CREATE AN AMD TREATMENT SYSTEM

❑ **Grade Level:** High School	❑ **Subject Areas:** Chemistry, Environmental	❑ **Setting:** Classroom
❑ **Duration:** 60 min.	❑ **PA Academic Standards:** 1.6.8A,C,E,F; 1.6.11A,C,E,F; 3.1.7E; 3.1.10A; 3.2.7B; 3.2.12D; 3.6.12C; 4.3.7A,B; 4.3.10A,B; 4.8.12A,B	❑ **Keywords:** Engineering, design, calculating, presenting

SUMMARY

Students will examine the decisions and processes organizations complete prior to designing a treatment system for Abandoned Mine Drainage discharges. Students will determine the type of system needed to treat a discharge and design the size of the system and develop drawings to present to the “board”.

OBJECTIVES

- Given the necessary data, the student will complete calculations needed to determine the chemistry and flow of mine water.
- After determining the chemistry and flow of the mine water, the student will determine the type of treatment system needed for the situation using the flowchart provided.
- After determining the type of treatment system needed, the student will design and sketch the type of system with depths, and sizes of each cell.
- After designing the treatment system, the student will prepare a 10 minute presentation explain the rationale for the treatment system.

MATERIALS

A. Student Handouts (One Per Group)
   1. WELOS Letter
   2. Yellow Boy Labs Letters
   3. Evaluating Mine Water and Determining a Treatment System
   4. Passive Treatment Options
   5. Instructions For Determining The Treatment System - Calculation Worksheet
   6. Treatment System Flow Chart

B. Poster Board

C. Miscellaneous supplies to design the systems

D. Calculators

E. Power Point Slide Show of each discharge

F. Acid Mine Drainage/Tums

BACKGROUND

The Chemical Reaction of AMD

The first reaction, which occurs in the mine, is the physical and chemical weathering of pyrite, which includes the oxidation of pyrite by oxygen to produce sulfate and ferrous iron. This reaction generates one mole of ferrous iron for each mole of pyrite oxidized.

(1) $$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$$

(1) Pyrite + Oxygen + Water → Ferrous Iron + Sulfate + Acidity

The second reaction, which occurs when the mine water comes in contact with oxygen, involves the oxidation of ferrous iron to ferric iron. Certain bacteria can increase the rate of oxidation from ferrous to ferric iron. This reaction rate is pH dependant with the reaction proceeding slowly under acidic conditions (pH 2-3) with no bacteria present and several orders of magnitude faster at pH values near 5. This reaction is referred to as the "rate determining step" in the overall acid-generating sequence.

(2) $$2\ Fe^{2+} + 1/2O_2 + 2\ H^+ \rightarrow 2\ Fe^{3+} + H_2O$$

(2) Ferrous Iron + Oxygen + Acidity → Ferric Iron + Water

The third reaction, which may occur, is the hydrolysis of iron. Hydrolysis is a reaction that splits the water molecule. The formation of ferric hydroxide precipitate (solid) is also pH dependant. The orange precipitate is seen more quickly if the pH is above about 3.5 but below pH 3.5 little or no solids will precipitate or will do so slowly.

(3) $$Fe^{3+} + 3\ H_2O \rightarrow Fe(OH)_3 \downarrow + 3\ H^+$$

(3) Ferric Iron + Water → Ferric Hydroxide (yellowboy) + Acidity

Reference: http://www.dep.state.pa.us/dep/deputate/minres/bamr/amd/science_of_AMD.htm

ACTIVE TREATMENT

Active treatment uses chemicals to add alkalinity in order to raise the pH and allow the iron and other metals to precipitate. The metals precipitate when they are exposed to air, forming the oxide of metal. Active treatment systems usually add limestone (calcium carbonate), hydrated lime (calcium hydroxide), Pebble Quick Lime (calcium oxide), soda ash briquettes (sodium carbonate) and other highly alkaline chemicals. Each chemical has certain specific application and each one is appropriate for specific situations. The group must decide based on money/funding, and the number of years the system will be needed.

Most active treatment systems are used in open mining situations, that is, mines that are currently being mined.

PASSIVE TREATMENT

Passive treatment requires no machines or people; it relies on the natural chemical and biological processes. Passive treatment was discovered when research showed that existing wetlands were currently treating mine drainage. Numerous wetland treatment theories and models were tested and proved that constructed wetlands were effective in treatment. Initial wetlands were constructed and sphagnum moss was placed in as vegetation. Future experiments with other vegetation proved that cattails were an excellent alternative. Also beneficial in the removal of the dissolved metals in mine drainage is the bacteria present in wetland soils. In order to ensure the existence of the beneficial bacteria, more research on the best organic material to support the bacteria was completed. The organic materials found to assist the bacteria and wetland plants were: soil, peat moss, spent mushroom compost, straw/manure, sawdust and hay bales.

