



Help Instruction File:

Wetlands 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).

Wetland Module Overview

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1.0 Objective

A Wetland is a passive treatment system (meaning no machinery or daily chemical addition required for its operation) that is typically used to enhance sedimentation.

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

2.0 Treatment Component Overview

The following section is organized into three sections, (1) Physical and Hydraulic Description and (2) Application and Treatment Chemistry. The first section provides a physical description and hydraulic profile for a Wetland to provide context for users of AMDTreat. The second section describes the common application of the Wetland component. The third section describes a generalized conceptual model describing the treatment chemistry to help familiarize users with terms and concepts represented throughout the AMDTreat modules.

2.1 Physical and Hydraulic Description

The geometric shape of a Wetland is an inverted trapezoidal prism consisting of four or five distinct “material layers” (Figures 1, 2, 3, 4, & 5). They always contain a freeboard, water, compost, and liner layers and may or may not contain a piping layer. The following discussion will provide a hydraulic description of Wetland from inlet to outlet.

Wetlands may or may not have an influent piping system. If influent piping is used, it is normally in a “tee” configuration of a single pipe conveying the mine drainage to the Wetland that connects to a “header” pipe that is perforated and positioned parallel to the width of the Wetland for flow distribution (Figure 6). Even flow distribution is extremely important as low flow velocities are required for many wetland plants and velocities that exceed 0.5 ft/min can cause a flow channel void of vegetation that promotes short circuiting (Figure 7). Wetlands that do not have an influent piping system may use a combination of a conveyance channel and inlet pool to promote flow distribution (Figures 8 & 9). The inlet pool helps to slow the velocity of the incoming water, distribute the flow, and capture suspended solids to protect the plants.

After the inlet, water flows through the vegetated section of the wetland. The bottom of the wetland consists of a liner overlain by 0.5 ft of soil. The typical water depth of the vegetated section is between 0.5 and 1.0 ft but may vary depending on the depth requirement of the wetland plants to be planted. Some designers opt to periodically install rock baffles in the wetland (Figure 10). Rock baffles can help to prevent the further migration of a short circuit channel void of vegetation by redistributing water across the wetland. In addition, rock baffles can serve as access point for excavators and tractors to perform maintenance (Figure 10). The baffles are constructed with AASHTO#1 type stone (Top size = 4”) containing a 2:1 side slope. The top of the rock baffles is typically equal to the water elevation or a few inches lower. It is important to note if the water level set equal to the baffle, the water level will rise as the porosity of the rock baffle clogs with sediment and organic debris. This could affect the growth of depth-sensitive plants.

2.2 Application and Treatment Chemistry

The application Wetlands have evolved over time. Originally, natural wetland bogs were observed to improve the quality of net acidic mine drainage by decreasing metal and acidity concentrations. Water quality improvements were attributed to sulfate reduction caused by anerobic conditions in the Wetland soils and metal uptake by Wetland plant roots and shoots. Further review found pH adjustment due to sulfate reduction was the primary mechanism for water quality improvement. Thus, in the 1980s Wetlands were constructed to treat net acidic mine drainage and while there was success, effective treatment required very large wetlands. The technology evolved to amending the Wetland soil with limestone to enhance treatment. Anerobic Wetlands were an improvement over traditional Wetlands, but the technology was not optimized because most of the water flows over top and not through the limestone amended soil. This led to a technological innovation of the Vertical Flow Wetland. The original Vertical Flow Wetlands were basically anerobic Wetlands that forced the water to flow vertically through the limestone amended soil to improve the contact between limestone and water. Further innovation led to the development of the Vertical Flow Wetland configured with distinct layers of water, compost, and limestone for improved treatment.

Traditional Wetlands were also used to treat ferruginous net alkaline mine drainage by serving as both an oxidation and sedimentation structure. Often Wetlands were used as the primary form of treatment, but excessive sedimentation of iron hydroxide affected plant growth and performance leading to maintenance issues. Currently, Wetlands are used as a form of secondary or tertiary treatment to enhance sedimentation after other types of passive treatment systems, chemical treatment systems or even clarifiers. There are many instances where 5.0 mg/L of suspended iron enters a wetland and is decreased to below 0.1 mg/L.

Wetlands enhance suspended iron removal by using wetland plant surfaces to decrease the sedimentation loading per unit area and decrease the settling distance like how an incline plate clarifier operates. An additional removal mechanism is the attraction between particles and organic matter though differences in surface charge. Wetlands are located after primary treatment and typically receive mine water between pH 6.0 and 8.0, where the net surface charge on iron hydroxide is positive and may have an electrical attraction to carboxyl and phenolic groups on organic matter. In any case, the removal efficiency depends on interaction between suspended particles and wetland plants, so plant density and growth are important.

Traditionally, cattails (*Typha*) were the preferred wetland treatment plant due to their rapid growth and ability to quickly colonize wetlands through wind transported seeds or multiplication from existing roots. Cattails aggressive growth and propagation often prevents or displaces other plants and leads to a monoculture. A monoculture treatment wetland is susceptible to performance issues if colonized by muskrats or other animals that feed on cattails. There are examples of muskrats causing extensive damage to embankments due to burrowing. As a result, many designers are opting to design diverse wetlands using a variety of wetland plants (Figure 20), including some that are resistant to grazing by animals. Some sites have focused on using wetland grasses, such as various types of Rushes (*Juncus Canadensis*), whose dense growth promotes strong iron removal and water clarity (Figures 21 & 22).

