Appendix A-3

COST MODULE FOR OPTION 2.5

(Nitrification + Partial Denitrification)

COST MODULE FOR OPTION 2.5
(Nitrification + Partial Denitrification)

1.0 COST OVERVIEW & ASSUMPTIONS

Effluent concentrations associated with Option 2.5 require nitrification and partial denitrification of meat and poultry product (MPP) wastewater (i.e., TKN is converted to nitrate/nitrite then to nitrogen gas). Option 2.5 long-term average (LTA) concentrations are shown in Table 2 of the main section of this document, titled "Revised Methodology For Estimating Incremental Capital and Operating and Maintenance Costs for the Meat and Poultry Products Effluent Limitations Guidelines and Standards." A facility with a wastewater treatment plant designed for nitrification can be upgraded to achieve nitrification and partial denitrification (N+PDN = Option 2.5) by installing anoxic tanks with accessory equipment, pumps, and mixers. A schematic of an N+PDN system for treating MPP wastewater is shown in Figure A-3.1.

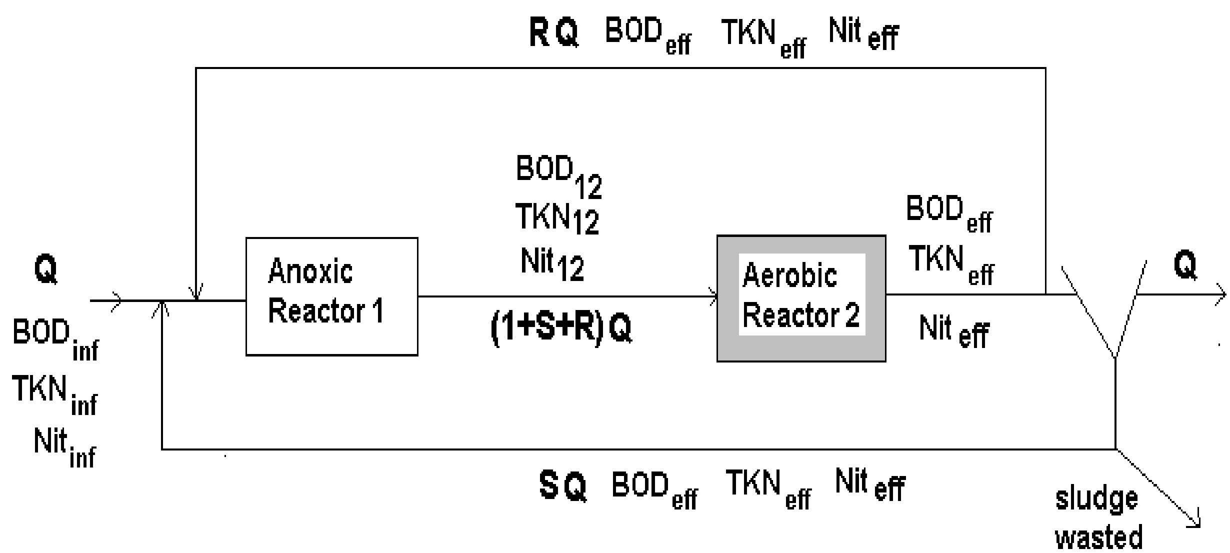

Figure A-3.1: Schematic of Nitrification and Partial Denitrification System (N+PDN)

In this model, a facility with a wastewater treatment plant designed for nitrification has an aerobic reactor in place (aerobic reactor 2 in the diagram) and is costed for (i) anoxic tanks (hereinafter referred to as anoxic reactor 1) with mixers before the existing aeration tanks; and (ii) pumps for recycling nitrate/nitrite from aerobic reactor 2 to anoxic reactor 1 to achieve Option 2.5 LTA concentrations.

In aerobic reactor 2, biochemical oxygen demand (BOD) removal and nitrification takes place. The nitrate/nitrite produced in the aerobic reactor is recycled to anoxic reactor 1 for denitrification. During the denitrification process, a significant amount of BOD is consumed, reducing the BOD load on aerobic reactor 2. The wastewater from aerobic reactor 2 flows into the clarifier(s) where the biomass is then separated from the wastewater. A portion of the biomass that is separated is recycled to anoxic reactor 1 while the other portion is wasted (i.e., removed for further processing and ultimate disposal).

To simplify the cost model, factors that do not contribute significantly to cost estimates are neglected. The following assumptions are applicable to the cost model:

a. The influent nitrate/nitrite-N concentration entering the N+PDN system is practically zero;
b. Endogeneous decay is neglected;
c. Nitrogen removal due to biomass growth is negligible; and
d Total mass of total Kjeldahl nitrogen (TKN) entering and leaving anoxic reactor 1 does not change.

2.0 NOTATIONS

The equations for the cost model are based on a mass balance of the N+PDN system shown in Figure A-3.1. The notations used in the cost equation are described below:

Q	= influent wastewater flow (gal/day)
R	= ratio of nitrate/nitrite recycle flow to influent flow
S	= ratio of sludge recycle flow to influent flow

Current Nitrification System

Influent Concentrations

$BOD_{inf\_current}$ = current influent BOD concentration (mg/L)
TKN_{inf} = influent TKN concentration (mg/L)
Alk_{inf} = influent alkalinity (mg/L)
Nit_{inf} = influent nitrate/nitrite-N concentration (mg/L)
= 0 (assumed)

Effluent Concentrations

$BOD_{eff\_current}$ = current effluent BOD concentration (mg/L)
$TKN_{eff\_current}$ = current effluent TKN concentration (mg/L)
$TSS_{eff\_current}$ = current effluent total suspended solids (TSS) concentration (mg/L)

N+PDN System (Option 2.5)

LTA Concentrations

BOD_{eff_LTA} = option effluent BOD LTA concentration (mg/L)
TKN_{eff_LTA} = option effluent TKN LTA concentration (mg/L)
TSS_{eff_LTA} = option effluent TSS LTA concentration (mg/L)
Nit_{eff_LTA} = option effluent nitrate/nitrite-N LTA concentration (mg/L)

Influent Concentrations

BOD_{inf_req} = influent BOD concentration requirement based on influent BOD:TKN ratio of 3 (mg/L)
BOD_{inf} = influent BOD concentration used in the analysis (mg/L)

