



Help Instruction File:

Ponds Module Overview

Provided by the Office of Surface Mining Reclamation and Enforcement (OSMRE), the Pennsylvania Department of Protection (PADEP), the U.S. Geological Survey's (USGS) and the West Virginia Department of Environmental Protection (WVDEP).

Ponds Module Overview

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1.0 Objective

The Ponds module is an ancillary treatment component within the AMDTreat program. The ancillary treatment components are not necessarily considered an active treatment or passive treatment component; but rather, are used for a specific purpose as part of a treatment facility. Typically, ponds are used to enhance oxidation of dissolved metals, sedimentation (settling), and/or to allow the oxidized metals (i.e. sludge) to accumulate in the pond by providing storage volume.

The objective of this overview is to: (1) Provide a basic understanding of the theory and application of Ponds and (2) Provide an overview of the module that guides users to develop a cost estimate to construct, operate, and maintain Ponds as a component of mine drainage treatment. Therefore, this overview will be presented in two sections, **Treatment Component Overview** and **Ponds Module Overview**.

2.0 Treatment Component Overview

The following section is organized into two subsections, (1) Physical and Hydraulic Description and (2) Application and Treatment Chemistry. The first subsection provides a physical description and hydraulic profile for a Pond to provide context for users of AMDTreat. The second subsection describes the common application of the Pond component to help familiarize users with terms and concepts represented throughout the AMDTreat module.

2.1 Physical and Hydraulic Description

The geometric shape of a Pond is an inverted trapezoidal prism consisting of up to five distinct “pond layers” (Figures 1, 2, & 3). The layers that make up a Pond consist of the following: freeboard, oxidation, settling/retention, sludge capacity and liner. Ponds can also include certain hydraulic structures (i.e. baffle(s), flow distribution structures, etc.) that help control water hydraulics into, through, and out of the pond. The following discussion will provide a hydraulic description and purpose of the Pond layers and from inlet to outlet.

The inlet or intake structures for a pond can vary, but can simply be an inlet pipe or a pipe with a ‘tee’ fitting into a perforated header pipe, which is positioned parallel to the width of the pond to spread out the incoming flow to minimize potential short-circuiting (Figure 4). If numerous ponds are being considered for larger mine drainage flows, flow distribution structures can be installed to properly distribute the flow to multiple ponds operated in parallel. In addition, the flow into a pond can be directed through an aeration feature (Figure 5 and 6) in order to promote the oxidation of the dissolved metals upon entering the pond. Ponds can be designed to contain sufficient volume in order to have an oxidation layer, followed by a settling/retention layer allowing precipitated metals to settle and accumulate in a sludge layer. Floating baffle(s) can be included in order to prevent short-circuiting, maximize retention time, and/or slow the velocity of flow in the pond to maximize the settling of solids (Figure 7 and 8). In order to prevent leakage through the bottom and/or the embankments of a pond, a liner can be installed (Figure 9). Typically, ponds will have a water level control structure (e.g. Agri-Drain) that are installed as part of the outlet to help ensure proper water-level height and retention time (Figure 10 and 11). If properly designed, the water will discharge into an outlet structure after metals and/or sediment has been retained in the pond. Upon discharging out of the pond, a properly sized outlet protection structure using rip-rap material should be installed to prevent any erosion and stability issues.

One of the main purposes of constructing a pond component for mine drainage treatment is to allow for metal oxides (i.e. solids or sludge) to settle out of the water column and accumulate in the bottom of the

pond (Figure 12). Sludge handling and disposal can be significant annual costs and must be considered to properly budget for maintaining a mine drainage treatment facility. An accurate estimate of sludge generation is an aspect of mine drainage treatment that can often be overlooked. An accurate sludge generation volume can be estimated if accurate flow, metal concentrations, percent solids (wt%) of sludge, density of solids, and additional solids (e.g., calcite) data is known and accounted for in the pond design. The chemical treatment method (i.e. lime product vs caustic soda) prior to the pond component can affect the volume of sludge and percent solids of the anticipated sludge.

Several examples of sludge handling (i.e. removing sludge from the pond) may consist of using vacuum trucks, pumping sludge from pond to drying beds (Figure 13), or mechanical excavation of sludge after pond has been dewatered (Figure 14). Drying beds may not be an option if there is insufficient space. Mechanical excavation may also be required after the sludge has dried out and needs loaded onto triaxle trucks and hauled to an off-site disposal facility. Vacuum trucks may also be used to haul the sludge off-site for disposal after removing it from the bottom of the pond (Figure 15). Other disposal methods may consist of utilizing a geotube(s) or pumping the sludge down a borehole into an adjacent abandoned underground mine. The user needs to consider the amount of sludge, frequency of sludge handling and disposal, and pond(s) design in order to properly estimate sludge related costs.

2.2 Application and Treatment Chemistry

One application of a Pond has been to provide sufficient retention of mine drainage in order for solids to settle out prior to the mine drainage discharging without causing sedimentation issues downstream of a treatment facility. Simple design modifications of ponds can be made to maximize the pond's retention time and efficiency of settling and removing solids. For example, floating baffles are utilized to slow water velocity and promote settling, and water-level control structures are used to help control retention time in ponds. Another benefit of ponds has been to provide additional time for oxidation and hydrolysis of the dissolved metals (e.g. ferrous iron). Prior to mine drainage entering a pond, it most likely has gone through chemical addition or limestone treatment to increase the pH and/or aeration to increase the oxidation rate of dissolved metals. There may not have been sufficient time in the prior treatment component to allow the necessary reactions to occur such as oxidation and precipitation of dissolved metals; therefore, ponds are needed.

Historically, operators did not account for and/or would underestimate the amount of sludge that would accumulate in their treatment pond(s). Therefore, based on the pond design in the AMDTreat program, the user can adjust parameters for the pond layers to consider the appropriate volume for each layer. The density and percent solids of the sludge, along with loading (flow & metal concentrations) will affect the volume and frequency at which sludge will need to be removed from the pond. The following equations, using Fe^{3+} as an example, shows how the metals' concentration and flow are used to estimate sludge produced and the required volume in a pond to retain the solids/sludge:

First, the concentration of the iron hydroxide (solid) is determined from the dissolved Ferric Iron (Fe^{3+}) concentration.

$$Fe(OH)_3 = Fe^{3+} \left(\frac{mg}{L} \right) * 1.9 \quad (1)$$

Where:

Fe^{3+} = Concentration of dissolved ferric iron in the water entering the pond.
 1.9 = Atomic weight of $Fe(OH)_3$ (106.84 g/mol) divided by Fe atomic weight (55.84 g/mol).
 $Fe(OH)_3$ = Concentration of iron hydroxide (solid) anticipated from the dissolved Fe^{3+} concentration.

To determine the total sludge produced or generated as solids or pounds (lbs) per minute, the following equation is used:

$$Sludge\ Generated = (Fe(OH)_3 + Fe(OH)_2 + Al(OH)_3 + Mn(OH)_2 + CaCO_3 + Misc) * Typical\ Flow * 0.0022 * 0.003785 \quad (2)$$

Where:

Sludge Generated = The weight (lbs) of solids generated on a per minute basis from the metal oxides, calcite, and any miscellaneous solids in the mine drainage.

The 'sludge generated' can be converted to pounds of sludge per year, by multiplying by 60 min/hr, by 24 hrs/day, and then by 365 days/year. However, in order to determine the volume of sludge per year, a composite sludge density must be estimated. The composite sludge density takes into account the metal's concentration (i.e. $Fe(OH)_3$) and their relative percentage (fraction) in the mine drainage water, or in this case a liter of mine drainage. It also takes into account the different densities of all the metal oxides. The following equations illustrate how the 'composite sludge density' formula and subsequent formulas are used to calculate the volume of sludge produced.

The fraction or percentage of the iron hydroxide relative to the other metal oxides is determined using equation (2):

$$Fe(OH)_3\text{Fraction} = \frac{Fe(OH)_3}{Al(OH)_3 + Fe(OH)_3 + Fe(OH)_2 + Mn(OH)_2 + CaCO_3 + Misc} \quad (3)$$

Where:

$Fe(OH)_3$ Fraction = The fraction (unitless) of $Fe(OH)_3$ relative to the other metal hydroxides in the mine drainage.

