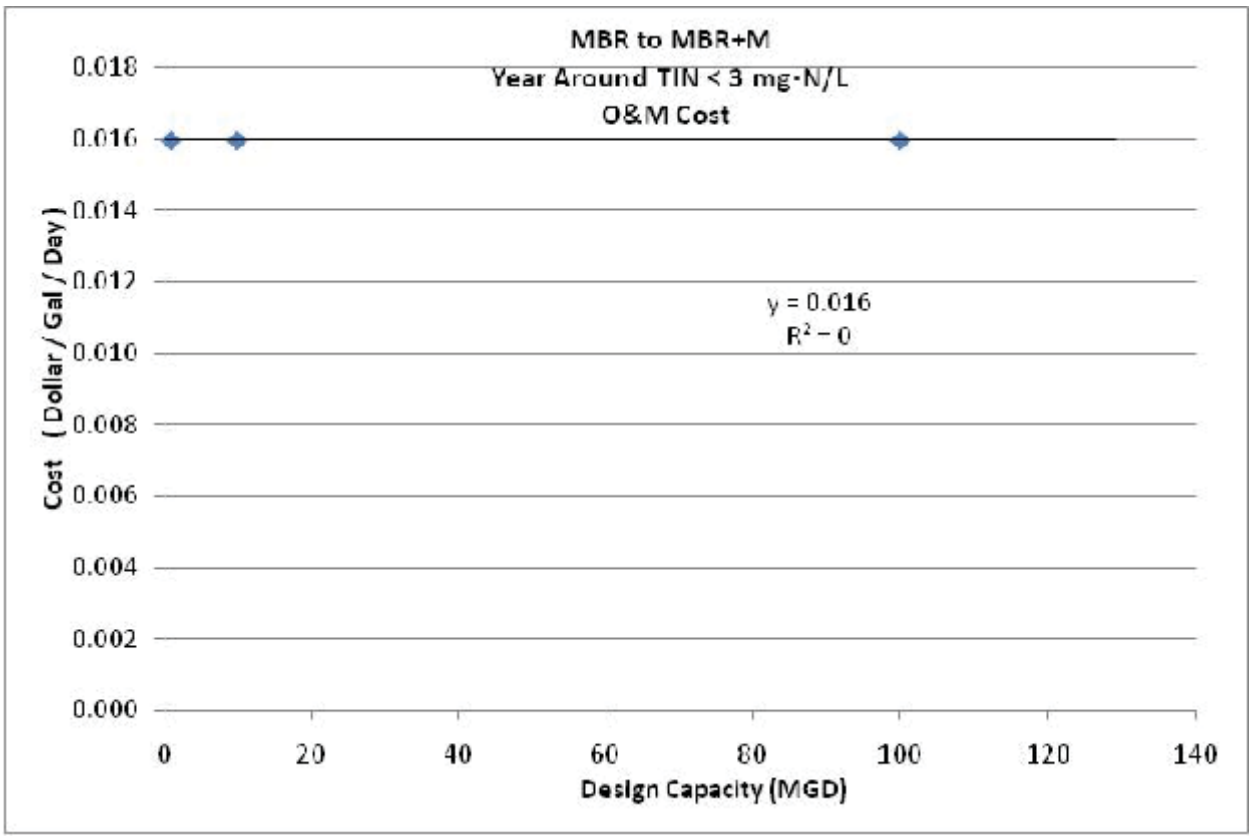

Figure 12-16. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective B Year-Round

TABLE 12-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$2,284	$2,916	$17,745
2014 O&M Cost	$17,973	$179,730	$1,797,297
Total Annual Cost	**$20,257**	**$182,646**	**$1,815,042**
Annual TIN Load Reduction (lb/yr)	9,527	95,265	952,650
Estimated Cost for TIN Reduction ($/lb TIN removed)	$2.13	$1.92	$1.91
Equation:[a]			$y = 2.6028x^{-0.024}$
R-Square Value:			0.7858

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.6 High-Purity Oxygen Activated Sludge Plants

Table 12-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for an HPO activated sludge plant. Figures 12-17 and 12-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-18 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	20-mgd Plant	220-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.60	$3.67
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.17

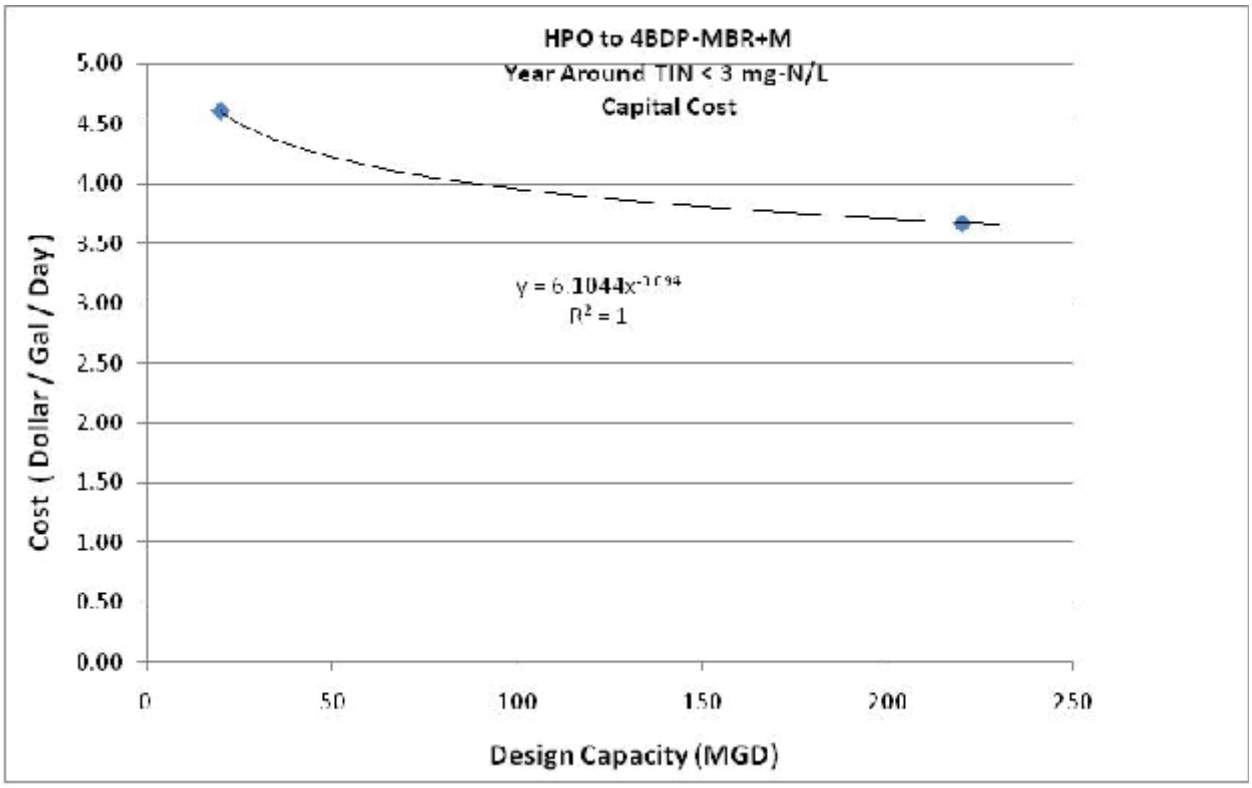

Figure 12-17. Capital Cost per Plant Capacity for HPO Plant Upgraded for Objective B Year-Round

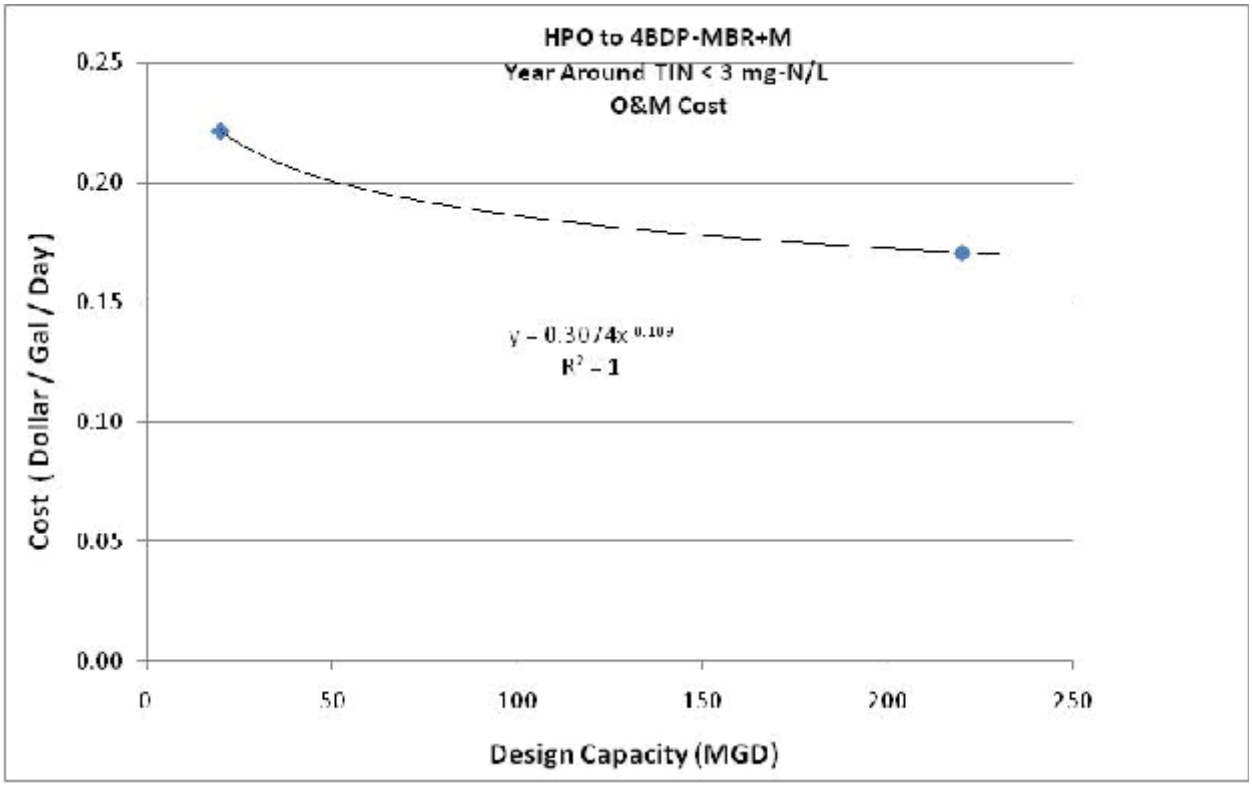

Figure 12-18. O&M Cost per Plant Capacity for HPO Upgraded for Objective B Year-Round

TABLE 12-18.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	20-mgd Plant	220-mgd Plant
Annualized Capital Cost	$6,760,000	$59,304,000
2014 O&M Cost	$4,991,000	$42,269,000
Total Annual Cost	**$11,751,000**	**$101,573,000**
Annual TIN Load Reduction (lb/yr)	962,870	10,591,570
Estimated Cost for TIN Reduction ($/lb TIN removed)	$12.20	$9.60
Equation:[a]		$y = 48.664x^{-0.100}$
R-Square Value:		1

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.1.7 Aerated or Facultative Lagoon Plants

Table 12-19 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B year-round for an aerated lagoon plant. Figures 12-19 and 12-20 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-20 and Figures 12-21 and 12-22 summarize these costs for a facultative lagoon plant. Tables 12-21 and 12-22 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 12-19.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$23.46	$17.78	$11.93	$7.75
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.10	$0.67	$0.30	$0.14

TABLE 12-20.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$23.32	$17.67	$11.84	$7.70
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.37	$0.90	$0.46	$0.17

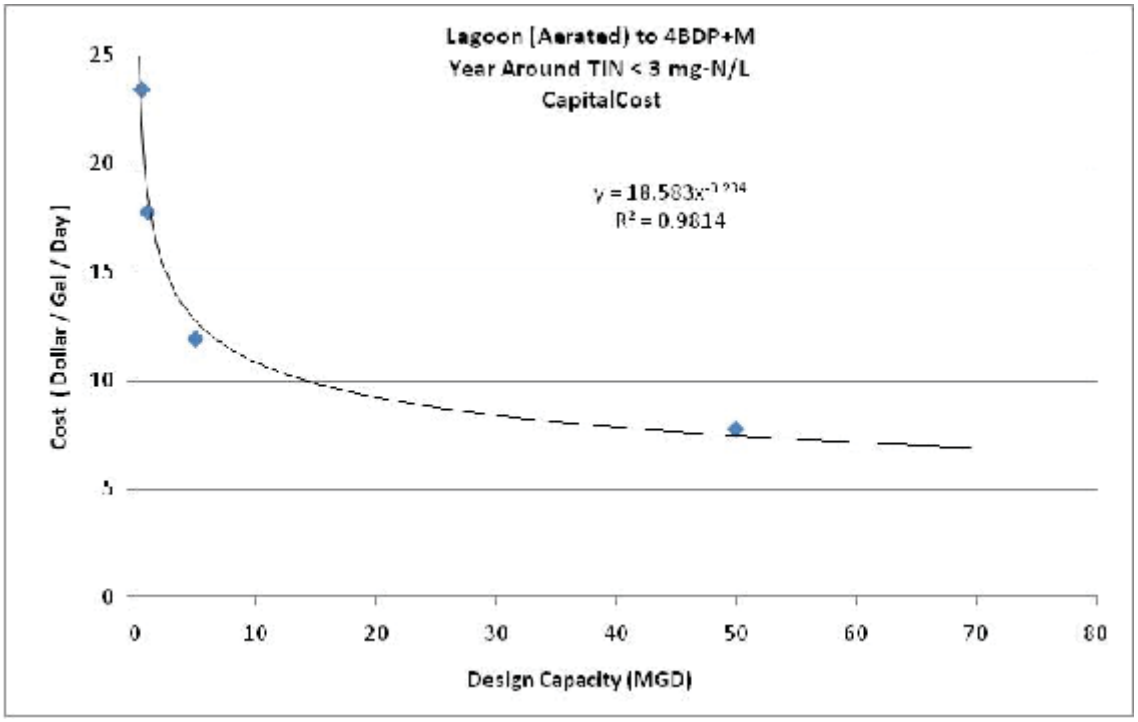

Figure 12-19. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective B Year-Round

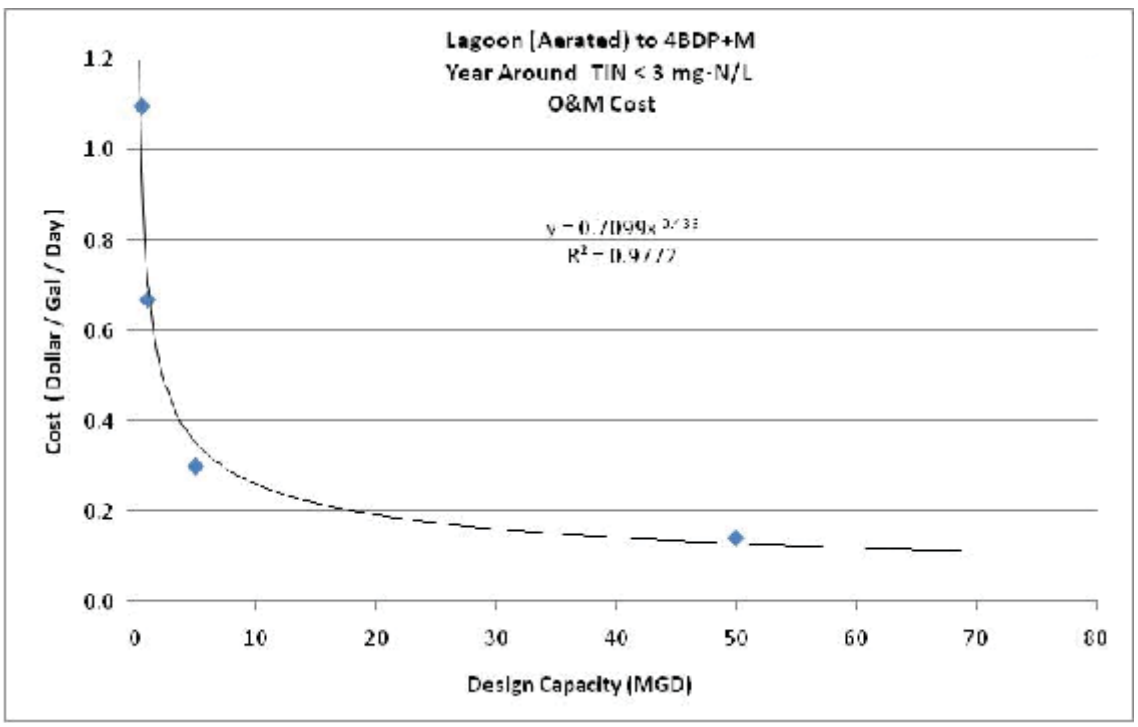

Figure 12-20. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective B Year-Round

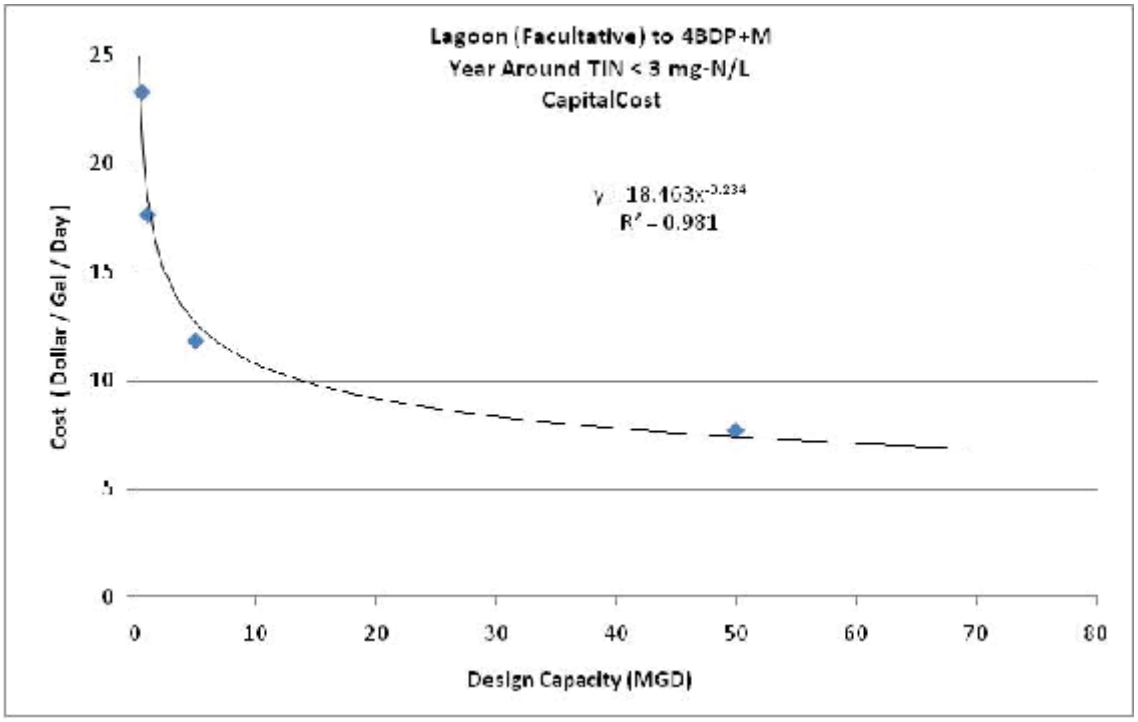

Figure 12-21. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective B Year-Round

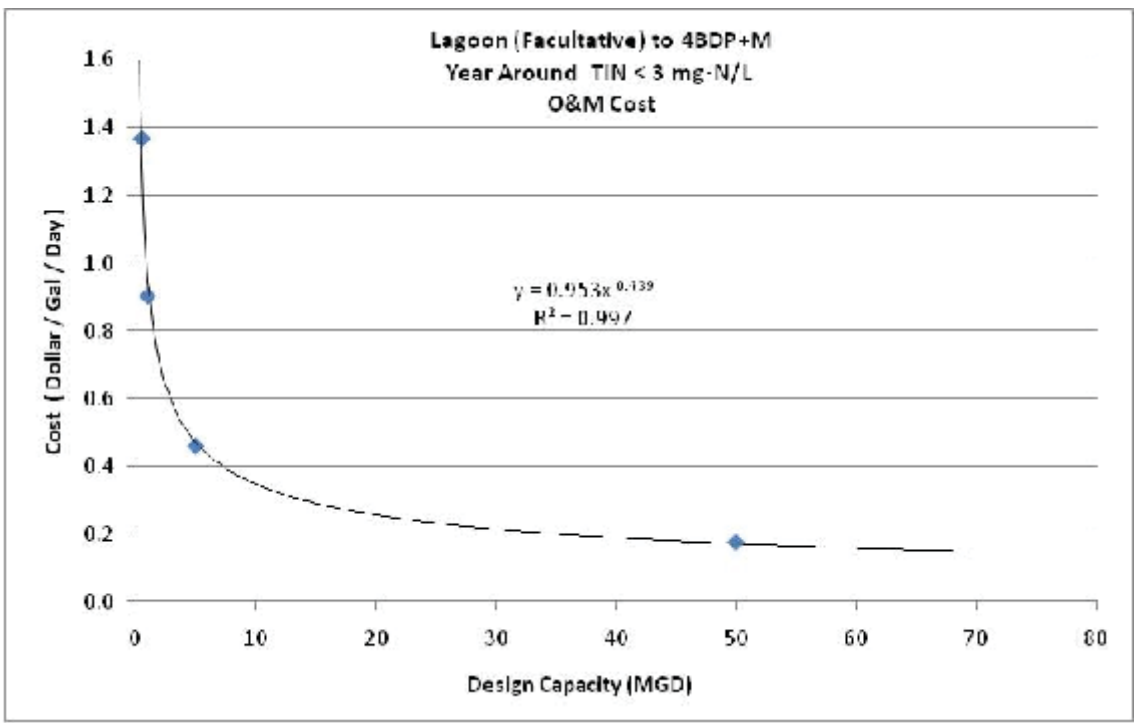

Figure 12-22. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective B Year-Round

TABLE 12-21.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$861,410	$1,306,182	$4,380,684	$28,454,843
2014 O&M Cost	$616,861	$752,106	$1,685,034	$7,948,371
Total Annual Cost	**$1,478,272**	**$2,058,287**	**$6,065,718**	**$36,403,214**
Annual TIN Load Reduction (lb/yr)	22,429	44,859	224,293	2,224,675
Estimated Cost for TIN Reduction ($/lb TIN removed)	$65.91	$45.88	$27.04	$16.36
Equation:[a]				$y = 1139.5x^{-0.295}$
R-Square Value:				0.9733

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-22.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$856,392	$1,297,709	$4,347,532	$28,280,447
2014 O&M Cost	$770,030	$1,015,784	$2,587,861	$9,835,641
Total Annual Cost	**$1,626,423**	**$2,313,496**	**$6,935,394**	**$38,116,088**
Annual TIN Load Reduction (lb/yr)	22,429	44,859	224,293	2,224,675
Estimated Cost for TIN Reduction ($/lb TIN removed)	$72.51	$51.57	$30.92	$17.13
Equation:[a]				$y = 1441.6x^{-0.306}$
R-Square Value:				0.9871

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2 SEASONAL NUTRIENT REMOVAL

12.2.1 Extended Aeration Plants

Table 12-23 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for an extended aeration plant using mechanical aeration. Figures 12-23 and 12-24 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-24 and Figures 12-25 and 12-26 summarize these costs for an extended aeration plant using diffuser aeration. Tables 12-25 and 12-26 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 12-23.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.96	$2.54	$2.30
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.32	$0.07	$0.02

TABLE 12-24.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.23	$1.06	$0.43
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.13	$0.01	($0.01)

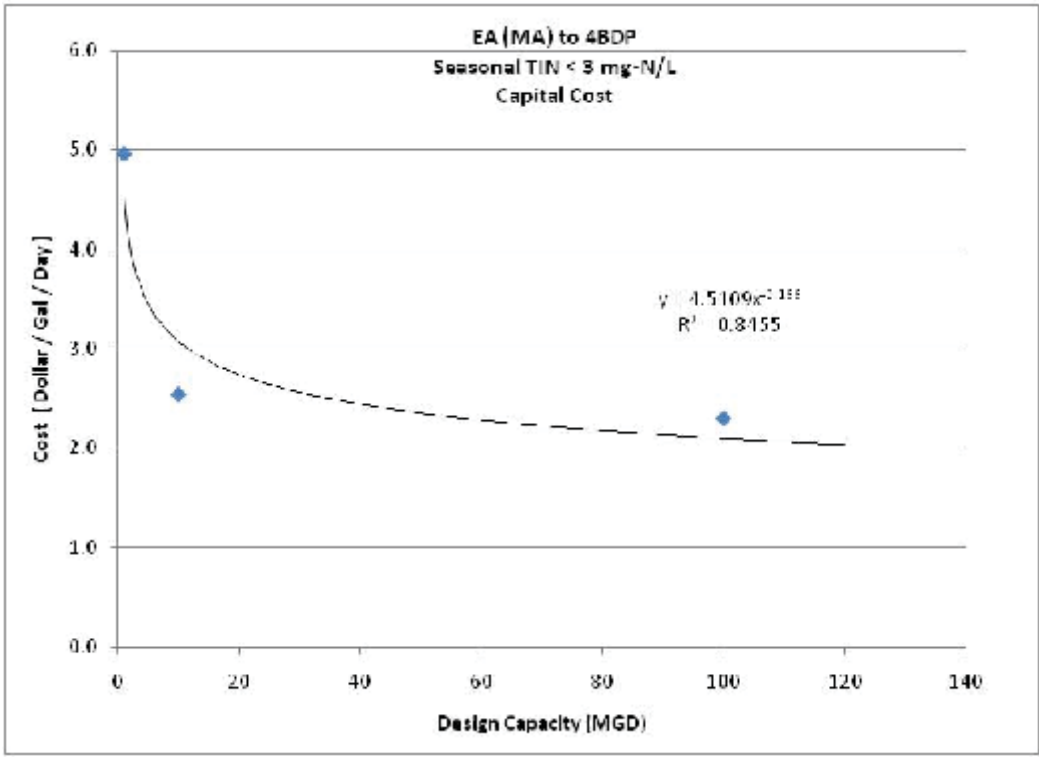

Figure 12-23. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective B Seasonally

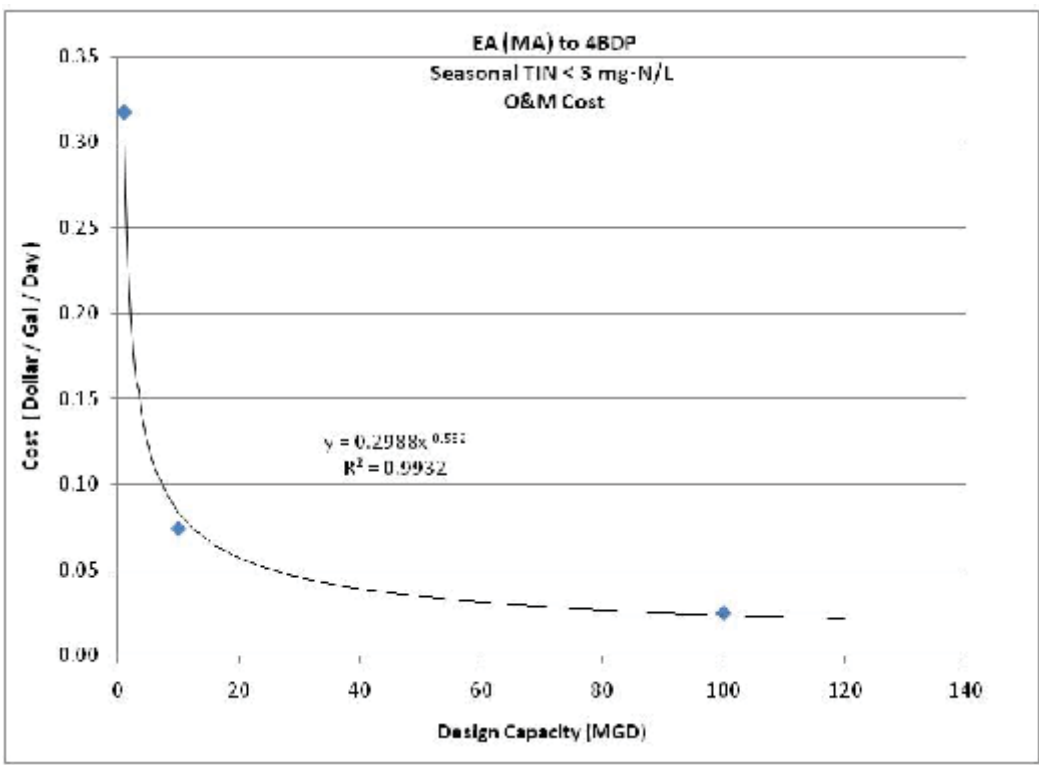

Figure 12-24. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective B Seasonal

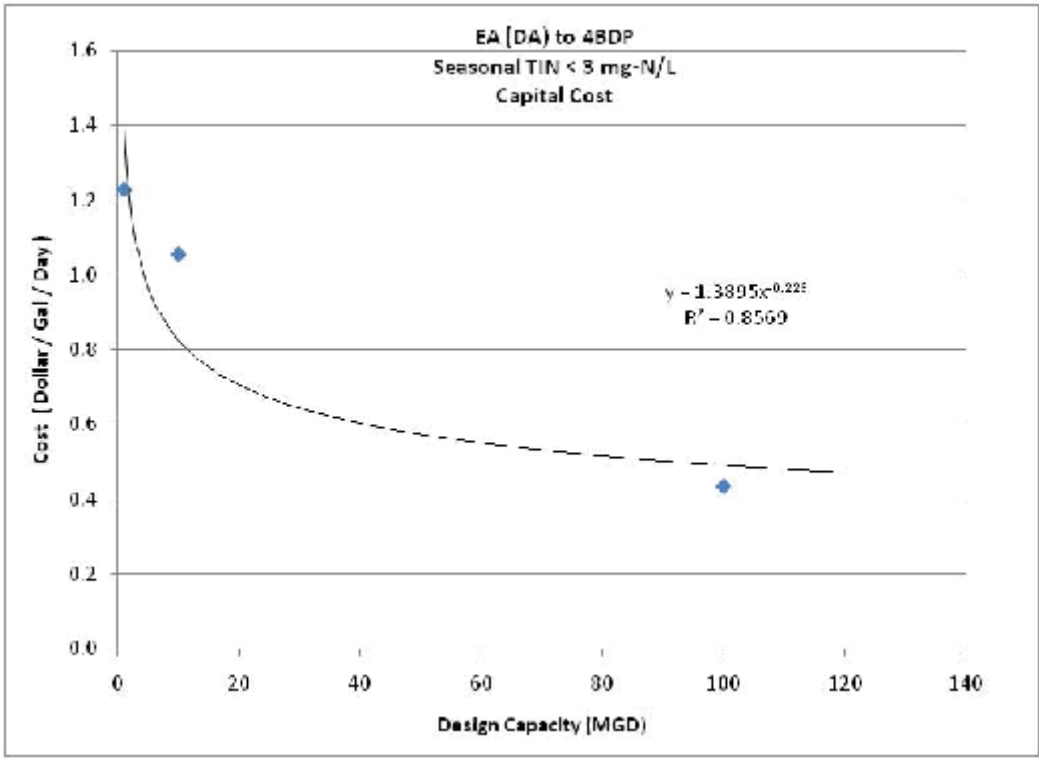

Figure 12-25. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective B Seasonally

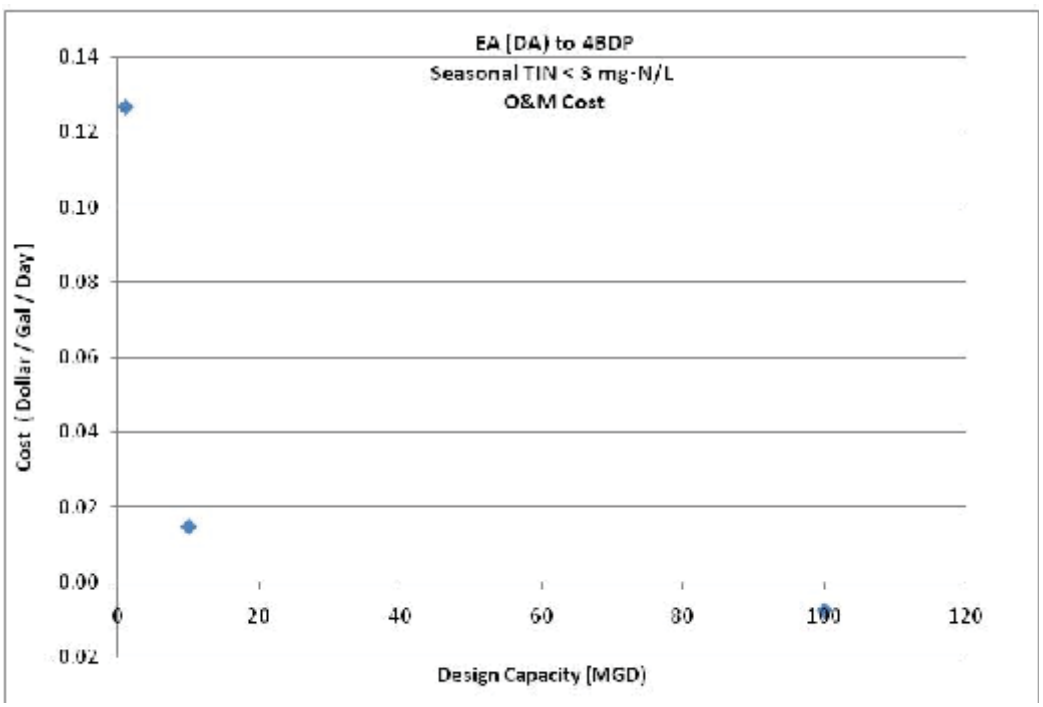

Figure 12-26. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective B Seasonal

TABLE 12-25.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$364,187	$1,869,240	$16,922,633
2014 O&M Cost	$357,321	$835,184	$2,809,833
Total Annual Cost	**$721,508**	**$2,704,424**	**$19,732,466**
Annual TIN Load Reduction (lb/yr)	23,305	233,053	2,330,525
Estimated Cost for TIN Reduction ($/lb TIN removed)	$30.96	$11.60	$8.47
Equation:[a]			$y = 469.64x^{-0.281}$
R-Square Value:			0.9188

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA ((DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$90,253	$775,153	$3,184,841
2014 O&M Cost	$142,686	$166,294	-$868,893
Total Annual Cost	**$232,940**	**$941,447**	**$2,315,948**
Annual TIN Load Reduction (lb/yr)	23,287	232,870	2,328,700
Estimated Cost for TIN Reduction ($/lb TIN removed)	$10.00	$4.04	$0.99
Equation:[a]			$y = 262.5x^{-0.331}$
R-Square Value:			0.9957

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.2 Conventional Activated Sludge Plants

Table 12-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for a conventional activated sludge plant. Figures 12-27 and 12-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$2.83	$1.62	$1.30
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.06	$0.03

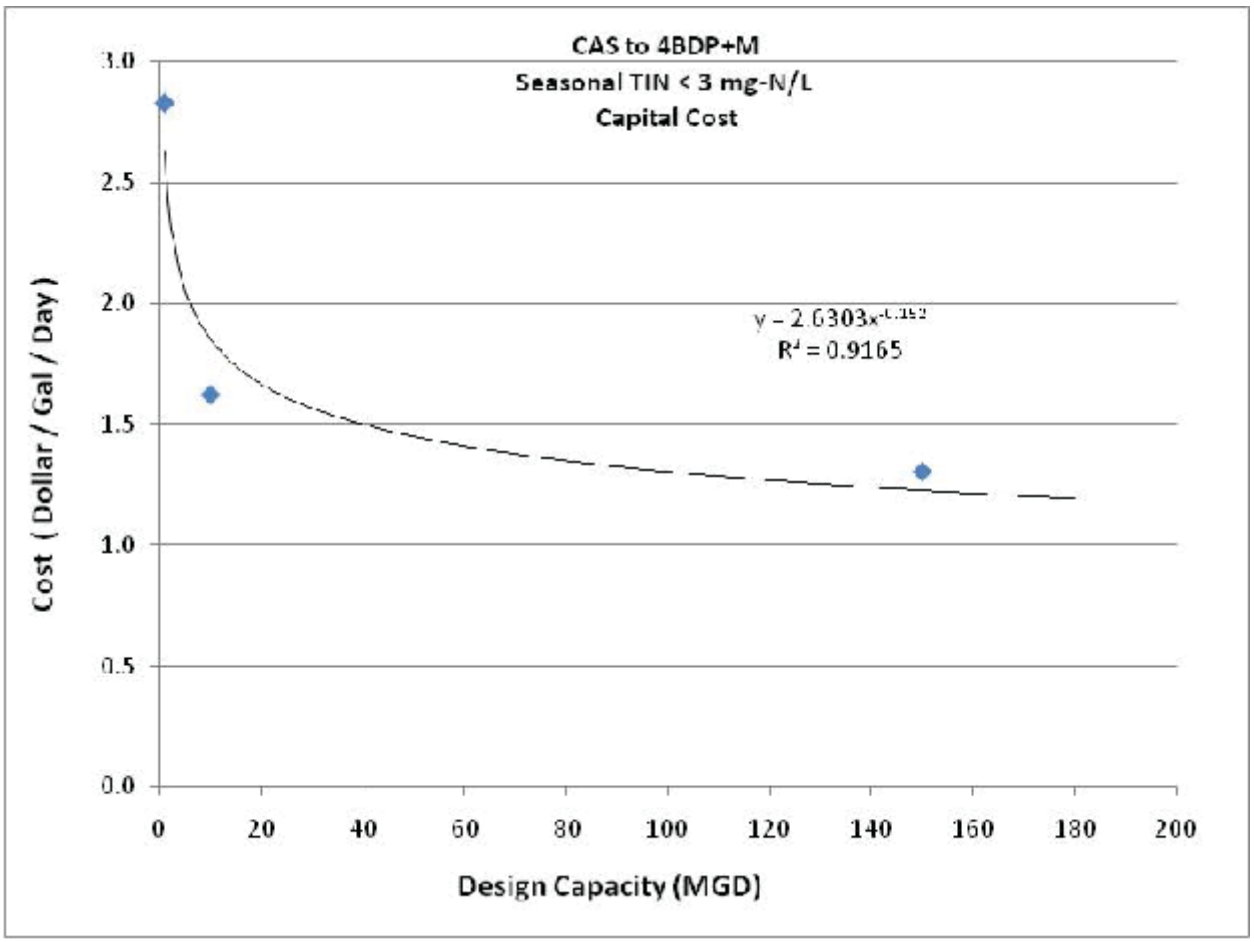

Figure 12-27. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective B Seasonally