Target Effluent Concentrations

BOD_{eff} = target effluent BOD concentration (mg/L)
TKN_{eff} = target effluent TKN concentration (mg/L)
TSS_{eff} = target effluent TSS concentration (mg/L)
Nit_{eff} = target effluent nitrate/nitrite-N concentration (mg/L)

Effluent from Anoxic Reactor 1

BOD_{12} = effluent BOD concentration (mg/L)
TKN_{12} = effluent TKN concentration (mg/L)

Nit_{12} = effluent nitrate/nitrite-N concentration (mg/L)

<u>All Reactors</u>

MLVSS = concentration of mixed liquor volatile suspended solids in the reactors (mg/L)

3.0 COST MODEL INPUT PARAMETERS

The following parameters are inputs to the model (i.e., entered in the "input" spreadsheet in the cost model):

Flows:

Q, R, and S

Influent concentrations:

$BOD_{inf\_current}$

TKN_{inf}

Alk_{inf} (if available)

Effluent concentrations:

$BOD_{eff\_current}$

$TKN_{eff\_current}$

$TSS_{eff\_current}$

Mixed liquor volatile suspended solids:

MLVSS

Option effluent LTA concentrations (entered in the "LTA" spreadsheet in the cost model):

BOD_{eff_LTA}

TKN_{eff_LTA}

TSS_{eff_LTA}

4.0 CONSTANTS

The various constants used in the cost model (i.e., "constants" spreadsheet in the model) are presented in Tables A-12.1 through A-12.5 in Appendix A-12. The constants used in the cost models to calculate the design parameters are shown in Table A-12.1 while the cost constants used to calculate costs are shown in Table A-12.2. Cost equations for estimating capital costs and annual operating and maintenance (O&M) costs are shown in Tables A-12.3 and A-12.4. One-time costs are shown in Table A-12.5.

5.0 DESIGN CALCULATIONS

The following section discusses the method used to determine the design parameters for the N+PDN system.

5.1 Concentrations and Removals

5.1.1 Influent BOD Concentration used for Analysis (BOD_{inf})

For optimal denitrification, the desirable influent BOD to TKN ratio is at least 3 (Table A-12.1). Therefore:

- BOD_{inf_req} mg/L = {[3] [TKN_{inf} mg/L]} (A-3.1)

where:

TKN_{inf} is input to the model
the factor of 3 is obtained from Table A-12.1

If adequate influent BOD is not present for denitrification, then an additional carbon source is required. Data from the MPP detailed surveys indicate that MPP wastewater normally has an adequate BOD:TKN ratio for denitrification. However, facilities that use anaerobic lagoon(s) for treatment may have a BOD:TKN ratio of less than 3. For those facilities, a portion of the influent wastewater to the lagoon may be bypassed directly to anoxic reactor 1 to supply additional BOD to the system (see Section 7.1). This type of bypass has been demonstrated within the MPP industry.

The model first compares the current influent BOD concentration ($BOD_{inf\_current}$) with the calculated BOD_{inf_req} (see equation A-3.1). Values for $BOD_{inf\_current}$ and TKN_{inf} are inputs to the model. If $BOD_{inf\_current} > BOD_{inf\_req}$ then $BOD_{inf\_current}$ is used in the calculation. However, if $BOD_{inf\_current} < BOD_{inf\_req}$, then BOD_{inf_req} is used for analysis and the facility incurs a one-time cost for a lagoon bypass. This algorithm in the model ensures that adequate BOD for denitrification is present in the influent.

Therefore:

- BOD_{inf} mg/L = Max [BOD_{inf_req} mg/L, $BOD_{inf\_current}$ mg/L] (A-3.2)

where:

the maximum value is selected
BOD_{inf_req} is obtained from equation A-3.1
$BOD_{inf\_current}$ is input to the model

5.1.2 Target Effluent Concentrations

The target effluent concentration is determined by comparing the Option LTA concentration and the current effluent concentration for a parameter and choosing the lower value.

Therefore:

- BOD_{eff} mg/L = Min [$BOD_{eff\_current}$ mg/L, BOD_{eff_LTA} mg/L] (A-3.3)
- TKN_{eff} mg/L = Min [$TKN_{eff\_current}$ mg/L, TKN_{eff_LTA} mg/L] (A-3.4)
- TSS_{eff} mg/L = Min [$TSS_{eff\_current}$ mg/L, TSS_{eff_LTA} mg/L] (A-3.5)

where:

the minimum value is selected

All parameters on the right-hand side of equation A-3.3 through A-3.5 are inputs to the model. The calculation for the target effluent nitrate/nitrite-N concentration is shown in Section 5.1.4.

5.1.3 Effluent Nitrate/Nitrite Concentration from Anoxic Reactor 1 (Nit_{12})

The nitrate/nitrite recycled to anoxic reactor 1 is denitrified in anoxic reactor 1. If adequate influent BOD is present, then practically all the nitrate/nitrite is denitrified, resulting in a low effluent nitrate/nitrite-N concentration from anoxic reactor 1. Because the model is designed to ensure that adequate BOD is present for denitrification (see discussion in Section 5.1.1), the nitrate/nitrite-N concentration leaving anoxic reactor 1 (Nit_{12}) is assumed to be very low. The value used in the cost model is taken from the data provided by the Industry Coalition in response to the proposed rule (Industry Comments, 2002):

- $Nit_{12} = [1 \text{ mg/L}]$ (A-3.6)

5.1.4 Effluent Nitrate/Nitrite Concentration from Aerobic Reactor 2 (Nit_{eff})

Performing a mass balance for nitrogen on aerobic reactor 2 yields:

- $\{[(1+S+R)\,(Q)\,(Nit_{12})] + [(1+S+R)\,(Q)\,(TKN_{12})]\}$
  $= \{[(1+S+R)\,(Q)\,(Nit_{eff})] + [(1+S+R)\,(Q)\,(TKN_{eff})]\}$ (A-3.7)

Performing a mass balance for TKN on anoxic reactor 1 and noting that there is no TKN removal in anoxic reactor 1 (see Section 1.0) yields:

- $\{[(Q)\,(TKN_{inf})] + [(R)\,(Q)\,(TKN_{eff})] + [(S)\,(Q)\,(TKN_{eff})]\}$
  $= \{[(1+S+R)\,(Q)\,(TKN_{12})]\}$ (A-3.8)

Combining equations A-3.7 and A-3.8 yields the nitrate/nitrite-N concentration leaving aerobic reactor 2:

- $Nit_{eff} \text{ mg/L} = \{[Nit_{12} \text{ mg/L}] + [(TKN_{inf} - TKN_{eff} \text{ mg/L}) / (1+S+R)]\}$ (A-3.9)

All parameters on the right-hand side of equation A-3.9 are either inputs to the model or have already been calculated.