It is good practice to both seed a constructed wetland and to manually plant small wetland plants (“plugs”) to ensure growth and distribution (Figures 21 & 23). For the eastern U.S. a seed mix, such as, ERNTS seed mix Passive Acid Mine OBL Wetland Mix (Item # ERNMX-176), is appropriate for treatment and instructions for seeding and germination must be followed.

Many people raise the question of treatment performance during winter months when vegetation is dormant. Wetlands with strong plant density will maintain interactions between plant matter and iron

particles during dormancy (Figure 21) and changes in water viscosity is more of an issue than plant dormancy. It is appropriate to size wetlands in northern climates using a sizing removal rate of 10 grams suspended iron/m² of wetland /day to account for variations in performance during winter. Lowering the water depth during the winter months to improve interaction between bent over plant matter suspended iron has proved an effective treatment strategy.

Wetlands can accumulate large volumes of decaying organic matter so ample freeboard is required to accommodate a fluctuating water elevation. Typically, 2.5 ft is desired. Wetlands containing ample freeboard may not require maintenance for several years. Wetlands with an effluent perforated header pipe may require yearly cleaning of the perforations to remove algae or plant growth.

Lastly, Wetlands have been shown to be capable of removing dissolved manganese, however, the use of Manganese Removal Bed is a better application of technology to treat dissolved Manganese. In addition, some designers still use Wetlands to oxidize and settle low concentrations of dissolved iron. While the preferred application of Wetlands is to enhance suspended iron removal, the water quality input allows users to enter either dissolved or suspended iron in the “Iron” water quality input.

3.0 Wetland 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 module inputs on the left-hand side are arranged into five sections: (1) Water Quality and Flow Input, (2) Sizing Methods, (3) System Properties, (4) Layer Materials, and (5) Other Items. The workflow of the module is for users to start at the top left-hand side and enter the design flow, dissolved manganese, and iron concentration (depending on the application, users can decide whether to use either dissolved, suspended, or total). The user then selects one of three sizing methods to determine the dimensions of the Wetland. Next, users specify design parameters, such as the depth of the freeboard, water and compost layers, and unit costs for items affecting the capital cost to construct the Wetland. Finally, users can enter a capital cost not captured by the module into the Other Items section, which includes such items as valves, flow distribution structures, and water level control structures. Module output is provided on the right-hand side of the module. The sizing summary in the upper right-hand side provides dimensional details for the system. Progressing down on right-hand side, the estimated cost to construct and operate the Wetland is provided under the Capital and Annual Cost headings. Lastly, users can opt to conduct a net present value (NPV) to obtain the total cost to operate and maintain the Wetland treatment component for a defined time period.

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 Wetland is provided under the *Capital Cost* and *Annual Cost* headings. Lastly, users can opt to conduct a Net Present Value (NPV) to obtain the total cost to operate and maintain a 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 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.

3.2.2 Sizing Methods:

AMDTreat offers two approaches to sizing a Wetland. The first approach is the most common as it relates the sizing of the treatment system based on flow and water quality characteristics. The second approach 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 existing treatment system. For this approach, users enter the desired length and width of the freeboard.

Use Water Quantity and Quality Information to Size Wetland

3.2.2.1 Retention Time – For this sizing method, user enter the desired time to retain water in the water layer of the wetland to achieve treatment. AMDTreat uses the retention time, along with other user-specified parameters to calculate the dimensions of the Wetland.

AMDTreat models all passive treatment systems, including ponds, as an inverted trapezoidal prism (Figure 1). AMDTreat calculates the overall dimensions of a passive treatment system by first breaking up the system into individual layers, such as the freeboard layer, water layer, compost mix layer, limestone layer, etc. Each individual layer is modeled as an inverted trapezoidal prism to determine the dimensions of the layer, which is used to calculate the excavation volume and material quantities (e.g. yd³ of compost mix).

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

$$V = \left(\frac{W_T L_T + W_B L_B}{2} \right) D \quad (1)$$

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 Retention Time sizing selected in the Wetland module, the volume of the Water Layer is known by dividing the user-specified retention time by the design flow rate. Moreover, users are required to specify the depth of the water layer, inside slope, and length-to-width ratio for the bottom of the water layer. The unknowns are the length and

width of the top and bottom dimensions of the trapezoidal prism. Thus, the equation is rearranged to a quadratic equation to solve for the bottom width of the water layer:

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

Where:

V = Volume of Water Layer

L_{BWL} = Bottom Length of Water Layer

D = Depth of Water Layer

S = Inside Side Slope of Wetland

R = Length to Width Ratio of Bottom of Water Layer

Once the Bottom Length is known, the Bottom Width of the Water Layer (W_{BWL}) is calculated by dividing the Bottom Length by the user-specified value for length-to-width ratio for bottom of Water Layer:

$$W_{BWL} = \frac{L_{BWL}}{R} \quad (3)$$

The two remaining unknown dimensions of the Water Layer are the Top Length and Width.