Misc = Represents miscellaneous (mg/L) solids in the mine drainage, not already included.

Then the fraction of $Fe(OH)_3$ is converted to density or pounds per one gallon of mine drainage (lbs/gal).

$$Wtd\ Fe(OH)_3 = 4.25 \left(\frac{g}{cm^3}\right) * Fe(OH)_3\text{Fraction} * \frac{3785.41\ cm^3}{1\ gallon} \div \frac{453.59\ grams}{1\ lb} \quad (4)$$

Where:

Wtd Fe(OH)₃ = Represents the lbs of Fe(OH)₃ in one gallon of mine drainage.
4.25 = Density (g/cm³) of Fe(OH)₃.

Once the relative (fraction) pounds per gallon for all the metals is determined, they are summed up then divided by the density of water to get a specific gravity for the solids, equation 5.

$$SG\ Solids = \frac{Total\ Wtd\ (\frac{lbs}{gal})}{8.34\ (\frac{lbs}{gal})} \quad (5)$$

Where:

SG Solids = Represents the specific gravity of the solids in the sludge.
Total Wtd = Represents the density (lbs/gal) of all the metal oxides in the sludge.

Then the sludge specific gravity along with the user specified ‘Thickened Percent Solids’ is utilized in the following equation (6) to get a density of the sludge. This would represent the sludge density (lbs/gal) of sludge that is accumulating in the bottom of the pond or identified as the ‘Sludge Capacity Layer’ in AMDTreat.

$$Thickened\ Sludge\ Density = \left(\frac{SG\ Solids}{SG\ Solids - \left(\frac{Thickened\ Percent\ Solids}{100} * (SG\ Solids - 1) \right)} * 8.34 \right) \quad (6)$$

Where:

Thickened Sludge Density = Composite density of thickened sludge.
SG Solids = Specific gravity of the solids.
Thickened Percent Solids = Percent solids (% wt) of the sludge. This is a user-specified value.

Once the ‘Thickened Sludge Density’ and ‘Sludge Generated’ per year are calculated they can be used to obtain the sludge volume (gallons) per year using the following equation (7). Again, this would represent the volume of sludge accumulating in the ‘Sludge Capacity Layer’ of the Pond:

$$Sludge\ Volume = \frac{Sludge\ Generated\ (\frac{lbs}{year})}{(Thickened\ Sludge\ Density\ (\frac{gal}{year}) * 7.48 * 27)} \quad (7)$$

Where:

Sludge Volume = Volume of thickened sludge in cubic yards per year.
Sludge Generated = lbs per year of sludge (solids) generated per year.
Thickened Sludge Density = Composite density of thickened sludge.

Subsequently, the ‘Dewatered Sludge Volume’ can be estimated by substituting the user specified ‘Dewatered Percent Solids’ in equation (6) for the Thickened Percent Solids to get a density and using that dewatered density value in equation (7). The dewatered sludge volume would represent sludge after it’s been dewatered, for example in drying beds/basins or Geotubes.

3.0 Ponds Module Overview

3.1 Layout and Workflow

The general layout of the module includes the left-hand side for the module inputs and calculated outputs are on the right-hand side. The Ponds module inputs on the left-hand side are arranged into eight sections: (1) Water Quality and Flow Input, (2) Pond Design, (3) System Properties, (4) Pond Layers, (5) Hydraulic Structures, (6) Other Capital Items, (7) Annual Cost Input, and (8) Other Annual Items. The workflow of the module is for users to start at the top left-hand side and enter the design flow, typical flow, ferrous iron, ferric iron, aluminum, and manganese concentrations. The user then selects one of the Pond Design methods to determine the dimensions of the Pond. There are two options for Pond Design, (1) Oxidation/Settling/Sludge and (2) User-Specified Dimensions. Both design methods requires the user to, at a minimum, to include a ‘Settling/Retention’ layer and ‘Freeboard’ layer for the pond. The other pond layers are optional; however, by default the oxidation and sludge capacity layers are included as part of the Pond design. If the user does not choose to include these additional layers (Oxidation & Sludge Capacity), the user can deselect the checkbox under that section. For the Liner layer, the user can specify if a liner is desired and the type of liner material preferred. The user will specify the inside slope, settling/retention layer bottom length to width ratio, and excavation cost under the System Properties section. The user will then select or choose to include items listed under the Hydraulic Structures, Other Capital Items, Annual Cost Input, and Other Annual Items sections. If the user decides to include a ‘Sludge Capacity’ layer, additional important parameters are to be chosen in order to properly estimate annual costs associated with sludge handling and disposal.

Module output is provided on the right-hand side of the module. Module outputs on the right-hand side are arranged into four sections: (1) Sizing Summary, (2) Capital Cost, (3) Annual Cost, and (4) Net Present Value. The sizing summary provides dimensional details for the system. The estimated cost to construct and operate the Pond is provided under the *Capital Cost* and *Annual Cost* headings. Lastly, users can opt to conduct a Net Present Value (NPV) analysis to obtain the total cost to operate and maintain the Pond treatment system for a defined time period.

A general overview of the module input and output sections are presented below, however, users are directed to the numerous tool tips located in the module that provide additional detailed information, such as definitions of terminology. In most cases, the tool tips are accessed by clicking on the information icon () in each of the subheadings in the module.

3.2 Module Inputs

3.2.1 Water Quality and Flow Input: The Water Quality and Flow Input section is where users specify the Design flow, Typical flow and water quality used to size the passive treatment system component. The definitions for the required input can be found in the tool tip for this section. Click on the information icon () on the right side of the Water Quality and Flow subheading. Please note the ‘raw water’ is defined as the quality of water entering the Pond component of the treatment system, which may not necessarily be the raw water entering the treatment system if the design consists of having prior treatment components.

Design Flow: Design flow should approximate the largest flow the system will be able to handle. Users are responsible for statistically characterizing their flow data to determine Design Flow. Design Flow is utilized to calculate the pond size; therefore, adjusting the Design Flow will affect the dimensions of the pond design in the Sizing Summary.

Typical Flow: Typical flow should approximate the ‘average’ or median flow for the system component. Users are responsible for statistically characterizing their flow data to determine Typical Flow. Typical Flow, along with metals’ concentrations, is utilized to calculate the *Sludge Generation* if the user decides to include a *Sludge Capacity* layer in the pond design.

Ferrous Iron: Represents the concentration of dissolved ferrous iron (Fe^{2+}) in the water. The user needs to make sure that the unfiltered total Fe is not used as the input parameter. For instance, the water sample would have been field filtered if applicable, properly preserved, and analyzed by the laboratory. The Fe^{2+} constituent is used to calculate the volume of sludge that is generated if the user decides to include the *Sludge Capacity* layer in the pond design.

Ferric Iron: Represents the concentration of dissolved ferric iron (Fe^{3+}) in the water. The user needs to make sure that the unfiltered total Fe is not used as the input parameter. The Fe^{3+} constituent is used to calculate the volume of sludge that is generated if the user decides to include the *Sludge Capacity* layer in the pond design.

Aluminum: Represents the concentration of dissolved aluminum in the raw water. The aluminum constituent is used to calculate the volume of sludge that is generated if the user decides to include the *Sludge Capacity* layer in the pond design.

Manganese: Represents the concentration of dissolved manganese in the raw water. The manganese constituent is used to calculate the volume of sludge that is generated if the user decides to include the *Sludge Capacity* layer in the pond design.

3.2.2 Pond Design:

AMDTreat offers two approaches to sizing or designing a Pond. The first approach, *Oxidation/Settling/Sludge*, is the most common as it relates the sizing of the Pond component based on flow and desired retention time. The second approach, *User-Specified Dimensions*, is used when the land area available for treatment is restricted or when someone wants to reverse engineer or develop a cost estimate for an Pond component. For this approach, users enter the desired length and width for the top of

the freeboard layer. Please note, the Settling/Retention and Freeboard layers are required input parameters and not optional to exclude as part of the Pond design. The sizing calculations are based on these layers.