Different combinations of R and S are entered in the input page for the model to obtain the target effluent nitrate/nitrite-N concentration. The target effluent nitrate/nitrite-N concentration is equal to the Option effluent nitrate/nitrite-N LTA concentration.

Therefore:

- Nit_{eff} mg/L = [Nit_{eff_LTA} mg/L] (A-3.10)

5.1.5 Nitrates/Nitrites Removed Daily in Anoxic Reactor 1

All nitrate/nitrite removals are expressed in terms of nitrogen.

Performing a mass balance for nitrate/nitrite on anoxic reactor 1 yields:

- {[(Q) (Nit_{inf})] + [(R) (Q) (Nit_{eff})] + [(S) (Q) (Nit_{eff})] - [nitrate/nitrite removed]}
  = {[(1+S+R) (Q) (Nit_{12})]} (A-3.11)

Simplifying equation A-3.11 and setting Nit_{inf} = 0 (see Section 1.0 and Section 2.0) yields:

- Nitrate/nitrite removed (mg/day)
  = {[(R+S) (Nit_{eff} mg/L)] - [(1+S+R) (Nit_{12} mg/L)]} {[Q gal/day] [3.78 L/gal]} (A-3.12)

where:

3.78 is a conversion factor

All parameters on the right-hand side of A-3.12 are either inputs to the model or have already been calculated.

Therefore:

- Nitrate/nitrite removed (lbs/day)
  = {[nitrate/nitrite removed (mg/day)] / [453,600 mg/lb]} (A-3.13)

where:
453,600 is a conversion factor
nitrate/nitrite removed (mg/day) in anoxic reactor 1 is obtained from equation A-3.12

5.1.6 BOD Removed in Anoxic Reactor 1

The ratio of BOD removed to nitrate/nitrite removed in an anoxic reactor treating MPP waste is obtained from Table A-12.1.

Therefore:

- BOD removed in anoxic reactor 1 (mg/day)
  = {[2.75] [nitrate/nitrite removed (mg/day)]} (A-3.14)

where:
2.75 is obtained from Table A-12.1
nitrate/nitrite removed (mg/day) in anoxic reactor 1 is obtained from equation A-3.12

- BOD removed in anoxic reactor 1 (lbs/day)
  = {[BOD removed (mg/day)] / [453,600 mg/lb]} (A-3.15)

where:
453,600 is a conversion factor

5.1.7 Effluent BOD Concentration from Anoxic Reactor 1

Performing a mass balance for BOD on anoxic reactor 1 yields:

- {[(Q)(BOD_{inf})]+ [(R)(Q)(BOD_{eff})] + [(S)(Q)(BOD_{eff})] - [BOD removed in anoxic reactor 1]}
  = {[1+S+R] [Q] [BOD_{12}]}

- BOD_{12} (mg/L)
  = {[(Q gal/day) (BOD_{inf} mg/L) (3.78 L/gal)] + [(R+S) (Q gal/day) (BOD_{eff} mg/L) (3.78 L/gal)] - [BOD removed (mg/day)]} / {[1+S+R] [Q gal/day] [3.78 L/gal]} (A-3.16)

where:

3.78 is a conversion factor
BOD removed (mg/day) in anoxic reactor 1 is obtained from equation A-3.15

All other parameters on the right-hand side of equation A-3.16 are either inputs to the model or have already been calculated.

5.1.8 BOD Removed in Aerobic Reactor 2

BOD removed in aerobic reactor 2 is expressed as:

- BOD removed (mg/day)
  = {[Q gal/day] [1+R+S] [BOD_{12} - BOD_{eff} mg/L] [3.78 L/gal]} (A-3.17)

where:

3.78 is a conversion factor
BOD_{12} (mg/L) is obtained from equation A-3.16

All other parameters on the right-hand side of equation A-3.17 are either inputs to the model or have already been calculated.

- BOD removed (lbs/day) = {[BOD removed (mg/day)] / [453,600 mg/lb]} (A-3.18) where:

453,600 is a conversion factor

5.1.9 TKN Removed in Aerobic Reactor 2

TKN removal occurs only in aerobic reactor 2 and is expressed as:

- TKN removed (mg/day) = {[Q gal/day] [TKN_{inf} - TKN_{eff} mg/L] [3.78 L/gal]} (A-3.19)

where:

3.78 is a conversion factor

All parameters on the right-hand side of equation A-3.19 are either inputs to the model or have already been calculated.

- TKN removed (lbs/day) = {[TKN removed (mg/day)] / [453,600 mg/lb]} (A-3.20)

where:

453,600 is a conversion factor
TKN removed (mg/day) is obtained from equation A-3.19

5.1.10 Mass of Biomass Required in Anoxic Reactor 1

- Mass of biomass required in anoxic reactor 1 (mg)
  = {[nitrate/nitrite removed (mg/day)] / [denitrification rate (mg/mg MLVSS-day)]} (A-3.21)

where:

nitrate/nitrite removed (mg/day) is obtained from equation A-3.12
denitrification rate = 0.171 mg nitrate/nitrite-N denitrified/mg MLVSS-day (Table A-12.1)

5.2 Reactor Volume and Detention Time

5.2.1 Minimum Anoxic Detention Time

The minimum detention time of anoxic reactors selected for denitrification is 2 hours (Table A-12.1).