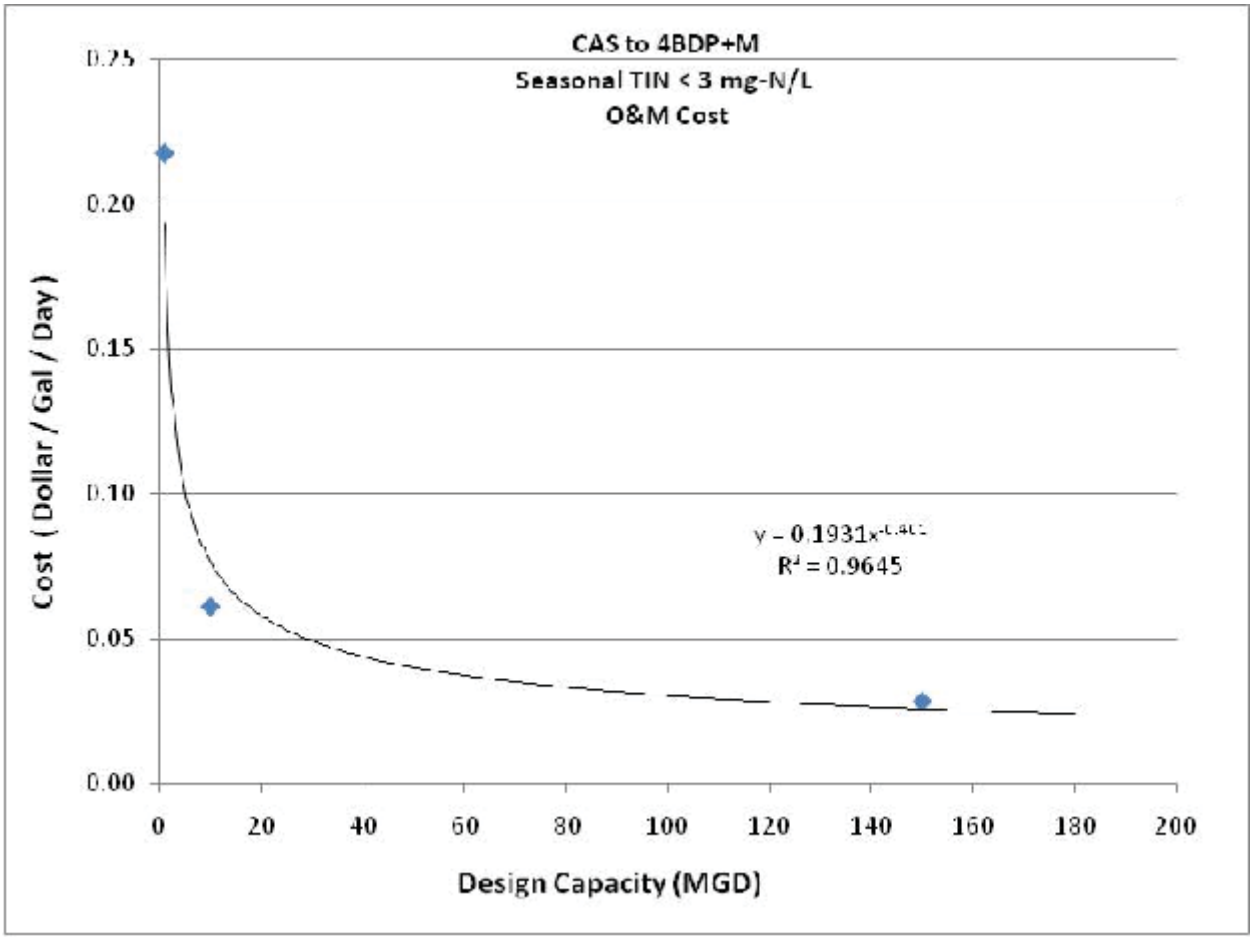

Figure 12-28. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective B Seasonal

TABLE 12-28.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$207,608	$1,190,435	$14,350,478
2014 O&M Cost	$245,065	$691,484	$4,846,582
Total Annual Cost	**$452,673**	**$1,881,920**	**$19,197,060**
Annual TIN Load Reduction (lb/yr)	22,685	226,848	3,402,713
Estimated Cost for TIN Reduction ($/lb TIN removed)	$19.95	$8.30	$5.64
Equation:[a]			$y = 217.78x^{-0.249}$
R-Square Value:			0.9303

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.3 Sequencing Batch Reactor Plants

Table 12-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for an SBR plant. Figures 12-29 and 12-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-30 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.81	$0.85	$0.50
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.59	$0.24	$0.10

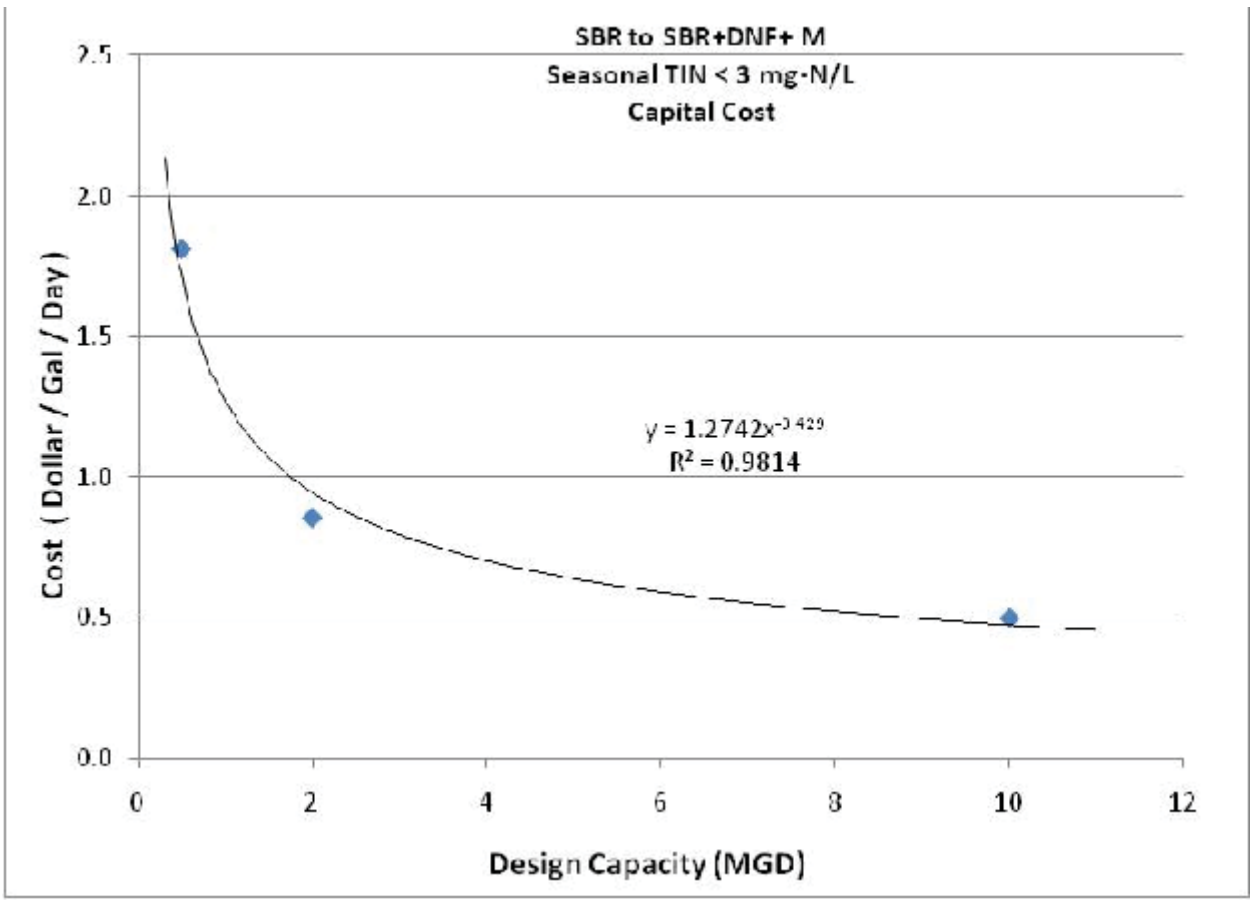

Figure 12-29. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective B Seasonally

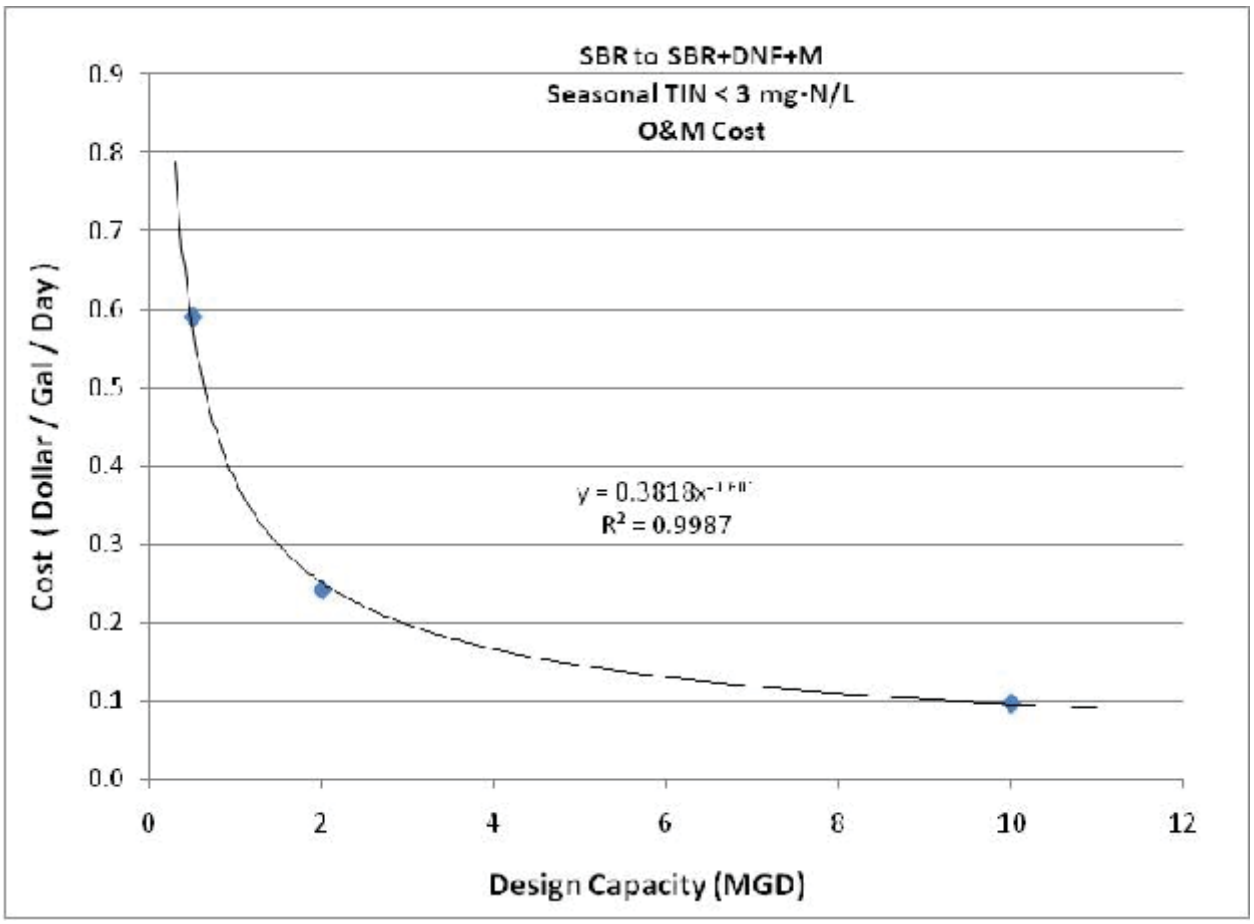

Figure 12-30. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective B Seasonal

TABLE 12-30.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$66,552	$125,538	$365,384
2014 O&M Cost	$332,581	$545,450	$1,098,542
Total Annual Cost	**$399,132**	**$670,988**	**$1,460,926**
Annual TIN Load Reduction (lb/yr)	475	1,898	9,490
Estimated Cost for TIN Reduction ($/lb TIN removed)	$841.16	$353.52	$153.94
Equation:[a]			$y = 26701x^{-0.566}$
R-Square Value:			0.997

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 12-31 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for a trickling filter plant. Figures 12-31 and 12-32 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-32 and Figures 12-33 and 12-34 summarize these costs for a trickling filter/solids contact plant. Table 12-33 and Figures 12-35 and 12-36 summarize these costs for an RBC plant. Tables 12-34, 12-35 and 12-36 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 12-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.17	$3.25	$2.08
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.28	$0.08	$0.03

TABLE 12-32.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.43	$2.56	$1.66
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.17	$0.06	$0.02

TABLE 12-33.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$5.19	$3.27	$2.12
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.33	$0.09	$0.03

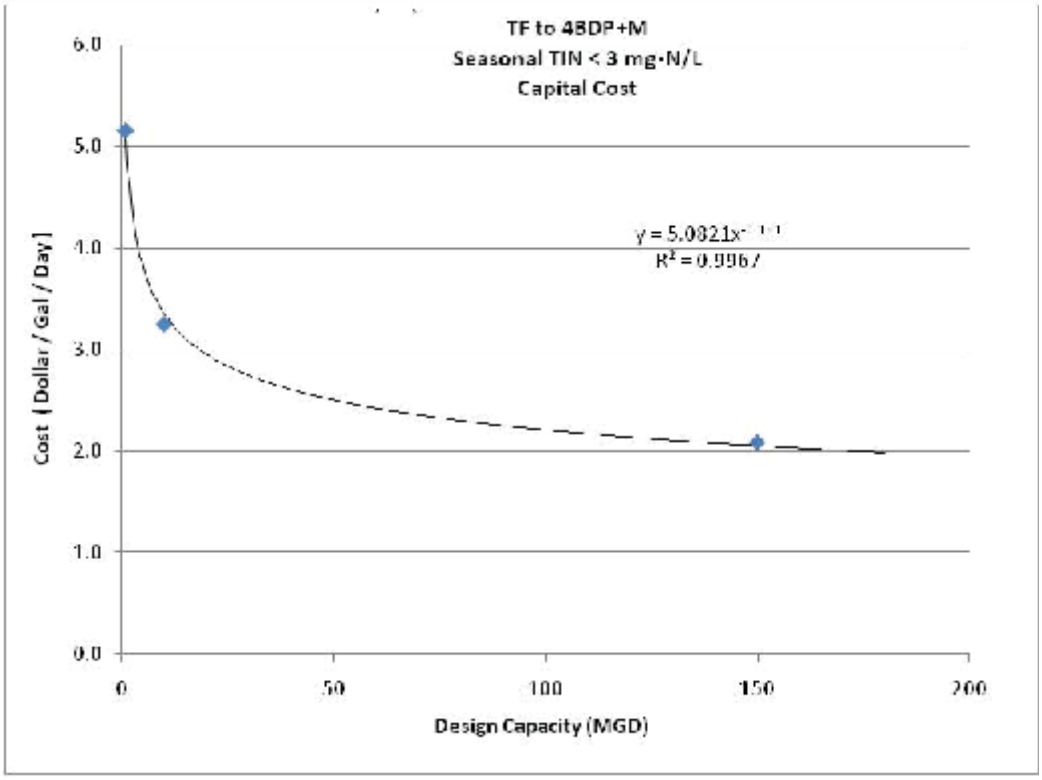

Figure 12-31. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective B Seasonally

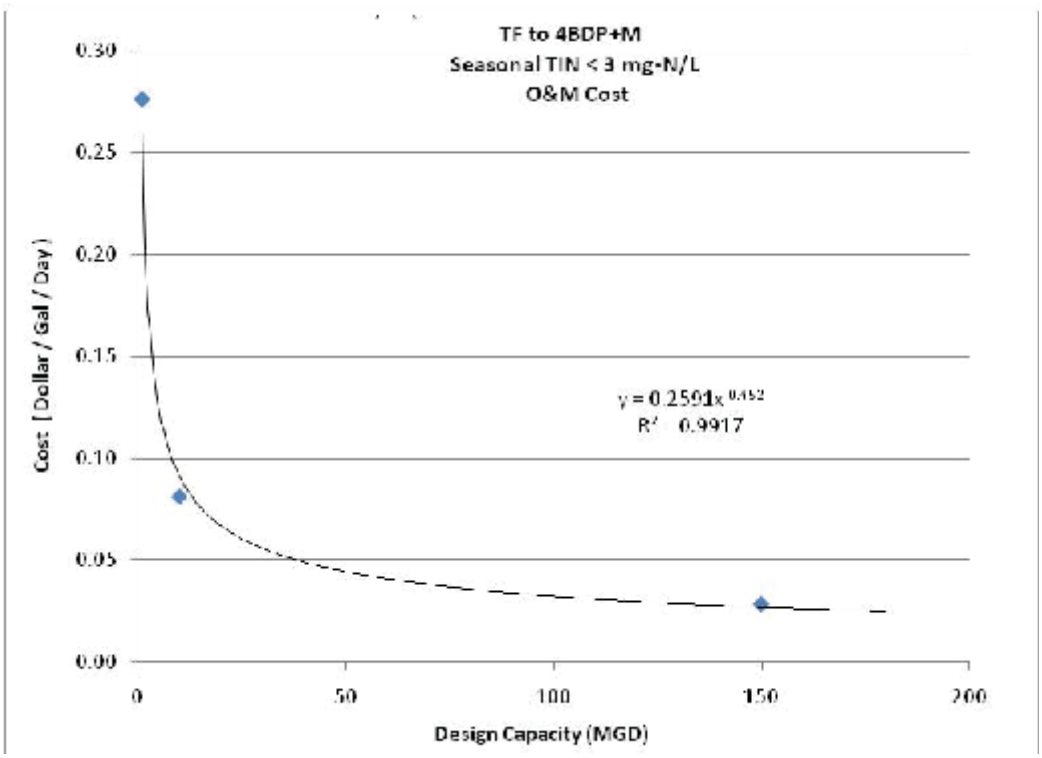

Figure 12-32. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective B Seasonal

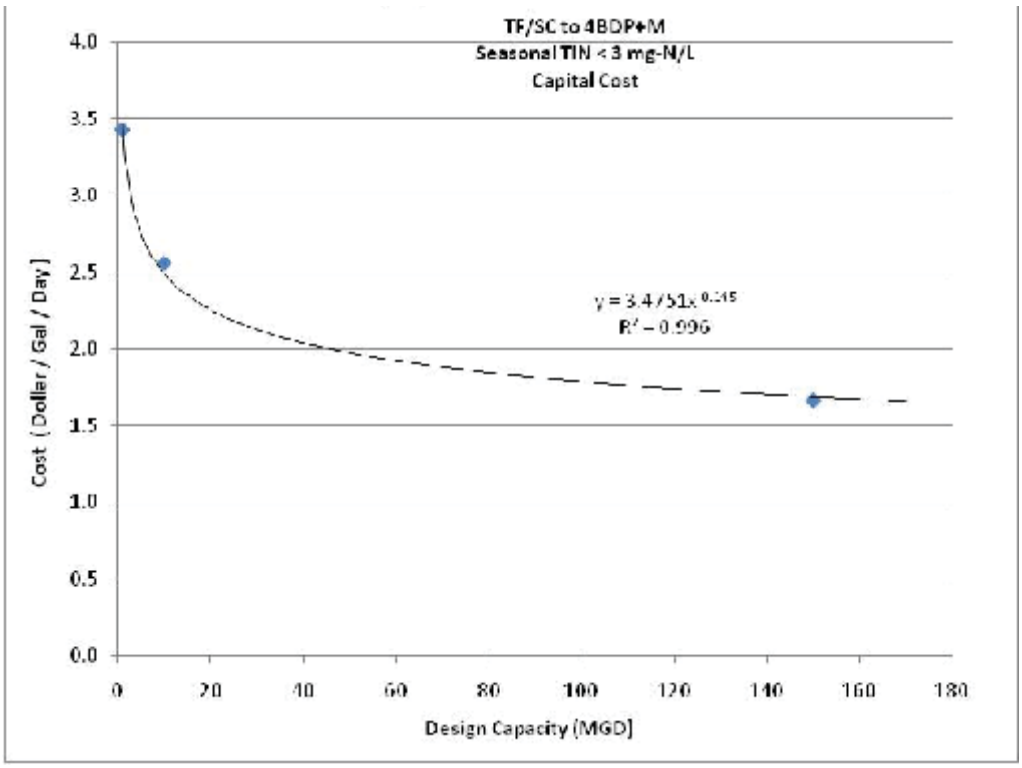

Figure 12-33. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective B Seasonally

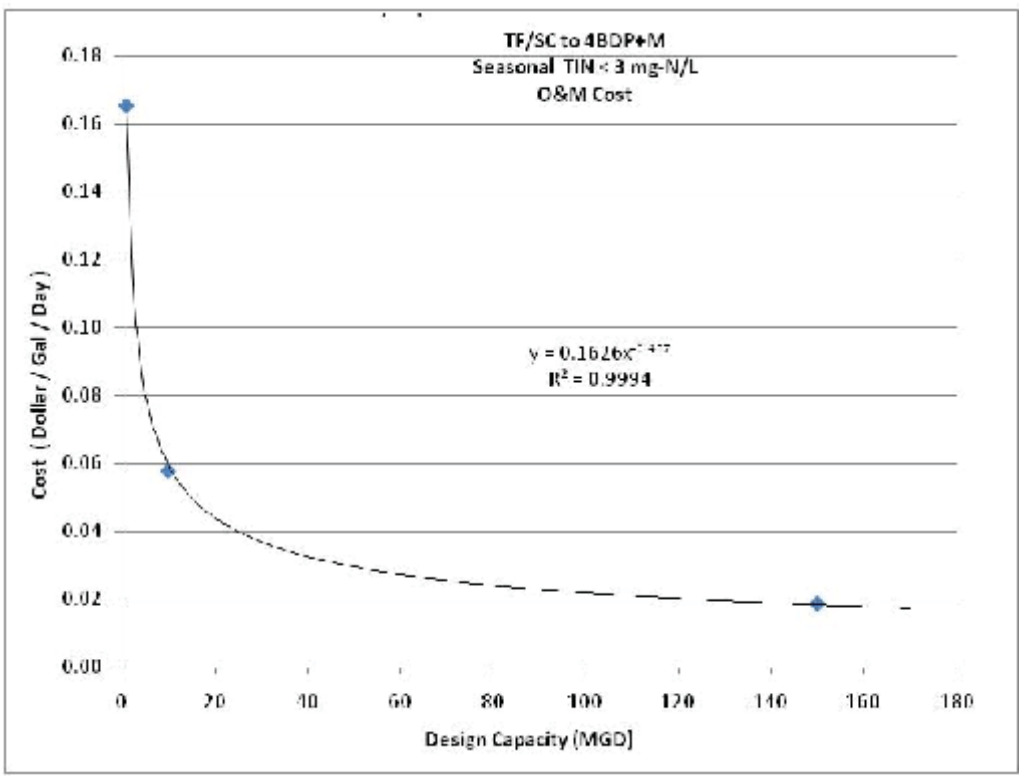

Figure 12-34. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective B Seasonal

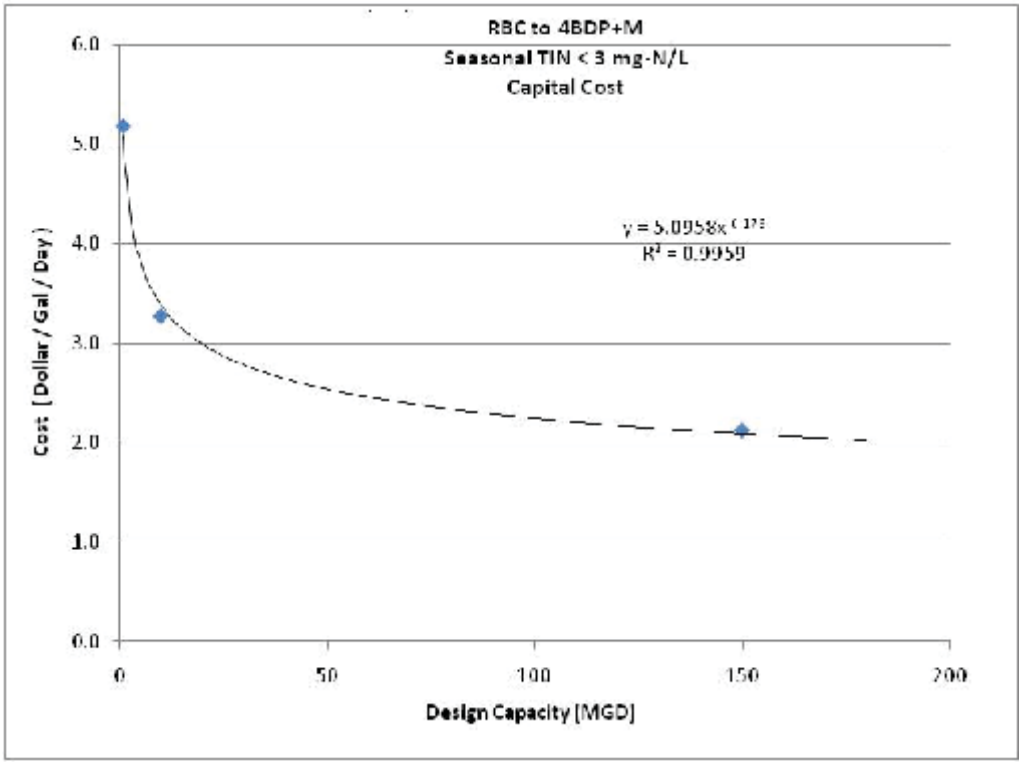

Figure 12-35. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective B Seasonally

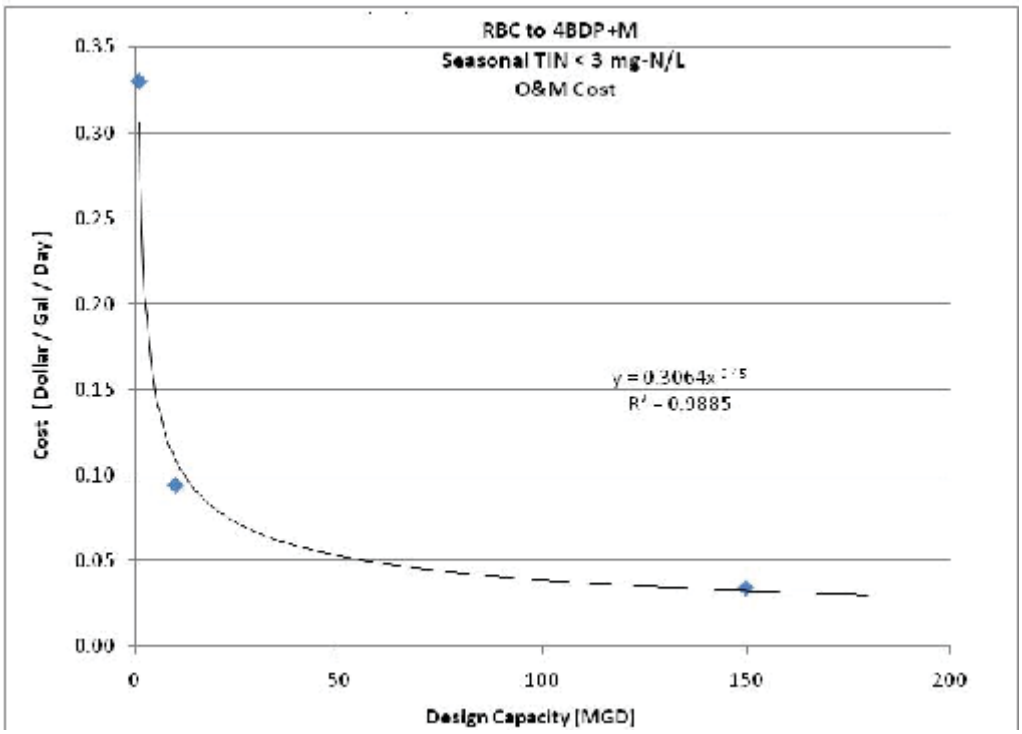

Figure 12-36. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective B Seasonal

TABLE 12-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$379,427	$2,386,145	$22,903,545
2014 O&M Cost	$311,020	$912,703	$4,786,367
Total Annual Cost	**$690,447**	**$3,298,848**	**$27,689,912**
Annual TIN Load Reduction (lb/yr)	22,685	226,848	3,402,713
Estimated Cost for TIN Reduction ($/lb TIN removed)	$30.44	$14.54	$8.14
Equation:[a]			$y = 400.95x^{-0.262}$
R-Square Value:			0.9866

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-35.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$251,616	$1,879,081	$8,336,346
2014 O&M Cost	$186,145	$649,053	$3,123,990
Total Annual Cost	**$437,761**	**$2,528,134**	**$21,460,337**
Annual TIN Load Reduction (lb/yr)	22,685	226,848	3,402,713
Estimated Cost for TIN Reduction ($/lb TIN removed)	$19.30	$11.14	$6.31
Equation:[a]			$y = 177.89x^{-0.223}$
R-Square Value:			0.9986

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$380,990	$2,403,585	$23,356,810
2014 O&M Cost	$372,040	$1,064,084	$5,793,697
Total Annual Cost	**$753,030**	**$3,467,669**	**$29,150,507**
Annual TIN Load Reduction (lb/yr)	22,685	226,848	3,402,713
Estimated Cost for TIN Reduction ($/lb TIN removed)	$33.20	$15.29	$8.57
Equation:[a]			$y = 464.91x^{-0.269}$
R-Square Value:			0.9831

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.5 Membrane Biological Reactor Plants

Table 12-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for an MBR plant. Figures 12-37 and 12-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-38 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.029	$0.004	$0.002
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.013	$0.013	$0.013

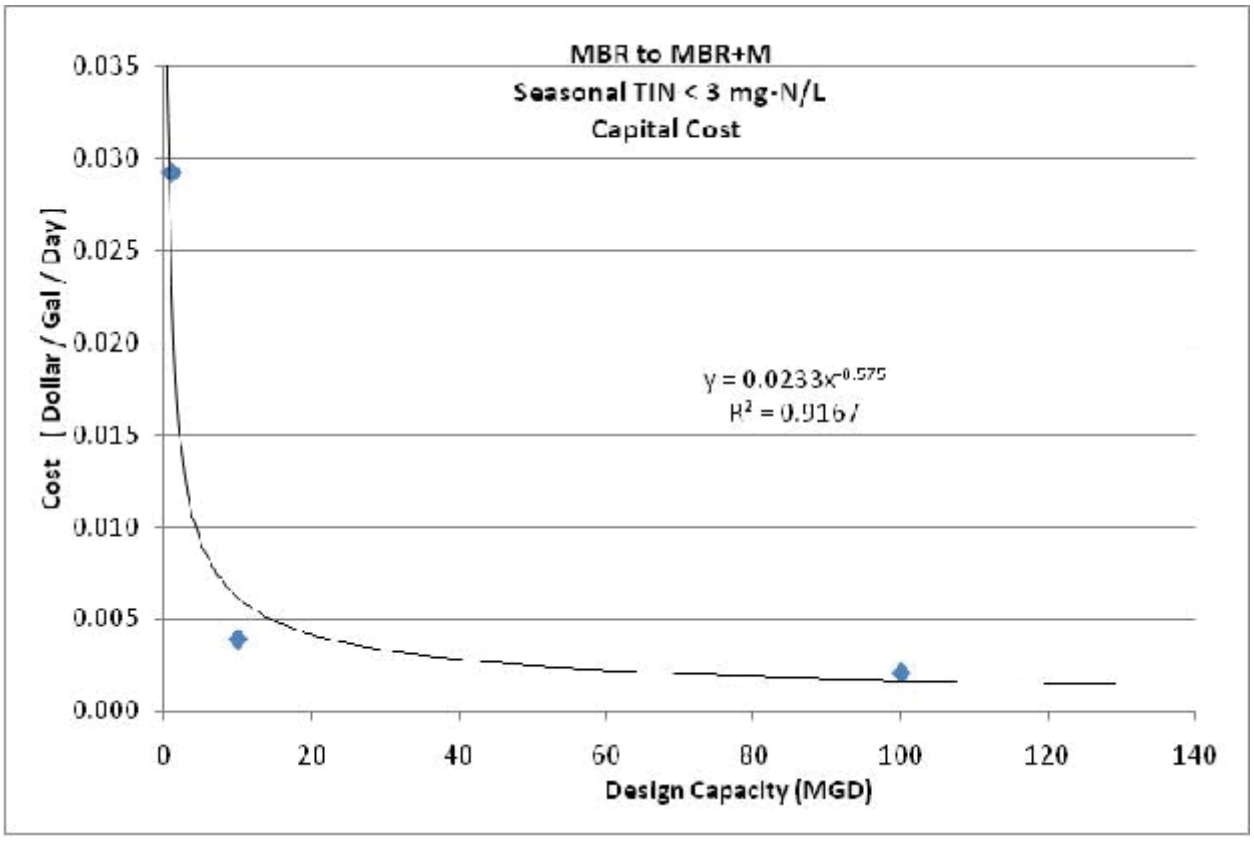

Figure 12-37. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective B Seasonally

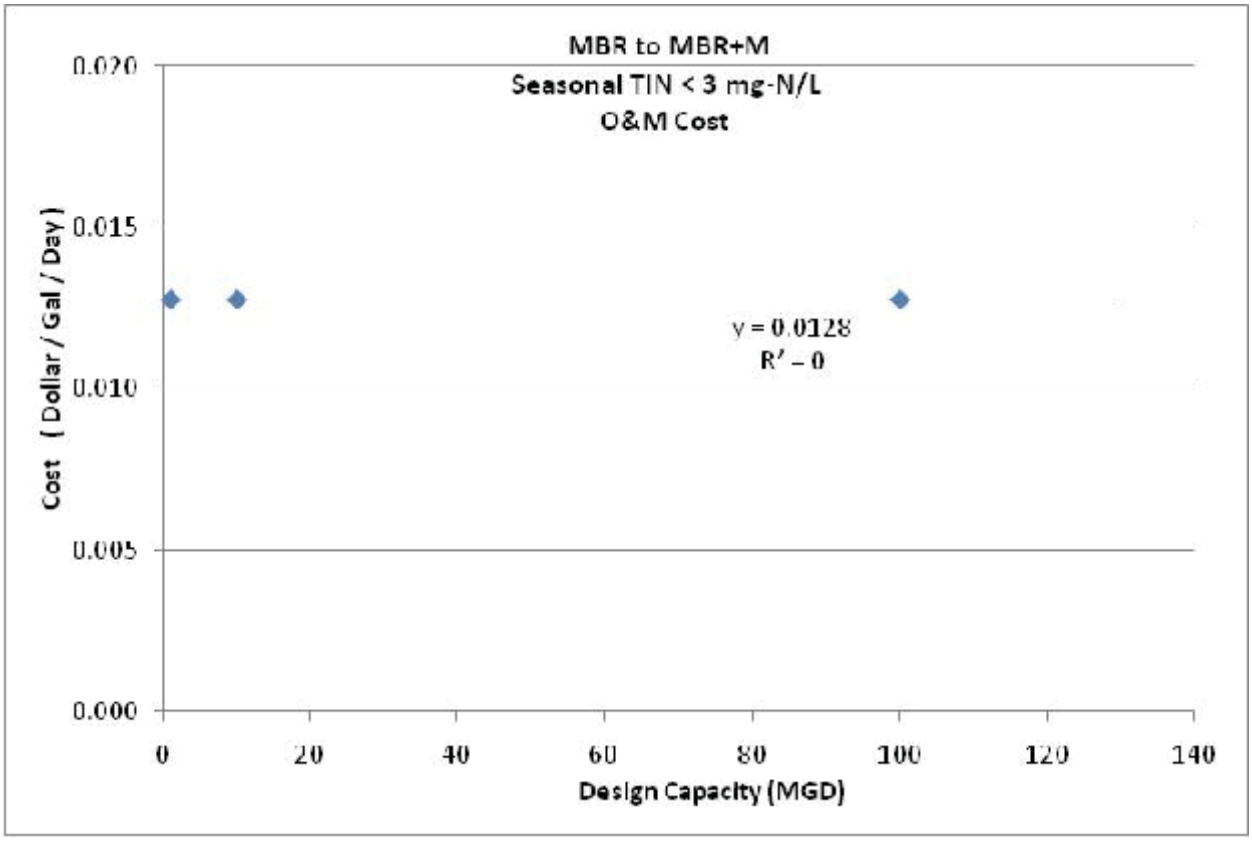

Figure 12-38. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective B Seasonal

TABLE 12-38.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$2,512	$2,864	$15,211
2014 O&M Cost	$14,378	$143,784	$1,437,838
Total Annual Cost	**$16,530**	**$146,648**	**$1,453,049**
Annual TIN Load Reduction (lb/yr)	3,814	38,143	381,425
Estimated Cost for TIN Reduction ($/lb TIN removed)	$4.33	$3.84	$3.81
Equation:[a]			$y = 5.3439x^{-0.028}$
R-Square Value:			0.7958

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.6 High-Purity Oxygen Activated Sludge Plants

Table 12-39 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for an HPO plant. Figures 12-39 and 12-40 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-40 presents the annualized unit costs for reducing nutrient loads.

