Operation and Maintenance for Passive Treatment systems

For:

Somerset County
Conservation District

1590 North Center Avenue, Suite 103
Somerset, PA 15501

By:

Damariscotta
650 Merle Street, Suite C
Clarion, PA 16214

June 2003

TABLE OF CONTENTS

Page

FIGURES

APPENDICIES

Acknowledgments

Damariscotta would like to thank the Somerset County Conservation District for funding and providing data for the production of this manual. Without their effort this manual would have not been possible. We would also like to thank John Dawes of the Howard Heinz Endowments for providing funding that initiated the operation and maintenance guidance manual idea.

In addition the following entities provided mapping, data, and/or personal experience in the individual case studies presented within this document: NRCS Northwest Engineering District – for REM Orcutt/Smail and Tangascootack; Jefferson County Conservation District – for REM Orcutt/Smail, Filson 1 & Filson 2, and Howe Bridge; Headwaters Charitable Trust - for REM Orcutt/Smail, Filson 1 & Filson 2, and Howe Bridge; Clarion University of Pennsylvania - for REM Orcutt/Smail, Filson 1 & Filson 2, and Howe Bridge; Pennsylvania Department of Environmental Protection - for REM Orcutt/Smail.

CHAPTER-1 *INTRODUCTION*

Introduction

This manual is intended as a general guide to explain and detail the operation and maintenance considerations associated with constructed wetlands (passive treatment systems) for treating various types mine of drainage throughout the world – although particular emphasis will be placed on treatment technologies within northern Appalachia in North America. This manual discusses the types of treatment technologies that are currently available and the limitations and applications of these technologies to various types of mine drainage. This ***is not*** a design manual, but a manual that will facilitate the selection of an appropriate technology for a particular type of mine drainage, and once chosen how best to operate and maintain this technology at maximum efficiency.

It is of ***utmost*** importance that the reader understand that the material that is presented, within this operation and maintenance manual, is the most up-to-date information available, but is certainly ***not*** the "final word" in operating and maintaining these types of systems. Current technologies are being refined and improved upon everyday, and as such the technology to operate and maintain them is also changing. The general guidelines that are explained within this manual, as with the technology itself, are sound and can be utilized as a staring point for further improvement in the overall technology.

History of Passive Treatment System Technology

Mining activities over the course of history, while providing for energy needs in the United States, have left a legacy of environmental burdens. The majority of these "burdens" have been manifested quite commonly in our water resources; resulting in higher than normal concentrations of various metals – mostly iron, aluminum, manganese, and sulfates, and lower than normal pH values. While the predictive technologies have improved to prevent waters from being degraded, during the normal course of mining, much of the problem persists. Prior to the development of predictive technologies (to prevent contaminated mine drainage) a significant number of mines would be reclaimed only to leave behind waters that remained contaminated.

The 1977 Surface Mine Control and Reclamation Act requires that mine drainage from all active and many inactive mines (providing a primary responsible party can be identified) comply with effluent criteria. The implementation of criteria associated with the 1977 SMCRA lead to the treatment of mine water to meet the criteria imposed by this act. The criteria are generally a pH between 6-9, iron less than 2 mg/L, manganese less than 4 mg/L and alkalinity that exceeds acidity. These criteria can be easily meet with chemical treatment; the chemicals are typically some form of alkaline material – ranging from caustic soda (NaOH) to ammonia (NH_3). While chemical treatment is very effective in meeting the criteria of SMCRA, it is both very costly and labor intensive, and is only effective when the treatment is in place. Thus, if treatment is missed, for whatever reason, the receiving body of water would collect water that is not in compliance with the SMCRA requirements. Because of the high continual costs and the intensity of labor involved in chemical treatment, constructed (passive*) wetland technology was developed around the time of the 1977 SMCRA requirements.

Passive Treatment Systems (PTS) provided an alternative to labor and cost intensive chemical treatment, *but* the state of the technology, ***at that time*** was such that only certain types of mine drainage could be effectively treated with constructed wetlands. This did not stop the use of the constructed wetlands for all types of mine drainage, and as a result led to the conclusion (Weider 1989 and Weider et al. 1990) that the feasibility of constructed wetlands for mine drainage treatment was marginal at best and practically was non-effective, overall, for most mine drainage