5.2.2 Minimum Volume of Anoxic Reactor 1

Based on a minimum detention time of 2 hours, the minimum volume of anoxic reactor 1 is expressed as:

- V_{anoxic_min} (gal) = {[(Q gal/day) (2 hrs)] / [24 hrs/day]} (A-3.22)

where:
Q gal/day is input to the model

5.2.3 Volume of Anoxic Reactor 1

- Required anoxic volume, V_{anoxic_req} (gal)
  = {[biomass required in anoxic reactor 1 (mg)] / [MLVSS mg/L]} / {3.78 L/gal} (A-3.23)

where:
3.78 is a conversion factor
biomass required in anoxic reactor 1 (mg) is obtained from equation A-3.21
MLVSS is input to the model

The maximum of the V_{anoxic_min} and V_{anoxic_req} is selected as the volume of anoxic reactor, $V_{anoxic1}$(gal).

Therefore:

- $V_{anoxic1}$(gal) = Max [V_{anoxic_min} (gal), V_{anoxic_req} (gal)] (A-3.24) where:

the maximum value is selected

V_{anoxic_min} and V_{anoxic_req} are obtained from equations A-3.22 and A-3.23, respectively.

5.2.4 Purchase Volume Required of Anoxic Reactor 1

The purchase volume of the reactor is 160% of the actual volume of reactor required (Table A-12.1). The extra 60% volume is added to account for peak flows, freeboard, low temperature conditions, multiple tanks, and for other factors that may affect the volume requirements.

Therefore, the volume of the anoxic reactor that needs to be purchased, $V_{anoxic\_purchase}$ (gal) is expressed as:

- $V_{anoxic\_purchase}$ (gal) = {[1.60] [$V_{anoxic1}$ (gal)]} (A-3.25)

where:

the factor 1.60 is obtained from Table A-12.1

$V_{anoxic1}$(gal) is calculated from equation A-3.24

5.3 Mixers

Mixers are required in anoxic reactor 1 to keep the mixed liquor solids suspended.

5.3.1 Mixing Power

Mixing requirement = 60 (HP/Mgal) (Table A-12.1)

The mixer power is obtained from the following equation:

- Mixer power required (HP) = {[60 HP/Mgal] [purchase volume of reactor (gal)]} (A-3.26)

where:

purchase volume of reactor is obtained from equation A-3.25

5.3.2 Purchase Mixer Power

The purchase mixer power is 150% of the required mixer power (Table A-12.1). The extra 50% is added to account for peak flows, multiple mixers, and for other factors that may affect the mixer power requirements and contribute to increased costs. Therefore, the purchase mixer power is expressed as:

- Purchase mixer power (HP) = {[1.50] [mixer power required (HP)]} (A-3.27)

where:

the factor 1.50 is obtained from Table A-12.1
mixer power required (HP) is obtained from equation A-3.26

5.4 Pumps

5.4.1 Pump Energy

The pump energy to recycle nitrate/nitrite from aerobic reactor 2 to anoxic reactor 1 is expressed as:

- Pump power (HP)
  = {[flow (gpm)] [total dynamic head (ft)] [specific gravity of liquid]} /
  {[3,960] [pump efficiency]}(Perry, 1984) (A-3.28)

where:

specific gravity	= 1 for water	(Table A-12.1)
pump efficiency	= 0.77	(Table A-12.1)
total dynamic head	= 15 ft	(Table A-12.1)
flow (gpm)	= {[R] [Q gal/day]} / {[24 hrs/day] [60 min/hr]}	

3,960 is a conversion factor
Q (gal/day) and R are inputs to the model

5.4.2 Maximum Flow of Pump

The maximum flow of the recycle pump is 150% of the average recycle flow (Table A-12.1). The extra 50% is added to account for peak flows, multiple pumps, and for other factors that may affect pump flow.

Therefore, the maximum flow of the recycle pump is expressed as:

- Maximum flow (mgd) = {[1.50] [average recycle flow (mgd)]} (A-3.29)

where:

average recycle flow (mgd) = {[R] [Q gal/day] [10^{-6} gal/Mgal]}
Q (gal/day) and R are entered into the model
10^{-6} is a conversion factor
the factor 1.50 is obtained from Table A-12.1

5.5 Feed Systems and Mix Tank

5.5.1 Methanol Feed System

For optimal denitrification, the influent BOD to TKN ratio entering anoxic reactor 1 should be at least 3 (Table A-12.1). Some MPP facilities with an anaerobic lagoon may not have the necessary BOD for denitrification. For those facilities, a portion of the influent wastewater to the lagoon may be bypassed directly to the anoxic reactor during the weekdays. During the weekends, when production normally does not occur and influent wastewater is not available for bypass, methanol may be added to supplement BOD in the influent wastewater. The methanol dose required is estimated using the method described in the methanol feed system module in Appendix A-6.

5.5.2 Polymer Feed System

Polymer may be added to wastewater at or before the secondary clarifier to improve the settleability of sludge and to lower the effluent TSS concentration. The required polymer dose and estimates of sludge generated as a result of polymer addition are developed using the methods described in the polymer feed system module in Appendix A-7.

5.6 Alkalinity Savings

5.6.1 Influent Alkalinity (Alk_{inf})

Influent alkalinity is entered into the cost model if the value is available. If an influent alkalinity value for a facility is not available, then the model assumes an influent alkalinity of 900 mg/L for facilities with anaerobic lagoons and 100 mg/L for facilities without anaerobic lagoons (Table A-12.1). The default value of influent alkalinity for facilities with anaerobic lagoons were estimated based on the data provided in the MPP detailed survey. The default value of influent alkalinity for facilities without anaerobic lagoons were based on typical alkalinity concentration in surface waters and domestic wastewaters.

5.6.2 Effluent Alkalinity (Alk_{eff})

Effluent alkalinity is assumed to be 100 mg/L (Table A-12.1). The default value of effluent alkalinity were based on typical alkalinity concentration in surface waters.

5.6.3 Current Alkalinity Requirement for the Nitrification System

Approximately 7.1 lbs. of alkalinity are destroyed per lb. of ammonia-N nitrified (Table A-12.1).