Use Water Quantity (Flow) Information to Size Pond

3.2.2.1 Oxidation/Settling/Sludge – For this sizing method, the user enters the desired retention time and depth of the Settling/Retention layer to achieve the desired size of the Pond. AMDTreat uses the retention time, depth, along with other user-specified parameters (Pond Inside Slope, Settling/Retention Bottom Length to Width Ratio) to calculate the dimensions of the Pond.

AMDTreat models nearly all passive treatment system components, including ponds, as inverted trapezoidal prisms (Figure 1). AMDTreat calculates the overall dimensions of a treatment component by first breaking it up into individual layers, such as the freeboard layer, oxidation layer, settling/retention layer, and sludge capacity layer for Ponds. Each individual layer is modeled as an inverted trapezoidal prism to determine the dimensions of the layer, which is used to calculate the excavation/layer volume.

For example, the volume of a trapezoidal prism is defined by:

$$V = \left(\frac{L_T W_T + L_B W_B}{2} \right) D \quad (8)$$

Where:

V = Volume of trapezoidal prism

L_TW_T = Length & Width of top of prism

L_BW_B = Length & Width of bottom of prism

D = Depth

If the Oxidation/Settling/Sludge sizing method is selected in the Ponds module, the volume of the Settling/Retention Layer is known by multiplying the user-specified retention time, converted from hours to minutes first, by the design flow rate. Please note, the retention time entered by the user is for the Settling/Retention layer. If additional layers are included in the design, the total retention time is also calculated as an output in the Sizing Summary. Moreover, users are required to specify the depth of the settling/retention layer, along with the pond's inside slope and length-to-width ratio for the bottom of the settling/retention layer. The unknown dimensions to be calculated are the top and bottom lengths and widths of the trapezoidal prism (settling/retention layer). Thus, the equation is rearranged as a quadratic equation to solve for the bottom width of the settling/retention layer:

$$L_{BSRL} = \frac{-\left(\frac{2DR}{S} + \frac{2D}{S}\right) \pm \sqrt{\left(\frac{2DR}{S} + \frac{2D}{S}\right)^2 - 4(2R)\left(\frac{4D^2}{S^2} - \frac{2V}{D}\right)}}{2(2R)} \quad (9)$$

Where:

V = Volume of Settling/Retention Layer

L_{BSRL} = Bottom Length of Settling/Retention Layer

D = Depth of Settling/Retention Layer

S = Inside Slope of Pond (rise/run)

R = Length to Width Ratio of Bottom of Settling/Retention Layer

Once the Bottom Length is known, the Bottom Width of the Settling/Retention Layer (W_{BSRL}) is calculated by dividing the Bottom Length by the user-specified value for the Length to Width Ratio of Bottom of the Settling/Retention Layer:

$$W_{BSRL} = \frac{L_{BSRL}}{R} \quad (10)$$

The two remaining unknown dimensions of the Settling/Retention Layer are the Top Length and Top Width.

The Top Length of the Settling/Retention Layer is calculated by:

$$L_{TSRL} = L_{BSRL} + 2 * S * (D_{SRL}) \quad (11)$$

Where:

L_{TSRL} = Top Length of Settling/Retention Layer

L_{BSRL} = Bottom Length of Settling/Retention Layer

D_{SRL} = Depth of Settling/Retention Layer

S = Inside Slope of Pond (rise/run)

The top width of the settling/retention layer is determined by using Equation 11. Now that all the dimensions of the settling/retention layer are known, the dimensions of the Oxidation, Freeboard and Sludge Capacity layers can be determined if the user has included them in the design:

Progressing upward from the Settling/Retention layer, the Bottom Length of the Oxidation layer (L_{BOL}) is equal to the Top Length of the Settling/Retention Layer (L_{TSRL}).

$$L_{BOL} = L_{TSRL} \quad (12)$$

The Top Length of the Oxidation Layer is calculated by:

$$L_{TOL} = L_{BOL} + 2 * S * (D_{OL}) \quad (13)$$

Where:

L_{TOL} = Top Length of Oxidation Layer

D_{OL} = Depth of Oxidation Layer

L_{BOL} = Bottom Length of the Oxidation Layer

S = Inside Slope of Pond (rise/run)

The Top Length of the Oxidation Layer (L_{TOL}) is equal to the Bottom Length of the Freeboard Layer (L_{BFL}).

$$L_{TOL} = L_{BFL} \quad (14)$$

The Top Length of the Freeboard layer is calculated by:

$$L_{TFL} = L_{BFL} + 2 * S * (D_{FL}) \quad (15)$$

Where:

L_{BFL} = Bottom Length of Freeboard Layer

L_{TFL} = Top Length of Freeboard Layer

S = Inside Slope of Pond (rise/run)

D_{FL} = Depth of Freeboard Layer

Now moving below the Settling/Retention layer, the program calculates the dimensions of the Sludge Capacity layer. The Bottom Length and Bottom Width of the Settling/Retention Layer is equal to the Top Length and Top Width of the Sludge Capacity layer, respectively. The Bottom Length of the Sludge Capacity Layer (L_{BSCL}) is calculated by the following:

$$L_{BSCL} = L_{TSCL} - 2 * S * (D_{SCL}) \quad (16)$$

Where:

L_{BSCL} = Bottom Length of Sludge Capacity Layer

L_{TSCL} = Top Length of Sludge Capacity Layer

S = Inside Slope of Pond (rise/run)

D_{SCL} = Depth of Sludge Capacity Layer

The Bottom Width of the Sludge Capacity Layer (W_{BSCL}) is calculated the same way as the Bottom Length of the Sludge Capacity Layer as follows:

$$W_{BSCL} = W_{TSCL} - 2 * S * (D_{SCL}) \quad (17)$$

Where:

W_{BSCL} = Bottom Width of Sludge Capacity Layer

W_{TSCL} = Top Width of Sludge Capacity Layer

S = Inside Slope of Pond (rise/run)

D_{SCL} = Depth of Sludge Capacity Layer

Now that all of dimensions of the freeboard, oxidation, settling/retention, and sludge capacity layers are known, the individual layer volumes are calculated using Equation (8).

In addition to assuming all passive treatment system components are constructed as an inverted trapezoidal prism, an additional assumption is that the excavation cut volume is equal to the summation of all the individual layer volumes, except for the freeboard layer that is considered fill volume (cut material is used as fill to form the embankment for the freeboard layer). In addition, if a clay liner is selected by the user, the volume of clay liner is also included in the excavation cut volume. Thus:

$$\begin{aligned} & \text{Pond Exavation Cut Volume} \\ & = \text{Oxidation Layer Volume} + \text{SettlingRetention Volume} \\ & + \text{Sludge Capcity Volume} + \text{Liner Volume} \quad (18) \end{aligned}$$

3.2.2.2 User Specified Dimensions - Mine drainage discharges often emerge along the base of hillsides and the available land area, between the point of emergence and the receiving stream, for constructing a treatment system can be limited. The use of other sizing/design methods may produce a Pond component that is larger than the available land area. Some folks may accept a smaller Pond, but this will most likely require more maintenance due to high metal loading or sedimentation per unit area and frequent costly sludge removal events. In these cases, users can utilize the user-specified dimensions sizing method to specify the area available for treatment. Users can specify the Top Length and Width of the Freeboard and AMDTreat will use these values along with user-specified Inside Pond Slope and depths of the Freeboard, Oxidation, Settling/Retention, and Sludge Capacity layers to calculate the dimensions and volumes of the individual layers of the Pond.