---

* The use of the word passive has been greatly misunderstood as related to constructed wetland technology. The implication associated with PTSs is that these types of systems require no human intervention. When, in fact, these types of systems were described as passive to indicate that they these systems were ***relatively*** maintenance free – compared with chemical treatment. In other words, chemical systems would require dosing constantly, which required a significant amount of human intervention; where as, passive systems do not need this degree of attention. To prevent further confusion, and to maintain some degree of standardization of vocabulary, we will use the term passive treatment system to describe systems that are constructed by man that will require some degree of human intervention (operation and maintenance), and this operation

and maintenance would typically be less than that of chemical treatment – for similar mine drainage.

applications. The primary reason for these types of conclusions were the pandemic use of constructed wetlands (exclusively aerobic wetlands, at that time) for ***all*** types of mine drainage, when in actuality passive treatment technology at the time did not allow for such usage. The application of passive treatment system technology was, and should have been, limited to net alkaline waters with low concentration of metals. Many of these early constructed wetlands were designed with the intention/attempt to mimic natural wetlands – cattail marshes and *Sphagnum* bogs.

Various investigators during the 1980's and 1990's continued to develop technologies, and a better understanding of mine water chemistry, to better deal with the limitations of the first constructed wetlands. These developments lead to systems that could be effective when the mine water was either net acidic or net alkaline, high flows, ***and*** with high metal concentrations. These developments included: 1) the anoxic limestone drain (ALD); 2) the Successive Alkalinity Producing System (SAPS) and synonymous variants (i.e. vertical downflow systems, reducing alkalinity producing systems, etc…); 3) compost wetlands; and 4) the Aluminator. These types of systems, when appropriately applied, provided for treatment that was both effective and long term* (*much of this technology is less than 15 years old, and thus the longevity data is just being developed).

Since the beginning of the use of constructed wetlands for mine water treatment, hundreds, if not thousands, of these wetlands have been implemented. The degree to which these wetlands have "worked" has varied significantly, which has maintained a degree of skepticism about constructed wetlands by those unfamiliar with the science and technology. This skepticism has, over the years, proven unfounded when the appropriate technology is applied to *specific* mine water ***and*** the system is properly designed, operated and maintained. While much has recently been devoted to the proper selection of the appropriate technology to specific mine water chemistry, little has been produced to help those who construct such systems operate and maintain them.

The ***effective*** treatment of Acid Mine Drainage (AMD), or simply mine drainage, is key to restoring thousands of miles of impacted streams throughout Appalachia. Technologies exist, and are being implemented at an ever increasing frequency, that can meet this end. These technologies, as stated previously, include (but are certainly not limited to): Open Limestone Channels, Anoxic Limestone Drains (ALDs), Aerobic Wetlands, Anaerobic Wetlands, and SAPS (Successive Alkalinity Producing Systems). These types of systems have been applied/constructed in a myriad of situations over the last several years; especially as the technologies have become more proven. The establishment of these types of systems to counter the affects of mine drainage throughout Appalachia, has necessitated the establishment of more standardized criteria, to be used by those implementing the technologies, for their operation and maintenance. This publication is for this purpose and relies on over a decade of experiences with all of these technologies ***and*** actual, implemented systems that are used as examples of what should, and should not, be done to ensure proper operation of the passive treatment system.

Without a consistent level of treatment, the ultimate goal of the treatment and restoration activities, based on these types of treatment, associated with abandoned mine drainage are obviously short-lived. Based on field experiences over the last 20 years, the principles of treatment of mine drainage are fundamental and sound, but the way that these principles are applied in the field (by individuals, consultants, state and federal governments) are vastly different. The result of these differences in applications has lead to even larger differences in the longevity and effectiveness of the systems.

Over the last several years we have examined several systems that initially functioned “normally”, only to decrease in treatment effectiveness to the point that treatment is minimal – if any. System design life spans that were calculated to be in the tens of years have been reduced, in some cases, to less than one year. This is particularly discouraging in that most of these systems have the proper components. Many times the only reason(s) for the decrease in efficiency is the lack of proper operation and maintenance. The remaining cases are, almost always, improper design/treatment selection.

It is the intention of this manual to discuss the various types of treatment systems that are currently in use, when and where they are applicable and how they should best be maintained to provide for maximum longevity and treatment effectiveness. We have also included case studies of systems that have not met their design life and/or treatment effectiveness goals and offer explanations as to why.

It is Damariscotta's position that effective, sustained AMD treatment requires sound and properly implemented technologies that can be and are maintained at their inherent maximum level of effectiveness for as long as is necessary to meet the needs of the project. If AMD treatment requires modification of an existing water chemistry, and if that modification can be accomplished through a given technology (e.g. SAPS), then the key aspect of this position has been met.