The Top Length of the Water Layer is calculated by:

$$L_{TWL} = L_{BWL} + 2 * S * (D_{WL}) \quad (4)$$

Where:

L_{TWL} = Top Length of Water Layer

L_{BWL} = Bottom Length of Water Layer

D_{WL} = Depth of Water Layer

S = Inside Side Slope of Wetland (rise/run)

The top width of the water layer is determined by the same approach. Now that all the dimensions of the water layer are known, the dimensions of the Freeboard and Compost Mix Layers can be determined:

The bottom length of the freeboard layer (L_{BFL}) is equal to the Top Length of the Water Layer (L_{TWL}).

$$L_{BFL} = L_{TWL} \quad (5)$$

The Top Length of the Freeboard Layer is calculated by:

$$L_{TFL} = L_{BFL} + 2 * S * (D_{FL}) \quad (6)$$

Where:

L_{TFL} = Top Length of Freeboard Layer

L_{BFL} = Bottom Length of Freeboard Layer

S = Inside Side Slope of Wetland (rise/run)

D_{FL} = Depth of Freeboard Layer

Likewise, the Top Length of the Compost Mix Layer (L_{TCML}) is equal to the Bottom Length of the Water Layer (L_{BWL}).

$$L_{TCML} = L_{BWL} \quad (7)$$

The bottom length of the compost mix layer is calculated by:

$$L_{BCML} = L_{TCML} - 2 * S * (D_{CML}) \quad (8)$$

Where:

S = Inside Side Slope of Wetland (rise/run)

D_{CML} = Depth of Compost Mix Layer

Now that all of dimensions of the freeboard and compost mix layers are known, the individual layer volumes are calculated using Equation (1).

In addition to assuming all passive treatment systems are constructed as an inverted trapezoidal prism, an additional assumption is that the excavation volume is equal to the summation of all the individual layer volumes, except for the freeboard layer. It is assumed the freeboard layer is constructed with a portion of the excavated earth. trapezoidal prism: Thus:

$$\text{Wetland Exavation Volume} = \text{Water Layer Volume} + \text{Compost Mix Volume} \quad (9)$$

3.2.2.2 Metal Removal Rates - The Bureau of Mines was an agency in the U.S. Department of Interior that is now retired but was instrumental in conducting some of the early research on how to design passive treatment systems for mine drainage. They published a sizing method to design Wetlands to remove iron and manganese (Hedin et al. 1994). AMDTreat incorporated the sizing method and allows users to specify a removal rate (grams of metal/m² of wetland/day), a design flow rate, and a design metal concentration to size a wetland for treatment. AMDTreat allows users to design the wetland for both iron and manganese removal and users simply adjust the metal removal rate to model the appropriate treatment mechanism. For example, users can adjust the

metal removal rate to simulate the oxidation, precipitation, and settling of iron in a wetland or lower the removal rate to simulate situations where wetlands are used to enhance the removal of suspended iron. In addition, AMDTreat allows users to size wetlands for the oxidation, precipitation, and settling of dissolved manganese. If both an iron and manganese concentration are entered, AMDTreat will independently calculate the surface area required to treat each metal and sum the areas to calculate the total surface area requirement. If a Wetland is not being designed for Manganese removal, users should set the design dissolved Manganese concentration to zero to prevent oversizing the wetland.

The program sizes the wetland by first using the design flow and iron and/or manganese concentration to calculate a daily metal loading. It then divides the metal loading by the metal removal rate to determine the surface area required for treatment. The surface area required for treatment is calculated by adding the surface area required for iron treatment to the area required for manganese treatment. Iron and manganese removal may occur concurrently, thus this sizing method may have an inherent safety factor for sizing. It is important to note the surface area required for treatment is the surface area at the top of the Water Layer. AMDTreat uses the surface area of the Top of the Water Layer along with the user-specified pond inside slope, bottom length-to-width ratio for the bottom of the Wetland, and the water layer and compost mix depths to calculate the bottom length of the Wetland:

$$L_{BCML} = \frac{-\left(2DS + \frac{2DS}{R}\right) \pm \sqrt{\left(2DS + \frac{2DS}{R}\right)^2 - \left(4\frac{1}{R}(4S^2D^2 - SA_{TWL})\right)}}{2\frac{1}{R}} \quad (10)$$

Where:

L_{BCML} = Bottom Length of Compost Mix Layer (bottom length of wetland)

SA_{TWL} = Surface Area of Top of Water Layer

D = Depth of Water Layer + Depth of Compost Mix Layer

S = Inside Side Slope of Wetland

R = Length to Width Ratio of Bottom of Compost Mix Layer (bottom of wetland)

Once the bottom length of the compost mix is known, the bottom width of the compost mix layer (W_{BCML}) is calculated by dividing the bottom length by the user-specified value for length-to-width ratio for bottom of water layer:

$$W_{BCML} = \frac{L_{BCML}}{R} \quad (11)$$

The two remaining unknown dimensions for the compost mix layer are the top length and width.

The top length of the compost mix layer is calculated by:

$$L_{TCML} = L_{BCML} + 2 * S * (D_{CML}) \quad (12)$$

Where:

L_{TWL} = Top Length of Water Layer

L_{BWL} = Bottom Length of Water Layer

D_{CML} = Depth of Water Layer

S = Inside Side Slope of Wetland (rise/run)

The top width of the compost mix layer is determined by the same approach. Now that all the dimensions of the compost mix layer are known, the volume of the compost mix layer is determined:

$$V_{CML} = \left(\frac{W_{TCML}L_{TCML} + W_{BCML}L_{BCML}}{2} \right) D_{CML} \quad (13)$$

Where:

V_{CML} = Volume of trapezoidal prism shaped Compost Mix Layer

W_{TCML} = Top Width Compost Mix Layer

L_{TCML} = Top Length Compost Mix Layer

W_{BCML} = Bottom Width Compost Mix Layer

L_{BCML} = Bottom Length Compost Mix Layer

D = Depth of Compost Mix Layer

Next, the dimensions and volumes of the water and freeboard layers are determined. The top length and width of the compost mix is the same as the bottom length and width of the water layer, thus Equation (12) can be adjusted and used to determine the top width and length of the water layer. Then Equation (13) can be adjusted to calculate the volume of the water layer and the same process can be used to determine the dimensions of the Freeboard Layer.