The passive treatment technologies that have been developed are specific to the chemistry of the mine water. Many times it is necessary to combine several of these systems to produce the best overall system for the drainage.

Most systems end with the settling pond and the aerobic wetland to allow the metal precipitates to settle out prior to discharging the water into the stream. The primary things needed for the dissolved iron to drop out of solution are time and oxygen. Vegetation helps to slow the water down in the wetland, when the water has to pass through a group of cattails, it must slow down. The surface area of the wetland is important, the oxidation reaction produces the precipitate, therefore, the more time the water has to react with the oxygen, the more iron that will precipitate. To increase the oxygen contact, air could be bubbled through one pond; the paths from one pond to another can contain a waterfall or pipe that would allow aeration.

When the chemistry and flow of the mine water is determined, the type of system can be considered. The system that is chosen must produce water the meets the effluent standards set by the governing officials if applicable.

PROCEDURE
Warm Up

Review pH

ASK:
If something was acidic, how could be neutralize it?
What chemical could we add to mine water that had a low pH?
What do you take when you stomach is upset? Do you know what is in Tums?

DEMONSTRATION:
Use acid mine water, measure the pH, add limestone or TUMS to the solution and measure the pH again, show the students that by adding the limestone, the acid has been neutralized. You can take it one step further and add hydrogen peroxide to the neutralized mine water and the iron should begin to precipitate out of solution and settle to the bottom.

When mine drainage is created, acid is produced and therefore, many of the metals that are found in rocks and soil are dissolved into the mine water as it travels under the ground. Most people recognize mine water from the orange color, often called “yellow boy”, this is actually the precipitation of iron from the mine water. When mine water exits the mine, it is colorless and if the water is acidic (low pH), the iron and other metals will stay in solution until the pH increased. If the mine water has a neutral pH, the iron will begin to precipitate after contact with oxygen. If you have acid mine drainage entering the stream and stream does not have a well-buffered system, the pH isn’t raised. If this is the case, you may not see the orange color until several miles downstream.

If you are treating acid mine drainage, the acidity must be removed in order for further treatment to take place, because the iron and other metals will not oxidize and drop out or precipitate until the pH is higher. The acid mine drainage also will destroy the ecosystem that assists with the final treatment phase.

Several types of alkaline materials are available to treat acid mine drainage:

- Powdered lime – for smaller flows
- Limestone (Calcium Carbonate $CaCO_3$)
- Hydrated Lime (Calcium Hydroxide CaOH)
- Quick Lime (Calcium Oxide CaO)
- Soda Ash briquettes (Sodium Carbonate $NaCO_3$)
- Caustic Soda (Sodium Hydroxide NaOH)
- Anhydrous Ammonia (NH_3)

When the pH of the mine water is raised, the metals can react with oxygen and precipitate out of solution as the metal hydroxide. The pH solubility of the common metals found in mine water (from most soluble to least soluble) is: Mn > Fe >Al. That means that at a pH of 6, aluminum and iron will precipitate, but manganese will stay in solution.

After the pH is raised and the metals react with oxygen to form a precipitate, the water then must be diverted to a settling pond or a wetland to allow the precipitate time to settle. If you have alkaline mine drainage, the wetland or settling ponds are all that is needed.

After investigating the chemistry of the mine water several things must be considered when determining the type of treatment system to install: amount of land, cost, and amount of time treatment is needed.

The Activity – Development of a Passive Treatment System for Abandoned Mine Drainage

1. Split the student up into groups, being sure that each group has individuals with varying talents.
2. Handout the “WELOS” Letter, one to each group.
3. Discuss what the WELOS Organization needs, and why.
4. Handout the sheet titled, “Evaluating Mine Water and Determining a Treatment System”.
5. Discuss the “Passive Treatment Options” with the students to ensure their understanding and knowledge.
6. Handout the “Yellow Boy Labs” Letters (one per group), each group would have a different discharge.
7. Hand out “The Steps To Evaluating An AMD Discharge And Creating A Treatment System”, the “Instructions for Determining a Treatment System”, and the Flow Chart.
8. Have the students use the data obtained through analysis completed by “Yellow Boy Labs” to complete the worksheet. The worksheet will guide them through the process of determining the appropriate system.
9. After calculations are complete, have the students determine the treatment system by using the flow chart.
10. Have the students design the treatment system; they can complete an engineering type drawing or complete a 3-D model.