TABLE 12-39.
ESTIMATED COST PER CAPACITY FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	20-mgd Plant	220-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.71	$1.60
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.13	$0.10

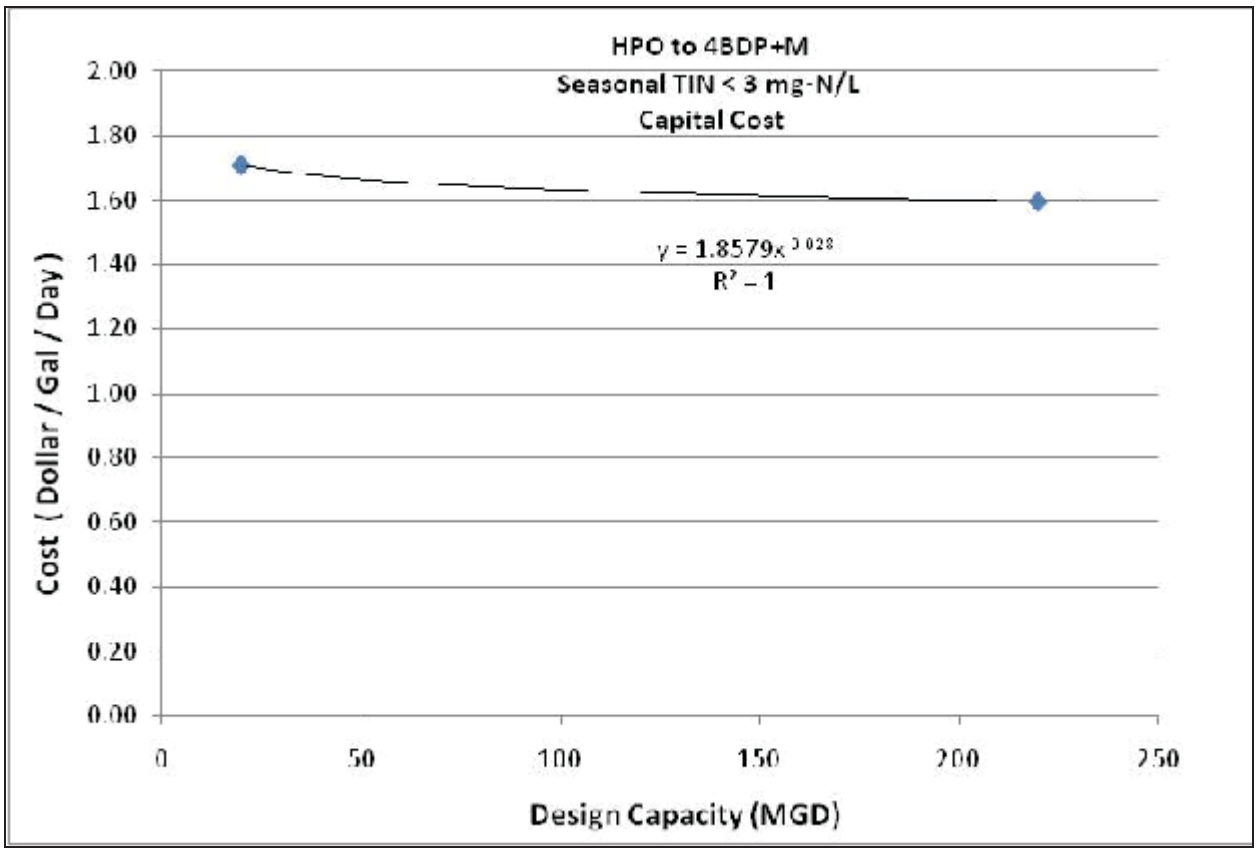

Figure 12-39. Capital Cost per Plant Capacity for HPO Plant Upgraded for Objective B Seasonal

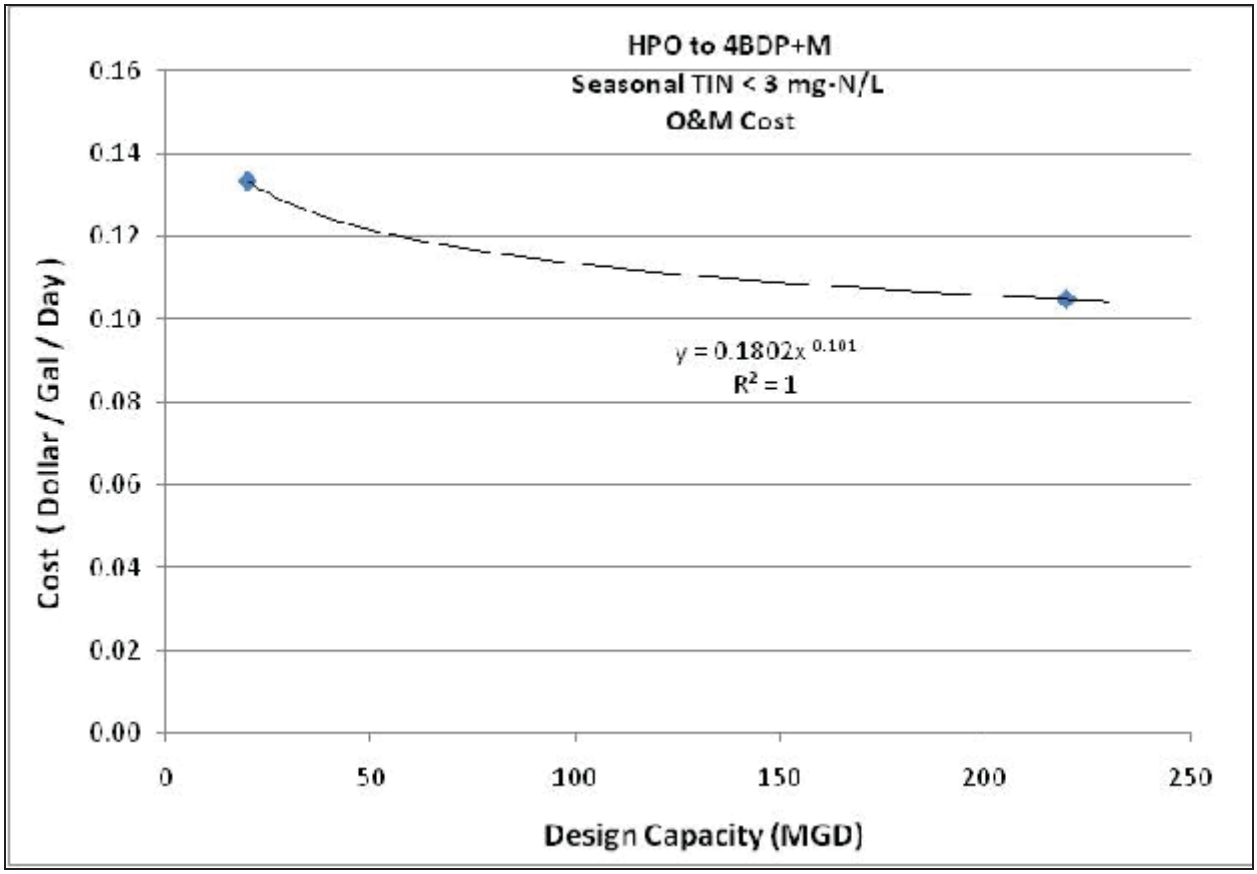

Figure 12-40. O&M Cost per Plant Capacity for HPO Upgraded for Objective B Seasonal

TABLE 12-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING HPO PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	20-mgd Plant	220-mgd Plant
Annualized Capital Cost	$2,508,000	$25,791,880
2014 O&M Cost	$3,002,000	$25,942,000
Total Annual Cost	**$5,510,185**	**$51,734,000**
Annual TIN Load Reduction (lb/yr)	479,975	5,279,725
Estimated Cost for TIN Reduction ($/lb TIN removed)	$11.50	$9.80
Equation:[a]		$y = 27.215x^{-0.066}$
R-Square Value:		1

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

12.2.7 Aerated or Facultative Lagoon Plants

Table 12-41 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective B seasonally for an aerated lagoon plan. Figures 12-41 and 12-42 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 12-42 and Figures 12-43 and 12-44 summarize these costs for a facultative lagoon plant. Tables 12-43 and 12-44 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 12-41.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$22.30	$16.67	$11.02	$6.65
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.02	$0.61	$0.26	$0.11

TABLE 12-42.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$22.16	$16.55	$10.93	$6.60
Incremental Annual O&M Cost per gpd of Plant Capacity	$1.29	$0.84	$0.42	$0.14

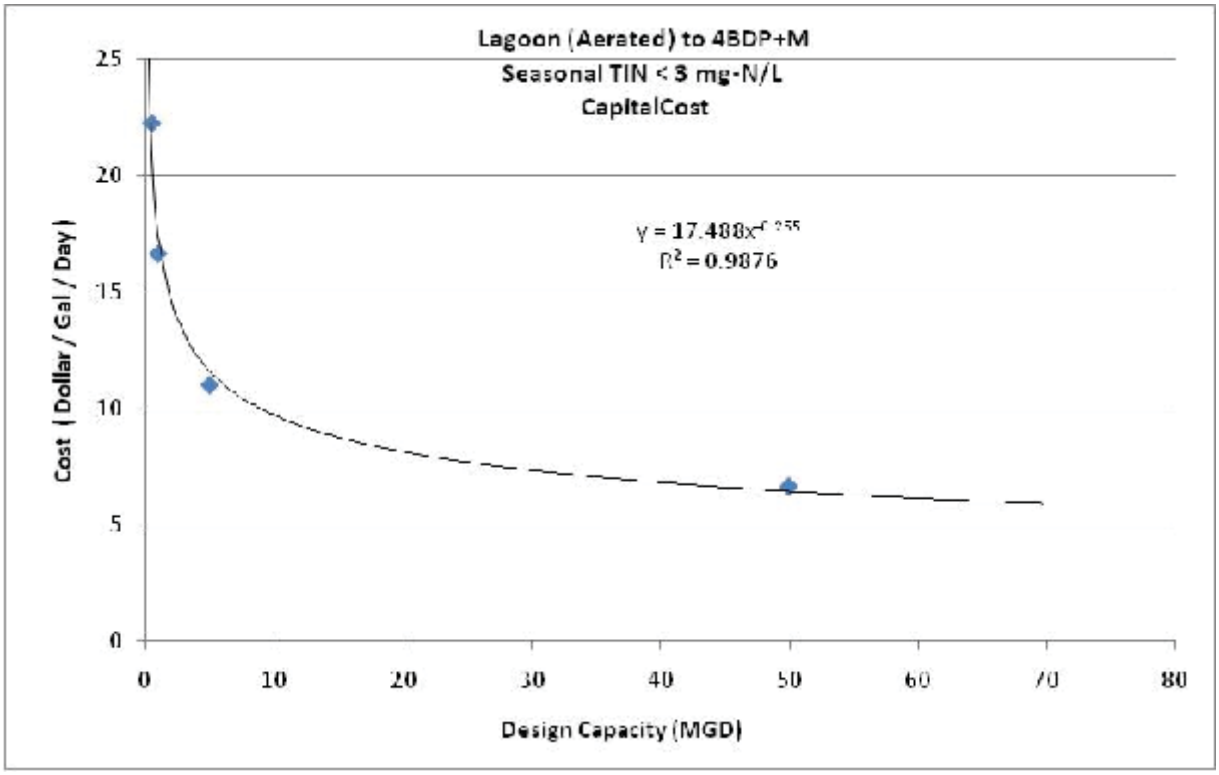

Figure 12-41. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective B Seasonally

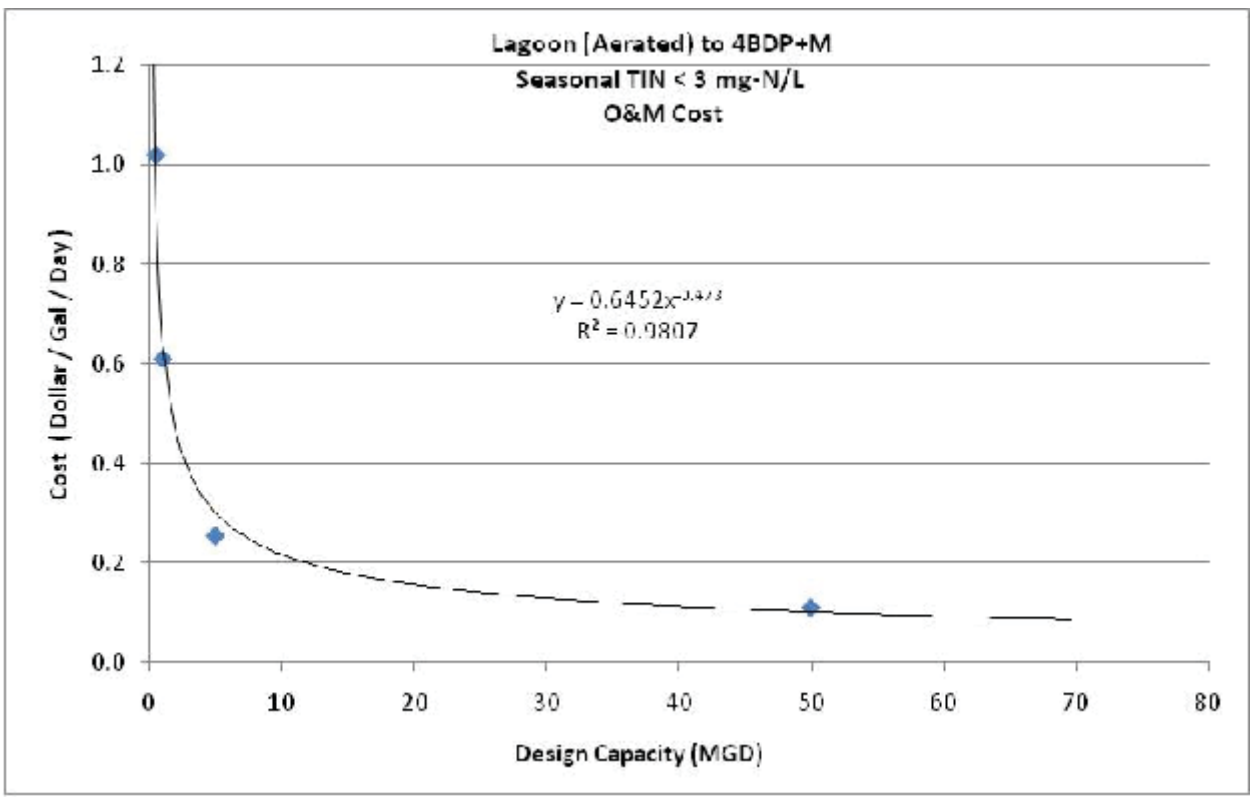

Figure 12-42. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective B Seasonal

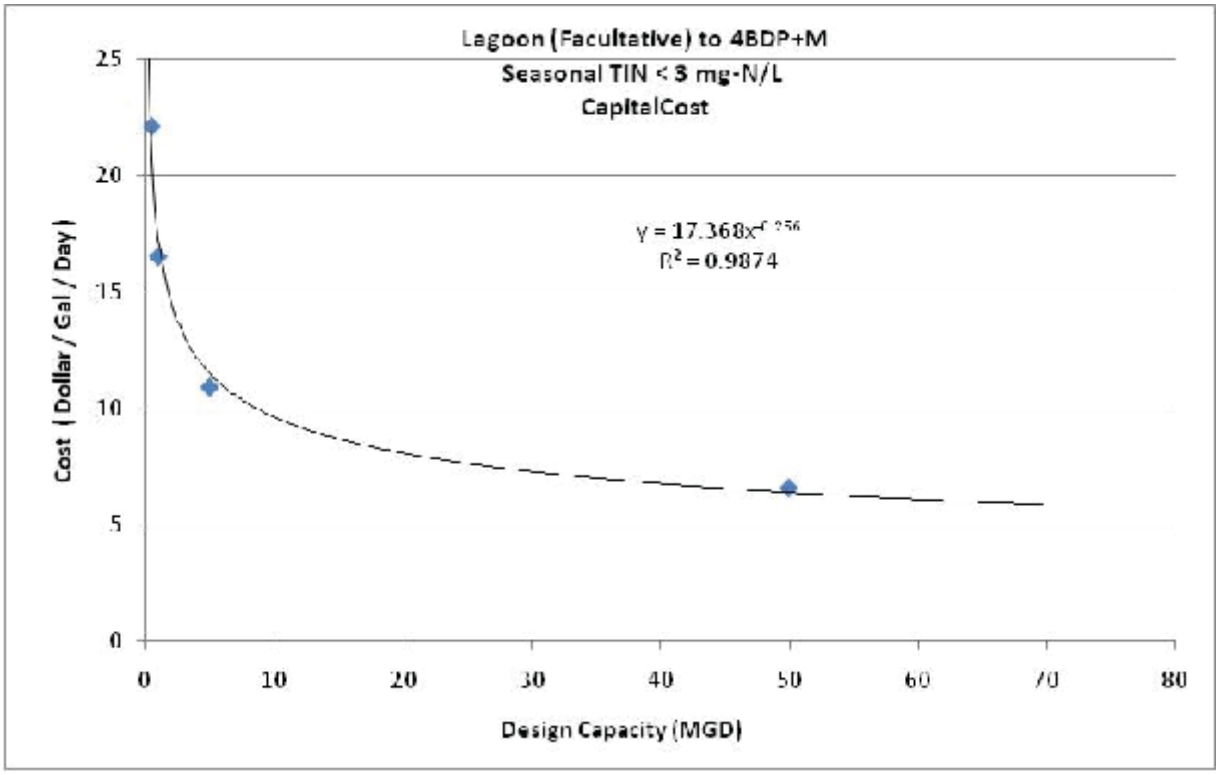

Figure 12-43. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective B Seasonally

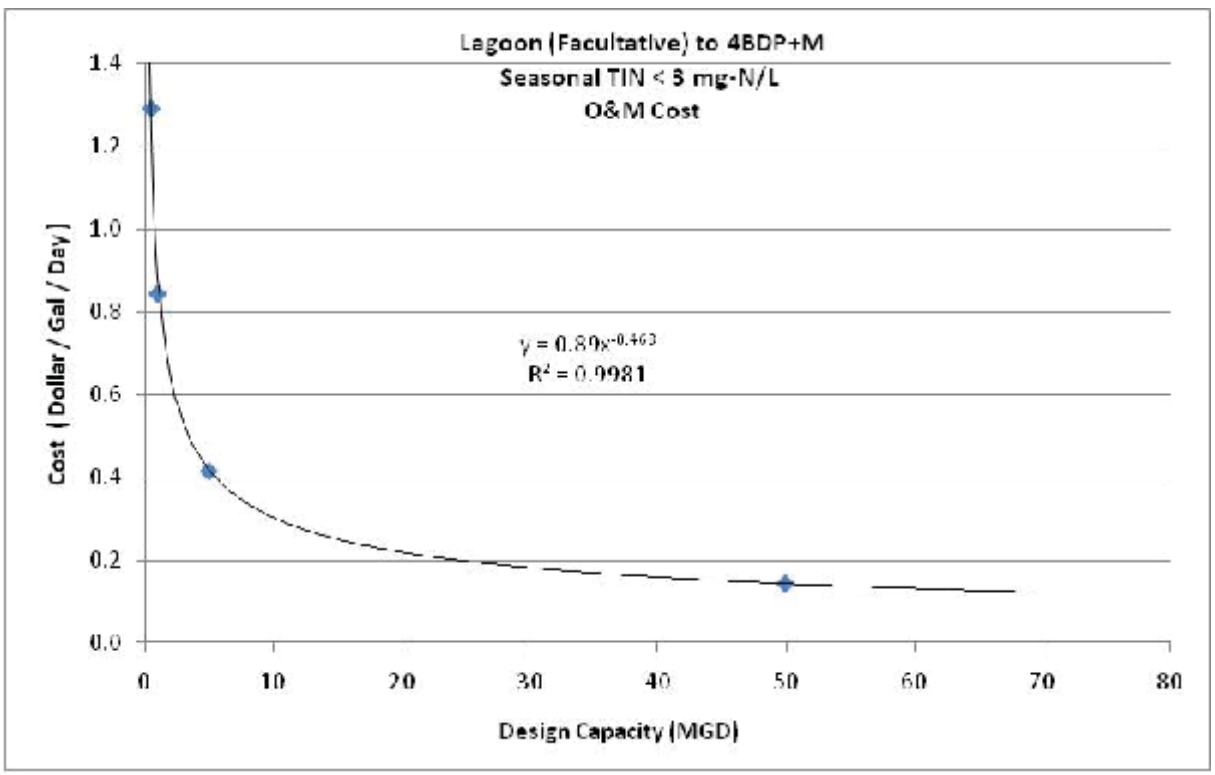

Figure 12-44. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective B Seasonal

TABLE 12-43.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$819,066	$1,224,063	$4,047,995	$24,419,256
2014 O&M Cost	$573,765	$687,016	$1,437,528	$6,243,366
Total Annual Cost	**$1,392,831**	**$1,991,080**	**$5,485,523**	**$30,662,622**
Annual TIN Load Reduction (lb/yr)	11,534	23,068	115,340	1,134,238
Estimated Cost for TIN Reduction ($/lb TIN removed)	$120.76	$82.85	$47.56	$27.03

Equation:[a] ..... $y = 2132.1x^{-0.318}$
R-Square Value: 0.979

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

TABLE 12-44.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE B SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$813,966	$1,215,590	$4,014,843	$24,244,860
2014 O&M Cost	$726,934	$950,695	$2,340,355	$8,130,636
Total Annual Cost	**$1,540,900**	**$2,166,285**	**$6,355,198**	**$32,375,496**
Annual TIN Load Reduction (lb/yr)	11,534	23,068	115,340	1,134,238
Estimated Cost for TIN Reduction ($/lb TIN removed)	$133.60	$93.91	$55.10	$28.54

Equation:[a] ..... $y = 2798.3x^{-0.332}$
R-Square Value: 0.9928

a. x = Annual TIN Load Reduction (lb), y= Estimated Cost for TIN Reduction ($/lb TIN removed)

CHAPTER 13.
COST EVALUATION, OBJECTIVE C

13.1 YEAR-ROUND NUTRIENT REMOVAL

13.1.1 Extended Aeration Plants

Table 13-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for an extended aeration plant using mechanical aeration. Figures 13-1 and 13-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-2 and Figures 13-3 and 12-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 13-3 and 13-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 13-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.78	$0.23	$0.24
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.14	$0.13

TABLE 13-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.00	$0.46	$0.29
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.14	$0.10	$0.09

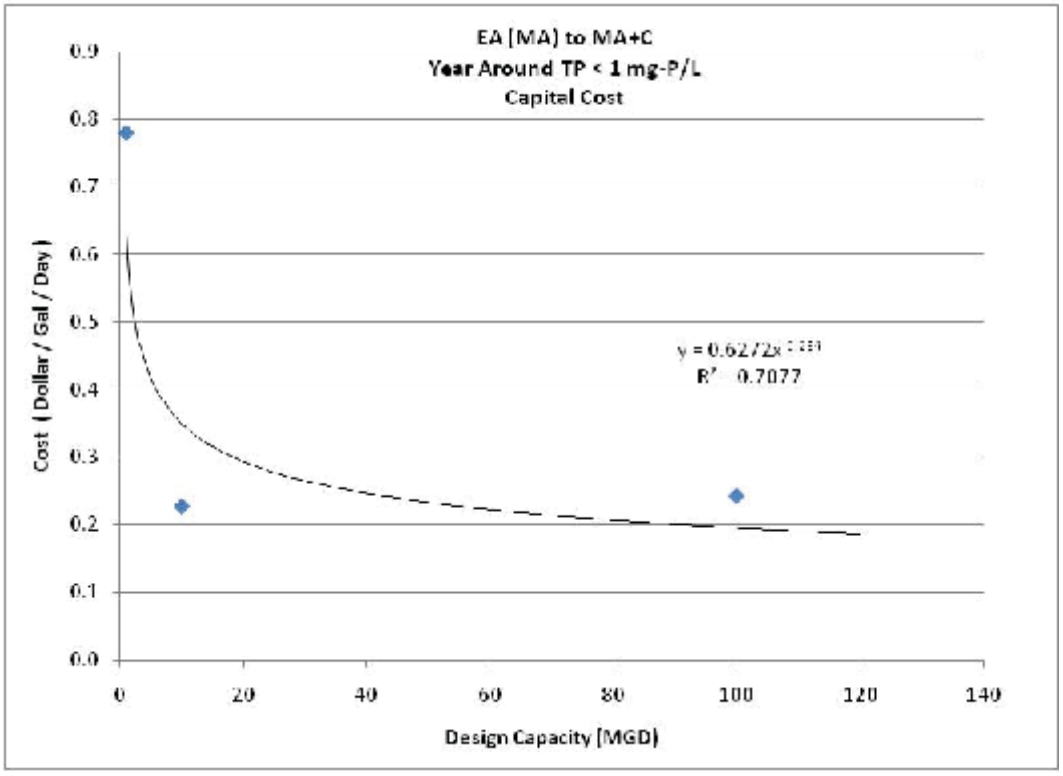

Figure 13-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective C Year-Round

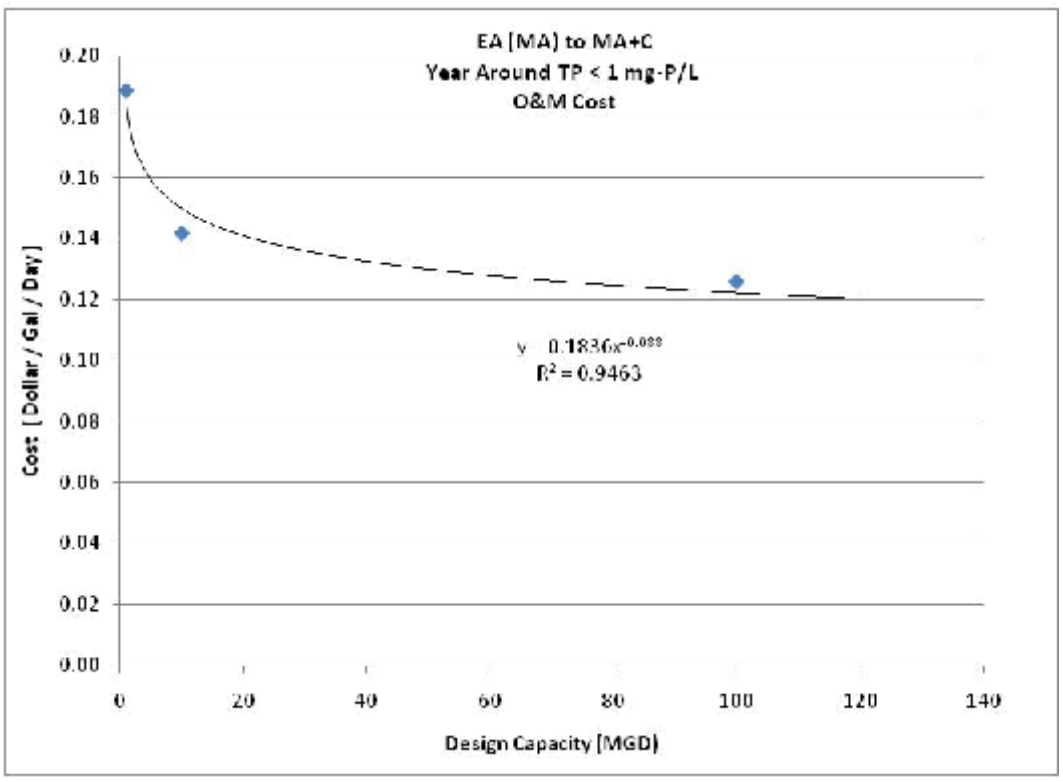

Figure 13-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective C Year-Round

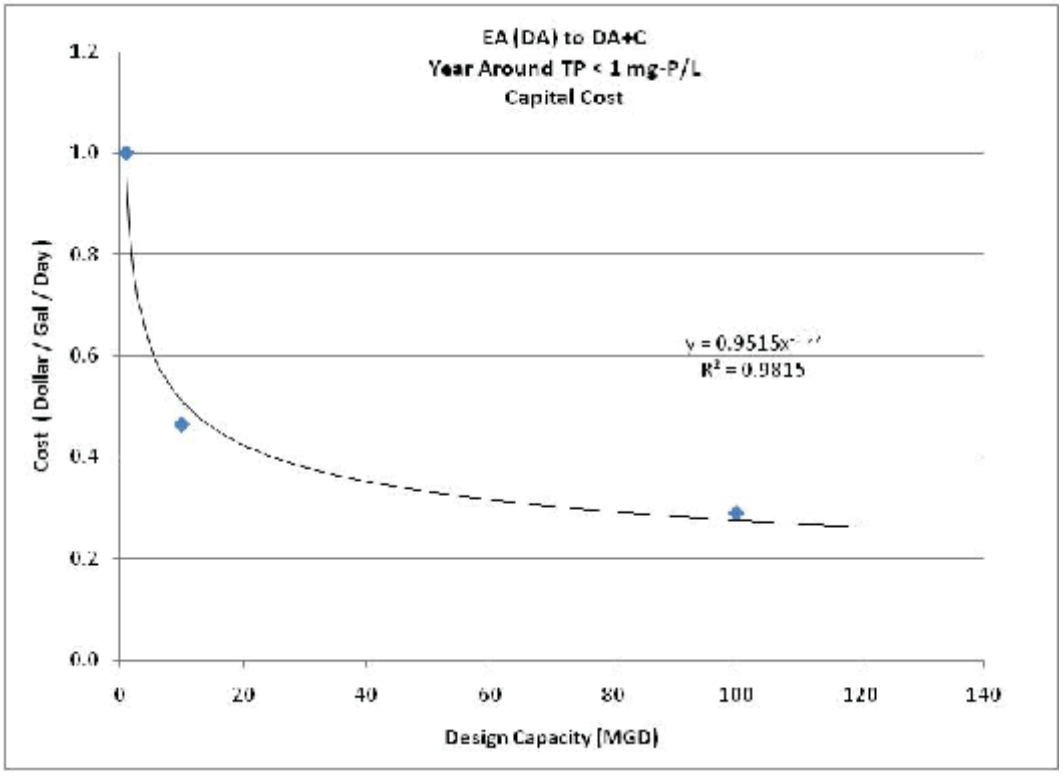

Figure 13-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective C Year-Round

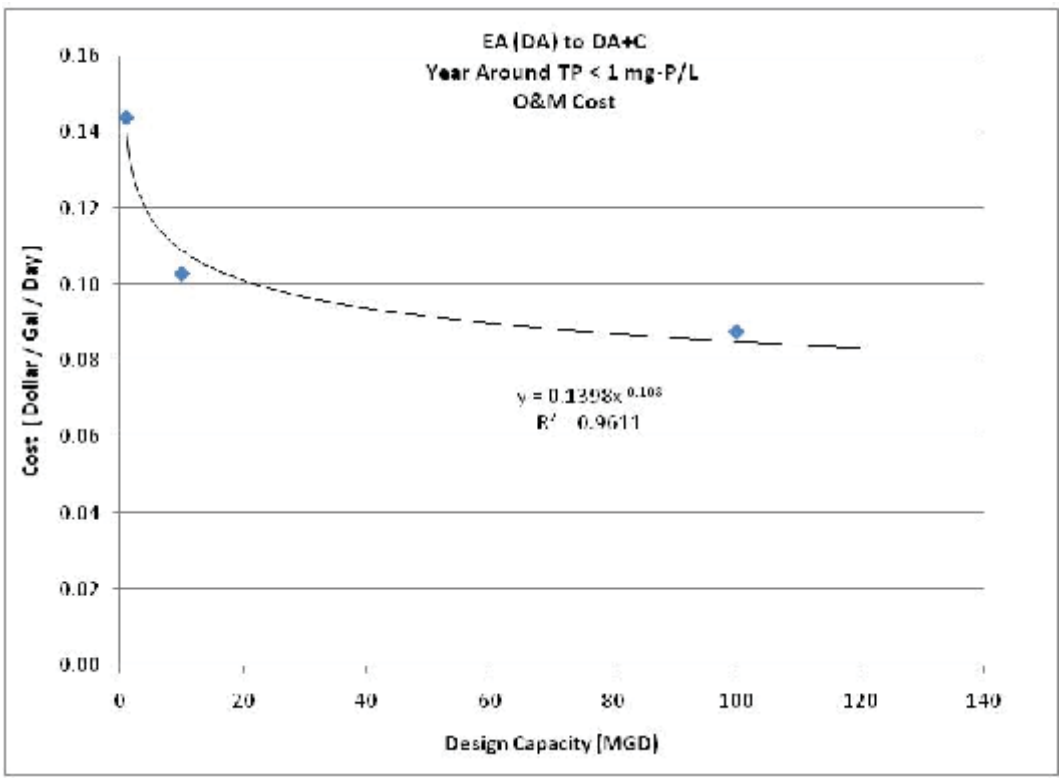

Figure 13-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective C Year-Round

TABLE 13-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$57,213	$166,499	$1,778,664
2014 Incremental O&M Cost	$212,440	$1,594,852	$14,156,762
Total Annual Cost	**$269,653**	**$1,761,350**	**$15,935,426**
Annual TP Load Reduction (lb/yr)	11,060	110,595	1,105,950
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$24.38	$15.93	$14.41

Equation:[a] ..... $y = 66.869x^{-0.114}$
R-Square Value: 0.8869

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$73,409	$340,278	$2,119,024
2014 Incremental O&M Cost	$161,961	$1,157,141	$9,837,060
Total Annual Cost	**$235,369**	**$1,497,419**	**$11,956,083**
Annual TP Load Reduction (lb/yr)	11,023	110,230	1,102,300
Estimated Cost for TP Reduction ($/lb TP removed)	$21.35	$13.58	$10.85

Equation:[a] ..... $y = 80.732x^{-0.147}$
R-Square Value: ..... $R^2 = 0.9636$

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.1.2 Conventional Activated Sludge Plants

Table 13-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for a conventional activated sludge plant. Figures 13-5 and 13-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$0.25	$0.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.14	$0.12