The Bottom Length of the Freeboard Layer is calculated by:

$$L_{BFL} = L_{TFL} - 2 * S * (D_{FL}) \quad (19)$$

Where:

L_{BFL} = Bottom Length of Freeboard Layer

L_{TFL} = User-Specified Top Length of Freeboard Layer
 D_{FL} = Depth of Freeboard Layer
 S = Inside Slope of Pond (Rise/Run)

The volume of the Freeboard Layer is determined by:

$$V_{FL} = \left(\frac{W_{TFL}L_{TFL} + W_{BFL}L_{BFL}}{2} \right) D_{FL} \quad (20)$$

Where:

V_{FL} = Volume of trapezoidal prism-shaped Freeboard Layer
 W_{TFL} = Top Width Freeboard Layer
 L_{TFL} = Top Length Freeboard Layer
 W_{BFL} = Bottom Width Freeboard Layer
 L_{BFL} = Bottom Length Freeboard Layer
 D_{FL} = Depth of Freeboard Layer

If the user includes the Oxidation Layer, the Top Length of the Oxidation layer (L_{TOL}) is equal to the bottom length of the Freeboard layer (L_{BFL}).

$$L_{TOL} = L_{BFL} \quad (21)$$

Additionally, the Top Width of the Oxidation Layer (W_{TOL}) is equal to the bottom width of the Freeboard Layer (W_{BFL}).

$$W_{TOL} = W_{BFL} \quad (22)$$

Now that the top width and length of the Oxidation layer are known, the User-Specified values for inside slope of pond and depth of oxidation layer are used in Equations 23 and 24 to calculate the bottom length and width of the oxidation layer.

$$L_{BOL} = L_{TOL} - 2 * S * (D_{OL}) \quad (23)$$

$$W_{BOL} = W_{TOL} - 2 * S * (D_{OL}) \quad (24)$$

Where:

L_{BOL} = Bottom Length of Oxidation Layer

L_{TOL} = Top Length of Oxidation Layer

D_{OL} = Depth of Oxidation Layer

S = Inside Slope of Pond (Rise/Run)

W_{BOL} = Bottom Width of Oxidation Layer

W_{TOL} = Top Width of Oxidation Layer

Equation (18) is used to calculate the volume of the oxidation layer.

$$V_{OL} = \left(\frac{W_{TOL}L_{TOL} + W_{BOL}L_{BOL}}{2} \right) D_{OL} \quad (25)$$

Where:

V_{OL} = Volume of trapezoidal prism-shaped Oxidation Layer

W_{TOL} = Top Width Oxidation Layer

L_{TOL} = Top Length Oxidation Layer

W_{BOL} = Bottom Width Oxidation Layer

L_{BOL} = Bottom Length Oxidation Layer

D_{OL} = Depth of Oxidation Layer

The same process is repeated to calculate the dimensions and volumes for the rest of the layers (settling/retention and sludge capacity). Lastly, the excavation cut volume is determined by adding the volumes for the oxidation, settling/retention, sludge capacity, and liner layers. The model assumes the excavated earth or cut material is used to construct the Freeboard Layer as fill material and any excess cut material is disposed of on-site.

3.2.3 System Properties: The system properties required to calculate the sizing and cost of a pond include Pond Inside Slope, Settling/Retention Layer Bottom Length to Width Ratio, and the Excavation Unit Cost. As discussed in Section 3.2.2, the inside slope and length-to-width ratio are used in the sizing calculations for the pond. The excavation unit cost is used to estimate the capital cost of the pond construction. The default values are set to what is considered typical inside slope and length to width ratios of a pond; however, based on site conditions or preferences these values can be adjusted by the user. The unit cost for excavation is cost per cubic yard of material and can also be adjusted by the user.

3.2.4 Pond Layers: Unlike other passive treatment system components (i.e. Vertical Flow Pond, Limestone Bed) in the AMDTreat program, the Pond module does not include ‘layers’ of different reagents (i.e. compost mix, limestone) but instead has ‘layers’ that theoretically perform specific purposes. As discussed in Section 2.0, there are a total of five layers for the user to consider in the Pond design. The purpose and description of each layer is described below:

3.2.4.1 Freeboard Layer: The freeboard layer is the layer between the top of the pond embankment and the top of the water surface, which is the oxidation layer if selected by the user

or it could be the settling/retention layer (see Pond cross-section diagram). The purpose of the freeboard layer is to accommodate a rising water surface elevation caused by increased flow into the pond or issues with the water level control structure that discharges water out of the pond. Typically, the freeboard layer contains an emergency spillway feature within the embankment to allow water to outlet from the pond due to flows in excess of the design flow or if there is a problem with the water level control structure also known as the principal spillway. The user can adjust the two foot default depth of the freeboard layer based on their design preferences but a general rule of thumb is to have at least one foot of freeboard between the crest of the emergency spillway and the top of the embankment and it is at the user's discretion how far above the water surface to construct the crest of the emergency spillway (e.g., 0.5 feet).

3.2.4.2 Oxidation Layer: The oxidation layer is the uppermost layer of a settling or oxidation pond and is the first to receive the influent water. The oxidation layer is optional in that the user can select not to include it by unchecking the box contained in the layer. The oxidation layer is intended to provide an opportunity for the dissolved metals within the mine drainage to oxidize and precipitate forming a solid particle in the water column. It is this precipitated solid that begins to vertically migrate downward in the water column to the next layer called the Settling/Retention layer. The user is able to adjust the depth of the oxidation layer in order for the software to calculate the dimensions and retention time within the layer.

3.2.4.3 Settling/Retention: The settling/retention layer may be the next layer proceeding down from the water surface following the optional oxidation layer. The settling/retention layer provides a relatively stagnant environment to encourage the precipitated solids that form in the oxidation layer or that enter the pond if no oxidation layer is selected in order to settle out of the water column and accumulate in the next lower level referred to as the sludge capacity layer. If the user selects Oxidation/Settling/Sludge as the sizing option under the Pond Design section, the user is able to adjust the depth and desired retention time of the Settling/Retention layer in order to customize the pond size. If the user selects the User-Specified Dimensions sizing method under the Pond Design section, the user is only able to adjust the depth of the Settling/Retention layer and not the retention time since this layer is not used to size the pond.

3.2.4.3 Sludge Capacity: The sludge capacity layer is an optional layer in a pond immediately below the settling/retention layer where the user can select not to include it by unchecking the box contained in the layer. The sludge capacity layer is where the solid particles that formed and/or settled out of the water column from the upper layer(s) are deposited and accumulated for eventual removal and disposal. The calculations for sludge volumes are included in Section 2.2. The user can compare the *Sludge Capacity Volume* and the *Thickened Sludge Volume* in the Sizing Summary in order to determine sufficient dimensions of the sludge capacity layer. However, the software does calculate the required frequency of sludge removal based on the calculated volumes of the sludge capacity layer and thickened sludge considering a user-specified percent solids for the thickened sludge.

3.2.4.6 Liner Layer: Many mine sites lack the soil characteristics required to prevent leaky passive treatment system components. AMDTreat offers three types of liner systems that prevent water leakage from the impoundment(s), including Clay, Synthetic (i.e. PVC), and Geosynthetic Clay (GCL) liners. The volume of clay required is calculated from the entire inside sloped area of the pond, from the top of freeboard to the base of the limestone (bottom of pond), plus the bottom

area of the Pond and multiplying it by the user-specified compacted thickness (typically 0.5 to 1.0 foot) and unit cost to purchase and install the Clay liner. The area required for Synthetic or Geosynthetic Clay liners is determined by calculating the inside sloped area and the bottom area of the Pond similar to the clay liner and adding an additional 2.0 ft of length on all sides to accommodate the incorporation (“tie in”) of the liner into the embankment near the top of the freeboard layer to secure the liner system. AMDTreat provides the option of adding non-woven geotextile as a separate material for all liner systems. Non-woven geotextile separation material is commonly used to protect the Synthetic or Geosynthetic Clay liner from the excavated inside surface of the pond and/or the limestone layer from the excavated surface of the pond or selected liner material.

3.2.4 Hydraulic Structures: The hydraulic structures consist of the Pipe, Baffle(s), and Appurtenances/Other Items, which were discussed in Section 2.1. All these items are included in the design by default unless the user determines to exclude them.