WRAP UP

After the students have determined the type of system, developed a drawing, aerial and cross sectional, have them prepare a presentation to bring to you, their boss, and the Department of Environmental Protection. The presentation should include a poster, PowerPoint or handouts showing the reasons for their choice and the drawing they have developed. The presentation should end with how the system will be evaluated for effectiveness.

ASSESSMENT

- The teacher will check the student’s completed “instructions for determining the treatment system” worksheet. **(Objective 1)**
- The teacher will evaluate the accuracy of the type of treatment system needed for the situation, using the answer key. **(Objective 2)**
- The teacher will evaluate the treatment system design and sketch produced by the student to ensure necessary items have been addressed. **(Objective 3)**
- The teacher will evaluate the student’s presentation for knowledge, content, formal speaking skills, and use of media. **(Objective 4)**

EXTENSIONS

RESOURCES

AMD Discharges in the Loyalhanna Watershed, PowerPoint Slides to show all the discharges evaluated by “Yellow Boy Labs” are available from Saint Vincent College EEC.

Evaluating Mine Water and Determining a Treatment System

Introduction:

When pyrite is exposed during mining, contact with water will cause the mineral to weather. This can take place in abandoned mines or during active mining operations. Most of the active mining sites use active treatment, which involves the constant addition of chemicals, with motors, pumps and instruments, to increase the pH (in the case of Acid Mine Drainage) and settling ponds to remove the precipitated metals. This treatment is costly and may need to be continued long after the mining is complete.

Until the 1977 Surface Mining Control and Reclamation Act (SMCRA) took effect, the mining companies were not required to minimize the disturbances of the streams and groundwater systems. These past mining techniques often exposed pyrite and mine operators did not know that the mineral they were exposing would create the problems we have today.

We have now acquired the knowledge and technology to clean up Abandoned Mine Drainage sites through the use of Passive Treatment technologies in which there is little maintenance and the cost is much less in relation to active treatment. Passive systems have a large initial start up cost and are dependent on the availability of the land for development of wetlands or settling ponds.

Passive treatment requires no machines or persons; it relies on the natural chemical and biological processes. Passive treatment was discovered when research showed that existing wetlands were currently treating mine drainage. Numerous wetland treatment theories and models were tested and proved that constructed wetlands were effective in treatment. Initial wetlands were constructed and sphagnum moss was placed in as vegetation. Future experiments with other vegetation proved that cattails were an excellent alternative. Also beneficial in the removal of the dissolved metals in mine drainage is the bacteria present in wetland soils. In order to ensure the existence of the beneficial bacteria, more research on the best organic material to support the bacteria was completed. The organic materials found to assist the bacteria and wetland plants were: soil, peat moss, spent mushroom compost, straw/manure, sawdust and hay bales.

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Most systems end with the settling pond and the aerobic wetland to allow the metal precipitates to settle out prior to discharging the water into the stream. The primary things needed for the dissolved iron to drop out of solution are time and oxygen. Vegetation helps to slow the water down in the wetland, when the water has to pass through a group of cattails, it must slow down. The surface area of the wetland is important, the oxidation reaction produces the precipitate, therefore, the more time the water has to react with the oxygen, the more iron that will precipitate. To increase the oxygen contact, air could be bubbled through one pond; the paths from one pond to another can contain a waterfall or pipe that would allow aeration.

When the chemistry and flow of the mine water is determined, the type of system can be considered. The system that is chosen must produce water the meets the effluent standards set by the governing officials if applicable.

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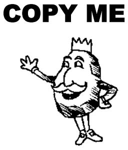

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PASSIVE TREATMENT OPTIONS

Aerobic Wetlands

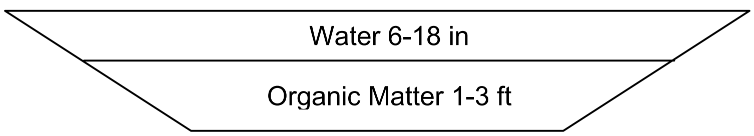
Aerobic or oxidizing wetlands are a low cost and low maintenance way of treating Abandoned Mine Drainage. These wetlands are usually man-made with large cells or ponds in succession to provide treatment for alkaline mine drainage. The cells are usually lined with plastic or clay to prevent seeping and are planted with wetland plants such as cattails. The process is simple; allow the mine water enough time to react with the oxygen in the air to precipitate the metals. The first cell or pond in an aerobic wetland is usually deeper so that cattails will not grow, this will allow the water a larger surface area and a longer reaction time with oxygen. The typical water depth is 6" – 18", but different levels are used to increase performance. Shallow ponds will freeze more quickly in winter months, but deeper ponds allow the precipitate to buildup.