CHAPTER 2. *Types of Passive Treatment Technologies*

Aerobic Wetlands

As mentioned previously, the first wetlands designed for mine drainage treatment, were intended to mimic natural wetlands (actually *Sphagnum* spp. peat wetlands). These natural wetlands, that received mine water, were observed ameliorating the drainage to some degree (i.e. removed some metals and pH values improved). The first attempts utilized *Sphagnum* (Weider, 1985), while later efforts utilized cattails (Hedin and others, 1994a; Skousen and others, 2000; *see* Figure 1).

The idea for the original aerobic wetlands was that the plants (mostly *Typha latifolia*) within the wetlands were absorbing metals, which helped adjust the pH upward. Subsequent investigations found that the plants did little in the way of metal removal, except provide for *adsorption* sites; and that it was only the aerobic wetlands that were implemented in net alkaline waters that provided significant mine drainage amelioration.

Figure 1. Typical Aerobic Wetland, Garrett County, Maryland.

These types of wetlands typically were shallow (1 foot or less) water, with the vegetation planted in organic material or available on-site material. The aeration that these types of wetlands typically provide, allows for the oxidation of Fe^{2+} and ultimately its precipitation and deposition (given adequate detention time) as FeOOH. Aerobic wetlands have proven acceptable treatment when the water is net alkaline, with iron concentrations not exceeding the alkalinity available to precipitate it (given oxygen and time) or mildly acidic water with little iron. Aluminum is typically not a design criteria, as the pH is such that if aluminum is present it is typically precipitated within the first portion of the constructed wetland. Manganese can be treated within these types of wetlands, but only if iron and aluminum are not present and the pH is above 6.0 (ideally even higher). If these parameters can be met, manganese can be removed from the mine drainage; but only with large surface areas and typically during the warmer months (as this process is biologically mediated). In addition, if sufficient amounts of alkalinity are not present in the mine water, the pH will decline as iron is removed, due to the generation of proton acidity by iron hydrolysis (Skousen and others, 1997).

Anoxic Limestone Drains

Anoxic limestone drains (ALDs) were developed by members of the Tennessee Valley Authority, as a result of limestone that was placed in contact with lower pH water, in the construction of a conduit underneath a roadway. Upon measuring the pH at the end of the limestone conduit it was noted that the pH was elevated. ALDs are simply buried limestone trenches (that vary greatly in width) that produce alkalinity

The only real limitations to aerobic wetlands are the iron concentration/alkalinity ratio (roughly 7 mg/L of alkalinity are required to compensate for every 1 mg/L of iron) and the surface area available relative to the Fe/alkalinity ratio. The surface area limitation can be partially compensated for, if volume is used to maximum advantage. In fact the use of “sedimentation” ponds as a portion of the treatment system in aerobic wetlands has been used to great advantage in some systems – provided that the volume of the pond is used to maximum advantage (e.g. with flow impeding curtains).

(bicarbonate – HCO_3^-) via limestone dissolution.

ALDs are typically constructed at the point of the mine discharge, and are built to capture the mine water underground. The trenches are then filled with relatively high concentration $CaCO_3$ limestone and then sealed with an “impervious” layer (clay and/or compacted soil) to prevent oxygen contact with the mine drainage (Hedin & Watzlaf, 1994). Acidic water that flows through the ALD dissolves the limestone and releases the bicarbonate alkalinity. These systems have demonstrated the ability to generate as much as 300 mg/L ($CaCO_3$ equivalent) with retention times less than 24 hours (Hedin and Watzlaf, 1994; Hedin and others, 1994a). Net alkalinity generation capabilities within an range of 150-250 mg/L are more in line with the typical capabilities of ALDs.

ALDs are typically a pretreatment of mine drainage to facilitate the precipitation of iron when net acidic conditions prevail. ALDs too have their limitations and when Aluminum or *Ferric* iron (Fe^{3+}) is present in the mine drainage, in significant concentrations & loadings (generally pounds/day), ALDs are most often ineffective. The primary reason for the ineffectiveness of the ALD systems, when these contaminants are present, is that they can precipitate in anoxic environments. The obvious ramifications of precipitants in a closed system, with limited outlet structures, is the potential for flow restriction. This has been documented in many ALDs with “higher” concentrations of Aluminum and/or ferric iron.

Anaerobic Wetlands

Anaerobic wetlands were modified from aerobic wetlands in an attempt to raise pH, which would help increase metal precipitation. The modification included the addition of a bed of limestone beneath an organic medium (usually composted manure of some type). These modifications were made to facilitate the generation of bicarbonate alkalinity through both limestone dissolution and microbial sulfate reduction (CH_2O representing biodegradable organic compounds). The intention was to raise the pH with the increased alkalinity, with would ultimately facilitate the precipitation of acid-soluble metals such as iron.