3.2.3.1 Pipe: The Pipe layer models the influent and effluent piping used to convey the water into and out of the Pond. The use of influent and effluent piping is optional in the module. Users opting to model piping can adjust the Influent/Effluent Pipe Length in order to account for all the piping included in the design. The Pond module offers users two methods to estimate the cost to purchase and install the piping network, the AMDTreat Piping Calculator or User-Specified Piping Layout. The User-Specified Piping Layout allows the user to specify up to three different pipe sizes and must also provide the length and unit cost to purchase and install the pipe(s). The default design of the AMDTreat Piping Calculator for Ponds is include influent/effluent pipe.

3.2.3.2 Baffle (Floating): Baffles are a common feature used in ponds to promote settling of precipitated particles in the water column by slowing the water velocity in the pond. The baffle is also referred to as a floating vinyl curtain since this is the most common type of baffle used in mine drainage treatment systems, but other types of materials and structures have been used to serve a similar purpose. The baffle is commonly anchored to the embankment and oriented across the width of the pond perpendicular to the flow path of the influent water. The floating vinyl curtain baffle is typically composed of a flotation type material sewn into the top and a heavy chain-like material sewn into the bottom or anchored with heavy weights attached to the bottom and placed in the pond bottom to keep the baffle taut in the water column.

3.2.3.3 Appurtenances/Other Items: Appurtenances/Other Items is a cost category that contains a variety of commonly used items in settling/oxidation ponds for mine drainage treatment. By default, these items are included. However, users can set the quantity to zero or the unit cost to \$0.00 to prevent AMDTreat from including an item in the Capital Cost.

Pump

One common method for removing sludge from a pond is to use a pump capable of handling slurry or high solids water. When a mine drainage treatment system generates a significant quantity of sludge that must frequently be removed from the pond(s) it may be practical to purchase and store a pump at the site, which is the purpose of including this item. The user must size the pump properly to ensure it is capable of removing the sludge in a timely manner but also make sure it is capable of conveying the sludge the necessary horizontal and vertical distance, referred to as hydraulic head, to the disposal or dewatering location. The pump size including the use of an electric or diesel-powered unit will dictate the capital cost associated with the purchase.

Valves:

Valves can be used at various locations in the piping network of passive treatment systems. They can be placed at the intake of a collection system, downflow of a flow splitting device to shut off flow to a cell during maintenance, or at the downstream end of a system to allow for flushing of the limestone layer. Other valve configurations are possible, depending on system design requirements, which vary due to designer's preference or water quality constraints. Valves can range from heavy duty stainless steel industrial models to lighter grade simple Polyvinyl Chloride (PVC) valves, again depending on system requirements, intended lifecycle, and designer's preference. The cost of the valves can vary greatly depending on the materials used for construction, applicable pipe diameter, and intended duty cycle.

Intake Structure:

Various methods of intake systems are used in passive treatment system design. Deep mine discharges with intact wet seals can be collected with simple pipe connections or open top structures to allow for inspection and cleanout. In cases where there is no pipe discharging from a deep mine, custom intakes need to be designed based on site constraints, water quality and flow to collect the deep mine discharge and connect it to a conveyance pipe or open channel leading to a flow splitting device or treatment system. Surface discharges or seeps can be collected with subsurface drainage infrastructure (French drains) or open top devices such as catch basins with appropriately designed openings. Stream intakes are typically designed to capture base flows while allowing higher stormwater flows to bypass the intake, assuming the surface discharge is diluted with non-AMD stormwater runoff. These types of intakes typically consist of concrete boxes, screen or weirs with pipe openings to convey the base flow to a flow splitter structure or directly to the treatment system. There are many options available to capture water for treatment and designers should select an alternative that accommodates the discharge flows and does not create an undue maintenance burden. Depending on water chemistry, any concrete used in intake structures must be coated inside and out with a heavy-duty epoxy paint or other suitable coating to prevent dissolution of the concrete from acidic conditions.

Flow Distribution:

Many passive treatment systems include multiple treatment cells or bypasses that require the flow split into multiple parts. Flow can be split with concrete structures or by large diameter pipes with multiple outlets. As mentioned in the intake structure section, depending on water chemistry, any concrete used for flow distribution structures must be coated inside and out with a heavy-duty epoxy paint or other suitable coating to prevent dissolution of the concrete from acidic conditions.

Water Level Control Structures:

Water level control structures are exactly as the name implies, a structure or series of structures used to control the level of water within the treatment component. Typically, the structure allows for the adjustment or manipulation of the water level for various reasons such as the need for greater head pressure to force the water through the treatment materials and outlet piping, greater retention times are needed or lowering of the water level for maintenance. Common water level outlet structures may include a PVC box-like structure with removable stop logs or vertical standpipes with Fernco fittings, both of which are installed in the downstream embankment and hydraulically connected to the piping layer within the treatment component and the effluent pipe for discharge to the subsequent treatment component.

Outlet Protection Structures:

These are typically rip-rap structures constructed in a trapezoidal shape at the outlet of the effluent pipe from the water level control structure and the inflow point to the next downstream treatment component or the final outfall. The purpose of these structures is to dissipate the energy generated by the gravity flow of water downslope in the effluent pipe from a water level control structure and prevent scouring/erosion at the point of discharge. A secondary benefit of the outlet protection structures is the potential to add dissolved oxygen into the water as it is agitated from striking the rip-rap material. It is important that an outlet protection structure be properly designed to provide the most appropriate rip-rap size (stone size) and the overall dimensions of the structure.

3.2.5 Other Capital Items: The *Other Capital Items* section allows users to consider the capital cost of any additional items that are not included as an existing line item in the module. The user is able to enter a description of the item, which will be transferred to the Capital Cost output section, once the quantity and unit cost values are entered.

3.2.5 Annual Cost Input: This section involves the annual costs associated with the volume of sludge generation, sludge handling method, and sludge disposal if the user determines to include the *Sludge Capacity* layer.

3.2.5.1 Sludge Generation: The generated sludge is calculated by taking into account the metal concentrations (i.e. Fe^{2+} , Fe^{3+} , Al, Mn) from the Water Quality and Flow section, along with the calcite and miscellaneous solids that the user can specify in this section. The user also specifies a density for the miscellaneous solids, a weight percent for thickened solids (solids/sludge that settles in the Sludge Capacity layer of the pond), and a weight percent of dewatered solids (solids/sludge that would be dewatered in a drying bed or Geotube).

Calcite as CaCO_3 : This parameter represents the calcite that would precipitate in the pond. Typically, calcite may be more likely to precipitate in the pond from treatment systems that use lime products [e.g., CaO, $\text{Ca}(\text{OH})_2$]; however, calcite precipitation may occur when utilizing other treatment chemicals such as caustic soda (NaOH). The user can estimate the calcite concentration by performing geochemical modeling (i.e. PHREEQC Tool) of the water entering the pond.

Miscellaneous Solids: Any additional solids (e.g., ZnO) accumulating in the sludge that is not accounted for otherwise (e.g., Fe, Mn, Al). This concentration estimate can also be estimated by performing geochemical modeling of the water entering the pond.

Miscellaneous Solids Density: User specified density of the ‘miscellaneous solids’ in lbs/gallon, which is used to determine the volume of sludge produced.

Thickened % Solids: User specified weight percent (% solids) of sludge that would be the initial sludge deposited/settled in the pond.

Dewatered % Solids: User specified weight percent (% solids) of metal oxides in dewatered sludge. For example, sludge that has been in a drying bed, Geotube, etc.

3.2.5.2 Sludge Handling: This section provides the user options for sludge handling and the ability to select which method(s) are appropriate based on-site conditions. The sludge handling methods use the calculated annual sludge volume to estimate the associated annual costs.

Mobilization/Demobilization: Represent the cost of contractor to mobilize and demobilize equipment to and from the location where sludge handling will occur.

Sludge Handling and Disposal: Represents a general method to account for both sludge handling and disposal costs by using the estimated sludge volume (in gallons) that would be handled and disposed. There is a default unit cost (\$/gal) that is provided based on averaging multiple sludge handling and disposal projects, but the user can adjust this value. This method represents an option if the user is not certain of the particular method for sludge handling and disposal but provides the user with an estimate for the annual costs.