After the precipitate is formed, the water needs slowed down to allow the precipitate to settle to the bottom of the wetland. Vegetation in the remaining cells slows the water down, and it provides another surface for the precipitate to stick.

Disadvantage, the oxidation of the mine water may increase the acidity and lower the pH.

MINIMUM SIZE OF THE WETLAND (acres):

[Fe Loading (lb/day)/180 lb/acre/day] + [Mn Loading (lb/day)/9 lb/acre/day]

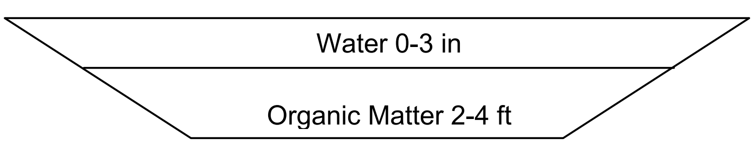


Anaerobic/Compost Wetlands

Anaerobic or non-oxygenated wetlands are very similar to aerobic wetlands. The major difference is that the mine water flows through a layer of thick, oxygen-free compost, usually spent mushroom compost with 10 percent calcium carbonate, to breakdown the sulfates and remove the oxygen. Other compost materials include peat moss, wood chips, sawdust or hay. The iron reducing bacteria is active at low pHs and can survive in low oxygen environments. In order to breakdown the sulfates, the oxygen is consumed, thus providing a low oxygenated water after this step. When the oxygen is removed from the sulfate, the sulfide ion is free to react with the metals and precipitate as metals sulfides. Typical compost depth is 12" – 24" with cattails or other wetland vegetation and 0" – 3" of water.

Again, this is a low cost way of treating Abandoned Mine Drainage and active mining discharges.

There are a couple limitations of the anaerobic wetland: (1) flow and chemistry determine the holding time, (i.e. larger the flow rate, the longer the holding time), (2) if the pH is less than 3, and it is not possible to increase the holding time, the addition of alkalinity is needed to increase the pH, (3) the effectiveness of the system is decreased in the winter months due to the bacteria being less active, (4) the organic layer may need replaced as the microbes break down and consume the material, and the precipitation can clog the bottom of the cells and require maintenance, (5) the wetlands can accept discharges with an acidity up to 500 mg/L.



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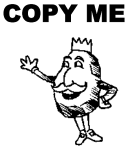

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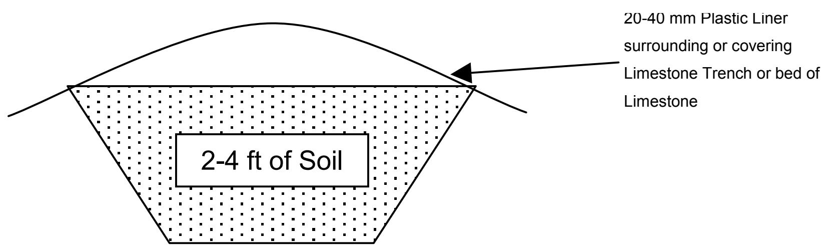
Anoxic Limestone Drains

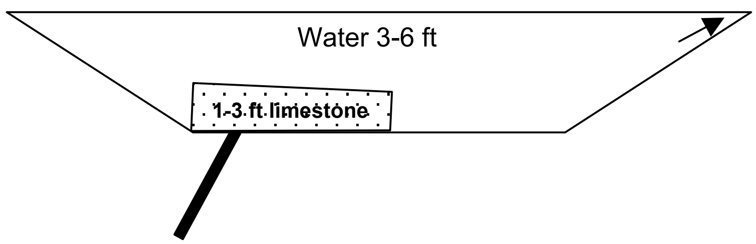
Anoxic Limestone Drains are trenches of limestone in which the acid mine drainage is channeled through. The mine water must have a dissolved oxygen less than 1.50 mg/L. As the mine water flows through the limestone, it is dissolved and the water pH increases and the alkalinity is increased. The oxygen is eliminated through the used of a cover to ensure that the limestone does not get armored.

Anoxic Limestone Drains can produce water between 275 and 300 mg/L of alkalinity, depending on the retention time of the water within the ALD. Retention times 14-15 hours is standard practice.