Hedin and others (1994a) reported anaerobic wetlands that were capable of removing iron at rates of up to 1,300 mg/day/ft^2. Overall, however, anaerobic wetlands are limited in their capability to raise pH, especially when flows and metals are high, and pH is low. The major limiting factor to the effectiveness of anaerobic wetlands is the slow mixing rates of the alkaline subsurface waters with the acidic waters near the surface. This can be overcome to some degree by increasing the size (retention times) of the wetland; however, this is also typically an impediment as land area available for construction is typically limited.

Successive Alkalinity Producing Systems

Successive Alkalinity Producing Systems (SAPS) are a hybrid of treatment mechanisms of both ALDs and anaerobic wetlands, with the benefit of compensating for the limitations of both of these systems (Kepler and McCleary 1994). The first SAPS type systems were developed in Virginia in 1987 by A.C. Hendricks (Hendricks 1991). In the early 1990s SAPS were also being implemented in western Pennsylvania (Kepler and McCleary 1994). These systems developed a piping system within the limestone layer to maximize the treatment effectiveness related to alkalinity production via limestone dissolution and microbial sulfate reduction. This subsurface piping system allows for sufficient contact time between the acidic water and the organic material/limestone layers, which facilitates a rise in pH and alkalinity and the ability of the overall treatment system to remove acid-soluble metals.

SAPS systems have been given a variety of names since their inception including: 1) RAPS – Reducing and Alkalinity Producing Systems; 2) APS – Alkalinity Producing Systems; and 3) Vertical Flow Systems – VFS. Independent of the names given to the system, the basis for design *should* be the same. Examined from the surface to the bottom of the system (*see* Figure 2), the components are: 1) standing water (typically 3-6 feet); 2) an organic material layer (typically 0.5-2 feet); and 3) a limestone layer (typically 2-5 feet).

These system are based on volume rather than surface area, which reduces area requirements over other systems (i.e. anaerobic wetlands), and because of this and the alkalinity generation ability of SAPS, more treatment can be accomplished in a smaller area. In addition, since these systems are usually implemented in highly net acidic waters, with significantly elevated metal concentrations, they are typically utilized as pre-treatment; and when necessary (because of metal concentrations/high acidity) can be used in succession when the alkalinity is depleted due to iron hydrolysis.