Therefore:

- Total alkalinity destroyed (lbs/day)
  = {[Q gal/day] [TKN_{inf} - $TKN_{eff\_current}$ mg/L] [8.34×10^{-6} lbs/gal-mg/L]}

where:

8.34×10^{-6} is a conversion factor

Therefore:

- Calculated alkalinity requirement for nitrification, Alk_N (lbs/day)
  = {[alkalinity destroyed (lbs/day)] + [effluent alkalinity (lbs/day)] - [influent alkalinity (lbs/day)]}
  = {[Q gal/day] [8.34×10^{-6} lbs/gal-mg/L]}{[(TKN_{inf} - $TKN_{eff\_current}$ mg/L) (7.1 lbs/lb)] + [effluent alkalinity mg/L] - [influent alkalinity mg/L]} (A-3.30)

As described in Sections 5.6.1 and 5.6.2, influent alkalinity and effluent alkalinity are taken from Table A-12.1. All other parameters on the right-hand side of equation A-3.30 are either inputs to the model or have already been calculated.

Use of equation A-3.30 for facilities with high influent alkalinity may result in a negative number. A negative alkalinity requirement indicates that no alkalinity is currently added to the nitrification facility.

Therefore:

- The current alkalinity requirement (lbs/day) = Max [0, Alk_N (lbs/day)] (A-3.31)

where:

the maximum value is selected
Alk_N (lbs/day) is obtained from equation A-3.30

5.6.4 Alkalinity Requirement for the N+PDN System

Approximately 7.1 lbs. of alkalinity are destroyed per lb. of ammonia-N nitrified (Table A-12.1).

Therefore:

- Total alkalinity destroyed due to nitrification for the N+PDN system (lbs/day)
  = {[Q gal/day] [TKN_{inf} - TKN_{eff} mg/L] [8.34×10^{-6} lbs/gal-mg/L] [7.1 lbs/lb]}

where:

8.34×10^{-6} is a conversion factor

Approximately 50% of the alkalinity destroyed during nitrification is recovered during denitrification. Typically, 3.57 pounds of $CaCO_3$ alkalinity are recovered per pound of nitrate/nitrite denitrified (Table A-12.1).

Therefore:

- Alkalinity recovered (lbs/day) = {[3.57 lbs/lb] [nitrate/nitrite denitrified (lbs/day)]} (A-3.32)

where:

nitrate/nitrite denitrified or removed (lbs/day) is obtained from equation A-3.13

Therefore:

- Calculated alkalinity requirement for the N+PDN system, Alk_N+PDN (lbs/day)
  = {[alkalinity destroyed by nitrification (lbs/day)] + [effluent alkalinity (lbs/day)]
  - [influent alkalinity (lbs/day)] - [alkalinity recovered due to denitrification (lbs/day)]}
  = {[Q gal/day] [8.34×10^{-6} lbs/gal-mg/L] [(TKN_{inf} - TKN_{eff} mg/L) (7.1 lbs/lb)
  + (effluent alkalinity mg/L) - (influent alkalinity mg/L)]}- {alkalinity recovered due to denitrification (lbs/day)} (A-3.33)

where:

8.34×10^{-6} is a conversion factor

As described in Sections 5.6.1 and 5.6.2, influent alkalinity and effluent alkalinity are taken from Table A-12.1. Alkalinity recovered due to denitrification is derived from equation A-3.32. All other parameters on the right-hand side of equation A-3.33 are either inputs to the model or have already been calculated.

Use of equation A-3.33 for facilities with high influent alkalinity and/or that generate significant amounts of alkalinity may result in a negative number. A negative alkalinity requirement indicates that no alkalinity is required.

Therefore:

- Alkalinity requirement for the N+PDN system (lbs/day) (A-3.34)
  = Max [0, Alk_N+PDN (lbs/day)]

where:

the maximum value is selected
Alk_N+PDN (lbs/day) is obtained from equation A-3.33

5.6.5 Net Alkalinity Savings due to the N+PDN System

- The net alkalinity savings due to the N+PDN system
  = {[current alkalinity requirement for nitrification system] - [alkalinity requirement for the N+PDN system]} (A-3.35)

The values in the right-hand side of equation A-3.35 are obtained from equations A-3.31 and A-3.34.

5.7 Energy Required for Oxygen Transfer

- Oxygen requirement for BOD removal
  = 1.25 lbs of oxygen/lb of BOD removed (Table A-12.1)

- Oxygen requirement for TKN removal (nitrification)
  = 4.6 lbs of oxygen/lb of TKN removed (Table A-12.1)

5.7.1 Oxygen Required for the Existing Nitrification System

- Oxygen required for the existing nitrification system (lbs/day)
  = {[oxygen required for BOD removal (lbs/day)] + [oxygen required for TKN removal (lbs/day)]}
  = {[(Q gal/day) ($BOD_{inf\_current}$ - $BOD_{eff\_current}$ mg/L) (8.34×10^{-6} lbs/gal-mg/L) (1.25 lbs oxygen/lb BOD)] + [(Q gal/day) (TKN_{inf} - $TKN_{eff\_current}$ mg/L) (8.34×10^{-6} lbs/gal-mg/L) (4.6 lbs oxygen/lb TKN)]} (A-3.36)

where:

8.34×10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-3.36 are inputs to the model.

5.7.2 Oxygen Required for the N+PDN System

- Oxygen required for the N+PDN system (lbs/day)
  = {[oxygen required for BOD removal in aerobic reactor 2 (lbs/day)]
  + [oxygen required for TKN removal in aerobic reactor 2 (lbs/day)]}
  = {[BOD removed in aerobic reactor 2 (lbs/day)] [1.25 lbs oxygen/lb BOD]}
  + {[TKN removed in aerobic reactor 2 (lbs/day)] [4.6 lbs oxygen/lb TKN]} (A-3.37)

The BOD and TKN removed in aerobic reactor 2 are obtained from equations A-3.18 and A-3.20, respectively.

5.7.3 Net Oxygen Required due to the N+PDN System

- Incremental oxygen required for the N+PDN system (lbs/day)
  = {[oxygen required for the N+PDN system (lbs/day) from equation A-3.37)]
  - [oxygen required for the existing nitrification system (lbs/day) from equation A-3.36)]} (A-3.38)

5.7.4 Incremental Energy Required for Oxygen Transfer

Typically, air diffusion systems transfer 4 lbs. of oxygen per KWh of energy (Table A-12.1).