Sludge Handling by Vacuum Truck: Represents an option for utilizing a vacuum truck for sludge handling purposes. The user enters the capacity of the vacuum truck along with estimated time to fill one vacuum truck of sludge and the unit cost (both truck and truck driver) to be at the pond location while performing sludge removal.

Sludge Removal by Pump: Represents option where a pump would be used to perform sludge handling. A rental pump can also be accounted for when a pump is not available at the site. The pump rate, along with either electric or fuel information is entered to estimate the annual costs. This option is typically used when sludge can be pumped to either a Geotube, sludge drying bed, or an injection borehole(s) where sludge is pumped into an abandoned underground mine.

Sludge Removal by Dewatering: Represents a way to remove sludge from the pond via mechanical excavation and placing sludge onsite (e.g., drying bed, Geotube) in order to allow dewatering of the sludge. The user can adjust the \$/cubic yard of sludge in order to estimate these sludge handling costs. Need clarification on this method since it is not possible to use mechanical excavation to get sludge into a Geotube.

3.2.5.3 Sludge Disposal: The user has the option to include or not include sludge disposal costs by selecting the checkbox. If not selected, the sludge disposal section will be grayed out and associated annual costs will be zeroed out. In addition, the *Landfill Tipping Fee* can also be turned on or off by selecting the checkbox, which would be included if the sludge is disposed of at a landfill facility. The sludge disposal options include:

Disposal by Triaxle: Represents the disposal method utilizing triaxle trucks to haul sludge to and from a disposal location. The triaxle truck volume, total roundtrip distance to the disposal location, and transportation unit cost all need specified by the user to calculate the disposal costs.

Disposal by Vacuum Truck: Represents the disposal method utilizing vacuum trucks to haul sludge to a disposal location. The vacuum truck volume, total hours of roundtrip to the disposal location, and transportation unit cost all need specified by the user to calculate the disposal costs.

Disposal by Borehole: Please note, this disposal method cost estimate is a **Capital Cost**, not an Annual Cost. Once the borehole is drilled into an abandoned underground mine, there is no additional costs associated with the borehole, only the associated pumping costs from the pond to the borehole(s). The borehole would be directing sludge into an abandoned underground mine for disposal. The borehole depth and unit cost (\$/ft) of

drilling the borehole are required by the user in order estimate the capital costs for installation.

Disposal by Geotubes: Represents the disposal method utilizing Geotubes that would be placed onsite. The program offers seven different volume sizes for Geotubes ranging from 25 to 1,185 yd³ per Geotube. The default unit cost per Geotube automatically adjusts based on the selected volume size; however, this default value can also be adjusted by the user. The program then calculates the number of Geotubes required per year based on the Geotube volume and estimated annual *dewatered sludge volume*. The program also assumes the Geotube(s) along with the dewatered sludge will have to hauled and disposed of at the disposal location. Therefore, additional input parameters associated with disposal truck volume, excavation time and hourly rate, round trip distance to the disposal location, and transportation unit cost need to be included to calculate the annual disposal cost.

3.2.5 Other Annual Items: The *Other Annual Items* section allows users to consider the annual cost of any additional items that are not included as an existing annual cost item in the module. The user is able to enter a description of the item, which will be included in the Annual Cost output section, once the quantity and unit cost values are entered.

3.3 Module Outputs

3.3.1 Sizing Summary: The Sizing Summary section contains all the calculated module outputs, such as the dimensions, volumes, and plug flow retention times for the various layers. Other important output parameters when considering sludge costs, are to compare the Sludge Capacity Volume to the Thickened Sludge Volume, Sludge Removal Frequency, and Dewatered Sludge Volume. Adjusting the Annual Cost Input parameters, along with the Typical Flow and Sludge Capacity layer parameters will affect these output parameters.

3.3.2 Capital Cost: This section provides the estimated costs for the various user-specified components and the total estimated cost to construct the entire Pond component of a treatment system.

3.3.3 Annual Cost: The annual costs associated with a Pond can vary significantly, depending on whether the user includes sludge handling and disposal. If these items or parameters are not included as part of the Pond design, the O&M annual costs would be rather minimal. However, if sludge handling and disposal is included, annual costs can significantly increase. The output for annual costs has these two items, sludge handling and disposal, as separate subheadings so the user is able to identify the annual costs associated with each of these tasks.

Annual costs, such as sampling, labor, and access road maintenance are “project-wide” costs since they apply to an entire treatment site, not each individual treatment component. Sampling, Labor, and Site Development (e.g., snow plowing) modules are located under the “Project Modules” section of the main user interface and capture these types of annual costs.

Annual maintenance costs are intended to keep the Pond functioning properly. They include activities such as, maintaining influent and effluent piping, manipulating the water level control structure (e.g., Agri

drain), varmint control and mowing. It is assumed that some years will not require the full amount of funds set aside for annual maintenance but will eventually be used over the system life. Users can estimate the annual maintenance costs by assuming a percentage of the capital cost (more expensive the system, the more expensive the maintenance) or specify a known annual maintenance cost. Annual maintenance costs are not a substitute for Recapitalization Costs (see. Section 2.18 Net Present Value) that considers the cost of periodic replacement of treatment system components.

3.3.4 Net Present Value: The Net Present Value (NPV) section determines the cost to operate a treatment system component over a specified time frame. The NPV calculates the present-day financial investment required to generate the income to pay for future operation and equipment/materials replacement costs. Both **Financial Variables** and **Cost Categories** are required to calculate the NPV.

3.3.4.1 Financial Variables - The *Term of Analysis*, *Inflation Rate*, and *Rate of Return* are three variables used in the NPV calculations. The default values for these terms are shown under the Net Present Value section of each module. Users must access the Net Present Value menu at the top of the main user interface to change the default values as they would apply to all modules used for an entire treatment system. While NPV is determined for each AMDTreat module activated by the user, the goal is to determine a total NPV for an entire mine drainage treatment system project (a collection of cost estimates for individual modules creates a treatment system project in AMDTreat). Therefore, a single value for *Term of Analysis*, *Rate of Return*, and *Inflation Rate* is applied to all modules and cannot vary between modules.

- Term of Analysis: The time period used for the NPV calculation to determine the financial investment required to pay for all future costs of the treatment system components.
- Inflation Rate: Represents the average price increase of goods and services over time. AMDTreat uses the inflation rate to calculate the future cost of the annual operation and maintenance (O&M) and recapitalization items (e.g., limestone).
- Rate of Return: Describes the expected profit on an investment.

3.3.4.2 Cost Categories - For each treatment module, AMDTreat provides a list of recommended equipment and materials that require recapitalization. In addition, AMDTreat provides recommendations (default values) for life cycle and replacement percentage. Users can click on the default values for *Life Cycle* or *Replacement Percentage* and use the +/- buttons to change the default values. In addition, users can select *Custom Cost* and enter a new cost to represent the current cost of the equipment. Users can add new recapitalization items or deactivate/delete existing items for calculating the NPV.

An example of how the recapitalization variables are used to determine NPV is to consider the following hypothetical scenario. Assume a vertical turbine pump has a life cycle of 50 years but requires the motor component of the pump to be rebuilt every 20 years. Let's assume the present-day cost to purchase the pump is \$500,000 and the cost to remove, rebuild, and reinstall the pump motor is only \$20,000. Now assume we want to determine the amount of investment required today (NPV) to generate the income to pay for the future cost of rebuilding the pump motor over a 50-year Term of Analysis, which is also equal to the life cycle of the pump. In addition, let's assume an inflation rate of 5.0% and Rate of Return of 8.1%. The goal is to place the money in a

relatively secure investment vehicle to generate 8.1% annually. The NPV will tell us the size of investment required to generate the income to pay for the future costs over 50 years.

There are several ways to model the replacement cost. One way is to replace 4% of the present-day cost of the pump (4% of \$500,000 = \$20,000) with a life cycle of every 20 years. If the Term of Analysis is 50 years, then the entire pump would not require recapitalization since the life cycle of the pump is 50 years. However, the motor would require two replacements (50 years / 20 years = 2.5 rounded down to 2).