Limestone Ponds

A Limestone Pond is a pond that is constructed on the mine drainage seep or at the discharge. The mine water flows up through the limestone and the pH increases and the alkalinity increases. Limestone ponds are useful for net acidic discharges with iron concentration less than 5 mg/L.



Vertical Flow Wetland/Alkalinity Producing Systems

Alkalinity Producing Systems combine anoxic limestone drains or limestone ponds with anaerobic wetland. This process is used when there is high acidity and high metal concentrations. Often times it is necessary to do the process several times to increase the pH and alkalinity enough, this is called successive alkalinity producing systems (SAPS).

The Mine water will flow into the SAPS ponds to react with oxygen and allow the precipitation and settling of metals. The water exits the pond or cell through a lower point, which forces the water to travel through an anoxic layer with organic matter or compost to remove oxygen and then through limestone. The removal of the oxygen is important to stop iron from armoring the limestone, which decreases the effectiveness. The water then flows through a pipe to an outlet where it can be aerated, held in a sedimentation pond or filtered through a wetland for settling of precipitates. This process can be repeated as many times as are necessary to increase the pH and remove the precipitates.

This system can also be used with a seep of mine drainage, by reversing the layers, the organic layer would be placed on top of the seep with limestone on top of that, and as the water seeps up through the bottom, the bacteria do their thing and then the limestone increases the pH and alkalinity. These systems are called Reverse Alkalinity Producing Systems.

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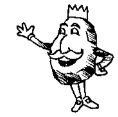

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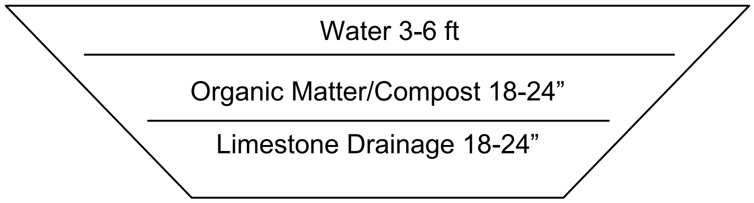
When looking at these systems, the topography and the amount of land available need to be considered, depending on the contaminants; a large system may be needed. The land must be conducive to the flows needed for the treatment system. Clogging of the pipes and systems may occur from the organic matter and the limestone may need replaced if armored or depleted.

The Alkalinity Producing Systems usually have 3’-6’ of free standing water to provide enough pressure to force the water down through the 18” – 24” of compost and through 18” – 24” of limestone containing drainage pipes. They are sized based on retention times typical retention times are 12 – 15 hours, and the amount of limestone necessary is calculated using the equation of the ALD.



EPA - A Citizens Handbook to Address Contaminated Coal Mine Drainage

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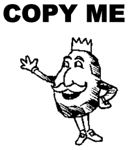

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STEPS TO EVALUATING AN AMD DISCHARGE AND CREATING A TREATMENT SYSTEM

1. Examine what the customer needs, what tests are needed, what the discharge is like, etc. (Read the WELOS letter)
2. Read the handout – Evaluating Mine Water and Determining a Treatment System.
3. Read the handout – Passive Treatment Options. Make notes as the information needed for each option.
4. Request the analytical results from Yellow Boy Labs for the WELOS Organization.
5. Complete - Instructions For Determining The Treatment System worksheet.
6. Use the Flow Chart to determine the system type required.
7. After you have determined your system, design your system. The design should include depths including additives, i.e. compost, size of each cell, overall size and aerial and cross sectional views.
8. Prepare a 10-minute presentation to bring to your superior and the Department of Environmental Protection. The presentation should include a poster, PowerPoint or handouts showing the reasons for your choice and the drawing you have developed. You should end the presentation with how the system will be evaluated for effectiveness (i.e. chemical analysis), be specific as to what will be monitored.

The following are some tips for your system:

1. The detention time of the water is important in the development of the wetland. The length of the wetland should be twice as long as it is wide.
2. The water can be slowed down by planting emergent plants (such as cattails, *Typhus latifolia*), and by designing a series of cells or ponds or by placing deflectors, or baffles, throughout the wetlands.
3. The sides should be designed with 18^{o} to 27^{o} slope. This maximizes stability, makes it easier for equipment that is building or maintaining the wetlands to operate, and to some degree discourages (but is not guaranteed to eliminate) mosquitoes.
4. The cells and the wetland should have a slight downward slope from the influent to effluent. If *Typhus latifolia* are to be planted, surface water column depths of more than 50 cm are usually detrimental
5. The wetland must be lined with a clay liner or an artificial liner to ensure that the groundwater will not mix with the treatment water.
6. It system must be designed to handle the highest average monthly flow rate that occurs during a twelve-month period.
7. It must have inlet and outlet structures that will allow for flow measurement and water sampling, (pipe outlet for bucket and stopwatch measurements, weir, flume, etc.).