Therefore:

- Energy requirement due to oxygen transfer (KWh/year)
  = {[incremental oxygen required (lbs/day) from equation A-3.38] [365 days/yr]}
  / {4 lbs/KWh} (A-3.39)

Note: A negative energy requirement indicates savings.

5.8 Excess Sludge Generated

The biokinetic values: $Y_{aerobic}$ (lbs biomass/lb BOD removed), Y_{anoxic} (lbs biomass/lb nitrate/nitrite-N), and $Y_{nitrification}$ (lbs biomass/lb TKN) are provided in Table A-12.1.

5.8.1 Sludge Generation by the Existing Nitrification System

Biomass Generation

- Biomass produced by the existing nitrification system (lbs/day)
  = {[biomass generated due to BOD removal (lbs/day)]
  + [biomass generated due to nitrification (lbs/day)]}
  = {[Q gal/day] [$BOD_{inf\_current}$ - $BOD_{eff\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [$Y_{aerobic}$ (lbs/lb)]} + {[Q gal/day] [TKN_{inf} - $TKN_{eff\_current}$ mg/L] [8.34 x 10^{-6} lbs/gal-mg/L] [$Y_{nitrification}$(lbs/lb)]} (A-3.40)

where:
8.34 x 10^{-6} is a conversion factor

Flow and concentrations on the right-hand side of equation A-3.40 are either inputs to the model or have already been calculated.

Other Solids

- MLVSS/MLSS = 0.80 (Table A-12.1)
  Other solids (other than the biosolids) present in the sludge (lbs/day)
  = {[biomass generated (lbs/day)] [1-0.80]} / {0.80} (A-3.41)

where:
biomass generated (lbs/day) is obtained from equation A-3.40

Total Sludge Produced by the Existing Nitrification System

- Total sludge produced (lbs/day)
  = {[biomass produced (lbs/day) from equation A-3.40]
  + [other solids present in the sludge (lbs/day) from equation A-3.41]} (A-3.42)

5.8.2 Sludge Generation by the N+PDN System

Biomass Generation

- Biomass produced by the N+PDN system (lbs/day)
  = {[biomass generated due to nitrate/nitrite removal in anoxic reactor 1 (lbs/day)] +
  [biomass generated due to BOD removal in aerobic reactor 2 (lbs/day)] +
  [biomass generated due to nitrification (lbs/day)]}
  = {[nitrate/nitrite removed in anoxic reactor 1 (lbs/day)] [Y_{anoxic} (lbs/lb)]} + {[BOD removed in aerobic reactor 2 (lbs/day)] [$Y_{aerobic}$ (lbs/lb)]} + {[TKN removed (lbs/day)] [$Y_{nitrification}$ (lbs/lb)]} (A-3.43)

Nitrate/nitrite removed, BOD removed in aerobic reactor 2, and TKN removed are obtained from equations A-3.13, A-3.18, and A-3.20 respectively.

Other Solids

The amount of other solids (other than the biosolids) in the sludge remains practically unchanged. The amount of other solids is obtained from equation A-3.41.

Sludge due to Incremental TSS Removal

If the Option effluent TSS LTA concentration is less than the current effluent TSS levels, then additional sludge is generated due to TSS removal.

Therefore:

- Sludge due to TSS removal (lbs/day)
  = {[Q gal/day] [$TSS_{eff\_current}$ - TSS_{eff} mg/L] [8.34 x 10^{-6} lbs/gal-mg/L]} (A-3.44)

where:

8.34 x 10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-3.44 are either inputs to the model or have already been calculated.

Sludge due to Polymer Addition

Sludge generation due to polymer addition is estimated based on the methodology and equations contained in the polymer feed module in Appendix A-7.

Total Sludge Produced by N+PDN System

- Total sludge produced due to the N+PDN system (lbs/day)
  = {[biomass generation (lbs/day) from equation A-3.43]
  + [other solids present in sludge (lbs/day) from equation A-3.41]
  + [sludge due to excess TSS removal (lbs/day) from equation A-3.44]
  + [sludge due to polymer addition (lbs/day) from Appendix A-7]} (A-3.45)

5.8.3 Incremental Sludge Produced due to N+PDN System

- Incremental sludge generation due to the N+PDN system (lbs/day)
  = {[sludge produced by the N+PDN system (lbs/day) from equation A-3.45]
  - [sludge produced by the existing nitrification system (lbs/day) from equation A-3.42]} (A-3.46)

Note: A negative number indicates a reduction in sludge generation due to the N+PDN treatment.

5.8.4 Percent Increase in Sludge due to N+PDN System

- Percent increase in sludge due to N+PDN system
  = {[incremental biomass generation due to N+PDN system (lbs/day) from equation A-3.46] [100]} / {[biomass produced by existing nitrification system (lbs/day) from equation A-3.42]} (A-3.47)

6.0 CAPITAL AND OPERATION AND MAINTENANCE (O&M) COSTS

This section describes the method used to calculate the incremental capital and O&M costs for a facility to convert a nitrification system to a N+PDN system. The facilities are costed for the following:

1. Biosystem consisting of:
   a. anoxic reactor 1 for denitrification,
   b. mixers for anoxic reactor 1,
   c. pumps for recycling the nitrate/nitrite from aerobic reactor 2 to anoxic reactor 1;

2. Polymer feed system;

3. Methanol feed system; and

4. Sludge dewatering system.

The cost constants and cost equations used in the model are provided in Tables A-12.2 through A-12.5 in Appendix A-12.