The excavation volume, shown under the Sizing Summary heading, is determined by adding the volumes of the water and compost mix layers. AMDTreat assumes the excavated material is used to construct the freeboard layer embankments and any excess material is graded into the site

3.2.2.3 User Specified Dimensions - Mine drainage discharges often emerge at 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 methods may produce a Wetland that is larger than the available land area. Some folks may accept a smaller Wetland, but this will most likely require more maintenance due to high metal loading per unit area. In these cases, users can utilize this sizing

method to specify the area available for treatment. Users can specify the Top Length and Width of the Freeboard and AMDTreat will use the user-specified values for Inside Pond Slope and the Freeboard, Water, and Compost Mix Layer Depths to calculate the dimensions and volumes of the individual layers of the Wetland.

The bottom length of the freeboard layer is calculated by:

$$L_{BFL} = L_{TFL} - 2 * S * (D_{FL}) \quad (14)$$

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 Wetland (Run/Rise)

The volume of the freeboard layer is determined by:

$$V_{FL} = \left(\frac{W_{TFL}L_{TFL} + W_{BFL}L_{BFL}}{2} \right) D_{FL} \quad (15)$$

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 = Depth of Freeboard Layer

The top length of the water layer (L_{TWL}) is equal to the bottom length of the freeboard layer (L_{BFL}).

$$L_{TWL} = L_{BFL} \quad (16)$$

Now that the top width and length of the water layer is known, the User-Specified values for inside slope of wetland and depth of water layer are used in Equation (14) to calculate the bottom width and length of the water layer. Equation (16) is used to calculate the volume of the water layer.

The same process is repeated to calculate the dimensions and volumes for the rest of the layers. Lastly, the excavation volume is determined by adding the volumes for the water and compost mix layers. The model assumes the excavated earth is used to construct the Freeboard Layer and any excess material is disposed of on-site.

3.2.3 System Properties: Inlet and Outlet pools are discussed in Section 2.1 (Physical and Hydraulic Description) and shown in Figures 2, 8, and 9. Under the System Properties heading users can opt to include inlet and/or outlet pools and can specify their water depth. Wetlands sized without and inlet or outlet pool are assumed to have the Compost Mix layer extend to the inlet/outlet pipe or ditch.

3.2.4 Layer Materials: Unlike active treatment systems which require the continuous addition of chemicals to maintain treatment of mine drainage, passive treatment systems typically consist of impoundments filled with enough reagent (e.g., limestone, compost) to provide treatment for many years. For some passive treatment system components, such as vertical flow ponds (VFP), different reagents are used at different elevations within the impoundment to manipulate the geochemistry and control oxidation/reduction and solubility reactions as the mine drainage flows through the system. AMDTreat considers each reagent or material as a “layer” in the impoundment. Both “reagent” and “material” are used to describe layers because not all layers are comprised of reagents or materials meant to manipulate water chemistry. For example, the freeboard layer is designed to accommodate fluctuations in flow or increasing water elevation due to permeability or plugging of layer materials from metal hydroxides or sediment. The *Layer Materials* section is where users can control the depth and other characteristics of the materials/layers used in a Wetland.

3.2.4.1 Freeboard Layer: Users specify the depth of the freeboard layer designed to produce enough storage to accommodate increases in the water layer due to increased flow events or accumulation of decaying plants. In most passive systems, the influent to the Wetland is within or at the top of the freeboard layer. The bottom of the Freeboard layer is the top of the water layer for the Wetland. A typical freeboard layer depth for a wetland is between 1.5 and 3.5 feet.

3.2.4.2 Water Layer: The water layer is in between the Freeboard and Compost Mix layers and serves as the primary layer that removes suspended material through interactions with plant surfaces. At times, the water elevation is manipulated to control the growth of aquatic plants that may occur in a Wetland or to improve treatment during winter months (lowering of water elevation). A typical water layer depth is between 0.5 and 1.5 feet depending on the species of Wetland plant.

3.2.4.3 Compost Mix Layer: Generally, topsoil or compost is used as the media to plant Wetland plants. Users can specify the depth of the compost mix layer and the unit cost of purchasing and placing the compost and the cost to purchase and plant the wetland plants. While no longer common practice, limestone fines were added to the compost layer (referred to as an anaerobic wetland) to help add alkalinity to net acidic mine water. Users have the option of adding limestone fines to the compost layer.

3.2.4.4 Wetland Rock Baffles: Wetland Rock Baffles were described in Section 2.1 (Physical and Hydraulic and Description) and shown in Figures 10. In short, rock baffles serve to periodically redistribute water in case a flow channel develops through the wetland plants. In addition, they serve as a bridge to allow equipment to access the middle of the wetland for maintenance activities. Rock baffles are often constructed out of limestone rock, although any type of durable

rock is acceptable, and users can specify the distance between rock baffles, the cost to purchase and place the rock, and the porosity within the wetland rock baffles section.