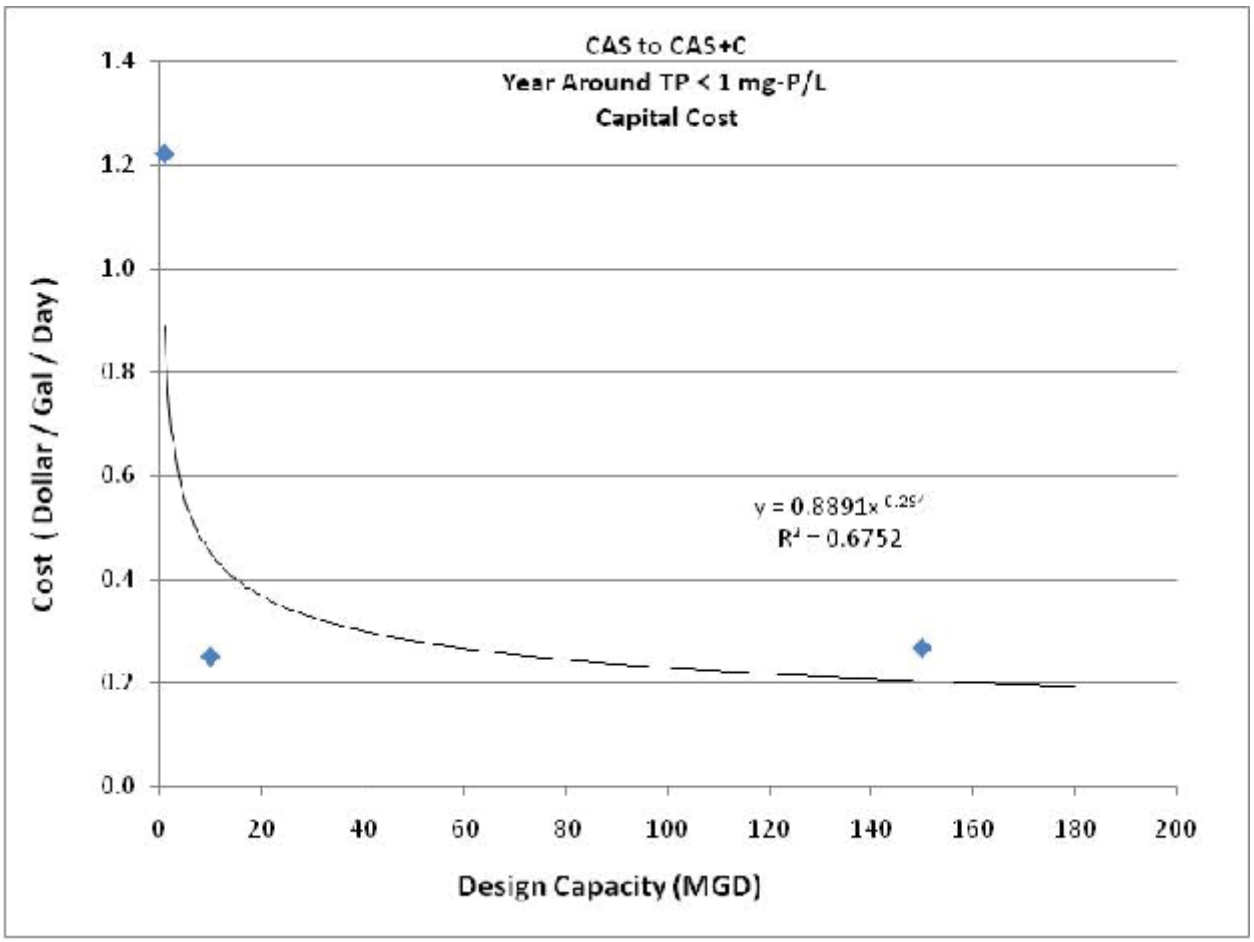

Figure 13-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective C Year-Round

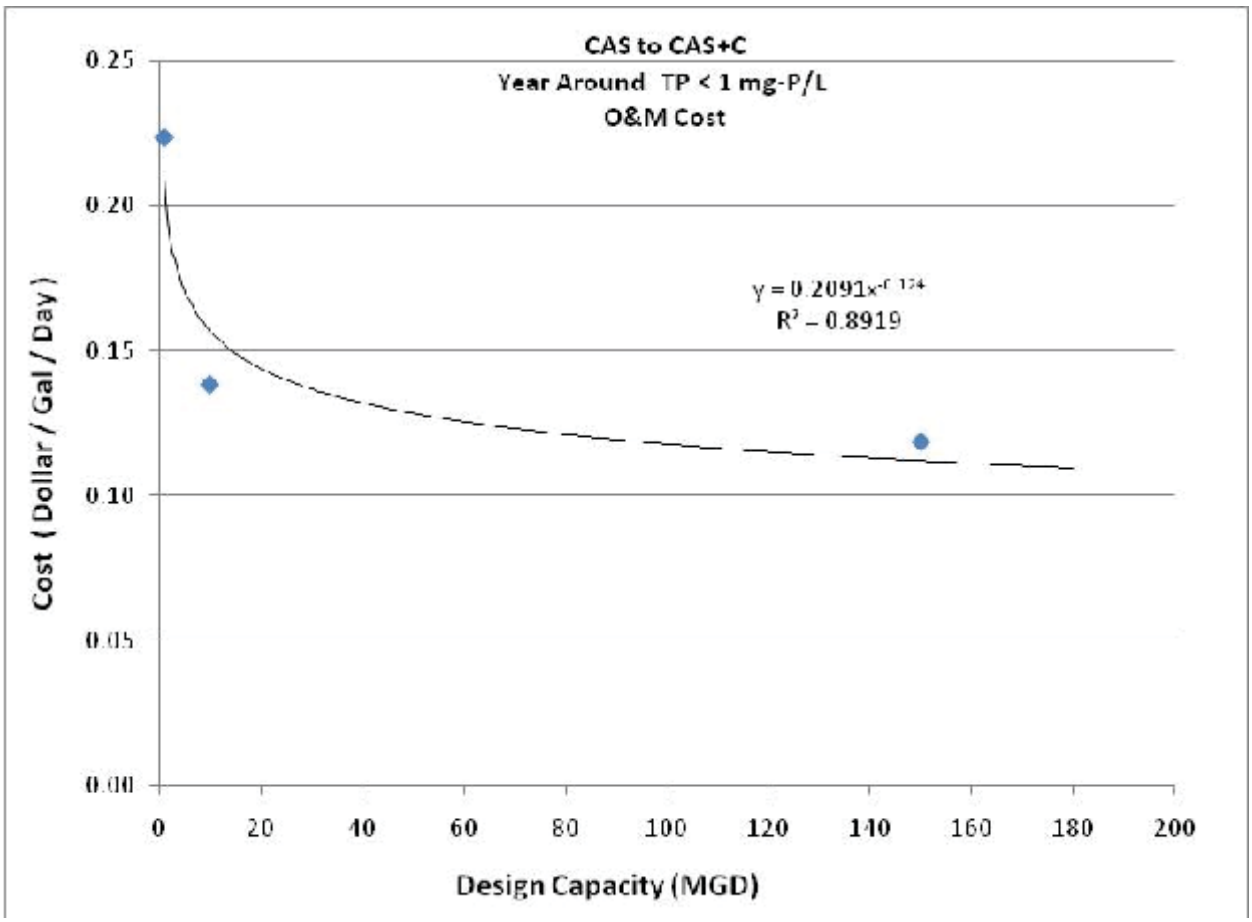

Figure 13-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective C Year-Round

TABLE 13-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$89,810	$184,134	$2,946,787
2014 O&M Cost	$251,872	$1,558,830	$20,042,160
Total Annual Cost	**$341,682**	**$1,742,963**	**$22,988,948**
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Cost for TP Reduction ($/lb TP removed)	$29.91	$15.26	$13.41
Equation:[a]	$y = 116.06x^{-0.157}$		
R-Square Value:	0.834		

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.1.3 Sequencing Batch Reactor Plants

Table 13-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for an SBR plant. Figures 13-7 and 13-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.44	$0.47	$0.20
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.10	$0.02	$0.01

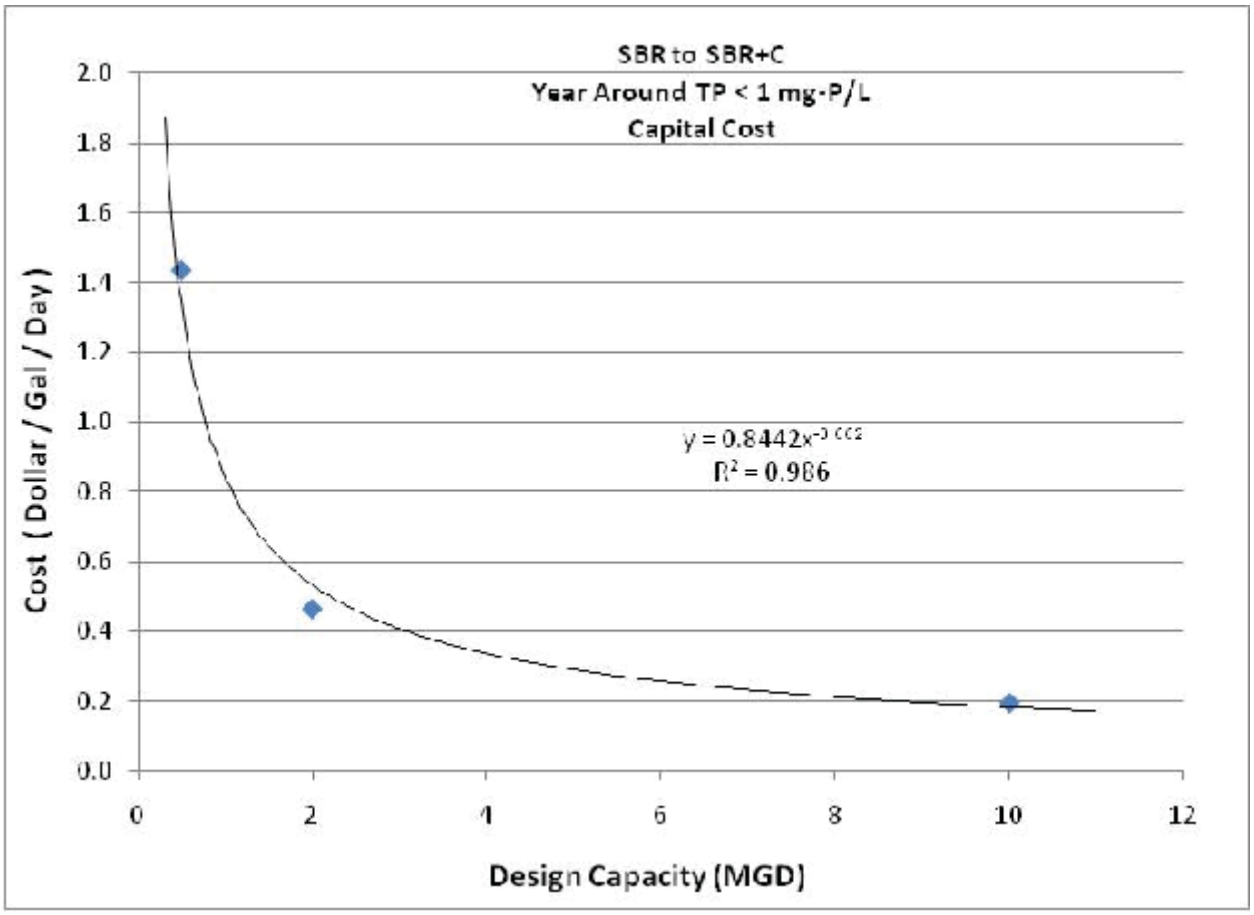

Figure 13-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective C Year-Round

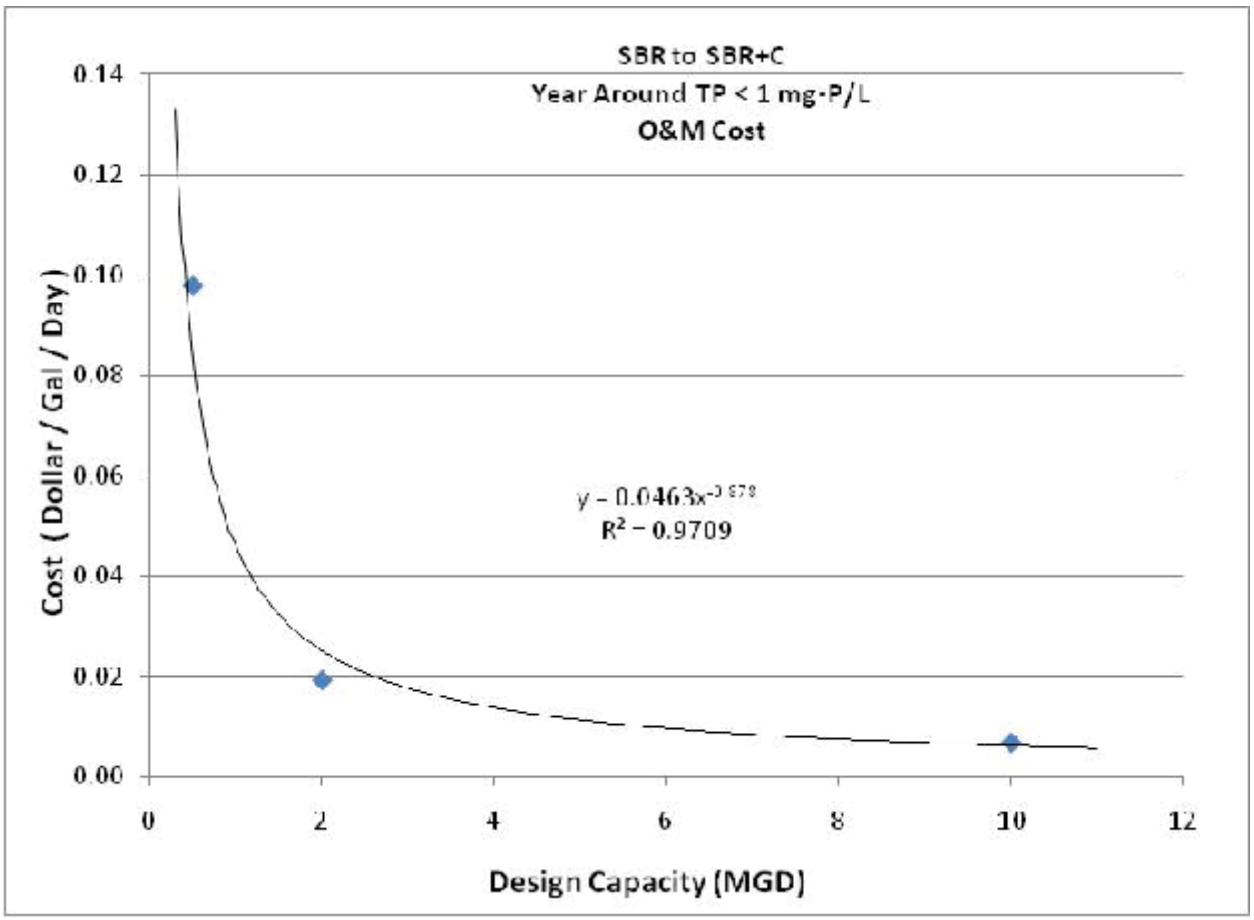

Figure 13-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective C Year-Round

TABLE 13-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$52,792	$68,370	$143,846
2014 O&M Cost	$55,144	$43,585	$77,885
Total Annual Cost	**$107,936**	**$1,11,956**	**$221,731**
Annual TP Load Reduction (lb/yr)	2,099	8,395	41,975
Estimated Cost for TP Reduction ($/lb TP removed)	$51.43	$13.34	$5.28
Equation:[a]			$y = 14903x^{-0.755}$
R-Square Value:			0.9777

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 13-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for a trickling filter plant. Figures 13-9 and 13-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-10 and Figures 13-11 and 13-12 summarize these costs for a trickling filter/solids contact plant. Table 13-11 and Figures 13-13 and 13-14 summarize these costs for an RBC plant. Tables 13-12, 13-13 and 13-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 13-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$0.25	$0.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.21	$0.13	$0.11

TABLE 13-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$0.25	$0.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.13	$0.11

TABLE 13-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.22	$0.25	$0.27
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.22	$0.13	$0.11

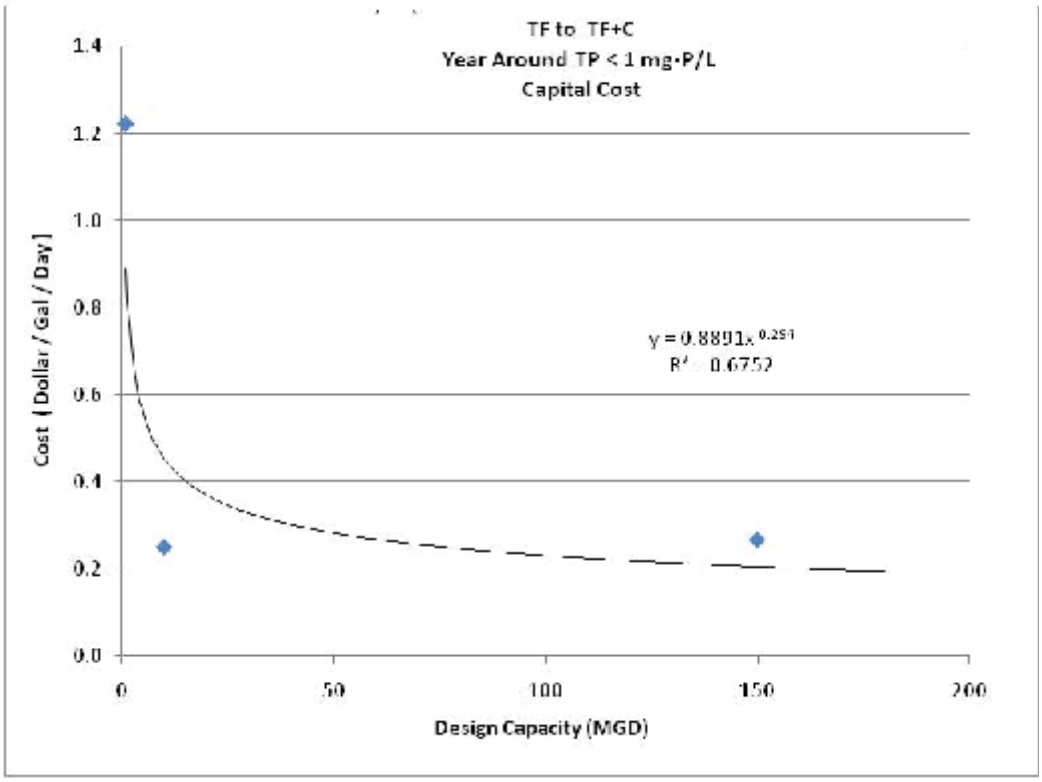

Figure 13-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective C Year-Round

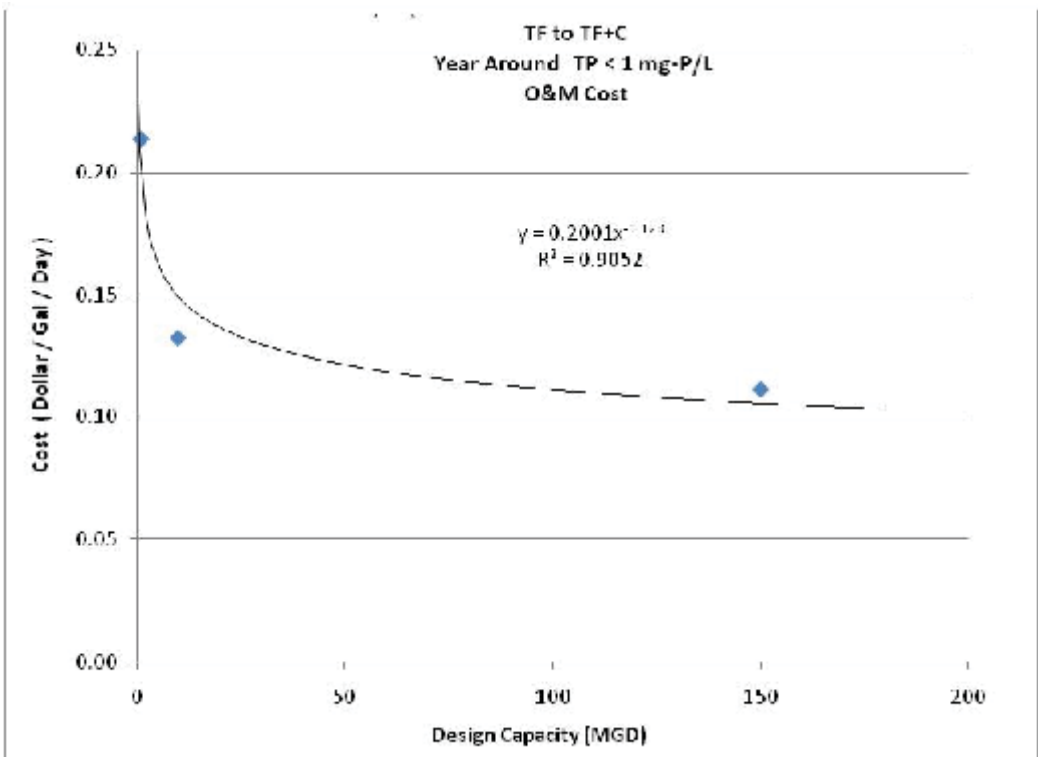

Figure 13-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective C Year-Round

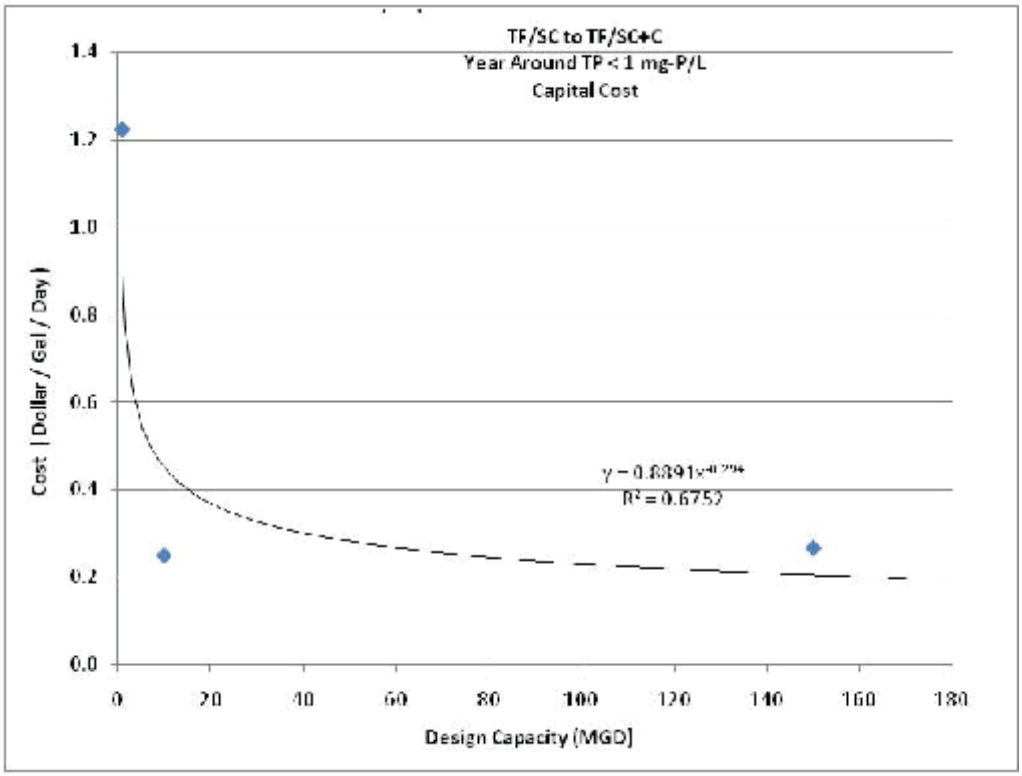

Figure 13-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective C Year-Round

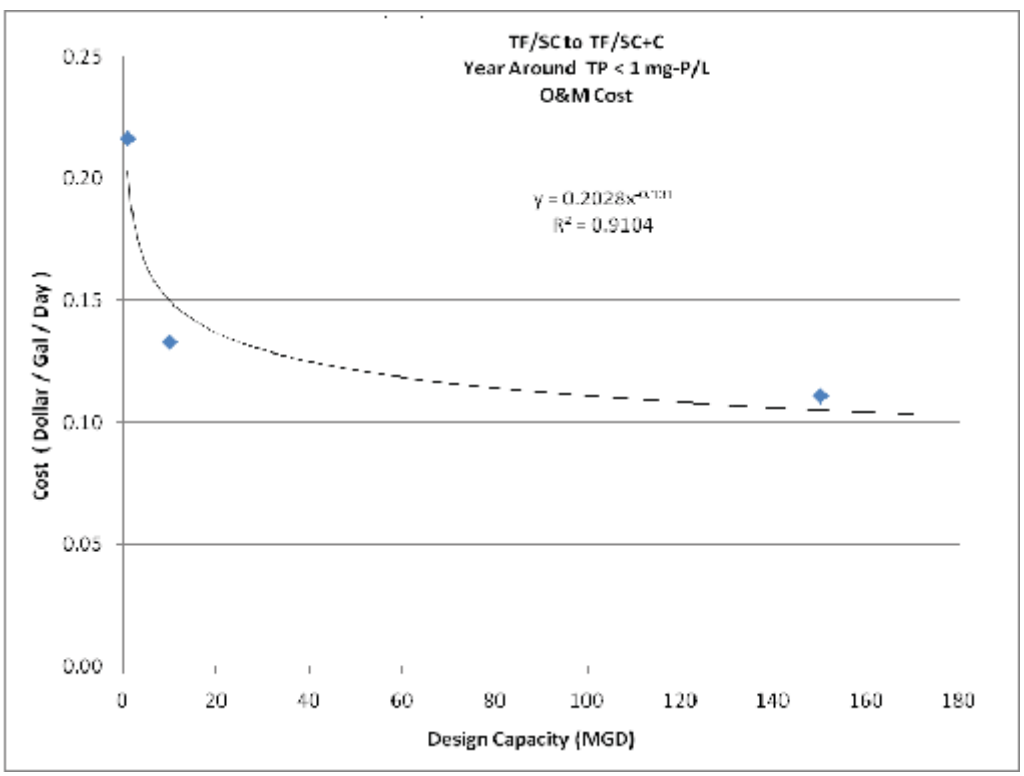

Figure 13-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective C Year-Round

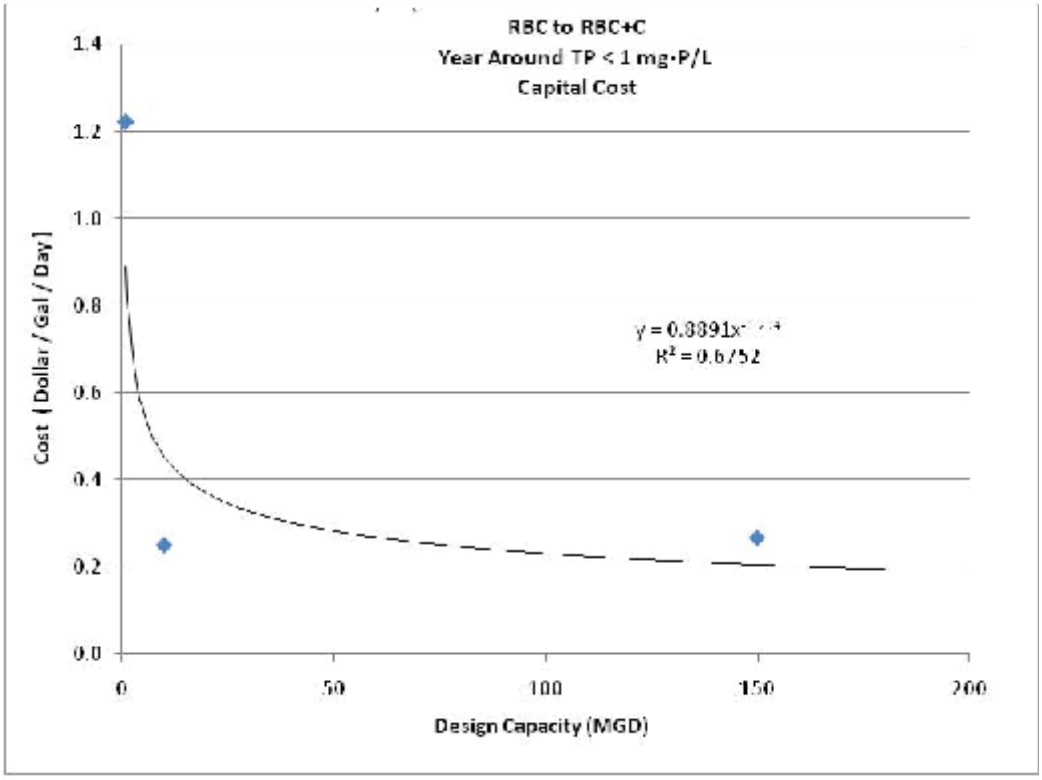

Figure 13-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective C Year-Round

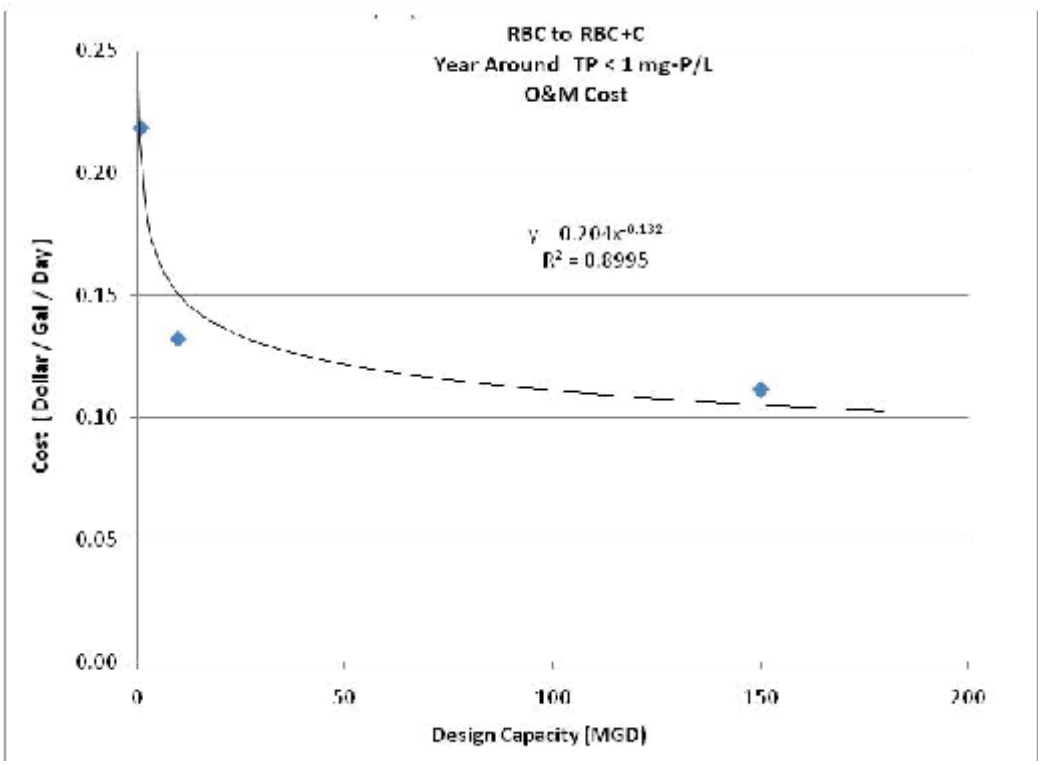

Figure 13-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective C Year-Round

TABLE 13-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$89,810	$184,134	$2,946,787
2014 O&M Cost	$240,206	$1,489,273	$18,823,234
Total Annual Cost	**$330,016**	**$1,673,407**	**$21,770,022**
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Cost for TP Reduction ($/lb TP removed)	$28.89	$14.65	$12.70
Equation:[a]			$y = 62.964x^{-0.116}$
R-Square Value:			0.9558

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$89,810	$184,134	$2,946,787
2014 O&M Cost	$243,470	$1,497,940	$18,738,821
Total Annual Cost	**$333,280**	**$1,682,073**	**$21,685,609**
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Cost for TP Reduction ($/lb TP removed)	$29.17	$14.72	$12.65
Equation:[a]			$y = 120.68x^{-0.164}$
R-Square Value:			0.8489

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$89,810	$184,134	$2,946,787
2014 O&M Cost	$246,053	$1,490,793	$18,841,805
Total Annual Cost	**$335,863**	**$1,674,926**	**$21,788,593**
Annual TP Load Reduction (lb/yr)	11,425	114,245	1,713,675
Estimated Cost for TP Reduction ($/lb TP removed)	$29.40	$14.66	$12.71
Equation:[a]			$y = 65.083x^{-0.119}$
R-Square Value:			0.9543

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.1.5 Membrane Biological Reactor Plants

Table 13-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for an MBR plant. Figures 13-15 and 13-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.32	$0.33	$0.23
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.16	$0.08	$0.06

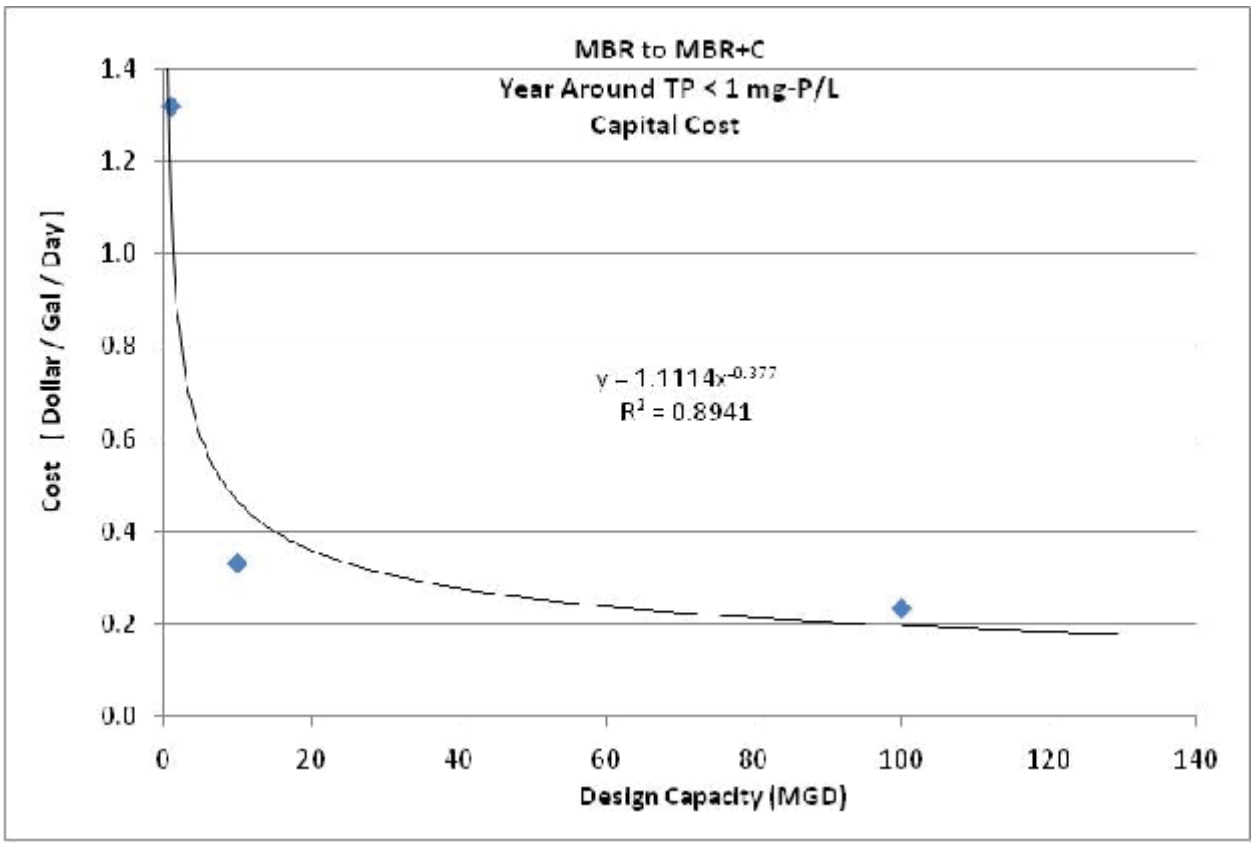

Figure 13-15. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective C Year-Round

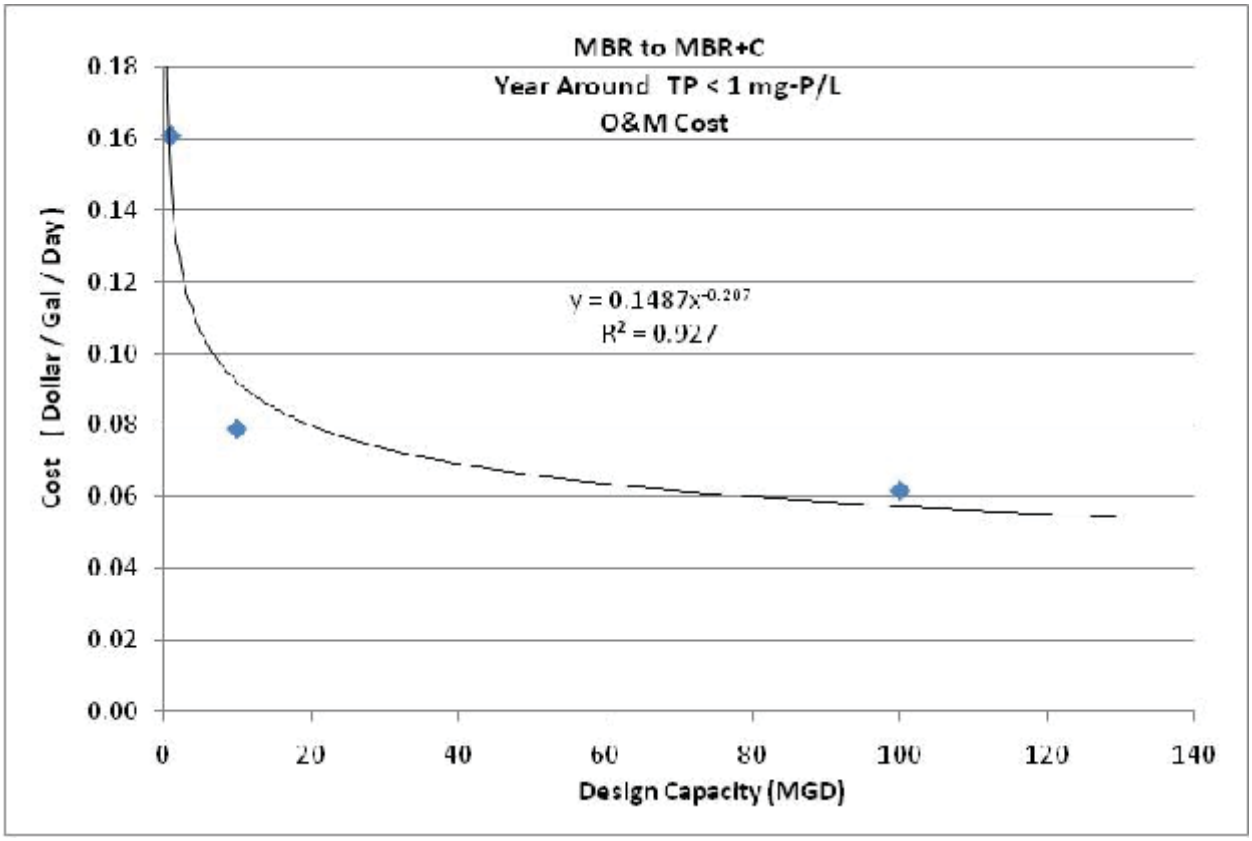

Figure 13-16. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective C Year-Round

TABLE 13-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$97,008	$242,560	$1,707,918
2014 O&M Cost	$180,864	$889,546	$6,960,248
Total Annual Cost	**$277,871**	**$1,132,106**	**$8,668,166**
Annual TP Load Reduction (lb/yr)	10,768	107,675	1,076,750
Estimated Cost for TP Reduction ($/lb TP removed)	$25.81	$10.51	$8.05
Equation:[a]			$y = 243.32x^{-0.253}$
R-Square Value:			0.9107

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.1.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective C were developed for these plants.