To determine the NPV to recapitalize rebuilding of the motor, AMDTreat calculates the future cost to rebuild the motor at each life cycle, 20 and 40 years. The program uses the Inflation Rate to inflate the present day default cost to rebuild the motor in 20 and 40 years from now. While the present day cost to rebuild the pump motor is \$20,000, the future cost to rebuild the motor in 20 years at a 5.0% Inflation Rate is \$53,065 (Equation 19) and \$140,799 in 40 years. Assuming an 8.1% Rate of Return, the 50-year NPV for the pump is \$17,422. In other words, an initial investment of \$17,422 is needed at an annual Rate of Return of 8.1% to generate the investment income required for the two motor rebuilds over the 50-year life cycle of the pump.

Cost to rebuild motor in 20 years =

$$\text{Present Day Cost} \times (100\% + \text{Inflation Rate})^{20} = \$20,000 \times (100\% + 5\%)^{20} = \$53,065 \quad (26)$$

- Annual Operation and Maintenance Cost: By default, AMDTreat transcribes the annual O&M cost from the Annual Cost section to the Net Present Value section. The program assumes the module is being used to first estimate the annual cost for a treatment system component, so it automatically transcribes the annual cost to the NPV section. If this is not the case or the user wants to use some other annual cost, the “Use Custom” box can be selected to allow the user input of a different annual cost to utilize in the NPV calculation.
- Recapitalization Cost: Certain treatment system components, especially mechanical and water conveyance equipment, require periodic replacement. The recapitalization cost of an item is an estimate of the amount of money required to pay for future replacement costs for the item. In addition to the Financial Variables described above, three additional values are required to calculate the NPV of recapitalization costs, the Present-Day Equipment Cost, the Life Cycle, and the Replacement Percentage.
- Default Cost: This represents the current cost to purchase the equipment or material.
- Life Cycle: The time span between equipment or material replacement is termed as its Life Cycle. Some equipment manufacturers provide recommended life cycles for their equipment to provide consumers with an estimate of how long the equipment is expected to be operational. Some life cycles, such as those used for treatment media (limestone), are based on best professional judgement. Some operators prefer to periodically purchase and replace equipment before failure to preserve the continuity of operations, while others wait until failure to replace an item.

- **Replacement Percentage:** The Replacement Percentage is an adjustment factor to the Default Cost to accommodate situations where the entire piece of equipment or all of the material does not require recapitalization. For example, a passive treatment component may be designed to contain enough limestone to neutralize the acidity load for 20 years, however, the accumulation of metal hydroxide precipitates within the void space of the limestone layer may require that 25% of the limestone be replaced every 7 years to prevent hydraulic failure such as plugging or short-circuiting. For this scenario, the initial cost of the limestone making up the limestone layer is discounted by 75% and assigned a life cycle of 7 years to determine the amount of money required to cover the cost of replacing 25% of the limestone layer every 7 years over the Term of Analysis.

3.3.4.3 Rationale for Recapitalization Recommendations:

Recapitalization recommendations are based on professional experience of the AMDTreat Team and may not apply to all situations. Users are encouraged to customize the recapitalization assumptions to their treatment scenario. AMDTreat Team members are located in Pennsylvania and West Virginia and have collective experience in design, funding, and/or operation/maintenance for over 100 passive treatment systems. Most passive treatment systems constructed in Pennsylvania and West Virginia are less than 15 years old, thus the industry is still gaining experience in life cycles for various components. However, the AMDTreat Team held discussions on personal experience to develop a list of recapitalization recommendations. Users may have different experiences and opinions.

By default, AMDTreat includes a list of five recapitalization items for Ponds. The items are listed even if they are not selected for the treatment system. The purpose of this is to inform the user of items they should think about recapitalizing or including in their treatment design. For example, Liner is listed as a recapitalization item even if no liner is selected in the cost estimation. In this case the recapitalization cost is set to \$0.00 but the item is still shown as a reminder to the user that a Liner is a common item that should be considered. If a liner is included in the cost estimation, the estimated liner cost is used to calculate a recapitalization cost for liner. Users can delete or modify any of the default Recapitalization items by either deselecting the item or by setting the Replacement % to zero. If the item is deselected the Total Cost for the item will still be shown but the cost will be subtracted from the Net Present Value Cost, shown in the Net Present Value Heading.

Pipe: Piping is often exposed at the surface and can become damaged by vandalism, falling trees, and other factors. AMDTreat assumes 100% of the piping will require replacement after 20 years of service.

Liner: Often liners are destroyed, especially synthetic, while conducting maintenance on passive treatment system components, if the equipment operator is inexperienced with passive systems. The default assumption is to replace 100% of the liner every 20 years for Liner recapitalization.

Other Items: The Other Items section in AMDTreat includes Flow Distribution Structures, Water Level Control Structures, and Outlet Protection Structures. These

structures are often durable, and many treatment systems have never experienced replacement of these items, however, AMDTreat Team members have had at least one experience of each of these items requiring replacement. Therefore, the Team decided to include these items for replacement consideration.

Other Capital Items: The Other Capital Items would include any items listed by the user in this input section of AMDTreat. If no items are listed by the user, this item will have a zero-total cost in the NPV section.

Borehole: If the user does not select the Borehole option under the Sludge Disposal section, this will be zero total cost in the NPV section. However, if the user selects to have a Borehole, the default Life Cycle is 20 years and the Replacement percent is 100%.

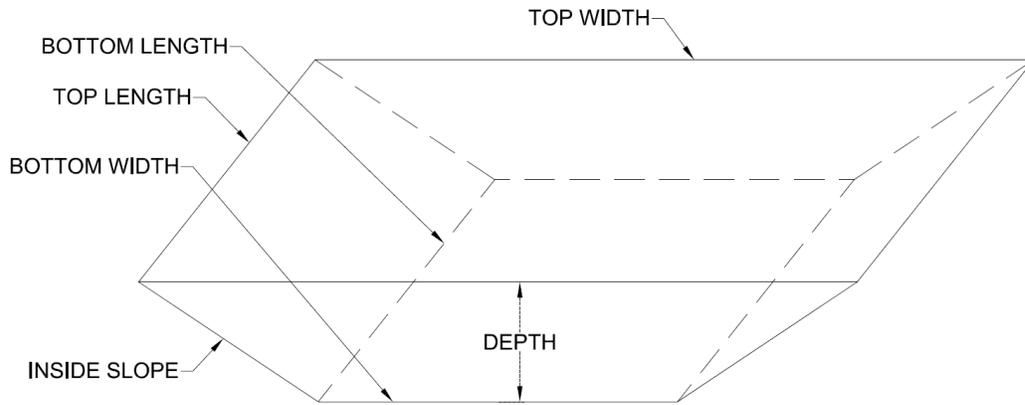
3.4 Assumptions of Design Sizing and Costs: AMDTreat is a cost estimation model that uses assumptions to provide treatment sizing and both capital and annual cost estimates. While there are many assumptions in the program, the ones provided below are important to consider for the Ponds module.

1. The Pond is assumed to be constructed on a flat surface, where the oxidation, settling/retention, sludge capacity, and liner layers are excavated below the existing or original ground, and that material is used to construct the freeboard embankments, which is considered fill material above the existing or original ground (see Figure 2). The program assumes an on-site balance of cut / fill, however, if this is not the case, the user can modify excavation cost default values to reflect the anticipated conditions based on the site characteristics.
2. The geometric shape of a Pond is an inverted trapezoidal prism. The volumetric equation for a trapezoidal prism is used to calculate the Pond layer volumes.
3. AMDTreat requires the bottom length of the Pond must be equal to or greater than the Bottom Width. In addition, AMDTreat will produce an error message if the input values create a Bottom Width less than 10 ft. The error message notifies users they must change the Design Flow rate, values associated with the selected sizing methodology (e.g. retention time), the inside slope of the Pond or the depths associated with any of the layers. In most cases, users will focus on decreasing the depth of one of the layers to eliminate the error. AMDTreat assumes a Pond with a Bottom Width of less than 10 ft is not practical to construct.