3.2.4.5 Pipe Layer: The Piping layer models the inlet and outlet piping used to convey the water into and out of the Wetland. The use of influent and effluent piping is optional in the module. Users opting to model piping can model the use of only influent piping, only effluent piping, or both influent and effluent piping. The Wetland 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 default design of the AMDTreat Piping Calculator for Wetlands is to use a use an inlet/outlet (Figures 3 & 9) conveyance pipe coupled to a perforated header pipe using a “Tee”. The Header pipe extends the width of the Wetland is meant to evenly distribute the inflow and evenly accumulate the treated water at the outlet end of the Wetland.

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 from leaking 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 Wetland 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 Wetland 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.

3.2.5 Other Items: The *Other Items* section allows users to consider the capital cost of inlet and outlet structures, valves, and flow distribution structures. **AMDTreat suggests default quantities and unit costs for construction of a single WETLAND component.**

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.

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 Wetland component of the passive treatment system.

3.3.3 Annual Cost: Since a Wetland is a passive treatment system component, the only annual cost considered is the cost for minor maintenance. 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, etc.) modules are located under the “Project Modules” section of the main user interface and capture these types of annual costs.

Annual maintenance costs are for keeping the Wetland 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 amount. Annual maintenance costs are not a substitute for Recapitalization Costs (see. Section 2.18 Net Present Value) that consider the cost of periodic replacement of treatment 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 is 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 and \$140,799 in 40 years (Equation 8). 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 =

$$\text{Present Day Cost} \times (100\% + \text{Inflation Rate})^{20} = \$20,000 \times (100\% + 5\%)^{20} = \$53,065 \quad (17)$$

- **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 lifecycles for various components. However, the AMDTreat Team held discussions on personal experience to develop a list of recapitalization recommendations. Users may have different experience and opinions.

By default, AMDTreat includes a list of five recapitalization items for Limestone Bed. 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.

Rock Baffles: Rock baffles can require maintenance and periodic partial replacement. Baffles can become clogged with metal precipitate or vegetation and cause an unwanted increase in water elevation. Therefore, the default recommendation in AMDTreat is to replace 50% of the Baffle Rock every 15 years.

Compost Mix: A portion of the Compost Mix may need to be replaced if the rate of vegetation accumulation is faster than the rate of decay. It is used to remove a high iron load. The iron precipitate can affect vegetation growth, thus treatment performance, and will require periodic removal. The existing compost will likely be removed along with

the iron precipitate, thus new Compost will be required to regenerate vegetation. AMDTreat recommends planning to replace 50% of the Compost every 15 years, however, compost replacement will be less frequent if placed on a low metal loading discharge.

Liner: Often liners are destroyed, especially synthetic, while conducting maintenance on passive treatment systems, if the equipment operator is inexperienced with passive systems. Thus, AMDTreat recommends planning to replace a portion of the liner while the Compost is being replaced. The default assumption is to replace 50% of the Compost every 15 years, so the same assumptions are recommended 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, thus the Team wanted to include these items for replacement consideration.

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 WETLAND module.

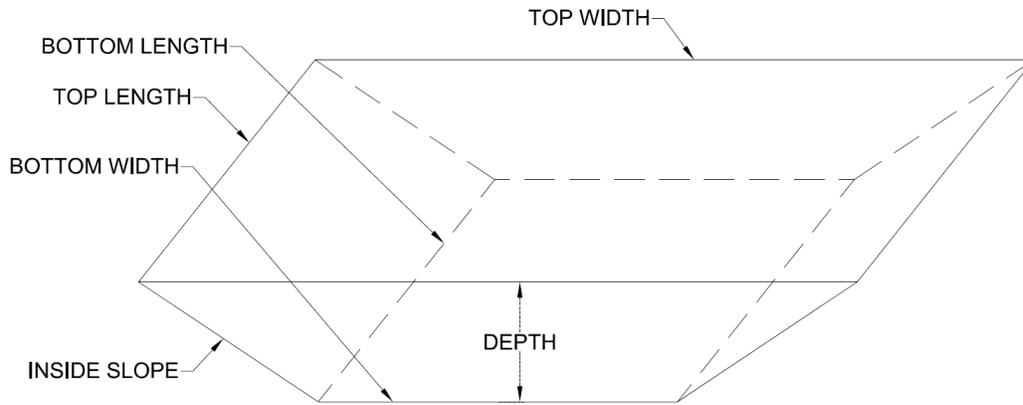
1. The Wetland is assumed to be constructed on a flat surface, where the water and Compost Mix layers are excavated or below the existing or original ground, and a portion of that material is used to construct the freeboard embankments which is considered fill material above the existing or original ground (see Figure 1). 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 Wetland is an inverted trapezoidal prism. The volumetric equation for a trapezoidal prism is used to calculate the WETLAND layer volumes.
3. None of the sizing methods provide a “design life” or are guaranteed to achieve an effluent standard. With that said, a properly sized and applied Wetland can achieve total iron concentrations below 0.2 mg/L.