13.1.7 Aerated or Facultative Lagoon Plants

Table 13-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C year-round for an aerated lagoon plant. Figures 13-17 and 13-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-18 and Figures 13-19 and 13-20 summarize these costs for a facultative lagoon plant. Tables 13-19 and 13-20 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 13-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.76	$3.87	$2.22	$2.45
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.34	$0.20	$0.08	$0.04

TABLE 13-18.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.76	$3.87	$2.22	$2.45
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.34	$0.20	$0.08	$0.04

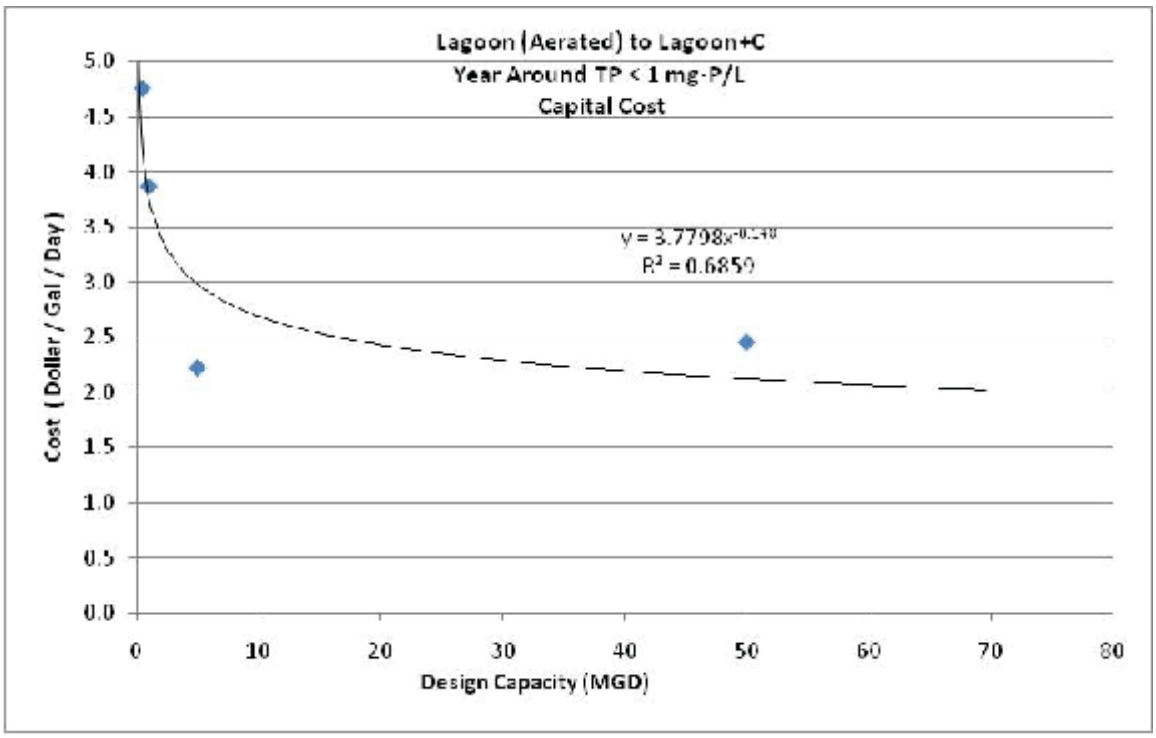

Figure 13-17. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective C Year-Round

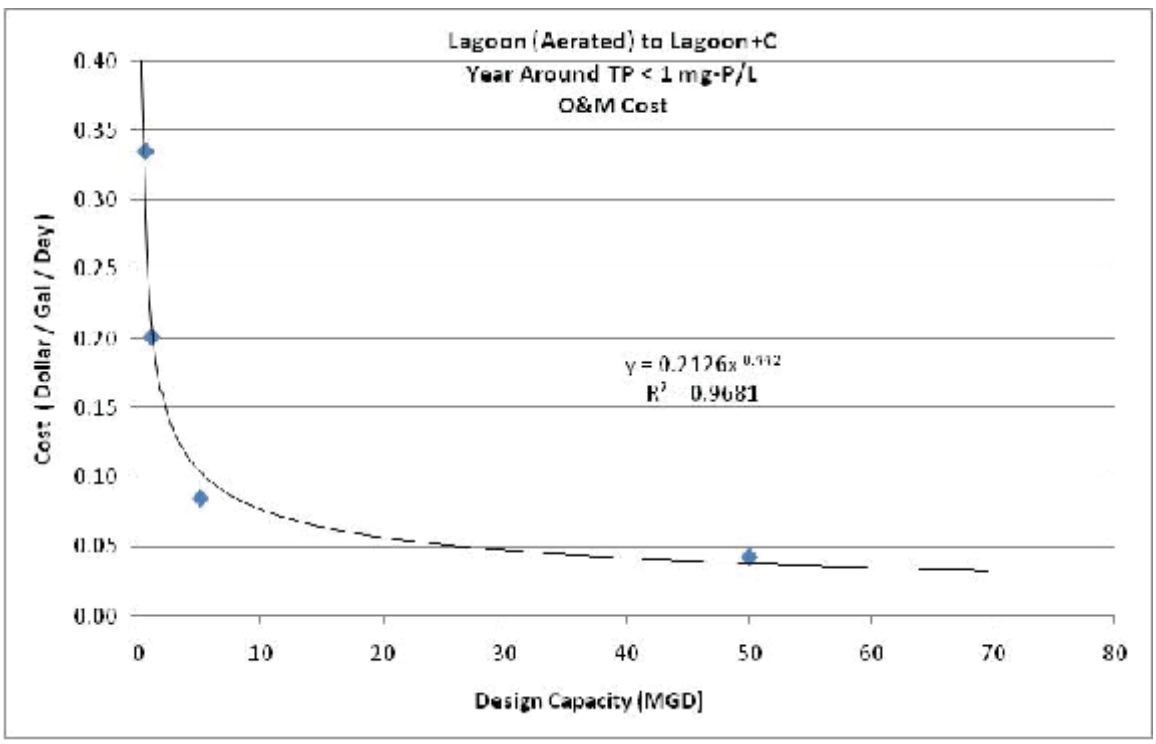

Figure 13-18. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective C Year-Round

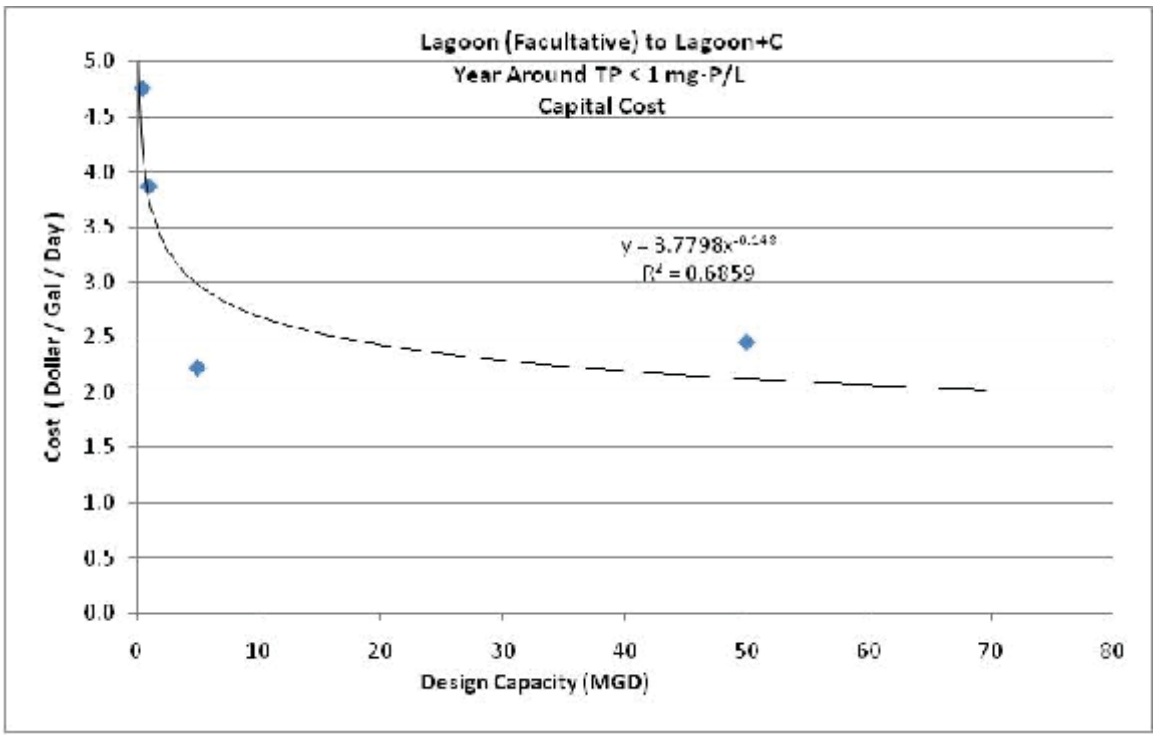

Figure 13-19. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective C Year-Round

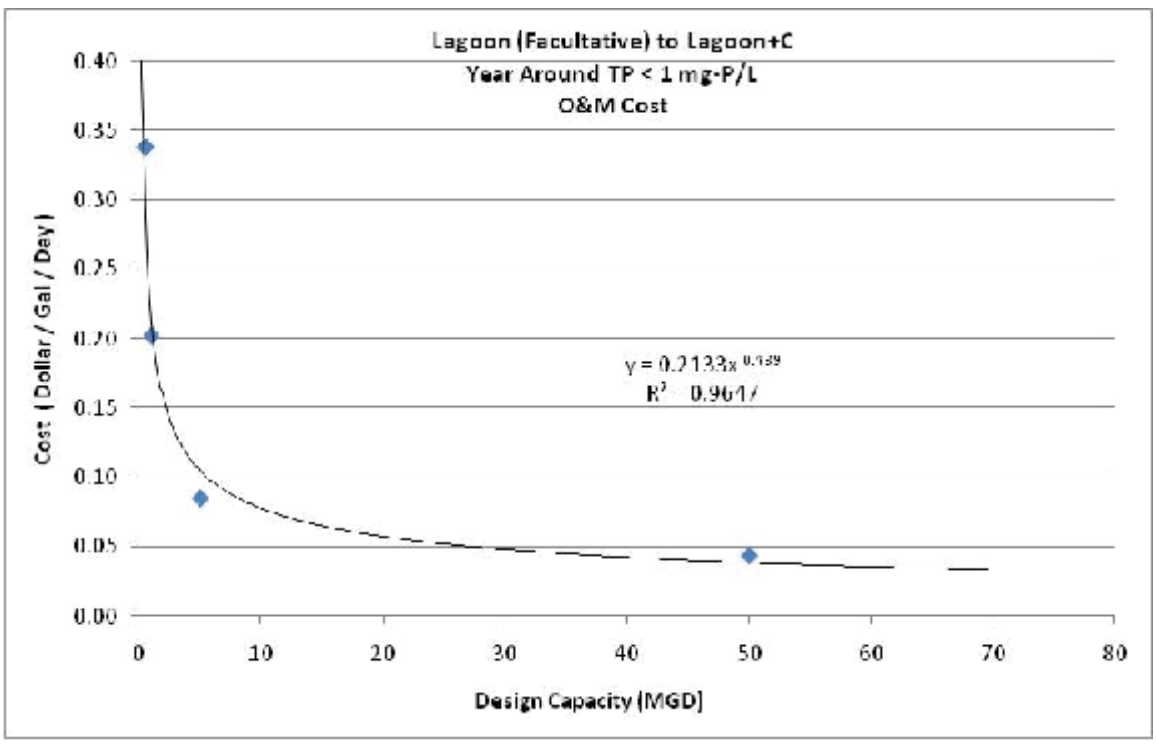

Figure 13-20. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective C Year-Round

TABLE 13-19.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$174,807	$284,062	$814,602	$9,002,573
2014 O&M Cost	$188,787	$226,632	$476,934	$2,370,547
Total Annual Cost	**$363,594**	**$510,694**	**$1,291,536**	**$11,373,119**
Annual TP Load Reduction (lb/yr)	5,712	11,425	57,123	571,225
Estimated Cost for TP Reduction ($/lb TP removed)	$63.65	$44.70	$22.61	$19.91

Equation:[a] ..... $y = 469.06x^{-0.25}$
R-Square Value:..... 0.8503

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-20.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$174,807	$284,062	$814,602	$9,002,573
2014 O&M Cost	$190,143	$227,358	$475,753	$2,419,844
Total Annual Cost	**$364,951**	**$511,420**	**$1,290,354**	**$11,422,417**
Annual TP Load Reduction (lb/yr)	5,712	11,425	57,123	571,225
Estimated Cost for TP Reduction ($/lb TP removed)	$63.89	$44.77	$22.59	$20.00

Equation:[a] ..... $y = 469x^{-0.25}$
R-Square Value:..... 0.8472

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2 SEASONAL NUTRIENT REMOVAL

13.2.1 Extended Aeration Plants

Table 13-21 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for an extended aeration plant using mechanical aeration. Figures 13-21 and 13-22 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-22 and Figures 13-23 and 13-24 summarize these costs for an extended aeration plant using diffuser aeration. Tables 13-23 and 13-24 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 13-21.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$0.77	$0.20	$0.21
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.12	$0.08	$0.07

TABLE 13-22.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.01	$0.47	$0.30
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.11	$0.06	$0.05

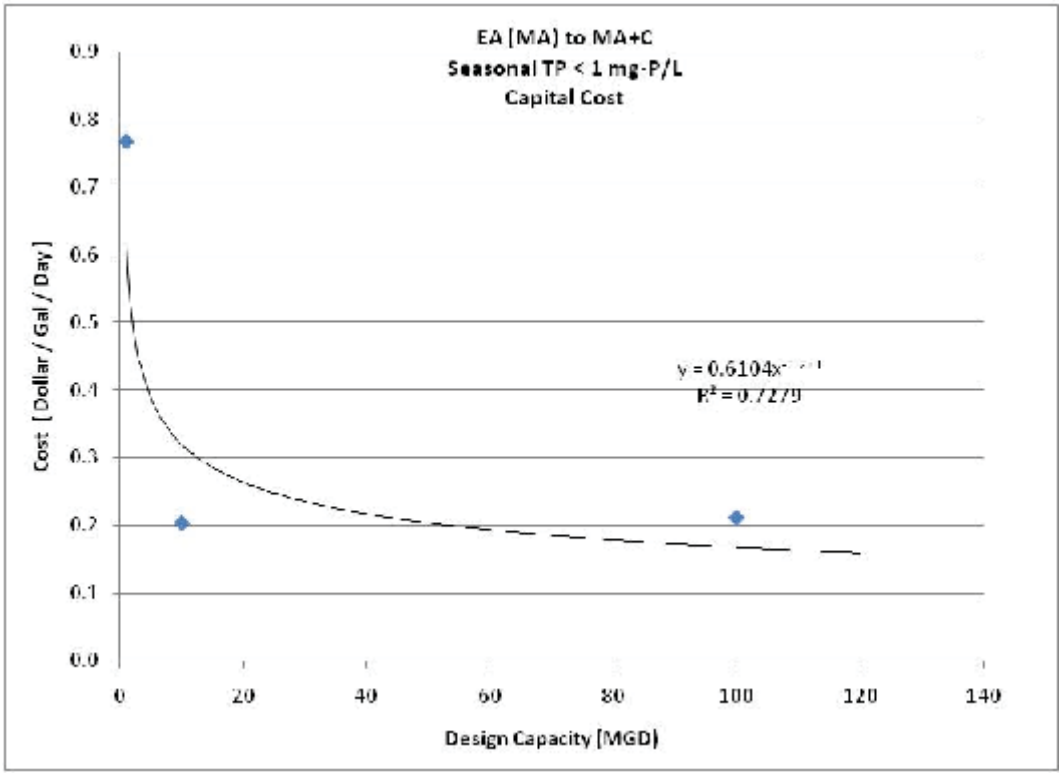

Figure 13-21. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective C Seasonally

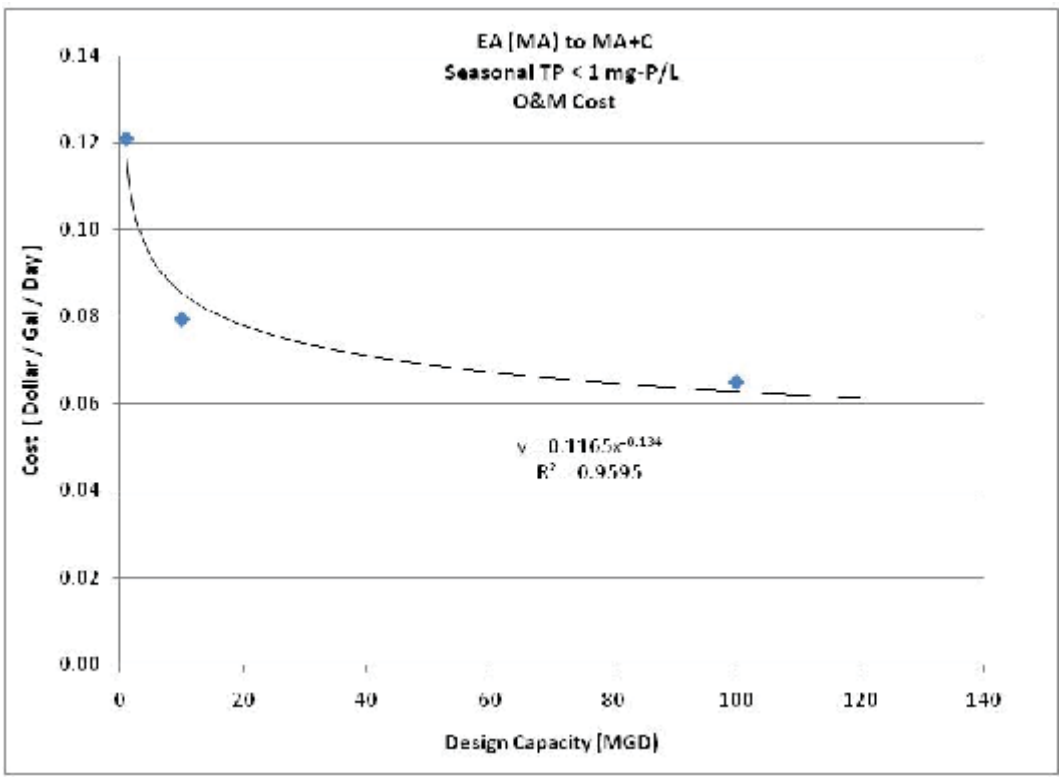

Figure 13-22. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective C Seasonal

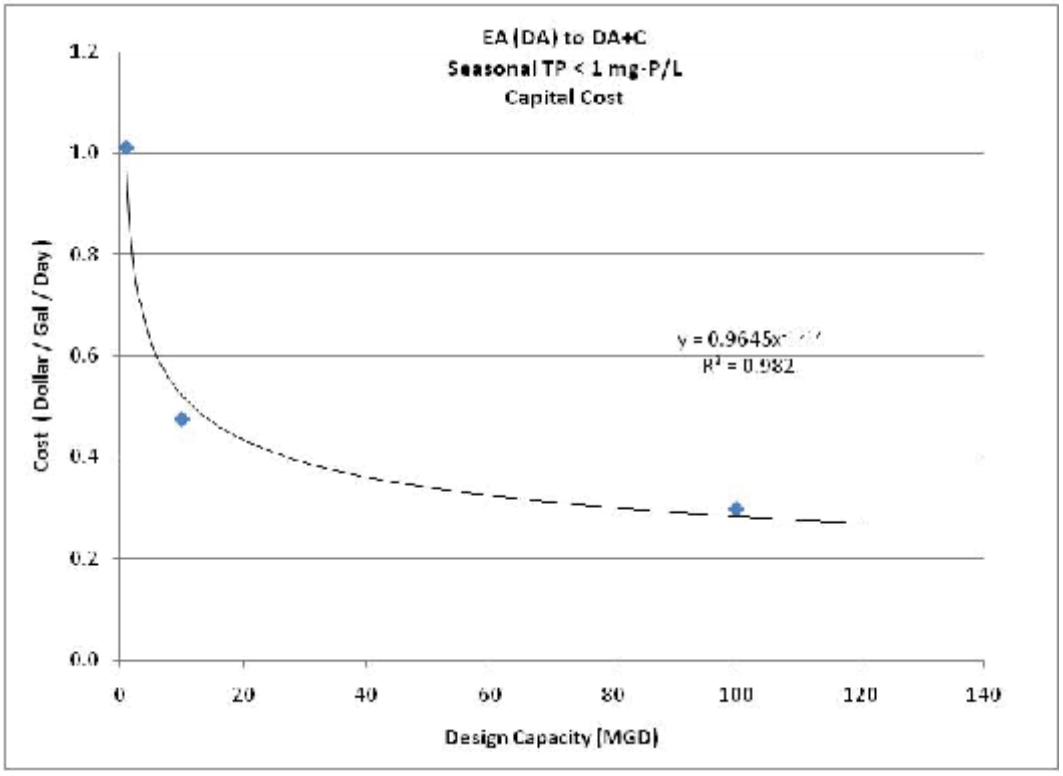

Figure 13-23. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective C Seasonally

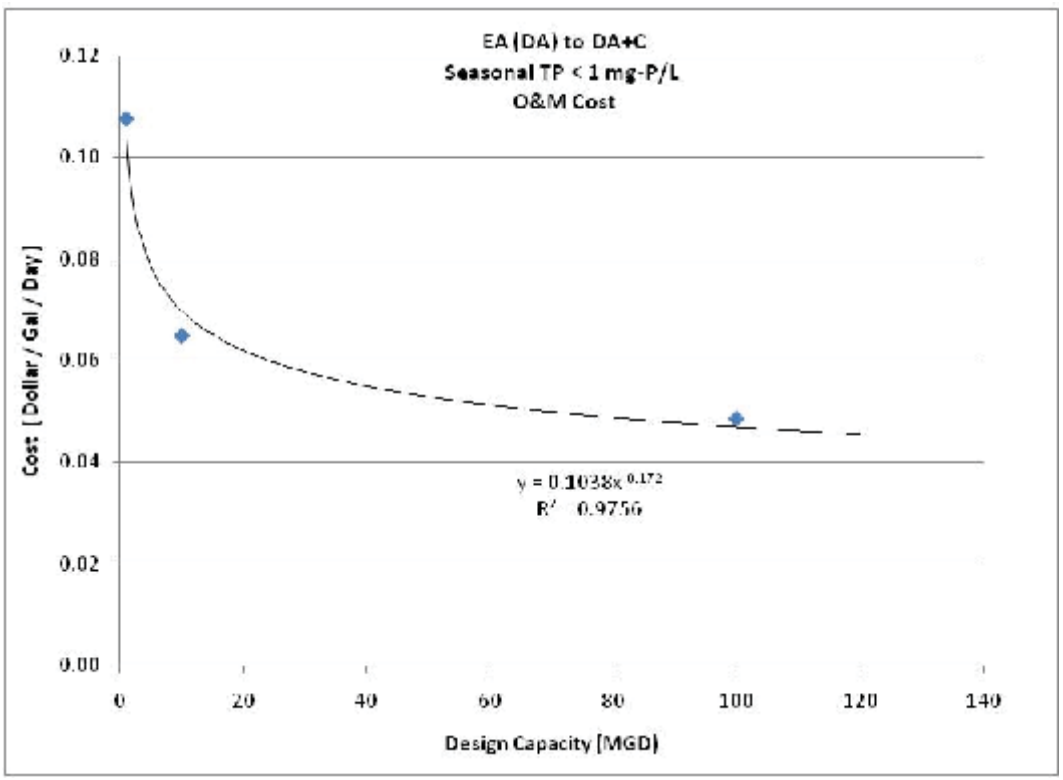

Figure 13-24. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective C Seasonal

TABLE 13-23.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$56,339	$148,668	$1,544,576
2014 O&M Cost	$136,074	$894,341	$7,326,837
Total Annual Cost	**$192,416**	**$1,043,009**	**$8,871,413**
Annual TP Load Reduction (lb/yr)	5,694	56940	569,400
Estimated Cost for TP Reduction ($/lb TP removed)	$33.79	$18.32	$15.58
Equation:[a]			$y = 134.13x^{-0.168}$
R-Square Value:			0.8987

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-24.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EA ((DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$74,334	$348,154	$2,175,939
2014 O&M Cost	$121,105	$730,579	$5,478,189
Total Annual Cost	**$195,439**	**$1,078,733**	**$7,654,128**
Annual TP Load Reduction (lb/yr)	5,694	56940	569400
Estimated Cost for TP Reduction ($/lb TP removed)	$34.32	$18.95	$13.44
Equation:[a]			$y = 191.4x^{-0.204}$
R-Square Value:			0.9768

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2.2 Conventional Activated Sludge Plants

Table 13-25 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for a conventional activated sludge plant. Figures 13-25 and 13-26 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-26 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-25.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.28	$0.32	$0.42
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.20	$0.10	$0.08

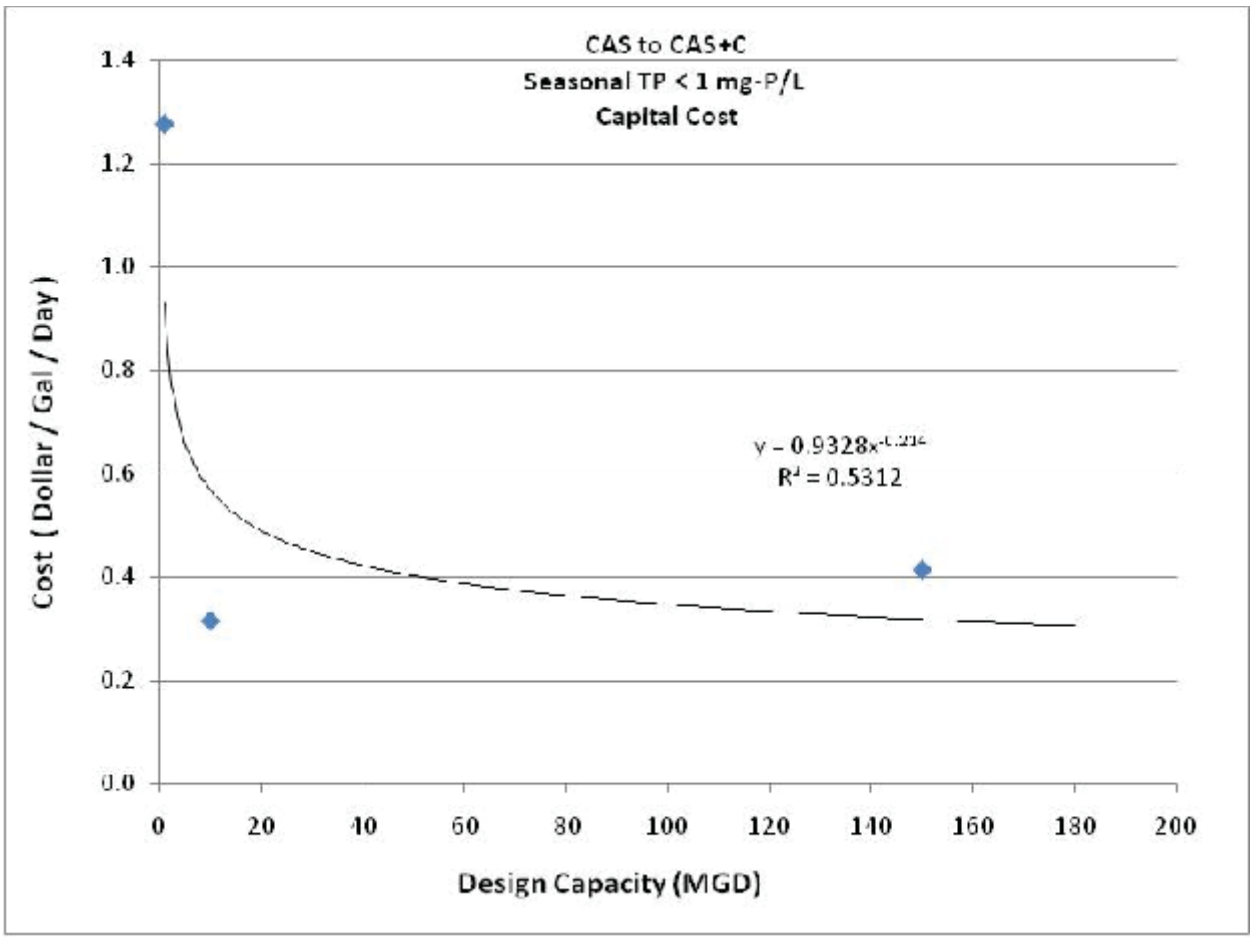

Figure 13-25. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective C Seasonally

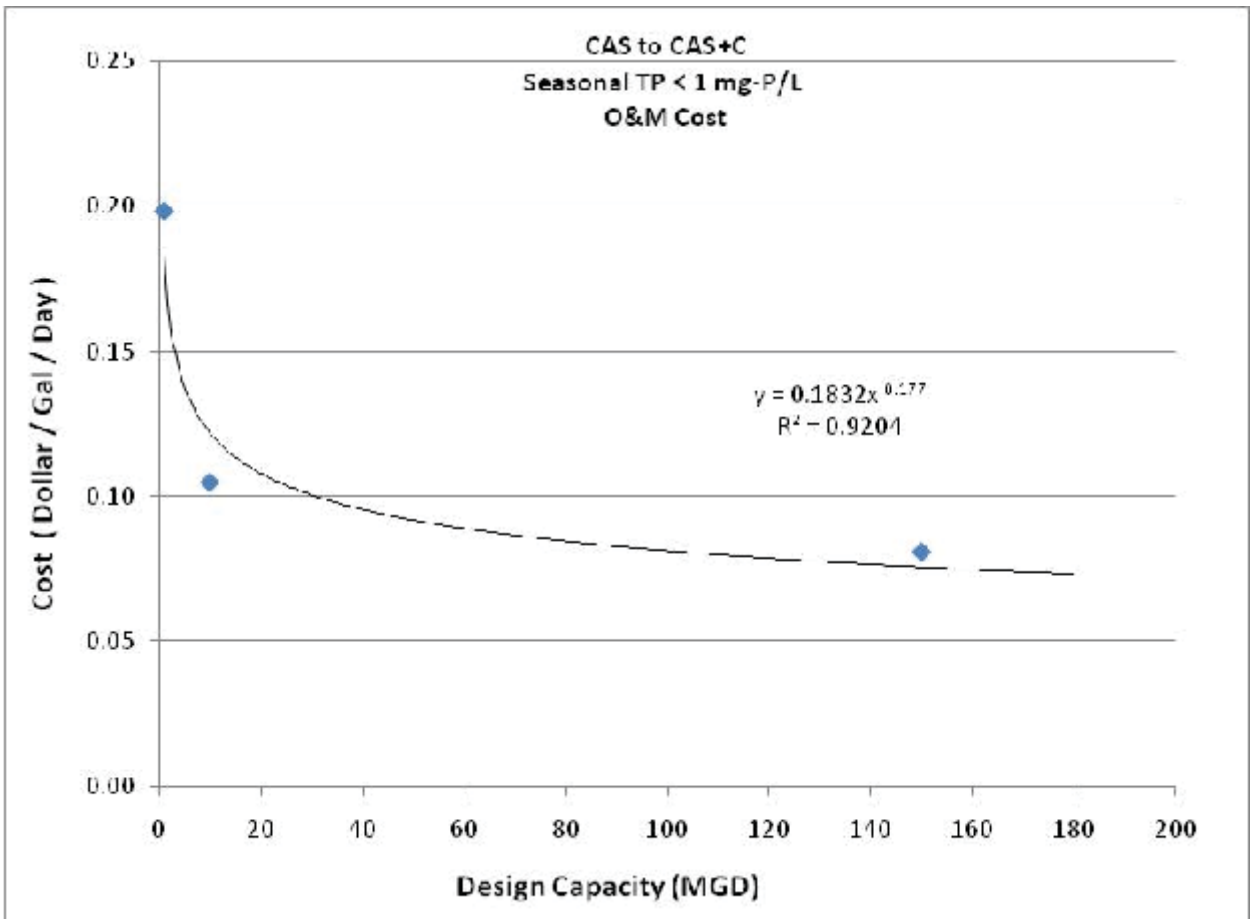

Figure 13-26. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective C Seasonal

TABLE 13-26.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$93,871	$233,501	$4,587,148
2014 O&M Cost	$223,605	$1,181,638	$13,681,122
Total Annual Cost	**$317,476**	**$1,415,139**	**$18,268,270**
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Cost for TP Reduction ($/lb TP removed)	$53.86	$24.01	$20.66
Equation:[a]			$y = 239.89x^{-0.187}$
R-Square Value:			0.8308

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2.3 Sequencing Batch Reactor Plants

Table 13-27 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for an SBR plant. Figures 13-27 and 13-28 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-28 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-27.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.41	$0.45	$0.18
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.09	$0.03	$0.01

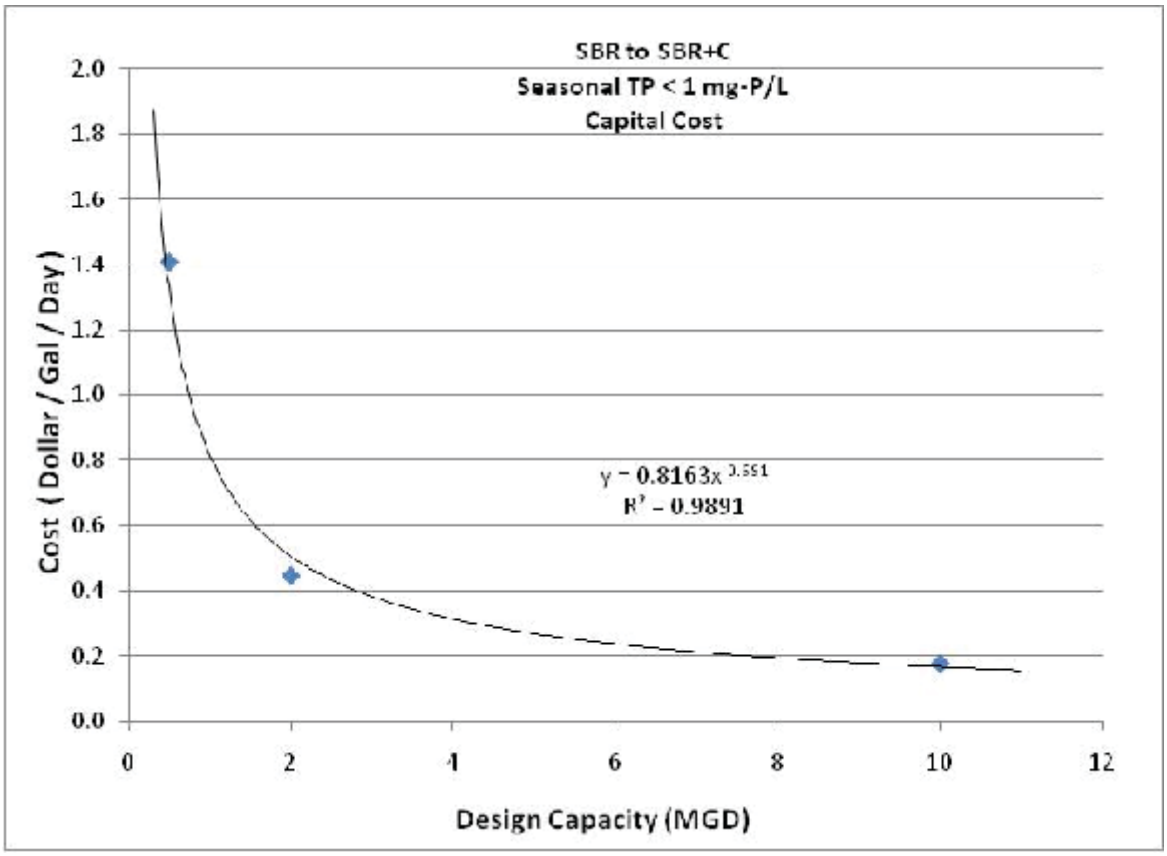

Figure 13-27. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective C Seasonally