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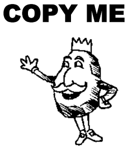

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We Love Our Stream
999 Wetland Drive
Waterfront, PA 11111
(724)145-1234

Ms. Sabrina Eager
Director of Labs
Wetlands Are Us
96 West Heron Street
Springdale, PA 19786

Dear Ms. Eager,

Our organization, WELOS, is in the process of applying for funding for the development of a passive wetland treatment system to treat an abandoned mine drainage discharge currently entering the stream. In order to receive funding, it is required that we show proof of the chemistry and flow of the water to be treated, as well as the proposed plans for the wetland.

We need your company to run some independent tests to help us learn as much as possible about the discharge so that we can pass the information on to our engineer to design the wetland. The following parameters need determined: flow, total iron, and manganese, pH, Alkalinity, Acidity, and sulfate concentration.

The discharge is alkaline, but the iron content seems to be relatively high. Although the discharge has a relatively low flow, it has been captured, and exits via a pipe therefore, a bucket and stopwatch flow should be fine.

Due to the nature of several of the tests, it will be necessary for you to collect the samples and record flow values. We will need at least three months of data to proceed. Please contact me at the above number with any questions.

Sincerely yours,

Yvonne X. Michaels
President
WELOS

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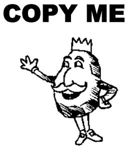

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INSTRUCTIONS FOR DETERMINING THE TREATMENT SYSTEM

Using the letter from the Yellow Boy Labs, the information provided and the flow chart, determine the type of treatment system needed for your abandoned mine water.

Compute the following data from the information provided.

1. Calculate the average flow for your discharge site:

2. Calculate whether the discharge is net acidic or net alkaline (use the average acidity and alkalinity for this calculation.): acidity – alkalinity = positive, the water is net acidic, negative, the water is net alkaline.

3. Calculate the average iron for your discharge site:

4. Calculate the average dissolved oxygen value for your discharge site, it is greater than or less than 1.5 mg/L?

5. Calculate the average aluminum value for your discharge site, is it greater than or less than 5 mg/L?

6. Calculate the average acidity value for your discharge site, is it greater than or less than 300 mg/L if your iron was greater than 5 mg/L, or is it greater than or less than 200 mg/L if your iron was less than 5 mg/L?

FILL IN THE CHART TO ASSIST WITH DETERMINATION OF THE TREATMENT SYSTEM:

Highest Flow	________________	Average Alkalinity	________________
Lowest Flow	________________	Average Acidity	________________
Average Flow	________________	Net Acidity	________________
Average Total Iron	________________	Average Dissolved Oxygen	________________
Average Total Aluminum	________________	Average Total Manganese	________________

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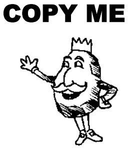

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7. Follow the Flow chart using the information from the handout, data from above and your letter from the analysis lab to determine the type of system that would treat the water most effectively.

8. If your discharge has net alkaline water, the size of your treatment system can be determined by using the loading rates and using the following equation:
   Calculate the Loading rates of the iron and manganese:
   To calculate the loading rates in pounds per day, multiply the flow rate (gpm) by the metal concentration (mg/L). Be sure to unit factor to convert gpm and mg/L to lbs/day.
   Hint: 1.05 quarts = 1 L, and 454 g = 1 lb
   Loading rate for Iron:

   Loading rate for Manganese:

   Size of wetland:
   [Fe Loading (lb/day)/180 lb/acre/day] + [Mn Loading (lb/day)/9 lb/acre/day]

9. On another piece of paper, develop a drawing of the system from the information provide in the treatment options descriptions include depths and amounts.

HELP!!!!!

Calculating Average:
Add up all the numbers and divide the answer by the number of values used in the addition.

Conversion Factors

1.05 quarts = 1 L
454 g = 1 lb
1000 ml = 1L
60 min = 1 hour
24 hours = 1 day

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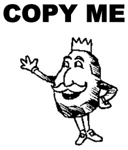

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NOTE: Original Chart has been revised and simplified to allow for ease of use.