4.0 References

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

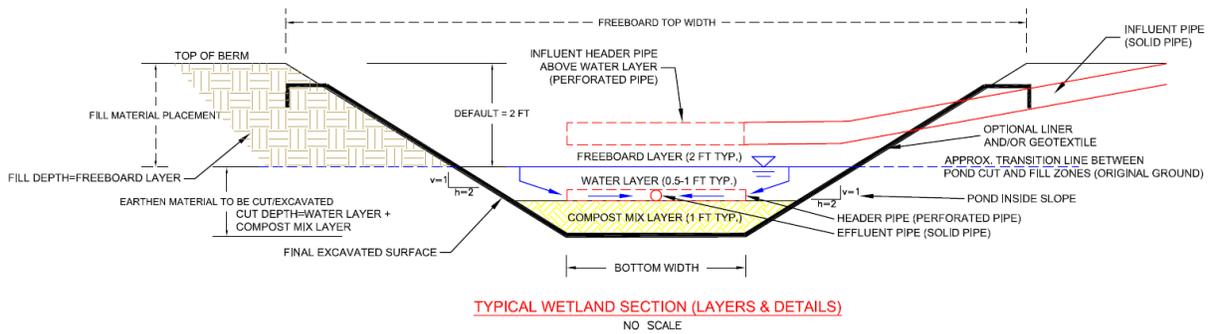
OSMRE website for the flight 93 wetlands <https://www.arcc.osmre.gov/programs/TDT/flight93.shtm>

5.0 Figures



TYPICAL INVERTED TRAPEZOIDAL PRISM
NO SCALE

Figure 1: Typical Inverted Trapezoidal Prism



TYPICAL WETLAND SECTION (LAYERS & DETAILS)
NO SCALE

Figure 2: Typical Cross Section View of a Wetland (without Inlet and Outlet Pools) Showing the Common Layers and Components

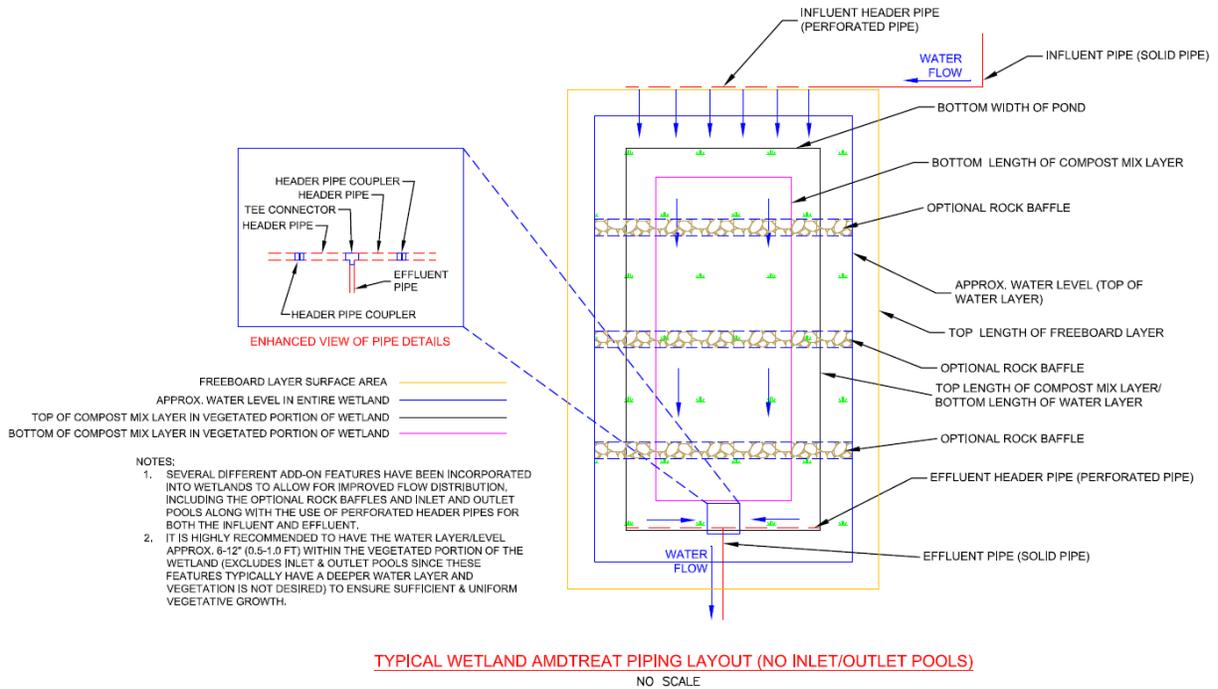


Figure 3: Plan View of Wetland (without Inlet and Outlet Pools) to Illustrate Common Layout and Components

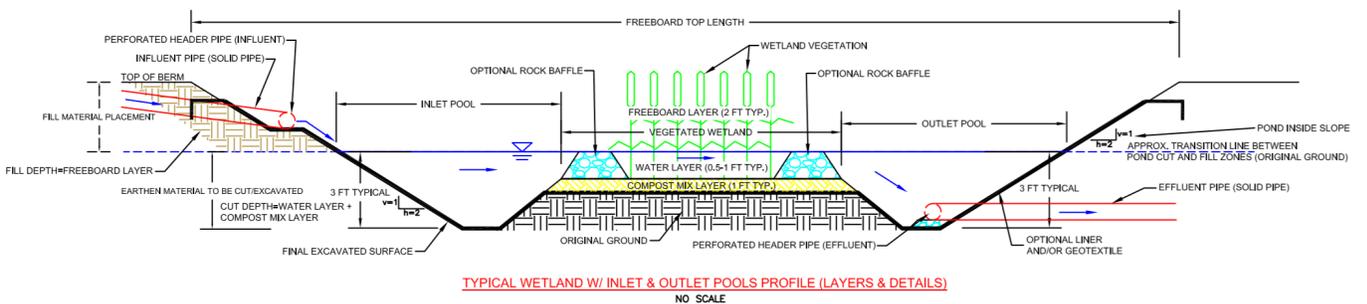


Figure 4: Typical Cross Section View of a Wetland containing Inlet and Outlet Pools and Common Layers and Components