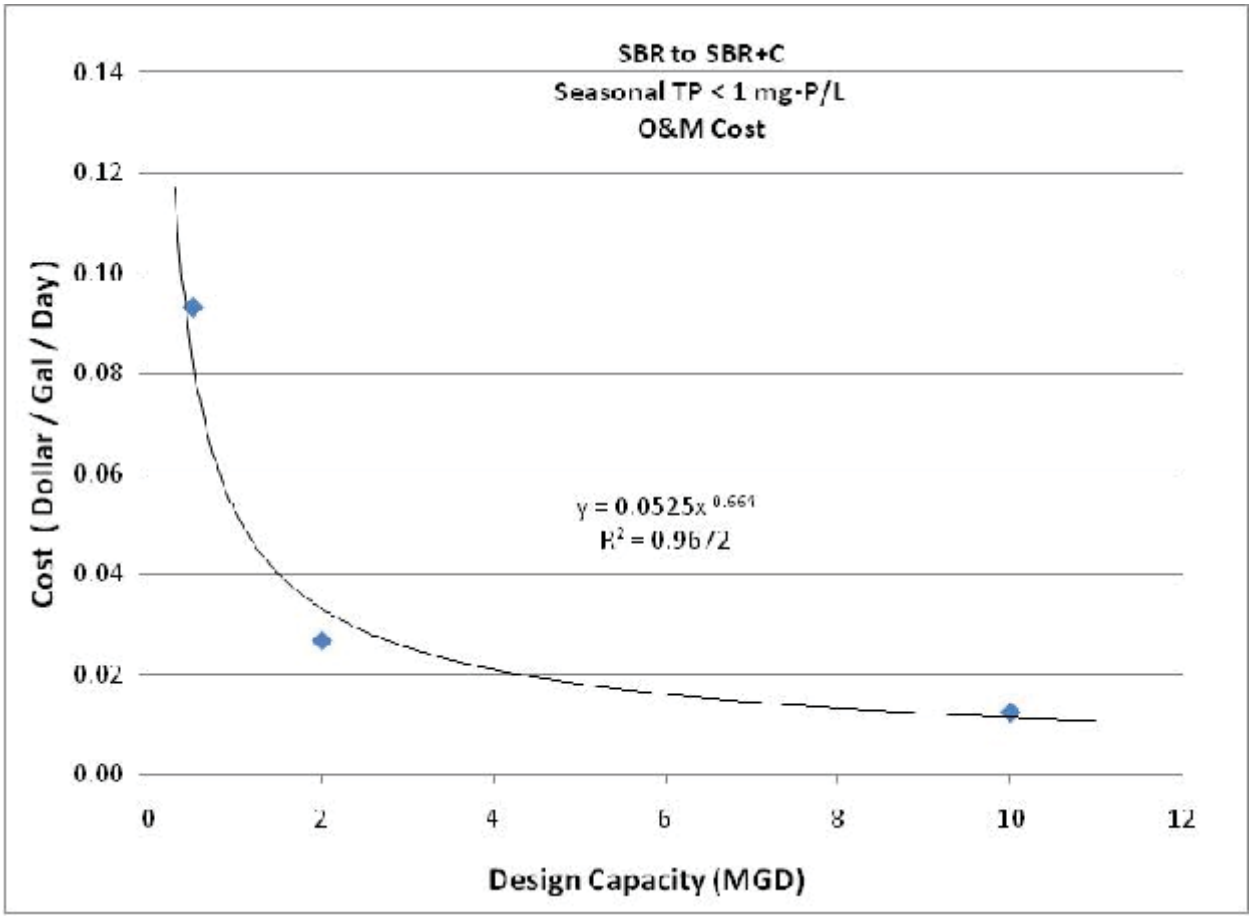

Figure 13-28. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective C Seasonal

TABLE 13-28.
UNIT NUTRIENT REMOVAL COSTS FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$51,764	$65,542	$129,450
2014 O&M Cost	$52,477	$60,384	$141,251
Total Annual Cost	**$104,240**	**$125,926**	**$270,701**
Annual TP Load Reduction (lb/yr)	1,141	4,563	22,813
Estimated Cost for TP Reduction ($/lb TP removed)	$91.39	$27.60	$11.87
Equation:[a]			$y = 9820.1x^{-0.677}$
R-Square Value:			0.9798

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 13-29 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for a trickling filter plant. Figures 13-29 and 13-30 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-30 and Figures 13-31 and 13-32 summarize these costs for a trickling filter/solids contact plant. Table 13-31 and Figures 13-33 and 13-34 summarize these costs for an RBC plant. Tables 13-32, 13-33 and 13-34 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 13-29.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.28	$0.32	$0.42
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.10	$0.07

TABLE 13-30.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.28	$0.32	$0.42
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.10	$0.07

TABLE 13-31.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.28	$0.32	$0.42
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.10	$0.07

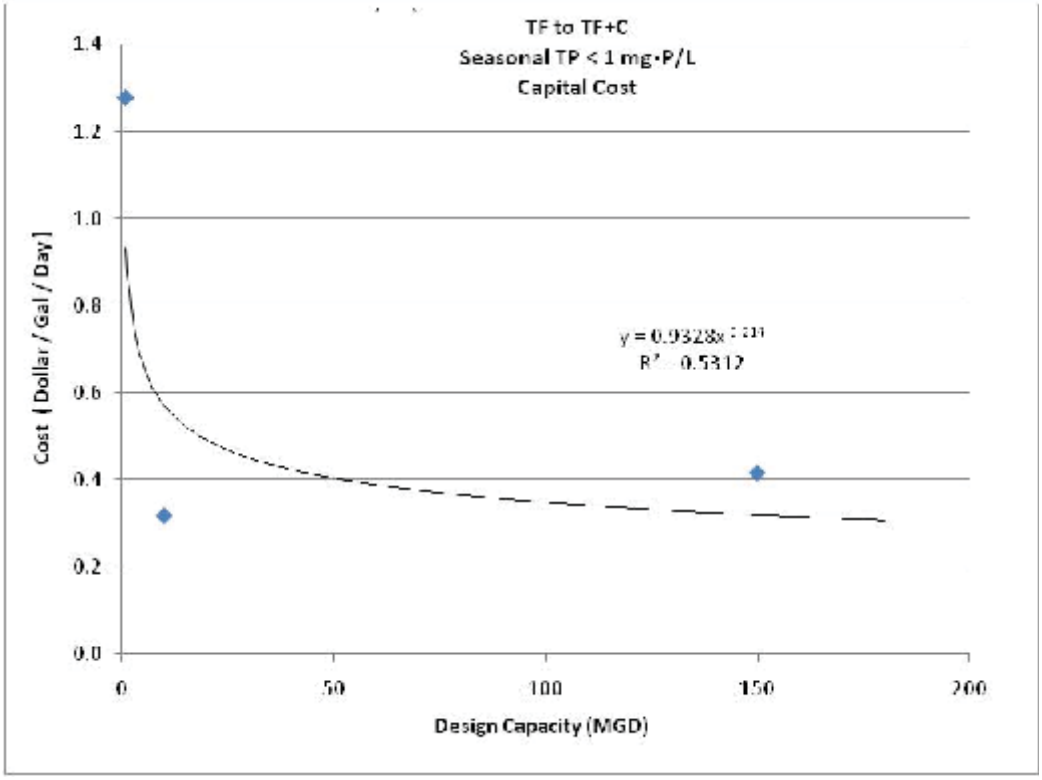

Figure 13-29. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective C Seasonally

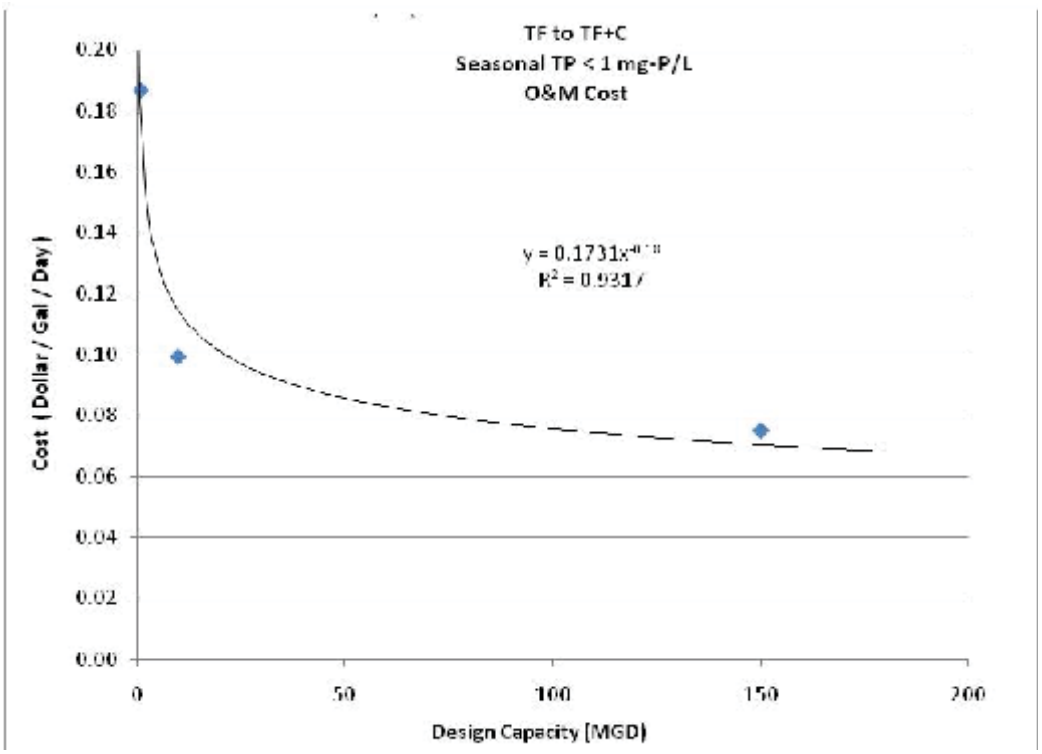

Figure 13-30. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective C Seasonal

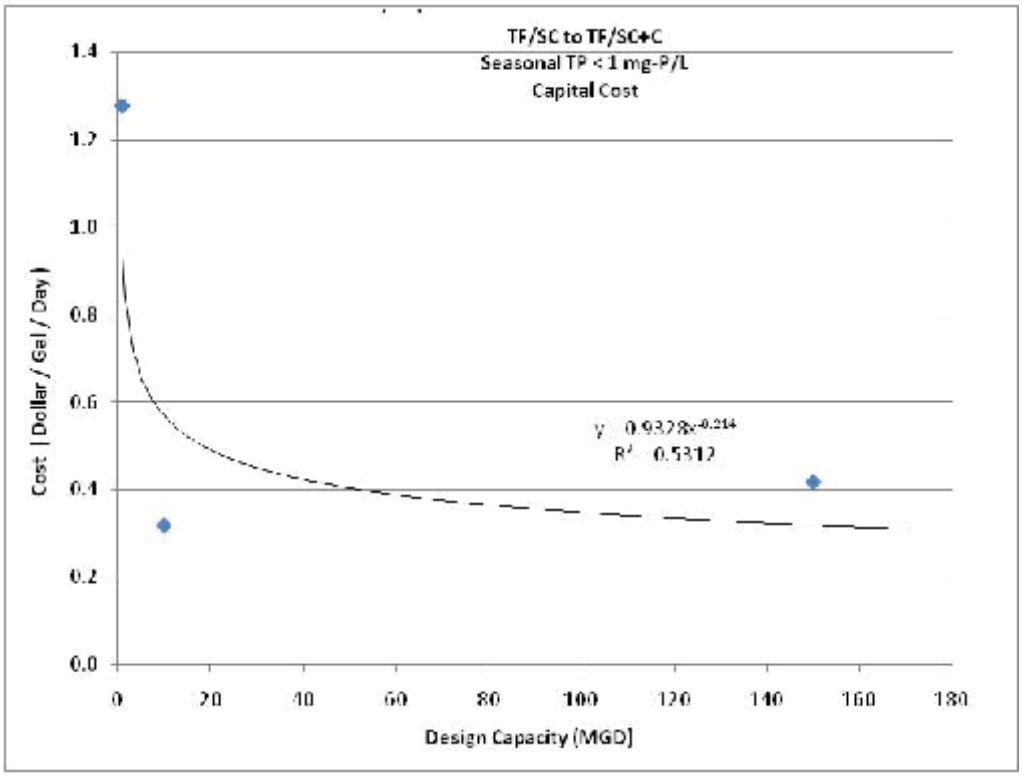

Figure 13-31. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective C Seasonally

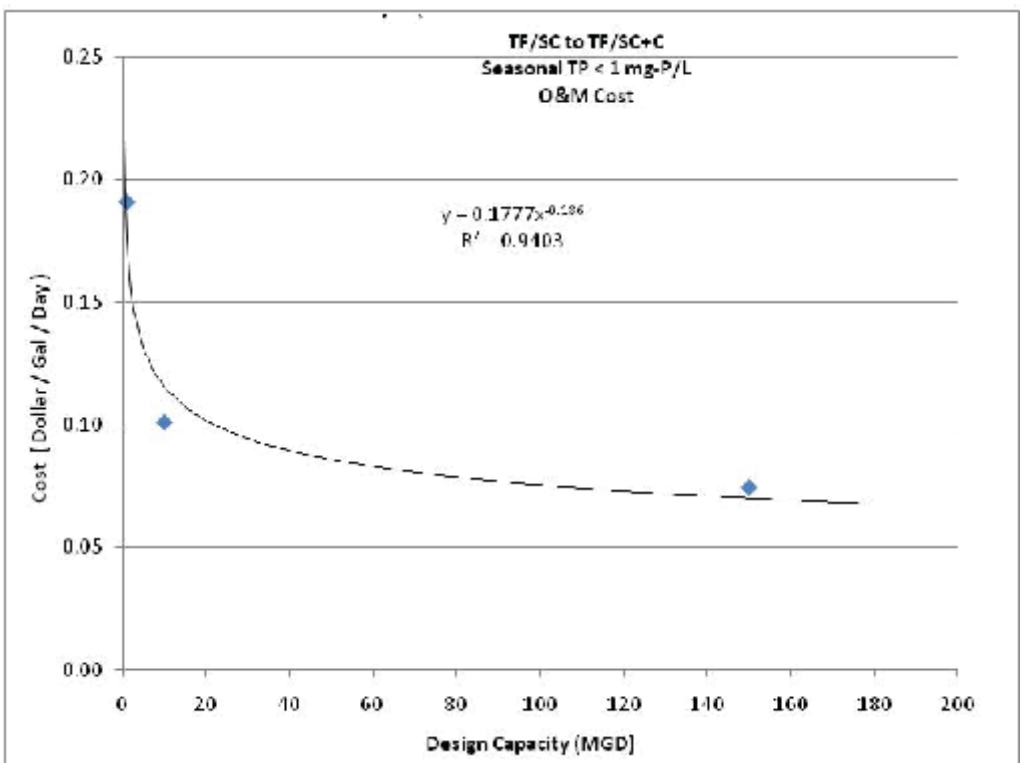

Figure 13-32. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective C Seasonal

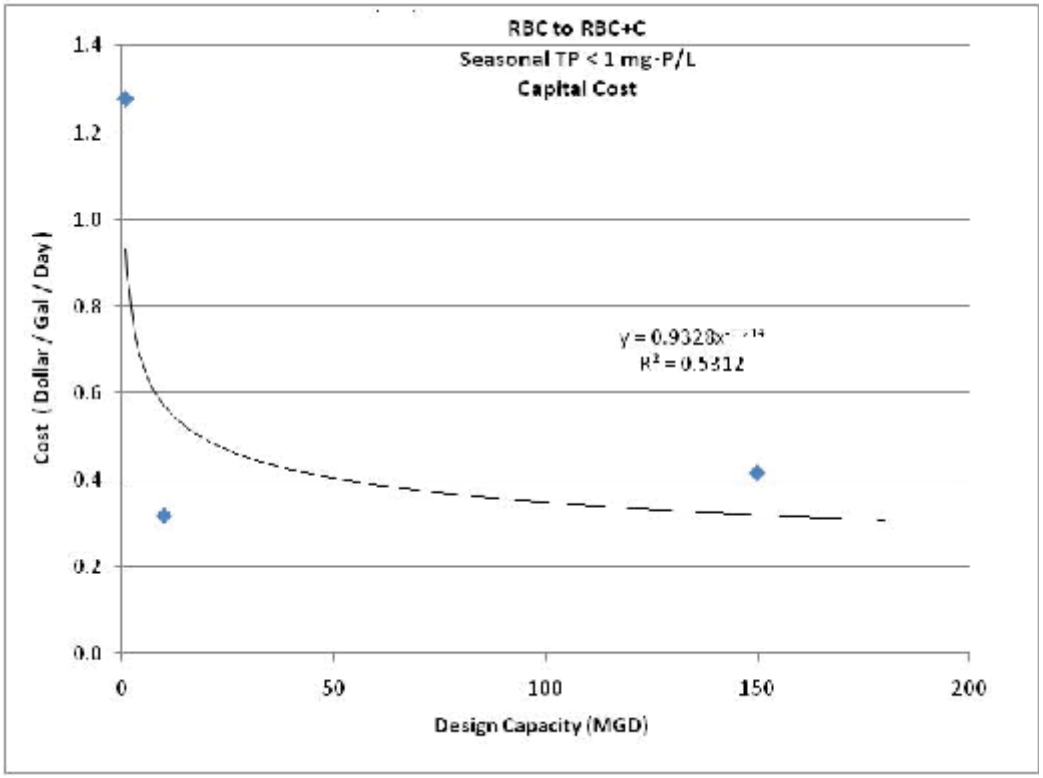

Figure 13-33. Capital Cost per Plant Capacity for RBC Plant Upgraded for Objective C Seasonally

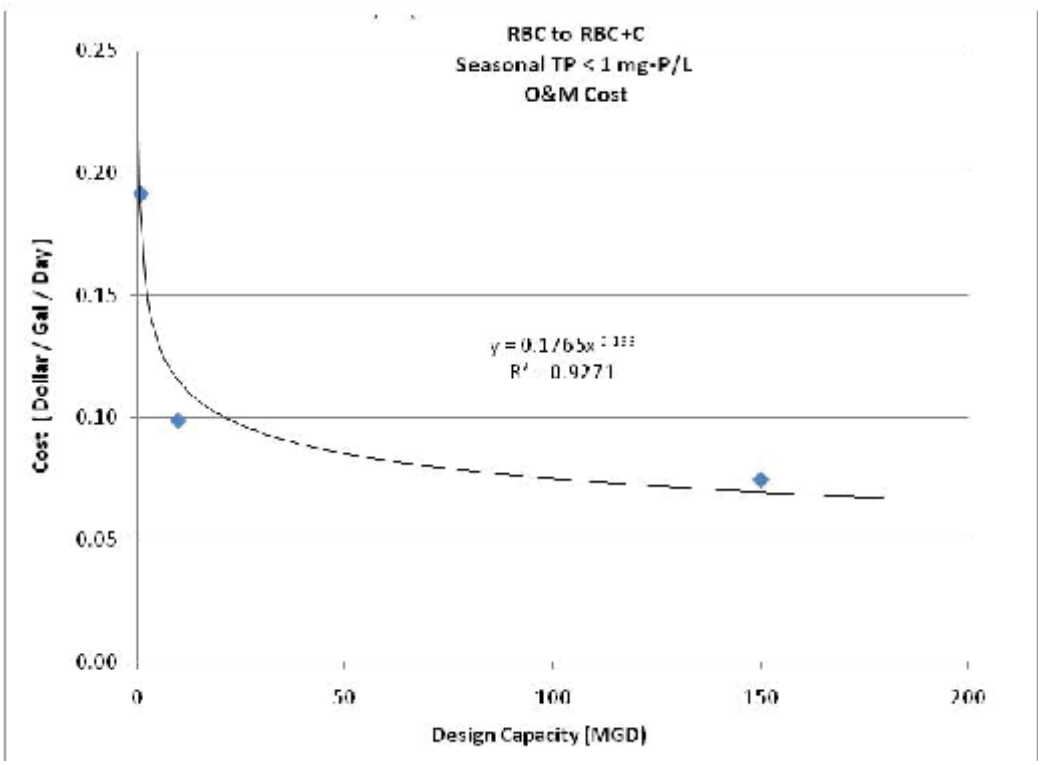

Figure 13-34. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective C Seasonal

TABLE 13-32.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$93,871	$233,501	$4,587,148
2014 O&M Cost	$210,217	$1,118,216	$12,659,160
Total Annual Cost	**$304,088**	**$1,351,717**	**$17,246,308**
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Cost for TP Reduction ($/lb TP removed)	$51.59	$22.93	$19.50
Equation:[a]			$y = 236.13x^{-0.19}$
R-Square Value:			0.838

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-33.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TF/SC PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$93,871	$233,501	$4,587,148
2014 O&M Cost	$215,237	$1,137,743	$12,568,557
Total Annual Cost	**$309,108**	**$1,371,244**	**$17,1557,04**
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Cost for TP Reduction ($/lb TP removed)	$43.06	$23.26	$19.40
Equation:[a]			$y = 153.11x^{-0.156}$
R-Square Value:			0.8815

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-34.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$93,871	$233,501	$4,587,148
2014 O&M Cost	$215,614	$1,112,475	$12,562,367
Total Annual Cost	**$309,485**	**$1,345,977**	**$17,149,514**
Annual TP Load Reduction (lb/yr)	5,895	58,948	884,213
Estimated Cost for TP Reduction ($/lb TP removed)	$52.50	$22.83	$19.40
Equation:[a]			$y = 225.71x^{-0.187}$
R-Square Value:			0.8407

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2.5 Membrane Biological Reactor Plants

Table 13-35 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for an MBR plant. Figures 13-35 and 13-36 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-36 presents the annualized unit costs for reducing nutrient loads.

TABLE 13-35.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.19	$0.27	$0.07
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.15	$0.07	$0.04

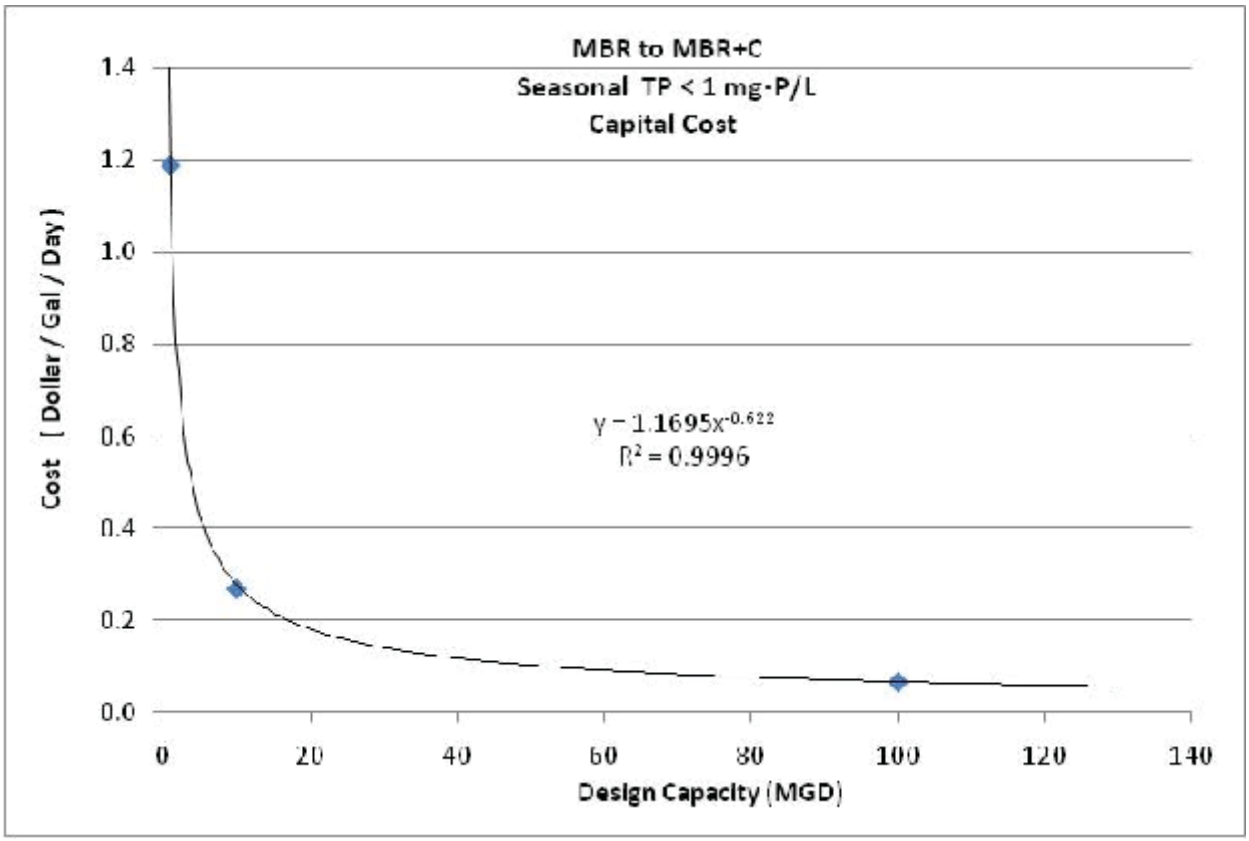

Figure 13-35. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective C Seasonally

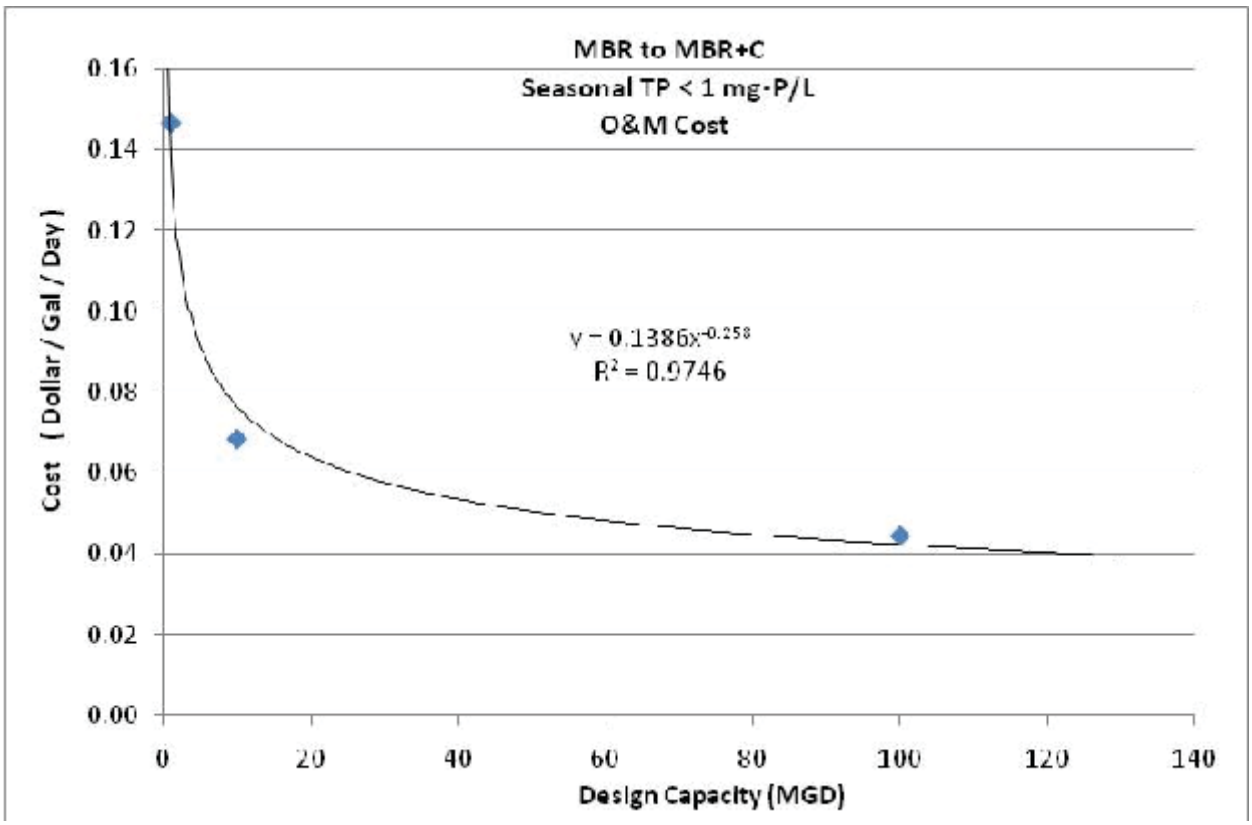

Figure 13-36. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective C Seasonal

TABLE 13-36.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$87,393	$198,159	$498,252
2014 O&M Cost	$164,904	$771,109	$5,026,973
Total Annual Cost	**$252,297**	**$969,268**	**$5,525,225**
Annual TP Load Reduction (lb/yr)	5,493	54,933	549,325
Estimated Cost for TP Reduction ($/lb TP removed)	$45.93	$17.64	$10.06
Equation:[a]			$y = 735.65x^{-0.33}$
R-Square Value:			0.9779

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

13.2.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective C were developed for these plants.

13.2.7 Aerated or Facultative Lagoon Plants

Table 13-37 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective C seasonally for an aerated lagoon plan. Figures 13-37 and 13-38 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 13-38 and Figures 13-39 and 13-40 summarize these costs for a facultative lagoon plant. Tables 13-39 and 13-40 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 13-37.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.55	$3.50	$1.83	$1.84
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.35	$0.22	$0.10	$0.04

TABLE 13-38.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$4.55	$3.50	$1.83	$1.84
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.32	$0.19	$0.07	$0.03

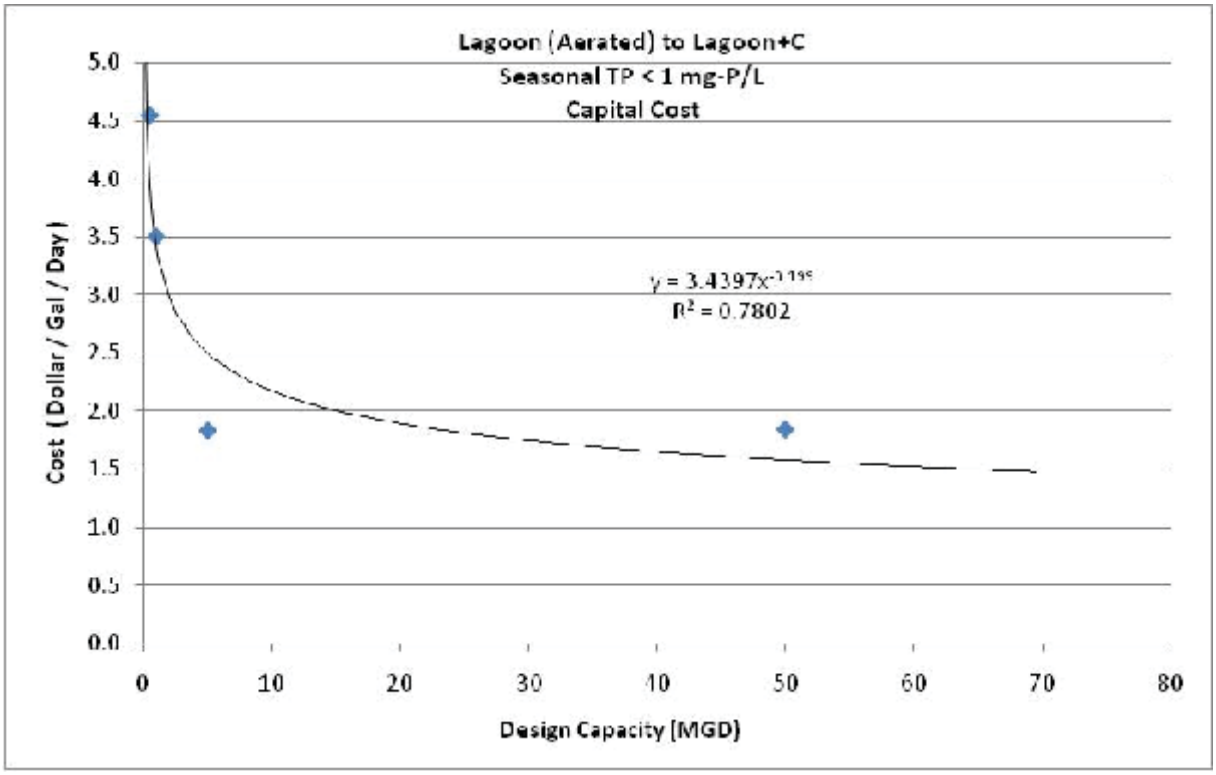

Figure 13-37. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective C Seasonally

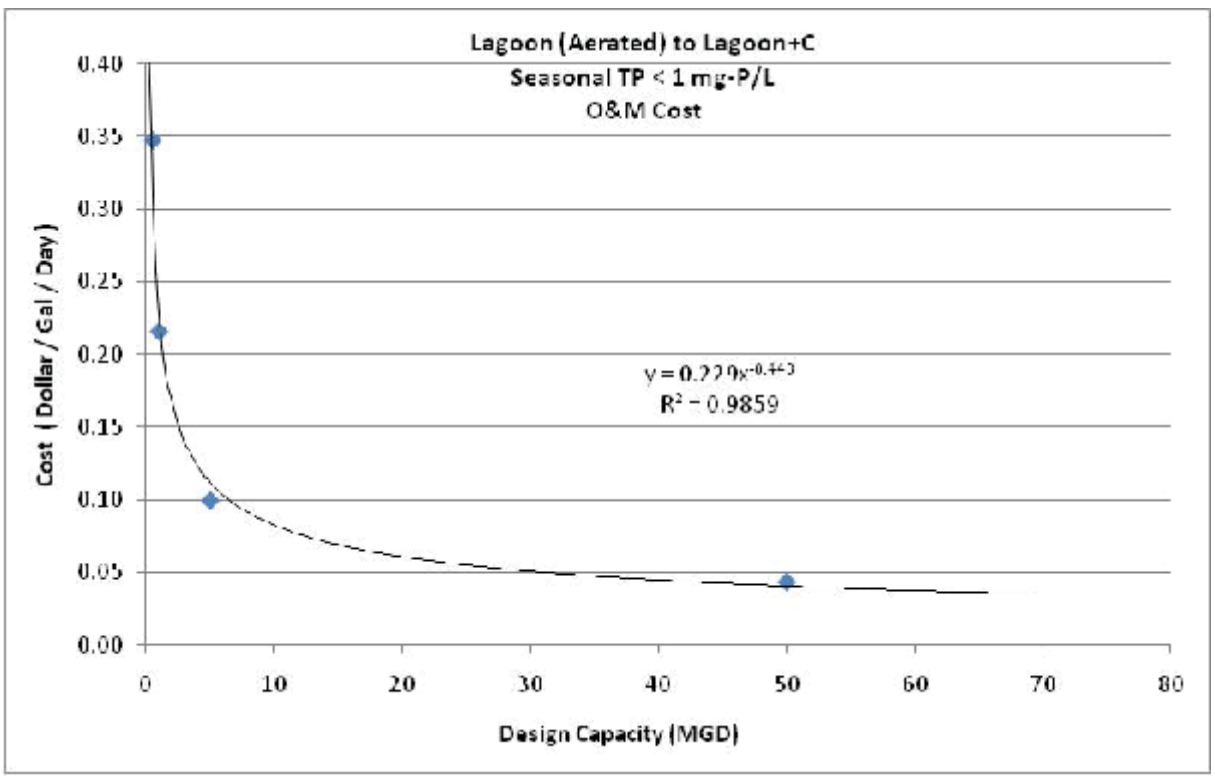

Figure 13-38. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective C Seasonal