4.0 References

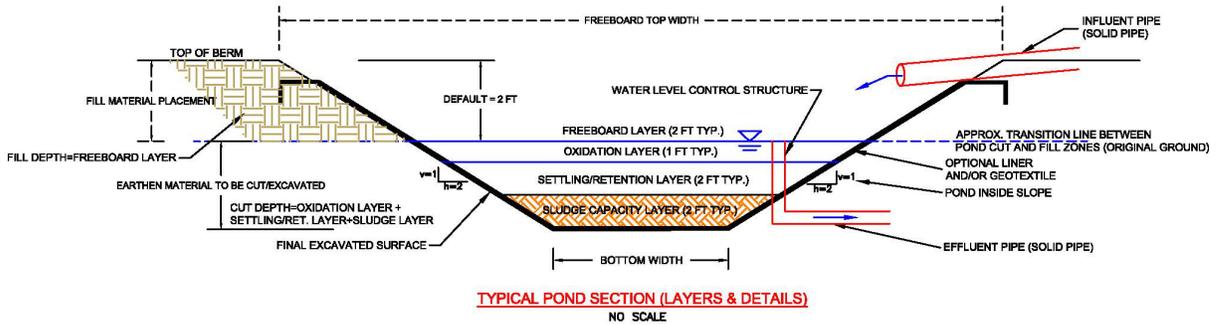
Hedin R.S., Nairn R.W, Kleinmann R.P, 1994 Passive Treatment of Coal Mine Drainage, Bureau of Mines Information Circular IC9389, United States Department of The Interior.

5.0 Figures



TYPICAL INVERTED TRAPEZOIDAL PRISM
NO SCALE

Figure 1: Typical Inverted Trapezoidal Prism



TYPICAL POND SECTION (LAYERS & DETAILS)
NO SCALE

Figure 2: Typical Cross Section View of a Pond with Optional Oxidation & Sludge Capacity Layers.

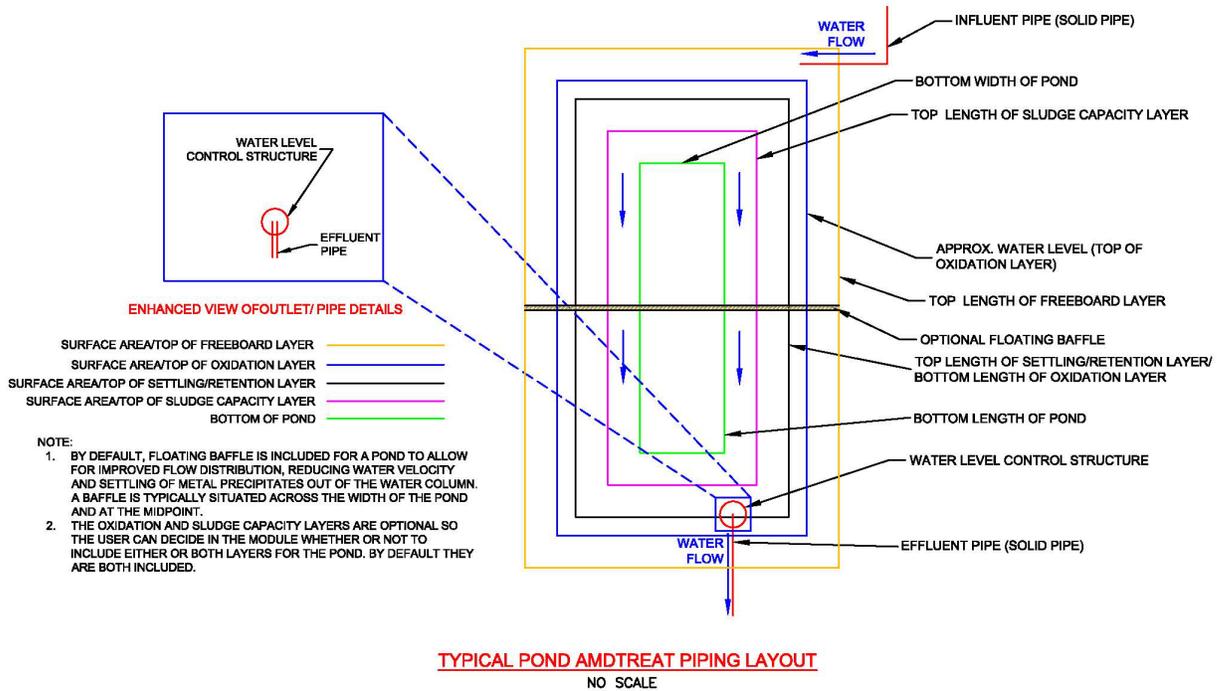


Figure 3: Plan View Diagram Showing the Optional Oxidation & Sludge Capacity Layers and Baffle in AMDTreat for a Pond.



Figure 4: Influent piping configuration commonly used to distribute flow across the width of the pond to promote uniform flow distribution.



Figure 5: Pond with aeration (venturi) device at inlet of pond.



Figure 6: Pond with raised standpipe promoting the aeration at the inlet of the pond.



Figure 7: Pond with a floating baffle across the width of the pond.



Figure 8: Floating baffles to promote settling of solids. The shallow narrow portion of the pond is to provide aeration and flow distribution as water flows through the pond.



Figure 9. Photo of liner being installed on inside embankments and bottom of pond.

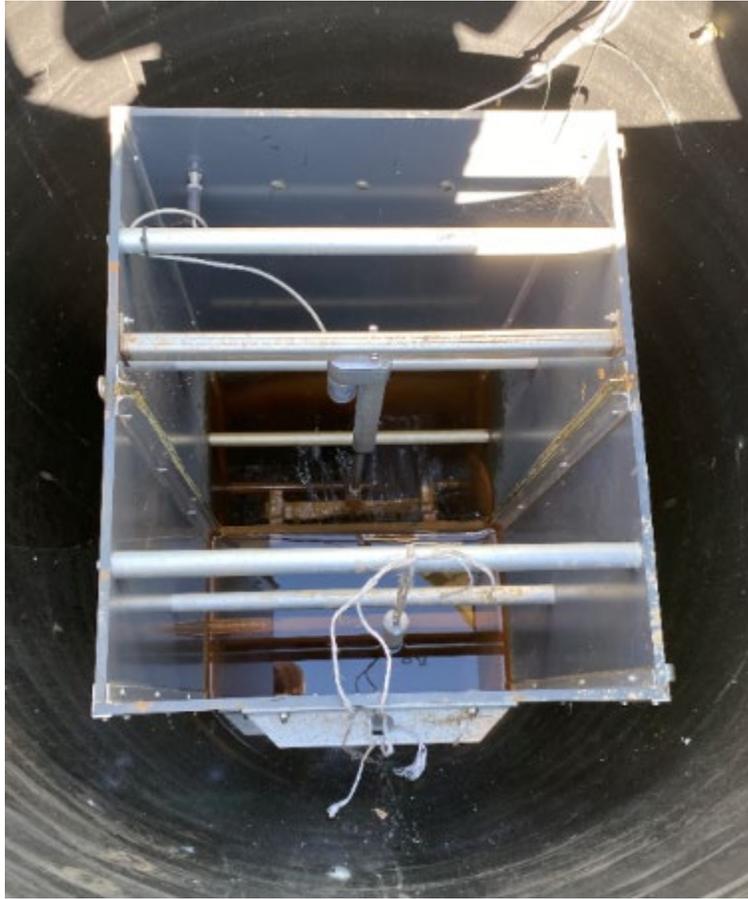


Figure 10: Photo looking down at the inside of an Agri Drain structure, which can be adjusted to control water level in the pond.



Figure 11. Agri Drain water level control structure being installed during construction of a passive treatment system.



Figure 12: Photo of pond with liner with oxidized iron settled out in pond.



Figure 13: Drying bed being utilized to allow sludge to dewater and dry out.



Figure 14: Photo illustrating the mechanical excavation of sludge from pond.



Figure 15: Vacuum trucks removing sludge from a pond.