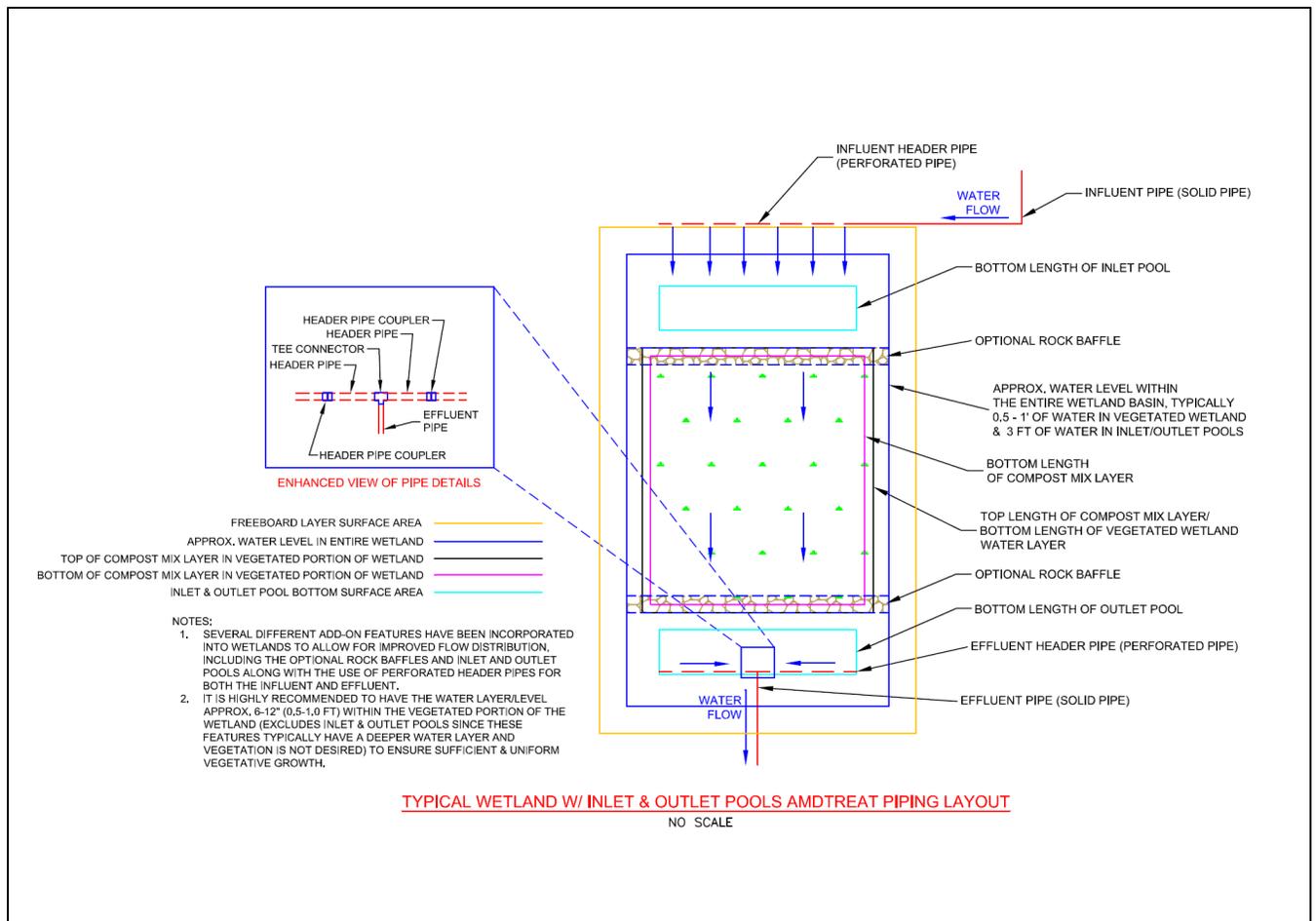


Figure 5: Plan view diagram showing the default influent and effluent piping scheme used in AMDTreat for a wetland



Figure 6: Influent piping configuration commonly used to distribute flow across the width of the wetland. A single pipe conveys mine drainage to the site and is connected to a perforated header pipe that extends the width of the wetland to promote uniform flow distribution.



Figure 7: Wetland containing a short circuit (right hand side of photo) void of vegetation due to increased flow velocity. Water bypasses the interaction with wetland plants required for enhanced sedimentation. A sedimentation filter sock and a few bales of straw were used to block and divert water to the vegetated section of the wetland to allow wetland plants to establish in the channel. After a few months, the channel was fully vegetated.



Figure 8: Water flows from the conveyance channel (right side of photo) into the inlet pool to promote flow distribution. The inlet pool is typically 3.0 ft deep to prevent the growth of wetland plants, capture suspended solids to protect vegetation, and to dissipate the energy of the water entering the wetland. Note the slightly submerged iron-coated rock apron that separates the inlet pool from the vegetation. The top of the rock apron level to promote even distribution of flow.



Figure 9: Alternative view of conveyance channel and inlet pool.