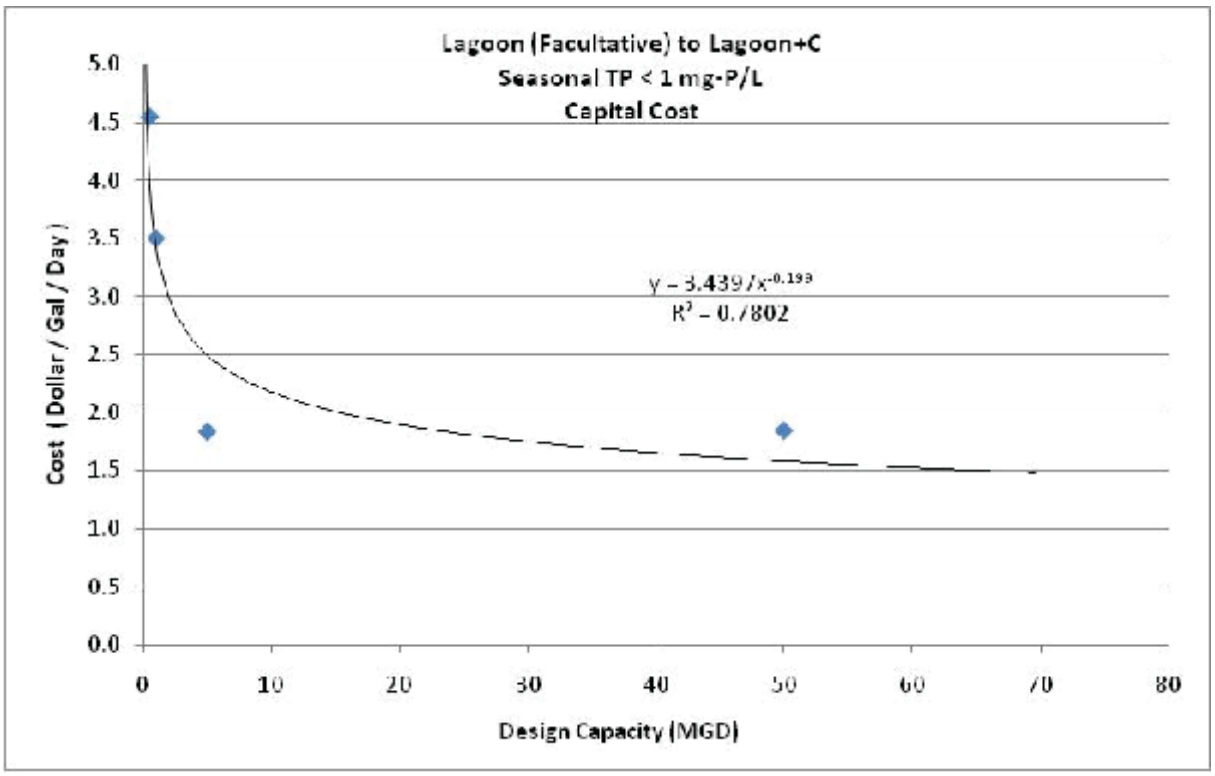

Figure 13-39. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective C Seasonally

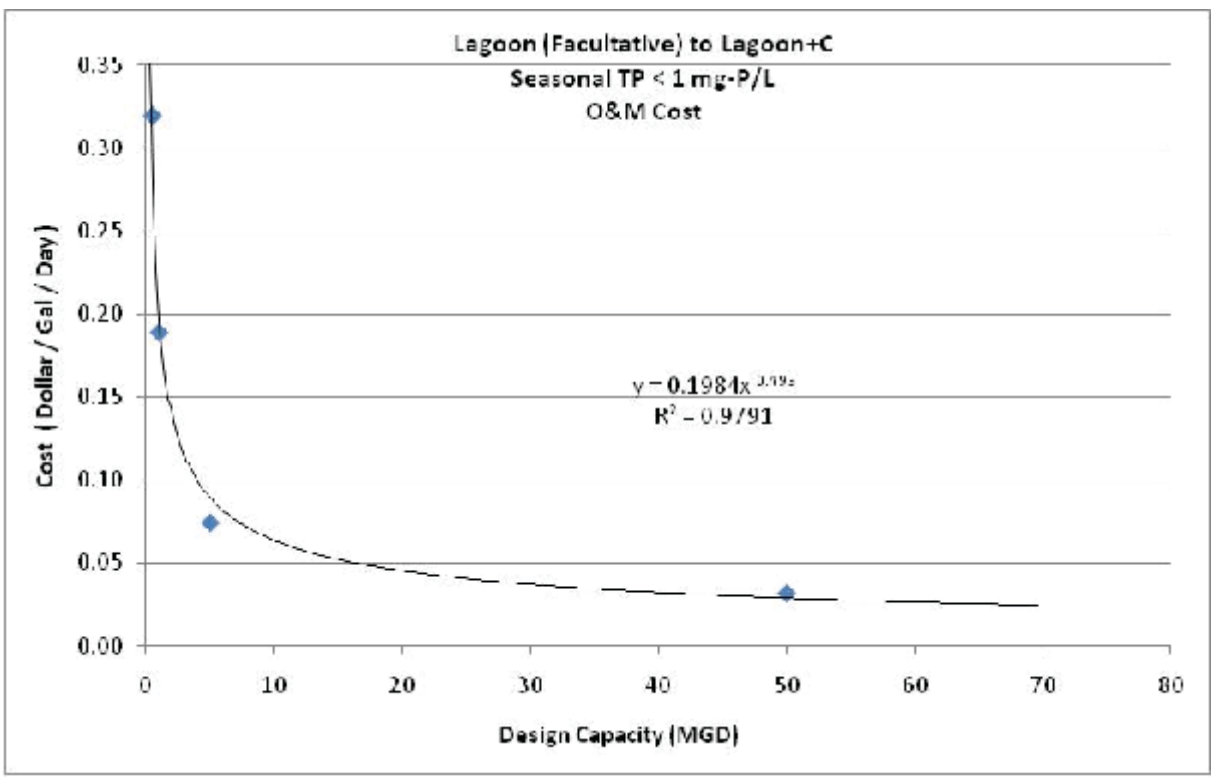

Figure 13-40. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective C Seasonal

TABLE 13-39.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$166,941	$256,967	$672,134	$6,756,300
2014 O&M Cost	$195,653	$242,885	$559,828	$2,441,060
Total Annual Cost	**$362,594**	**$499,851**	**$1,231,962**	**$9,197,359**
Annual TP Load Reduction (lb/yr)	2,947	5,895	29,474	294,738
Estimated Cost for TP Reduction ($/lb TP removed)	$123.02	$84.80	$41.80	$32.21

Equation:[a] ..... $y = 1053.4x^{-0.288}$
R-Square Value: 0.9023

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 13-40.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE C SEASONALLY

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Annualized Capital Cost	$166,941	$256,967	$672,134	$6,756,300
2014 O&M Cost	$179,868	$212,603	$419,196	$1,792,767
Total Annual Cost	**$346,808**	**$469,570**	**$1,091,330**	**$8,549,066**
Annual TP Load Reduction (lb/yr)	2,947	5,895	29,474	294,738
Estimated Cost for TP Reduction ($/lb TP removed)	$117.67	$79.66	$37.03	$29.01

Equation:[a] ..... $y = 1109.9x^{-0.301}$
R-Square Value:..... 0.8912

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

CHAPTER 14.
COST EVALUATION, OBJECTIVE D

14.1 YEAR-ROUND NUTRIENT REMOVAL

14.1.1 Extended Aeration Plants

Table 14-1 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for an extended aeration plant using mechanical aeration. Figures 14-1 and 14-2 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-2 and Figures 14-3 and 14-4 summarize these costs for an extended aeration plant using diffuser aeration. Tables 14-3 and 14-4 present the annualized unit costs for reducing nutrient loads for mechanical aeration and diffuser aeration plants, respectively.

TABLE 14-1.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.14	$1.40	$1.01
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.29	$0.21	$0.19

TABLE 14-2.
ESTIMATED COST PER CAPACITY FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.38	$1.65	$1.07
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.24	$0.18	$0.15

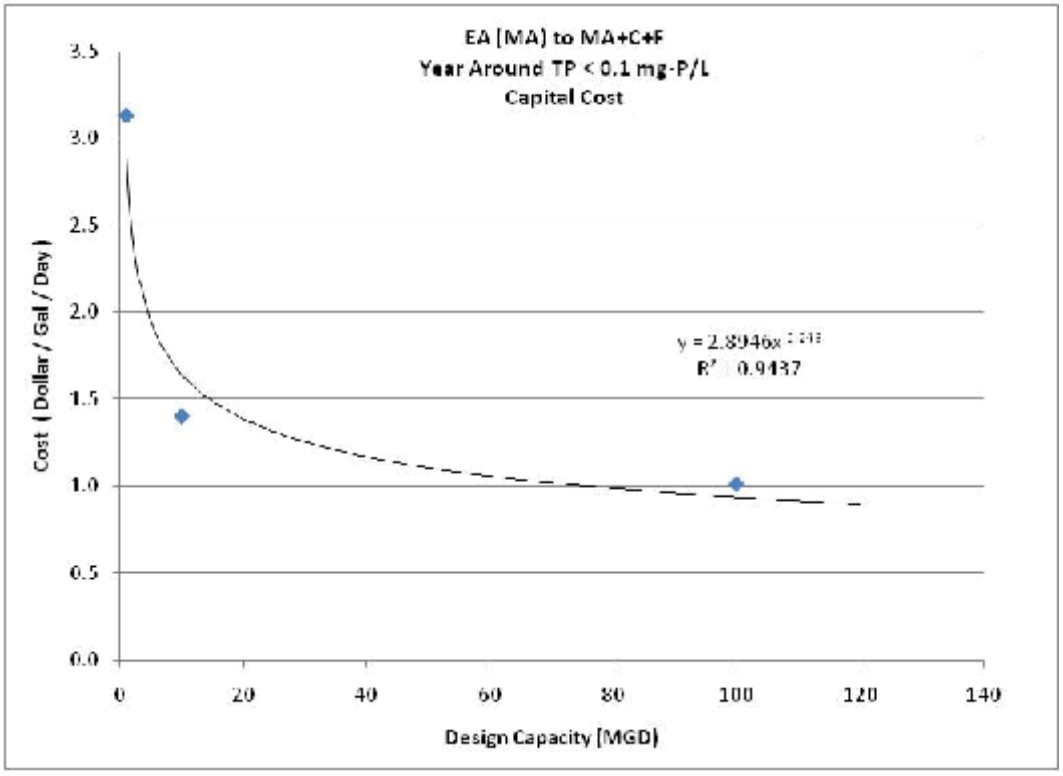

Figure 14-1. Capital Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective D Year-Round

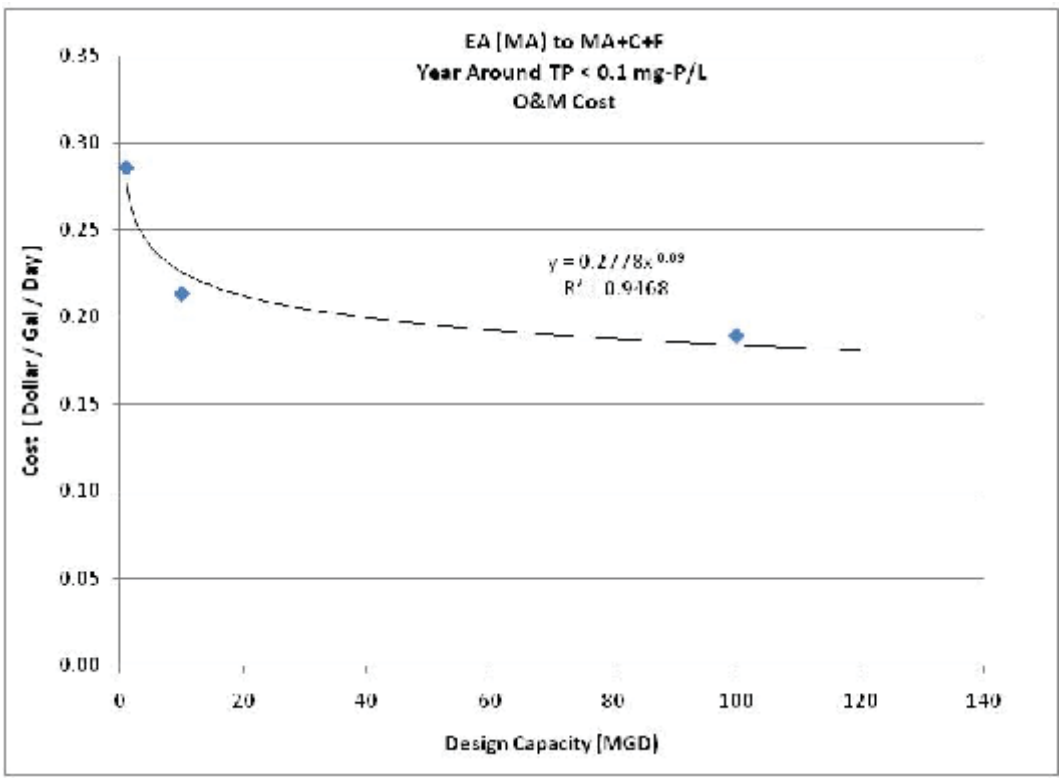

Figure 14-2. O&M Cost per Plant Capacity for Extended Aeration (Mechanical Aeration) Plant Upgraded for Objective D Year-Round

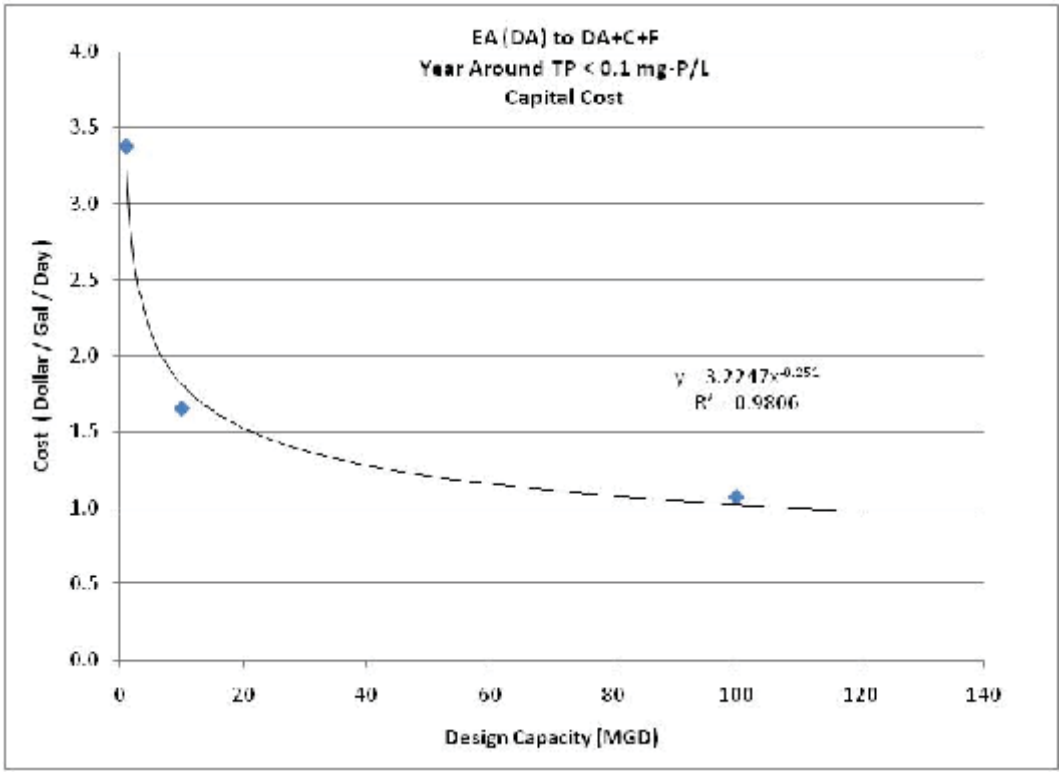

Figure 14-3. Capital Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective D Year-Round

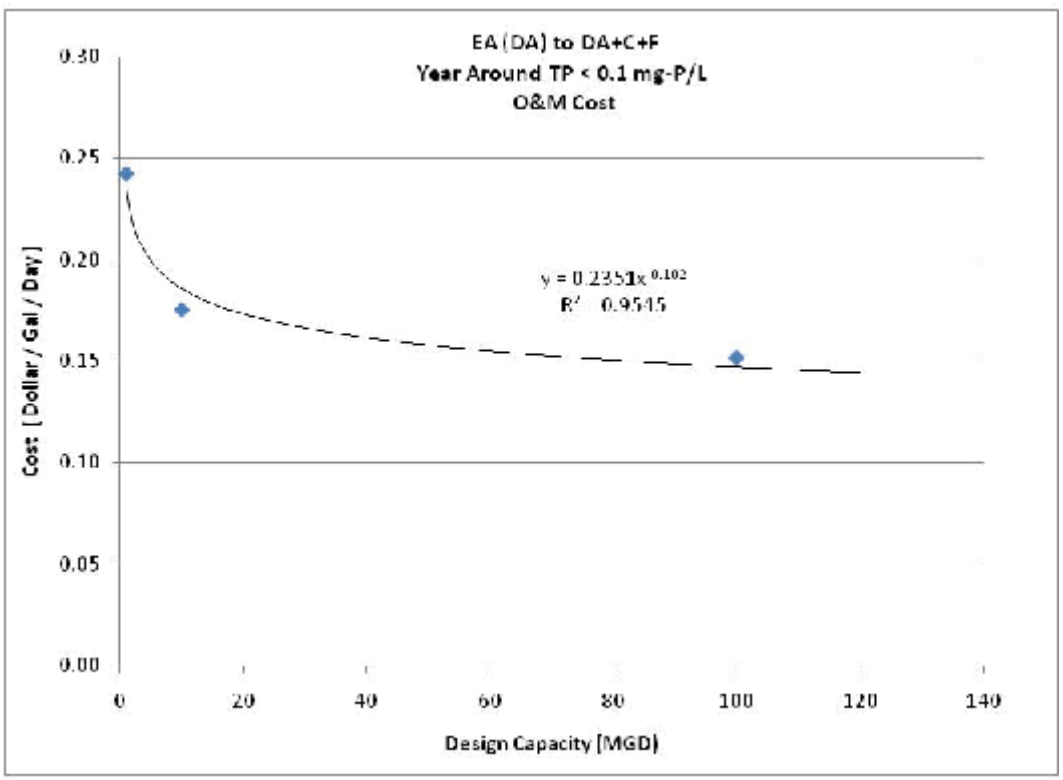

Figure 14-4. O&M Cost per Plant Capacity for Extended Aeration (Diffuser Aeration) Plant Upgraded for Objective D Year-Round

TABLE 14-3.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (MECHANICAL AERATION) PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$230,273	$1,028,735	$7,420,567
2014 Incremental O&M Cost	$321,614	$2,402,989	$21,274,480
Total Annual Cost	**$551,887**	**$3,431,725**	**$28,695,047**
Annual TP Load Reduction (lb/yr)	12,775	127,750	1,277,500
Estimated Unit Cost for TP Reduction ($/lb TP removed)	$43.20	$26.86	$22.46

Equation:[a] ..... $y = 157.5x^{-0.142}$
R-Square Value: 0.936

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-4.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING EXTENDED AERATION (DIFFUSER AERATION) PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$248,216	$1,211,255	$7,830,850
2014 Incremental O&M Cost	$272,598	$1,971,976	$17,039,753
Total Annual Cost	**$520,814**	**$3,183,231**	**$24,870,603**
Annual TP Load Reduction (lb/yr)	12,739	127,385	1,273,850
Estimated Cost for TP Reduction ($/lb TP removed)	$40.89	$24.99	$19.52

Equation:[a] ..... $y = 179.07x^{-0.161}$
R-Square Value: 0.9646

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.1.2 Conventional Activated Sludge Plants

Table 14-5 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for a conventional activated sludge plant. Figures 14-5 and 14-6 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-6 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-5.
ESTIMATED COST PER CAPACITY FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.60	$1.42	$0.96
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.28	$0.18	$0.15

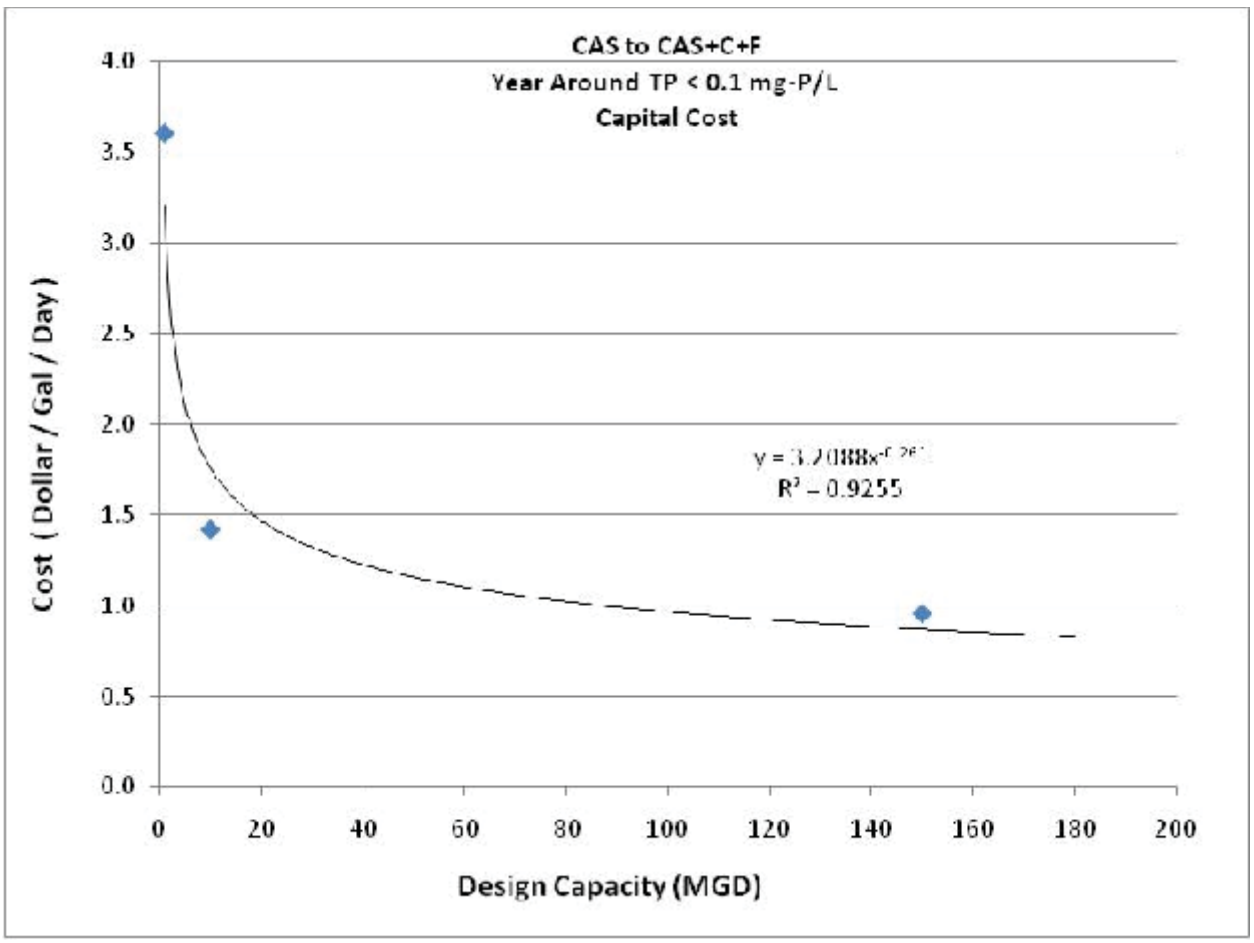

Figure 14-5. Capital Cost per Plant Capacity for CAS Plant Upgraded for Objective D Year-Round

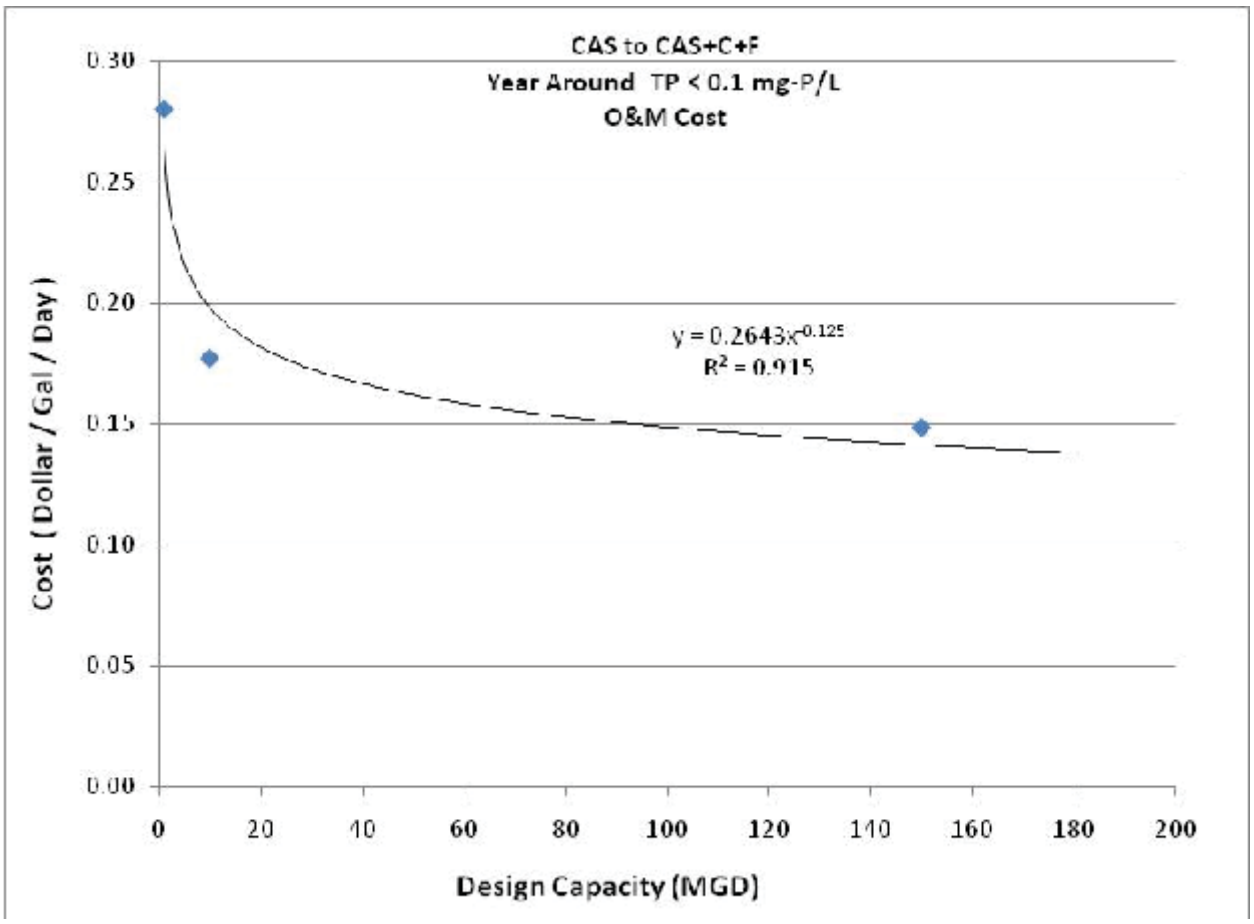

Figure 14-6. O&M Cost per Plant Capacity for CAS Plant Upgraded for Objective D Year-Round

TABLE 14-6.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING CAS PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$264,517	$1,043,049	$10,550,902
2014 O&M Cost	$315,750	$1,997,694	$25,088,042
Total Annual Cost	**$580,367**	**3,040,743**	**$35,638,944**
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Cost for TP Reduction ($/lb TP removed)	$44.17	$23.14	$18.08

Equation:[a] ..... $y = 214.81x^{-0.176}$
R-Square Value: 0.9129

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.1.3 Sequencing Batch Reactor Plants

Table 14-7 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for an SBR plant. Figures 14-7 and 14-8 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-8 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-7.
ESTIMATED COST PER CAPACITY FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.27	$2.21	$1.36
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.12	$0.09

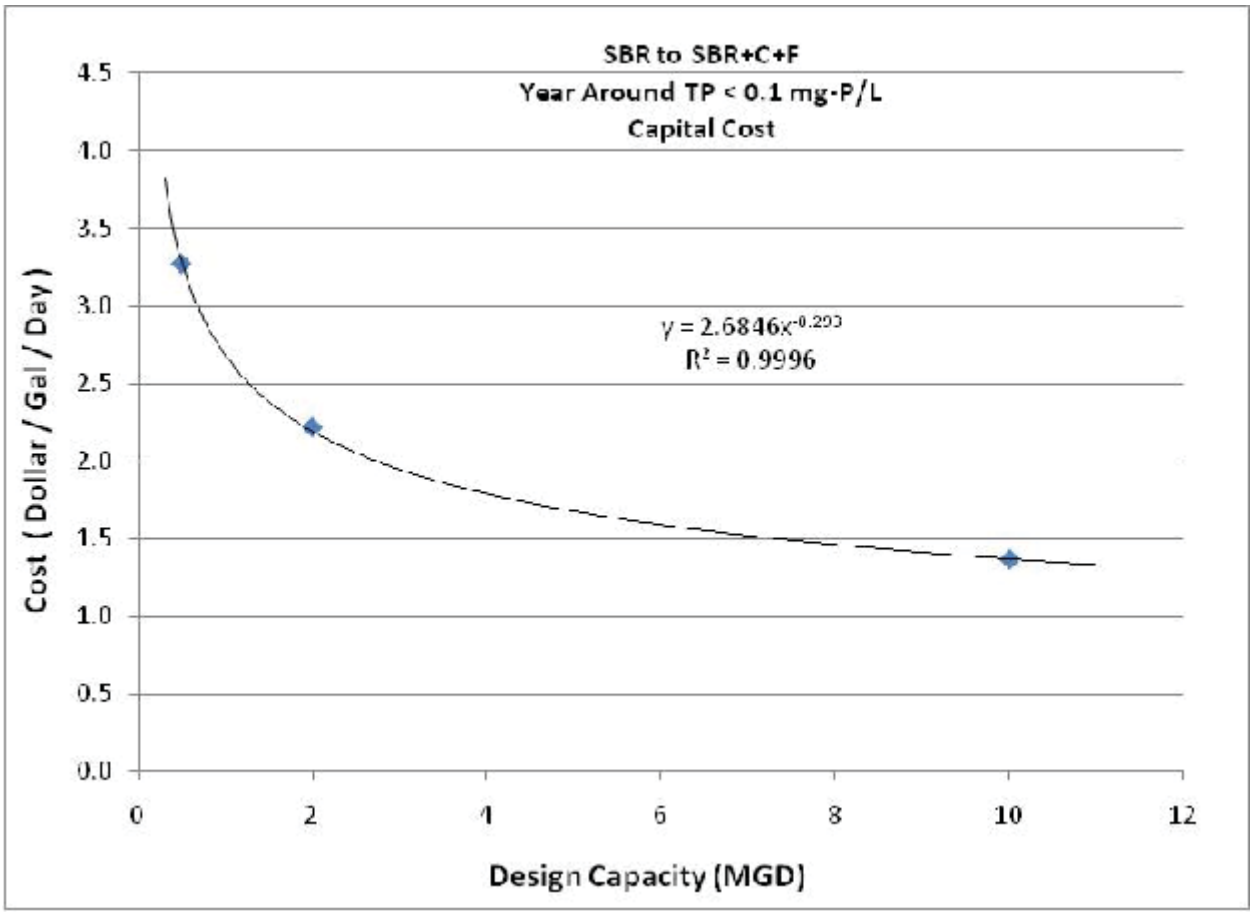

Figure 14-7. Capital Cost per Plant Capacity for SBR Plant Upgraded for Objective D Year-Round

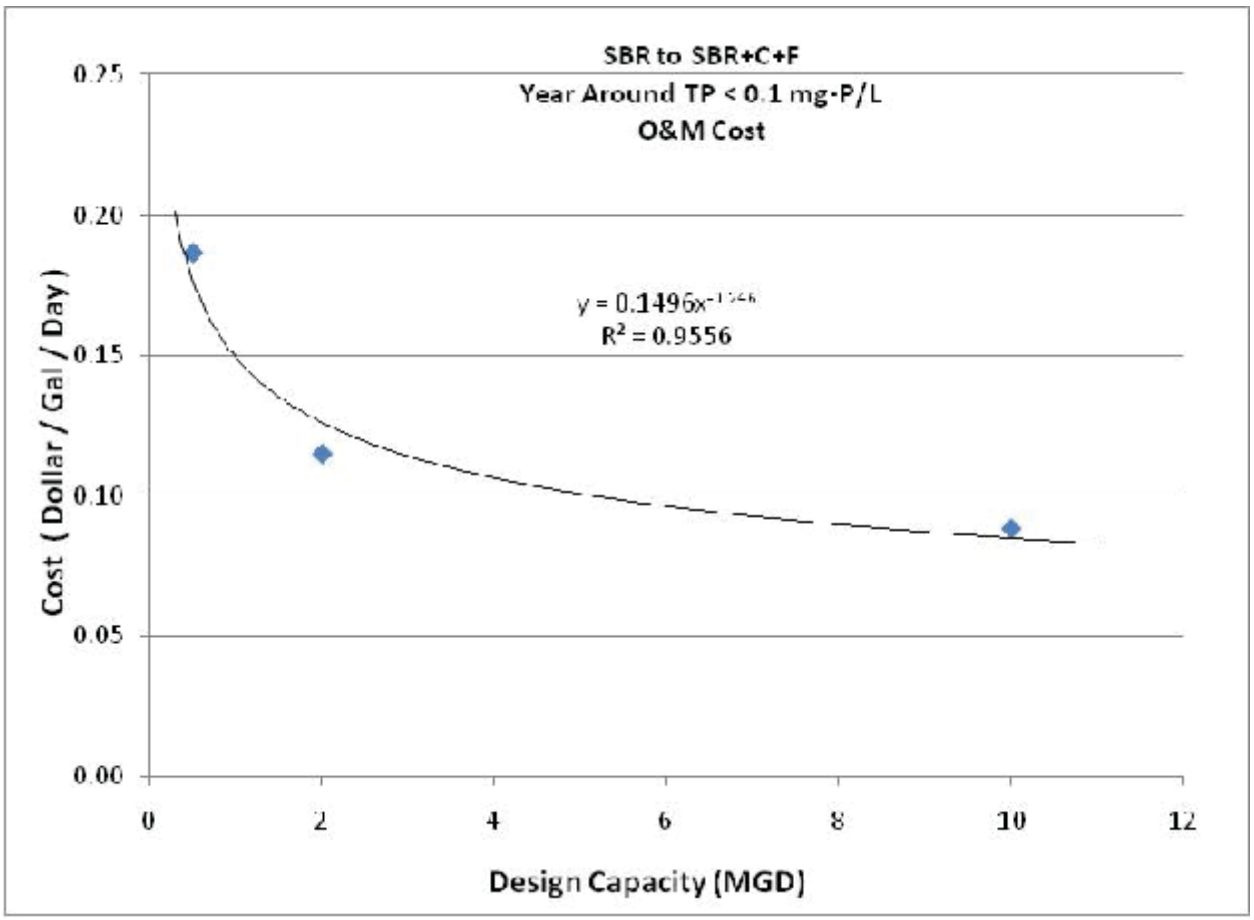

Figure 14-8. O&M Cost per Plant Capacity for SBR Plant Upgraded for Objective D Year-Round

TABLE 14-8.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING SBR PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	2-mgd Plant	10-mgd Plant
Annualized Capital Cost	$120,093	$325,337	$999,877
2014 O&M Cost	$104,836	$259,036	$996,931
Total Annual Cost	**$224,928**	**$584,373**	**$1,996,808**
Annual TP Load Reduction (lb/yr)	2,957	11,826	59,130
Estimated Cost for TP Reduction ($/lb TP removed)	$76.08	$49.41	$33.77
Equation:[a]			$y = 646.37x^{-0.27}$
R-Square Value:			0.9937

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.1.4 Trickling Filter, Trickling Filter/Solids Contact and Rotating Biological Contactor Plants

Table 14-9 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for a trickling filter plant. Figures 14-9 and 14-10 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-10 and Figurse 14-11 and 14-12 summarize these costs for a trickling filter/solids contact plant. Table 14-11 and Figures 14-13 and 14-14 summarize these costs for an RBC plant. Tables 14-12, 14-13 and 14-14 present the annualized unit costs for reducing nutrient loads for TF, TF/SC and RBC plants, respectively.