6.1 Biosystem Costs

6.1.1 Capital Cost of BioSystem

Capital Cost of Anoxic Reactor 1

The capital cost of anoxic reactor 1 is calculated using the following equations (Table A-12.3):

- For $V_{anoxic\_purchase}$ (gal) $\leq$ 100,000

  $$\text{Capital Cost (\$)} = \{[\$2.81/\text{gal}]\ [V_{anoxic\_purchase}\ (\text{gal})]\}$$

- For 100,000 < $V_{anoxic\_purchase}$ (gal) < 443,000

  $$\text{Capital Cost (\$)} = \{[\$1.2126/\text{gal}]\ [V_{anoxic\_purchase}\ (\text{gal})]\} + \{\$159{,}483\}$$

- For $V_{anoxic\_purchase}$ (gal) $\geq$ 443,000

  $$\text{Capital Cost (\$)} = \{[\$0.3406/\text{gal}]\ [V_{anoxic\_purchase}\ (\text{gal})]\} + \{\$545{,}494\} \qquad \text{(A-3.48)}$$

where:

$V_{anoxic\_purchase}$ is obtained from equation A-3.25

Capital Cost of Mixers

The capital cost of mixers is calculated using the following equation (Table A-12.3):

- $$\text{Capital Cost (\$)} = \{[\$2{,}750.2/\text{HP}]\ [\text{Purchase mixer power (HP)}]\} + \{\$6{,}657\} \qquad \text{(A-3.49)}$$

where:

purchase mixer power (HP) is obtained from equation A-3.27

Capital Cost of Pumps

The capital cost of recycle pumps is calculated using the following equation (Table A-12.3):

- Capital Cost ($) = {[$36,915/mgd] [max flow (mgd)]} + {$18,042} (A-3.50)

where:

max flow (mgd) is obtained from equation A-3.29

Total Capital Cost of Biosystem

- Total Capital Cost of biosystem ($)
  = {[Capital Cost ($) of anoxic reactor 1 from equation A-3.48] + [Capital Cost ($) of mixers from equation A-3.49] + [Capital Cost ($) of pumps from equation A-3.50]} (A-3.51)

6.1.2 O&M Cost of Biosystem

The cost constants and the cost equations used for the calculations are provided in Tables A-12.2 and A-12.4 in Appendix A-12.

Maintenance Cost

- Maintenance Cost ($/yr) = 3% of Capital Cost (Tables A-12.2 and A-12.4) (A-3.52)

where:

capital cost ($) is obtained from equation A-3.51

Labor Cost

- Additional labor required = 3 hrs/day (Table A-12.1)

  Labor rate = $25/hr (Table A-12.2)

  Labor Cost ($/yr) = {[$25/hr] [3 hrs/day] [365 days/yr]}
  = $27,375/yr (A-3.53)

Sampling and Analysis Cost for Process Control

For the N+PDN System, the sampling and analysis cost is estimated at $5,200 per year (Table A-12.4).

Mixer Energy Cost

The energy costs are based on $0.06/KWh with a 75% motor efficiency (Table A-12.1 and Table A-12.2).

- Mixer Energy Cost ($/yr)
  = {[mixer power (HP)] [0.746 KW/HP] [24 hrs/day] [365 days/yr] [$0.06/KWh]}
  / {0.75} (A-3.54)

where:
mixer power (HP) is obtained from equation A-3.26
0.746 is a conversion factor

Pump Energy Cost

The energy costs are based on $0.06/KWh with a 75% motor efficiency (Table A-12.1 and Table A-12.2).

- Pump Energy Cost ($/yr)
  = {[pump power (HP)] [0.746 KW/HP] [24 hrs/day] [365 days/yr] [$0.06/KWh]}
  / {0.75} (A-3.55)

where:
pump power (HP) is obtained from equation A-3.28
0.746 is a conversion factor

Incremental Energy Cost for Oxygen Transfer

The incremental energy required for oxygen transfer per year (KWh/yr) is obtained from equation A-3.39. A negative number in energy requirement (KWh/yr) from equation A-3.39 indicates savings. As a conservative estimate only 60% of the savings is used in the calculations. The energy costs are based on a rate of $0.06/KWh with a 75% motor efficiency (Tables A-12.1 and A-12.2).

Therefore:

- If incremental energy required (KWh/yr) < 0

Then:

- Incremental Energy Cost for oxygen transfer ($/yr)
  = {[0.6] [incremental energy required (KWh/yr)] [$0.06/KWh]} / {0.75}

Note: a negative number indicates savings

- If incremental energy required (KWh/yr) > 0

Then:

- Incremental Energy Cost for oxygen transfer ($/yr)
  = {[incremental energy required (KWh/yr)] [$0.06/KWh]} / {0.75} (A-3.56)

Total Energy Cost

- Total Energy Cost ($/yr)
  = {[Mixer Energy Cost ($/yr) from equation A-3.54] + [Pump Energy Cost ($/yr) from equation A-3.55] + [Energy Cost for oxygen transfer ($/yr) from equation A-3.56]} (A-3.57)

Excess Sludge Disposal Cost

The cost for sludge disposal is $75/ton (Table A-12.2). The incremental sludge generated per day (lbs/day) is obtained from equation A-3.46. A negative number in sludge generation indicates savings. As a conservative estimate only 60% of the savings is used in the calculations.

Therefore:

- If incremental sludge generated (lbs/day) < 0

Then:

- Incremental Sludge Disposal Cost ($/yr)
  = {[0.60] [incremental sludge generated (lbs/day)] [365 days/yr][$75/ton]} / {2,000 lbs/ton}

Note: a negative number indicates savings

- If incremental sludge generated (lbs/day) > 0

Then:

- Incremental Sludge Disposal Cost ($/yr)
  = {[incremental sludge generated (lbs/day)] [365 days/yr] [$75/ton]} / {2,000 lbs/ton} (A-3.58)

where:
2,000 is a conversion factor

Alkalinity Savings

From the MPP detailed survey, it was observed that caustic is frequently used as a source of alkalinity. Typically, 1 lb. of caustic is equivalent to 1.25 lbs. of alkalinity with a cost of $0.15/lb (Table A-12.2). Approximately 50% of the alkalinity destroyed during nitrification is recovered during denitrification which provides an opportunity of savings. Alkalinity Savings are discussed in Section 5.6 and the amount of net alkalinity savings in lbs/day is obtained from equation A-

3.35. A positive number in net alkalinity savings from equation A-3.35 indicates savings. As a conservative estimate, only 60% of the savings is used in the calculations.