Figure 10: Installation of rock baffles with 80 ft spacing during construction of a 2.0-acre Wetland. Note darker colored soil layer in 2nd, 3rd, and 4th wetland cells.



Figure 11: Wetland rock baffle used to transport tractor mower across Wetland



Figure 12. Closeup of Wetland outlet pool showing perforated header collection pipe.



Figure 13: Aerial view of Wetland with a conveyance ditch/inlet pool and outlet pool with submerged header pipe connected to a water control structure to discharge effluent and control water elevation in wetland. The three linear channels that extend the width of the wetland in between the inlet and outlet pools are rock baffles. They are used to redistribute flow if a short circuit develops and used as a bridge for heavy equipment to access the Wetland if repair work is required. Note the difference in water coloration/clarity between the inlet and outlet pools.



Figure 14. Agri Drain water control structure being installed during construction of a passive treatment system. The blue line indicates the flow of water from the system to the Agri Drain. The water flows vertically up one side of the Agri Drain, over the adjustable weir plate, and down the other side to the discharge pipe. Several six-inch-height weir plates (stop logs) are in the Agri Drain box and operators can add or remove weir plates to adjust the discharge elevation (See Figure 12). Agri Drain boxes are often enclosed in corrugated pipe before being backfilled to protect the structure (See Figure 15). The embankment will be constructed to within 2 ft of the top of the Agri Drain.

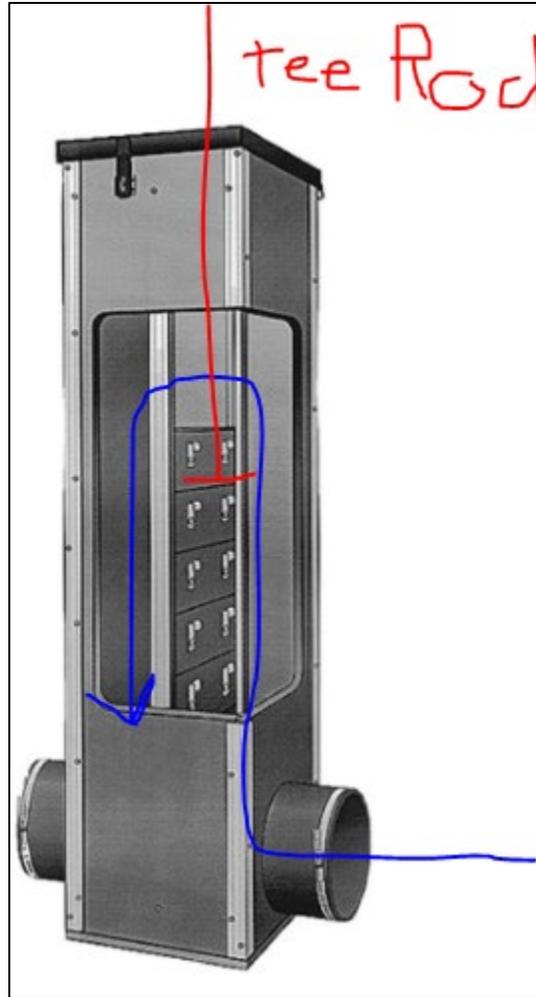


Figure 15: Depiction of Agri Drain water control structure. Water elevation is controlled by adding or removing the rectangular stop logs that set the discharge elevation. Operators use a metal tee rod to add or remove stop logs to control water elevation.



Figure 16: Agri Drain water control structure during construction before being fitted to pipes.



Figure 17: Agri Drain water control structure and anti-seep collar to prevent leakage around pipe that extends through embankment. Note the collar is “keyed” into the base of the embankment.



Figure 18: Three Agri Drain water control structures protected by black corrugated pipe. This is not installed into a Wetland. The photo is being used to show how Agri Drain boxes are protected by corrugated pipe.



Figure 19: Discharge pipe from treatment system with Fernco Coupler. The Fernco coupler is the black rubber boot with two stainless steel bands used to tighten against PVC pipe to prevent leakage. The coupler has enough space that the upper elbow can be raised or lowered to change the discharge elevation (photo credit Tim Danehy of Biomost).



Figure 20: Several discharge pipes with Fernco Couplers to control discharge elevation (photo credit Tim Danehy of Biomost)



Figure 21: Wetland planted with a wide variety of wetland plant species, including *Scripus Atrovirens*, *Peltandra Virginica*, *Sagittaria Laifolia* , *Scripus Cyperinus*, *Juncus Canadensis*, and other species.



Figure 22: Iron removal wetland using wetland grasses in place of cattails. This 2-acre wetland receives 1000 gpm containing 7 mg/L of suspended iron. The high density of Canadian Rush (*Juncus Canadensis*) reduces the iron to an effluent concentration of 0.2 mg/L.



Figure 23: Effluent of 2-acre wetland receiving a suspended iron load of 60 lbs/day. The effluent iron concentration is less than 0.2 mg/L. Note lack of iron-stained rocks near effluent pipe and water clarity in water-filled tube.



Figure 24: A variety of wetland plant plugs for manual planting.



Figure 25: Wetland just after seeding and manually planting wetland plant plugs. A small amount of water (no more than 0.5 ft) will be added to wetland to promote seed germination and plug growth.



Figure 26: Photo taken at a cattail wetland in late Winter/early Spring in Pennsylvania. While much of the vegetation is dormant, iron removal still occurs because of interactions between dormant plant matter and suspended iron particles.