TABLE 14-9.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.60	$1.42	$0.96
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.26	$0.17	$0.14

TABLE 14-10.
ESTIMATED COST PER CAPACITY FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.60	$1.42	$0.96
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.27	$0.17	$0.14

TABLE 14-11.
ESTIMATED COST PER CAPACITY FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Capital Cost per gpd of Plant Capacity	$3.60	$1.42	$0.96
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.27	$0.17	$0.14

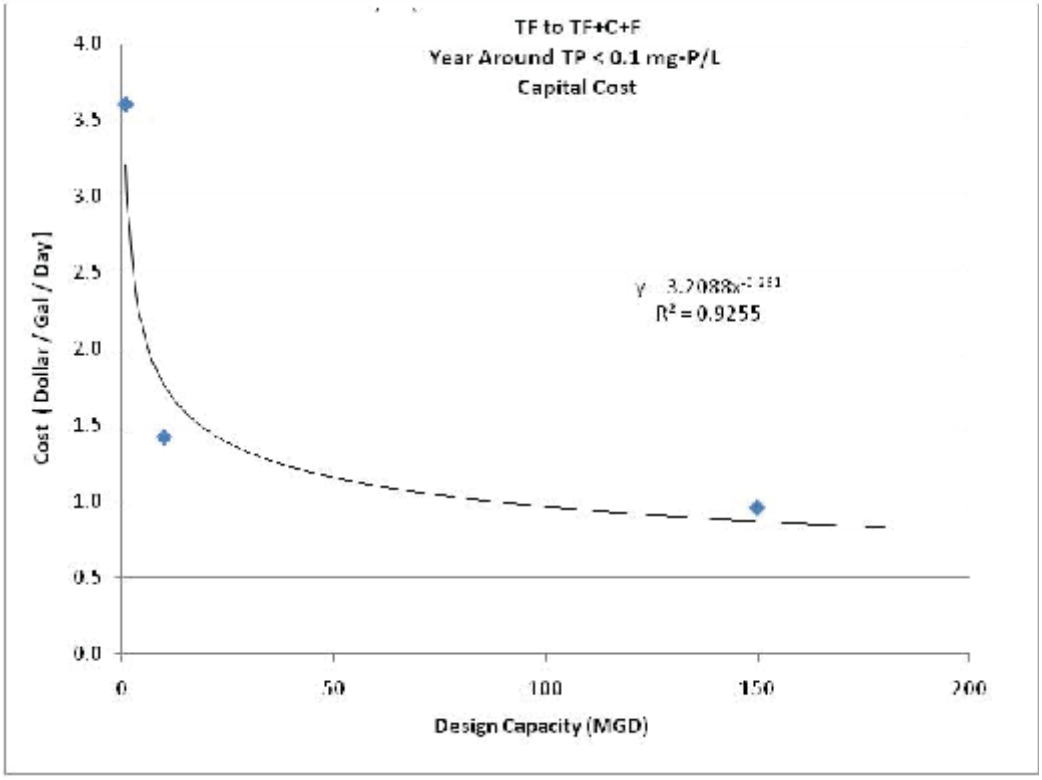

Figure 14-9. Capital Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective D Year-Round

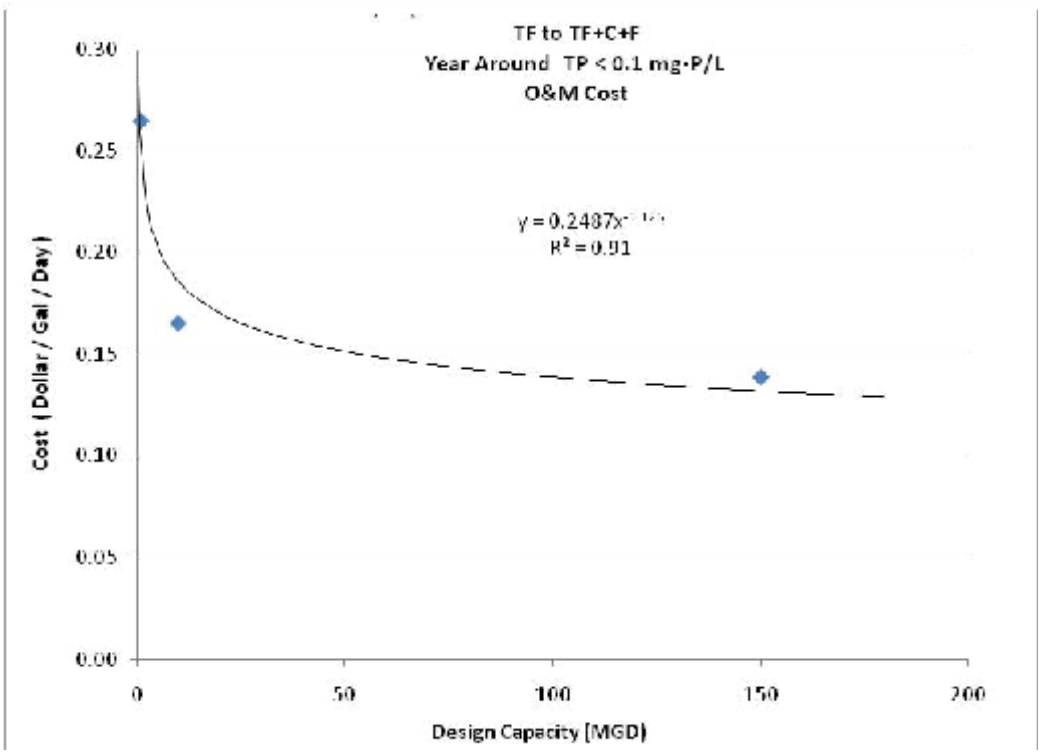

Figure 14-10. O&M Cost per Plant Capacity for Trickling Filter Plant Upgraded for Objective D Year-Round

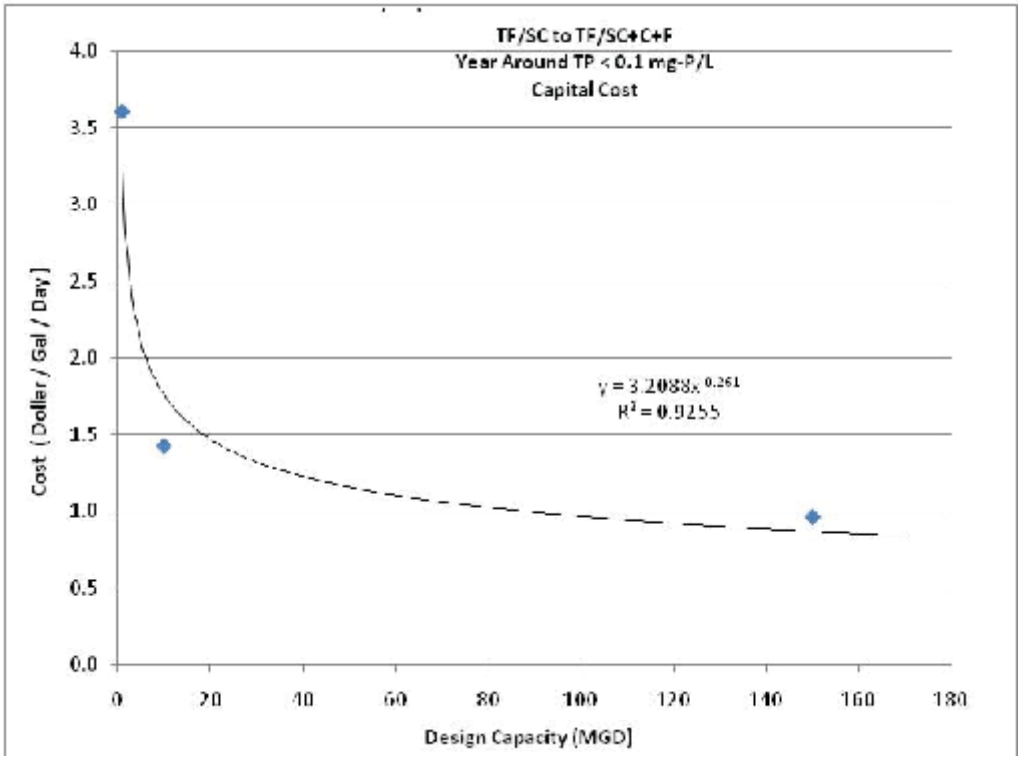

Figure 14-11. Capital Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective D Year-Round

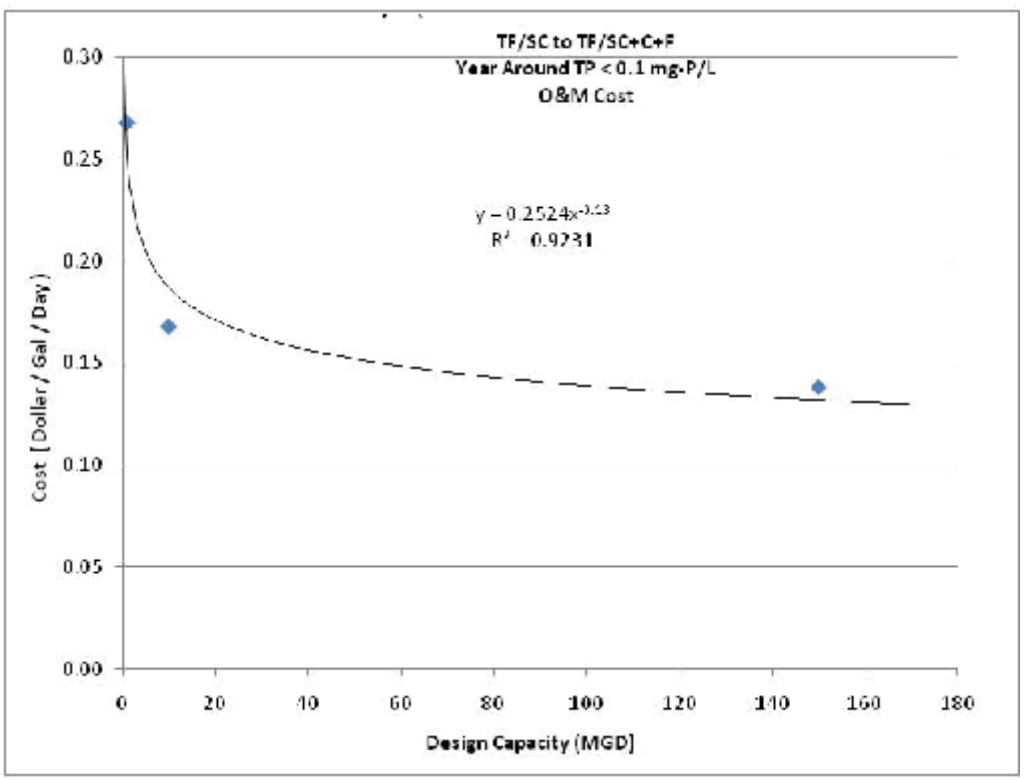

Figure 14-12. O&M Cost per Plant Capacity for Trickling Filter/Solids Contact Plant Upgraded for Objective D Year-Round

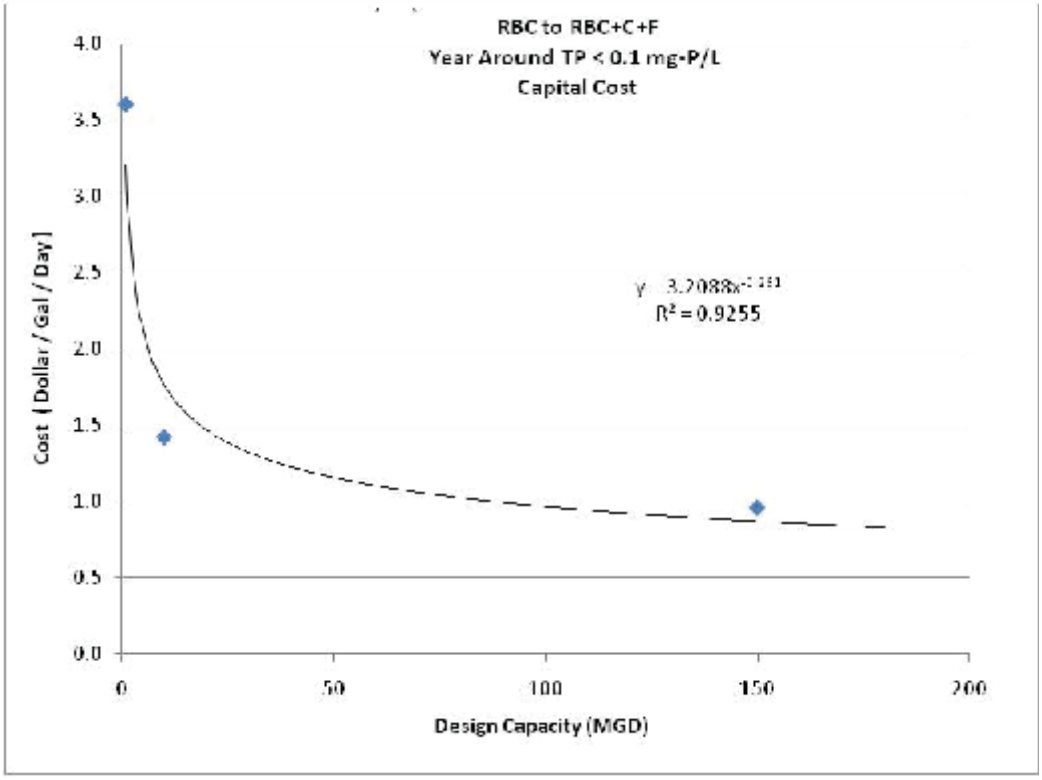

Figure 14-13. Capital Cost per Plant Capacity for RBC Upgraded for Objective D Year-Round

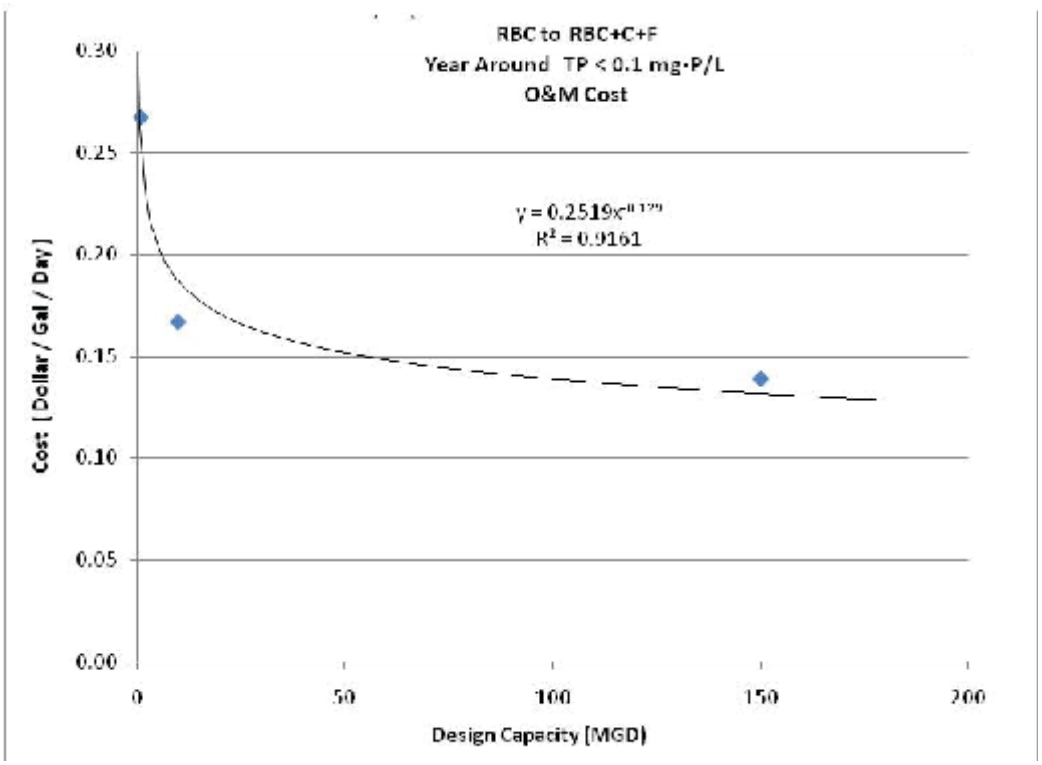

Figure 14-14. O&M Cost per Plant Capacity for RBC Plant Upgraded for Objective D Year-Round

TABLE 14-12.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$264,617	$1,043,049	$10,550,902
2014 O&M Cost	$297,872	$1,864,659	$23,490,382
Total Annual Cost	**$562,489**	**$2,907,708**	**$34,041,284**
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Cost for TP Reduction ($/lb TP removed)	$42.81	$22.13	$17.27

Equation:[a] ..... $y = 213.36x^{-0.179}$
R-Square Value: 0.911

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-13.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING TRICKLING FILTER/SOLIDS CONTACT PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$264,617	$1,043,049	$10,550,902
2014 O&M Cost	$301,209	$1,891,108	$23,384,021
Total Annual Cost	**$565,826**	**$2,934,157**	**$33,934,923**
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Cost for TP Reduction ($/lb TP removed)	$43.06	$22.33	$17.22

Equation:[a] ..... $y = 218.9x^{-0.18}$
R-Square Value: 0.9173

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

TABLE 14-14.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING RBC PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	150-mgd Plant
Annualized Capital Cost	$264,617	$1,043,049	$10,550,902
2014 O&M Cost	$301,383	$1,878,840	$23,420,038
Total Annual Cost	**$566,000**	**$2,921,889**	**$33,970,940**
Annual TP Load Reduction (lb/yr)	13,140	131,400	1,971,000
Estimated Cost for TP Reduction ($/lb TP removed)	$43.07	$22.24	$17.24

Equation:[a] ..... $y = 218.09x^{-0.18}$
R-Square Value: 0.9141

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.1.5 Membrane Biological Reactor Plants

Table 14-15 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for an MBR plant. Figures 14-15 and 14-16 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-16 presents the annualized unit costs for reducing nutrient loads.

TABLE 14-15.
ESTIMATED COST PER CAPACITY FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Capital Cost per gpd of Plant Capacity	$1.32	$0.34	$0.28
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.19	$0.11	$0.09

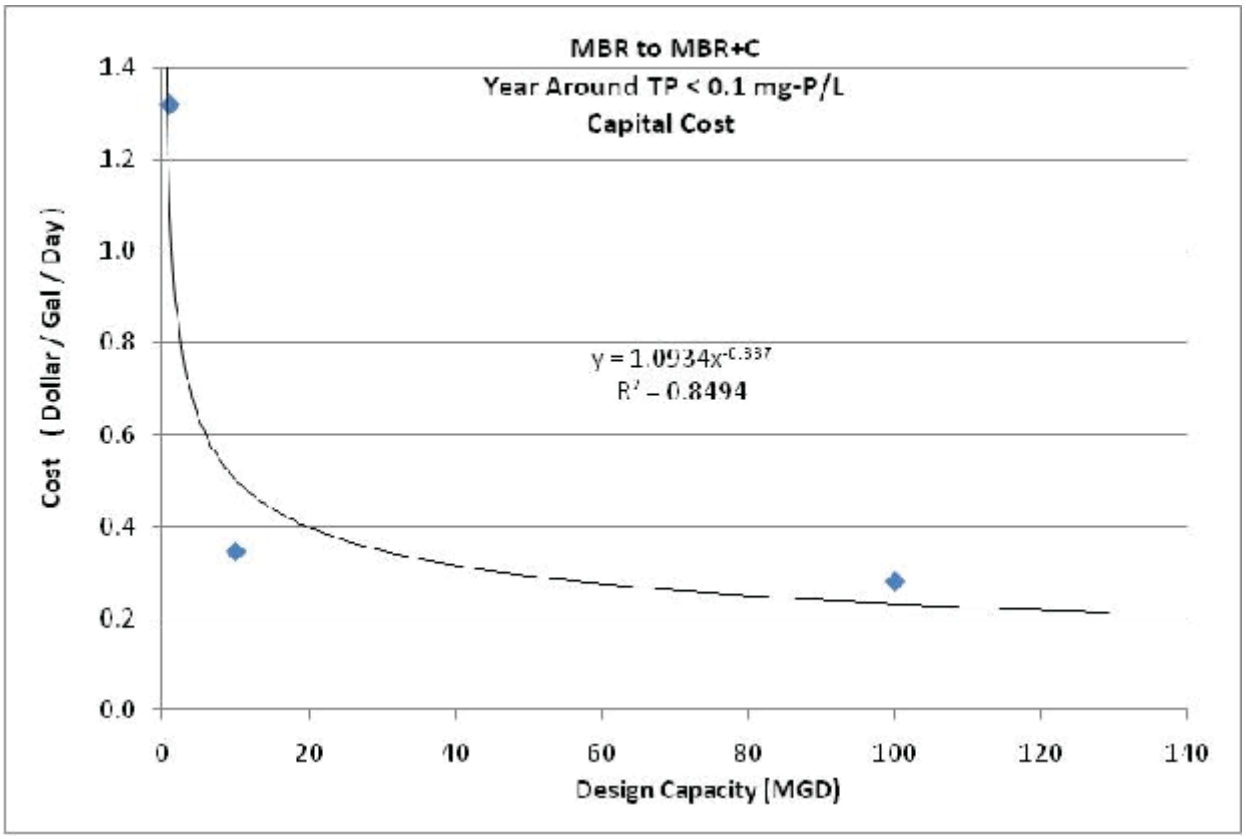

Figure 14-15. Capital Cost per Plant Capacity for MBR Plant Upgraded for Objective D Year-Round

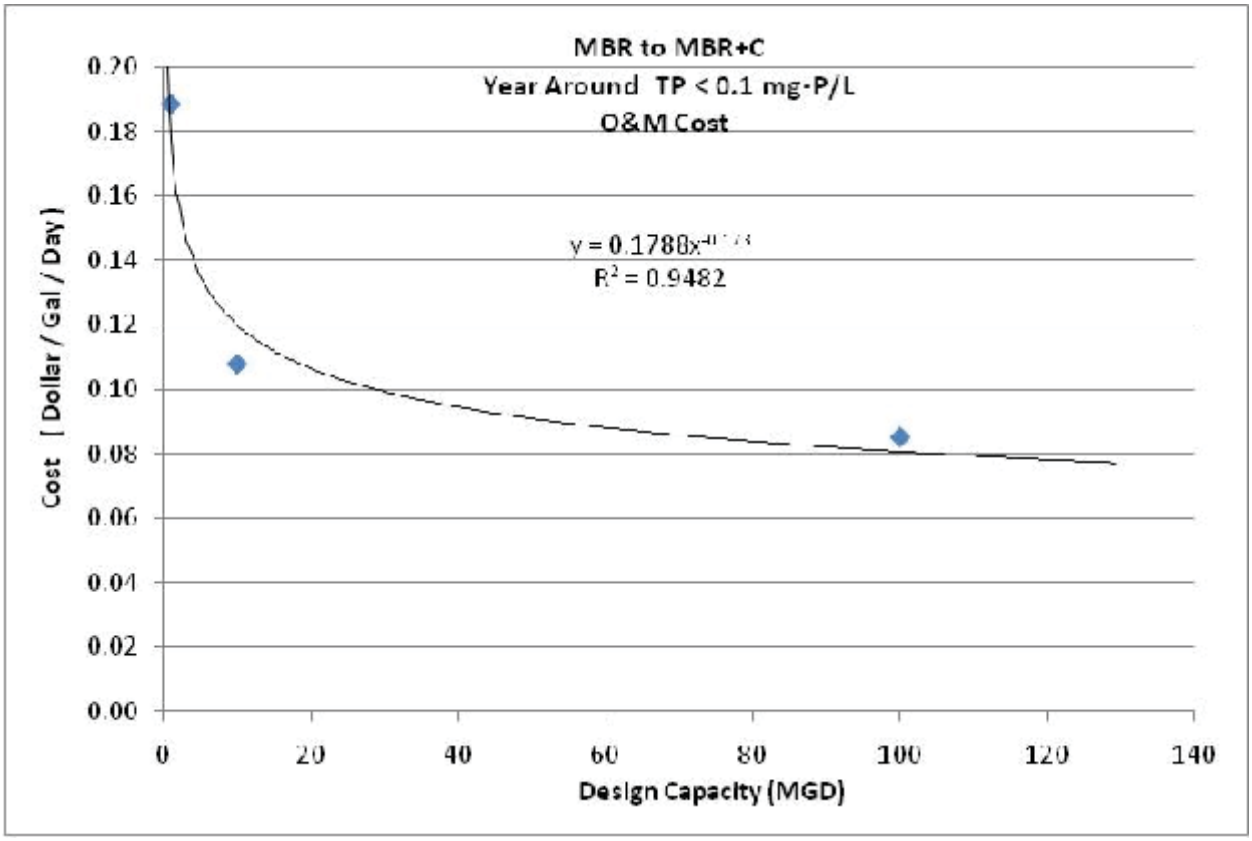

Figure 14-16. O&M Cost per Plant Capacity for MBR Plant Upgraded for Objective D Year-Round

TABLE 14-16.
ESTIMATED COST PER WEIGHT OF NUTRIENT REMOVAL FOR UPGRADING MBR PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	1-mgd Plant	10-mgd Plant	100-mgd Plant
Annualized Capital Cost	$97,008	$253,136	$20,51,414
2014 O&M Cost	$212,293	$1,213,732	$9,578,080
Total Annual Cost	**$309,301**	**$1,466,868**	**$11,629,494**
Annual TP Load Reduction (lb/yr)	12,483	124,830	1,248,300
Estimated Cost for TP Reduction ($/lb TP removed)	$24.78	$11.75	$9.32
Equation:[a]			$y = 168.53x^{-0.212}$
R-Square Value:			0.9155

a. x = Annual TP Load Reduction (lb), y= Estimated Cost for TP Reduction ($/lb TP removed)

14.1.6 High-Purity Oxygen Activated Sludge Plants

High-purity oxygen activated sludge plants were not evaluated for any objectives that include phosphorus removal, so no costs associated with Objective D were developed for these plants.

14.1.7 Aerated or Facultative Lagoon Plants

Table 14-17 summarizes estimated capital costs and incremental O&M costs (compared to the existing plant) for achieving Objective D year-round for an aerated lagoon plant. Figures 14-17 and 14-18 show graphs of the capital and O&M costs, respectively. The estimates are given in dollars per gallon per day of plant capacity. Table 14-18 and Figures 14-19 and 14-20 summarize these costs for a facultative lagoon plant. Tables 14-19 and 14-20 present the annualized unit costs for reducing nutrient loads for aerated lagoon and facultative lagoon plants, respectively.

TABLE 14-17.
ESTIMATED COST PER CAPACITY FOR UPGRADING AERATED LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.85	$6.37	$3.72	$3.41
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.39	$0.25	$0.12	$0.07

TABLE 14-18.
ESTIMATED COST PER CAPACITY FOR UPGRADING FACULTATIVE LAGOON PLANT TO ACHIEVE OBJECTIVE D YEAR-ROUND

	0.5-mgd Plant	1-mgd Plant	5-mgd Plant	50-mgd Plant
Capital Cost per gpd of Plant Capacity	$6.85	$6.37	$3.72	$3.41
Incremental Annual O&M Cost per gpd of Plant Capacity	$0.39	$0.25	$0.12	$0.07

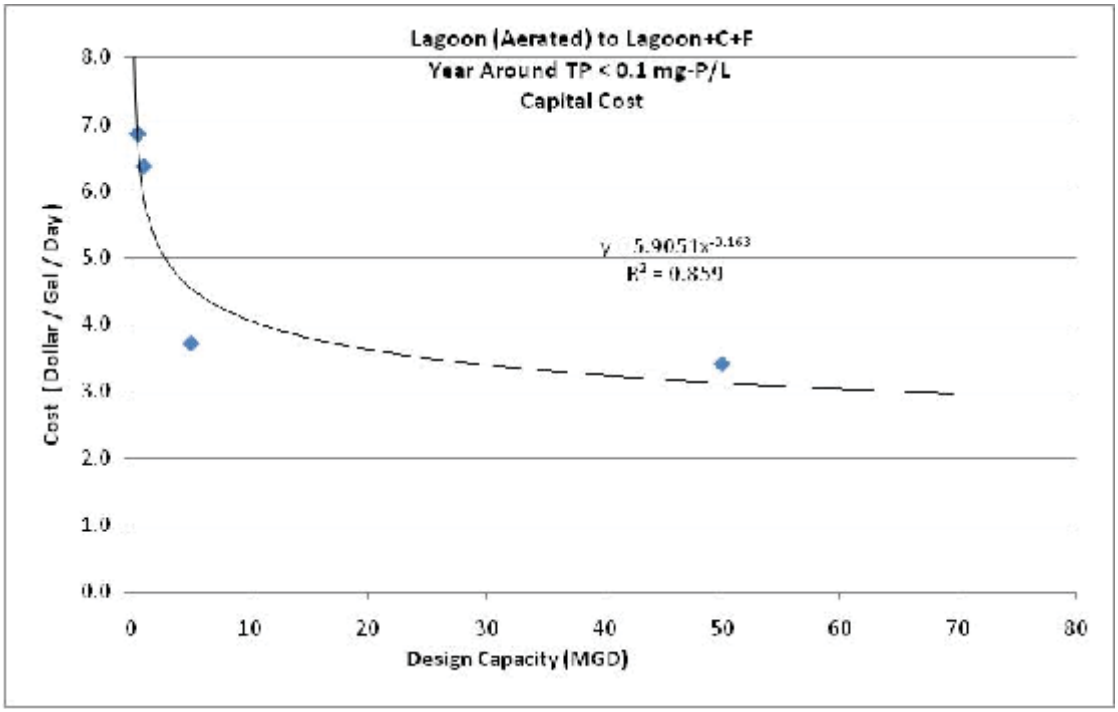

Figure 14-17. Capital Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective D Year-Round

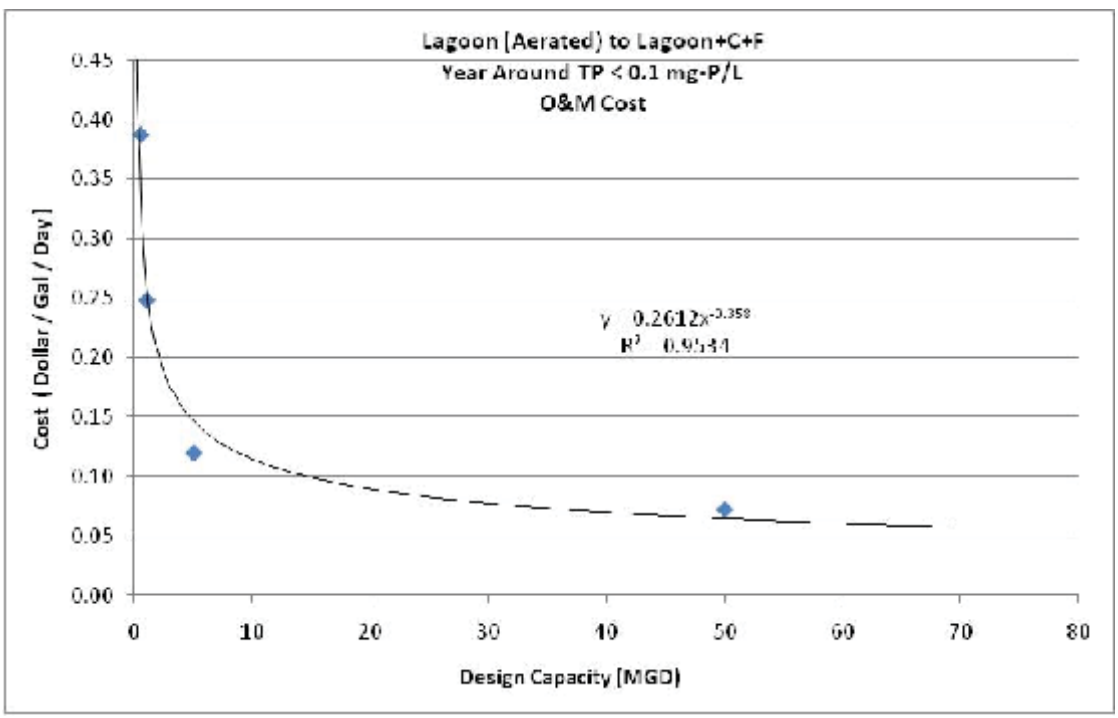

Figure 14-18. O&M Cost per Plant Capacity for Aerated Lagoon Plant Upgraded for Objective D Year-Round

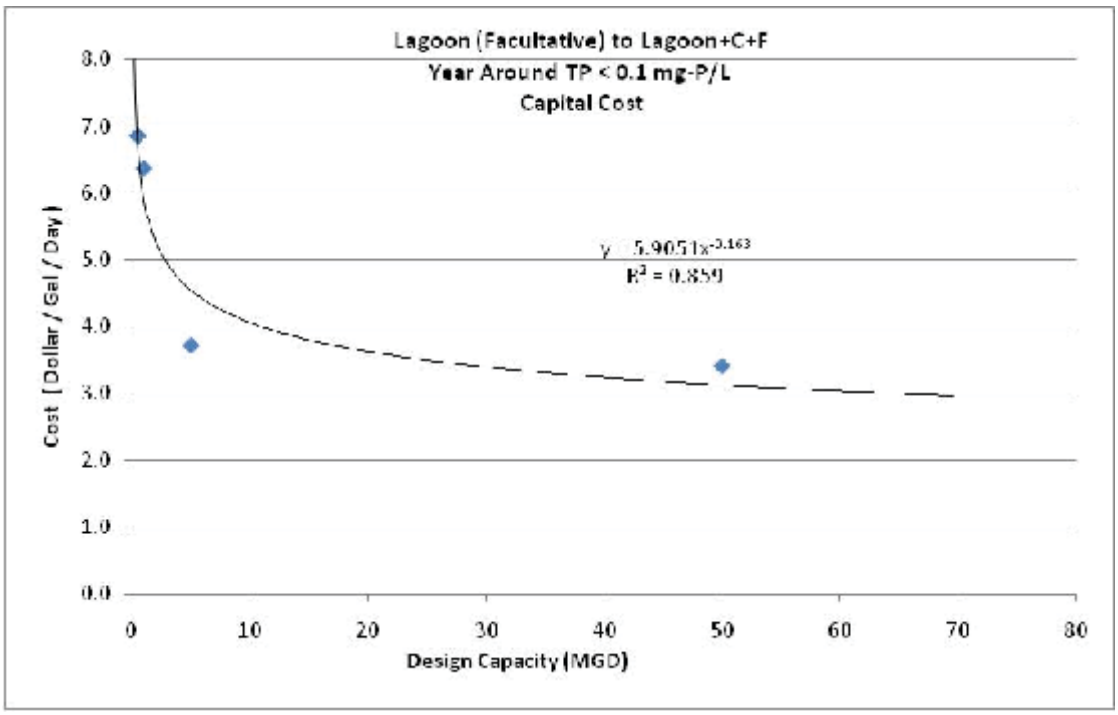

Figure 14-19. Capital Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective D Year-Round

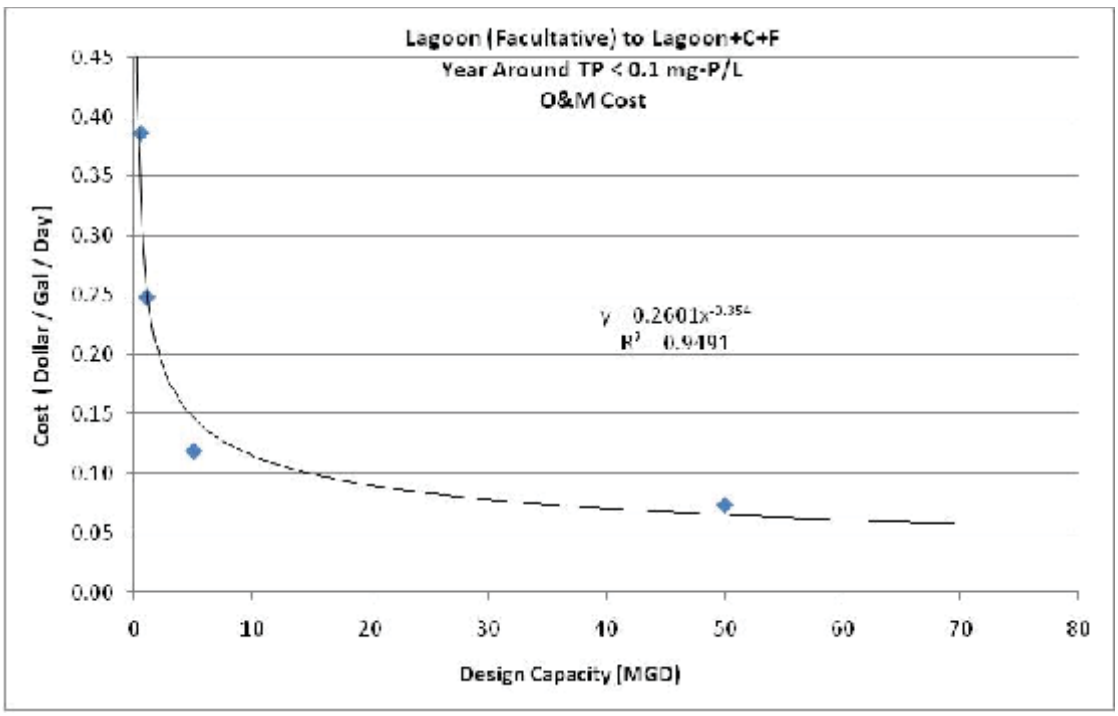

Figure 14-20. O&M Cost per Plant Capacity for Facultative Lagoon Plant Upgraded for Objective D Year-Round