Therefore:

- If the net alkalinity savings (lbs/day) > 0

Then:

- Alkalinity Savings ($/yr)
  = {[0.6] [net alkalinity savings (lbs/day)] [365 days/yr] [$0.15/lb]} / {1.25 lbs/lb}

- If the net alkalinity savings (lbs/day) < 0

Then:

- Alkalinity Savings ($/yr)
  = {[net alkalinity savings (lbs/day)] [365 days/yr] [$0.15/lb]} / {1.25 lbs/lb} (A-3.59)

Total O&M Cost of Biosystem

- Total O&M Cost ($/yr)
  = {[Maintenance Cost ($/yr) from equation A-3.52] + [Labor Cost ($/yr) from equation A-3.53] + [Sampling and Analysis Cost of $5,200/yr] + [Energy Cost ($/yr) from equation A-3.57] + [Sludge Disposal Cost ($/yr) from equation A-3.58] - [Alkalinity Savings ($/yr) from equation A-3.59]} (A-3.60)

6.2 Methanol Feed System

As discussed in Section 5.5.1, methanol is added during the weekends to supplement BOD in the influent wastewater. The capital and O&M costs of a methanol feed system are obtained from Appendix A-6.

6.3 Polymer Feed System

Polymer may be added to wastewater at or before the secondary clarifier to improve the settleability of sludge and to lower the effluent TSS concentration. The capital and O&M costs of a polymer feed system are obtained from Appendix A-7.

6.4 Sludge Dewatering System

Excess sludge, if generated as a result of the N+PDN system, needs to be dewatered before disposal. The percent increase in sludge generation from the N+PDN system is calculated in equation A-3.47. Based on engineering judgement it is assumed that the dewatering device present in the facility is capable of handling excess sludge of up to 15% of the current sludge generation rate. If the incremental sludge generated is greater than 15% of the current sludge generation, then the facility is costed for new thickeners and filter presses. The capital and O&M costs of a sludge dewatering device (thickener + filter press) are obtained from the sludge dewatering module in Appendix A-10. However, facilities that waste sludge to the anaerobic lagoon or to a waste sludge pond do not require sludge a dewatering device. They incur costs only for sludge hauling, which is estimated in equation A-3.58.

6.5 Other Annual Costs

6.5.1 Performance Cost

Some facilities have the same treatment technology in place but are not achieving option 2.5 LTA concentrations. It is assumed that those facilities can improve the process performance and achieve the Option LTA concentrations with an estimated $25,000 per year (Table 12.4).

6.5.2 Compliance Cost

Practically all of the direct discharge facilities who submitted detailed surveys are already required by their NPDES permits to monitor for many of the pollutants being considered for regulation under the MPP effluent guidelines, especially "conventional" pollutants (e.g., BOD, TSS, pH). Some are also currently required to monitor for one or more of the following pollutants: ammonia-N, total nitrogen, nitrates, and phosphorus. Based on these existing monitoring requirements, compliance cost of $15,000 per year (Table A-12.4) is estimated to accommodate the increase in frequency and number of pollutants that may need to be monitored for Option 2.5.

6.5.3 Methane Revenue Loss

Some facilities recover biogas from anaerobic lagoon and do not have adequate BOD for denitrification. For those facilities a portion of the lagoon influent wastewater may be bypassed directly to the anoxic reactor to provide supplemental carbon (see section 7.1). Bypassing the lagoon results in BOD loss for methane generation in the anaerobic lagoon. The model is designed to bypass the lagoon on weekdays (5 days a week) and feed methanol on the weekends (2 days a week). Methanol addition on weekends is necessary for MPP facilities that operate 5 days per week so that practically no wastewater is available for bypass during the weekends. The loss in revenue due to reduced methane generation is estimated at $0.035 per pound of BOD bypassed (Appendix A-19).

- BOD bypassed (lbs/yr)
  $= \{[\text{Q gal/day}]\ [\text{BOD}_{inf} - \text{BOD}_{inf\_current}\ \text{mg/L}]\ [8.34 \times 10^{-6}\ \text{lbs/gal-mg/L}]\ [5\ \text{days}/7\ \text{days}]\}$

- Methane Revenue Loss ($/yr)
  $= \{[\text{BOD bypassed (lbs/yr)}]\ [\$0.035/\text{lb})]\}$
  $= \{[\text{Q gal/day}]\ [\text{BOD}_{inf} - \text{BOD}_{inf\_current}\ \text{mg/L}]\ [8.34 \times 10^{-6}\ \text{lbs/gal-mg/L}]\ [5\ \text{days}/7\ \text{days}]\ [\$0.035/\text{lb}]\}$ (A-3.61)

where:

8.34×10^{-6} is a conversion factor

All parameters on the right-hand side of equation A-3.61 are either inputs to the model or have already been calculated.

6.6 Total Incremental Costs

6.6.1 Total Incremental Capital Cost

- The total incremental Capital Cost ($)
  = {[Capital Cost ($) of biosystem from equation A-3.51] + [Capital Cost ($) of methanol feed system from Section 6.2] + [Capital Cost ($) of polymer feed system from Section 6.3] + [Capital Cost ($) of sludge dewatering device from Section 6.4]}
  (A-3.62)

6.6.2 Total Incremental O&M Cost

- The total incremental O&M Cost ($/yr)
  = {[O&M Cost of biosystem ($/yr) from equation A-3.60] + [O&M Cost of methanol feed system ($/yr) from Section 6.2)] + [O&M Cost of polymer feed system ($/yr) from Section 6.3] + [O&M Cost of sludge dewatering ($/yr) from Section 6.4] + [Performance Cost ($/yr) from Section 6.5.1] + [Compliance Cost ($/yr) from Section 6.5.2] + [Methane Revenue Loss ($/yr) from equation A-3.61]}
  (A-3.63)

7.0 ONE-TIME COST

7.1 Anaerobic Lagoon Bypass

For optimal denitrification, the influent BOD to TKN ratio entering anoxic reactor 1 should be at least 3. If adequate BOD is not present, an additional carbon source is required. Meat and poultry product wastewater normally has an adequate BOD:TKN ratio. However, some facilities with anaerobic lagoons may have a BOD:TKN ratio of less than 3. For those facilities, a portion of the influent wastewater to the lagoon may be bypassed directly to anoxic reactor 1 to provide a supplemental carbon source during the weekdays. The cost for the bypass is estimated at $20,000 (Table A-12.5).

7.2 Miscellaneous Costs

The costs for piping are included in the cost equations for equipment (see Appendix A-13). However, for a conservative estimate, an additional one-time cost of $10,000 is assumed for miscellaneous piping and other expenses.