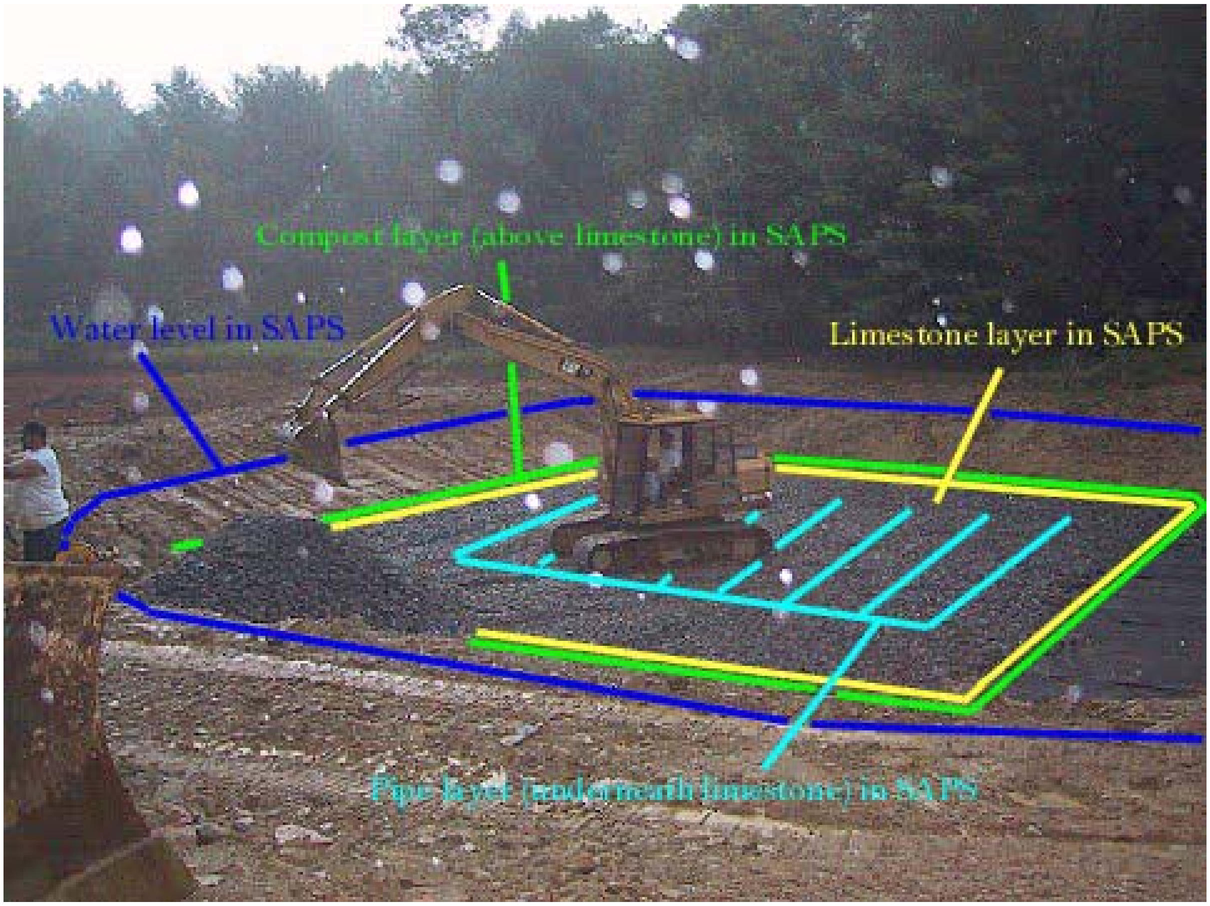


Figure 2. SAPS under construction with typical layers illustrated, Howe Bridge, Jefferson County, Pennsylvania.

The organic layer prevents dissolved oxygen from interacting with the mine water in the limestone layer, which prevents limestone armoring from the iron present in the mine water. The organic layer also has the added benefit of producing alkalinity via microbial sulfate reduction, this is typically only beneficial in the warmer weather months. In the limestone layer, $CaCO_3$ is dissolved by the acidic, anoxic waters moving to the drainage system, producing the majority of the alkalinity for the system.

The plugging that could occur with ALDs, with aluminum and ferric iron, is prevented to a large degree by a valved flushing system *that* is connected to the piped drainage system and a reducing zone, respectively. The valved drain is typically from 4-10 feet below the level of the standing water within the SAPS pool. The standing water creates head pressure that moves water through the system rapidly, flushing the aluminum (and typically ***small*** amounts of iron) from the limestone layer. The frequency of the flushing events is dependent on the loading rate of metals (primarily aluminum) to the system. If more that one SAPS unit is installed on a mine drainage *that* contains aluminum, subsequent units rarely require the flushing frequency of the first unit, as the majority of aluminum is typically removed in the first SAPS unit. Ferric iron is reduced to ferrous iron in the organic layer which prevents coating of the limestone (rendering this component useless or marginally effective).

Open Limestone Channels & Diversion Wells

Open Limestone Channels (OLCs) are, as their name implies, channels that are open to the atmosphere, and lined with limestone. These are typically applied when the mine drainage must be conveyed over some distance prior to the utilization of treatment. These channels are typically most effective when placed on slopes that are greater than 20% (Ziemkiewicz and others, 1997). Diversion wells are systems that contain small sized limestone/alkaline material, in a relatively small enclosed container (300-1000 gallon cisterns are common). Water from an upstream pool (utilized to create head pressure) is piped to the cistern containing the limestone/alkaline material which circulates the depressed pH water in the cistern with the limestone. This circulation action dissolves the limestone/alkaline material and, theoretically, prevents the limestone from being coated.

Open limestone, either in channels or in diversion wells, are a treatment technology approach that is appropriate when metal concentrations (other than manganese) are *very low*, and the pH and acidity are relatively low. These types of systems have been used successfully *when* these conditions have been met with the mine source water. In situations where these types of systems have been utilized, when the metals are elevated and/or the acidity is also high, they have met with *limited success*. The use of limestone to ameliorate high metal containing mine drainage has been attempted decades ago and the usefulness of such treatment was not, and is not cost effective. This was the primarily due to the fact that the limestone becomes coated quickly and it's ability to generate alkalinity is thus reduced dramatically. However, when iron is low, or not present, the effectiveness of these types of systems is improved dramatically. These types of systems have been employed successfully in watershed restoration activities in watershed that suffer from depressed pH and alkalinity. The amount of alkalinity that these systems can usually generate (in appropriate conditions) is usually sufficient to raise the pH of the stream to at or near 6 s.u. and enough buffering capacity to compensate for "acid slugs" associated with high waters.

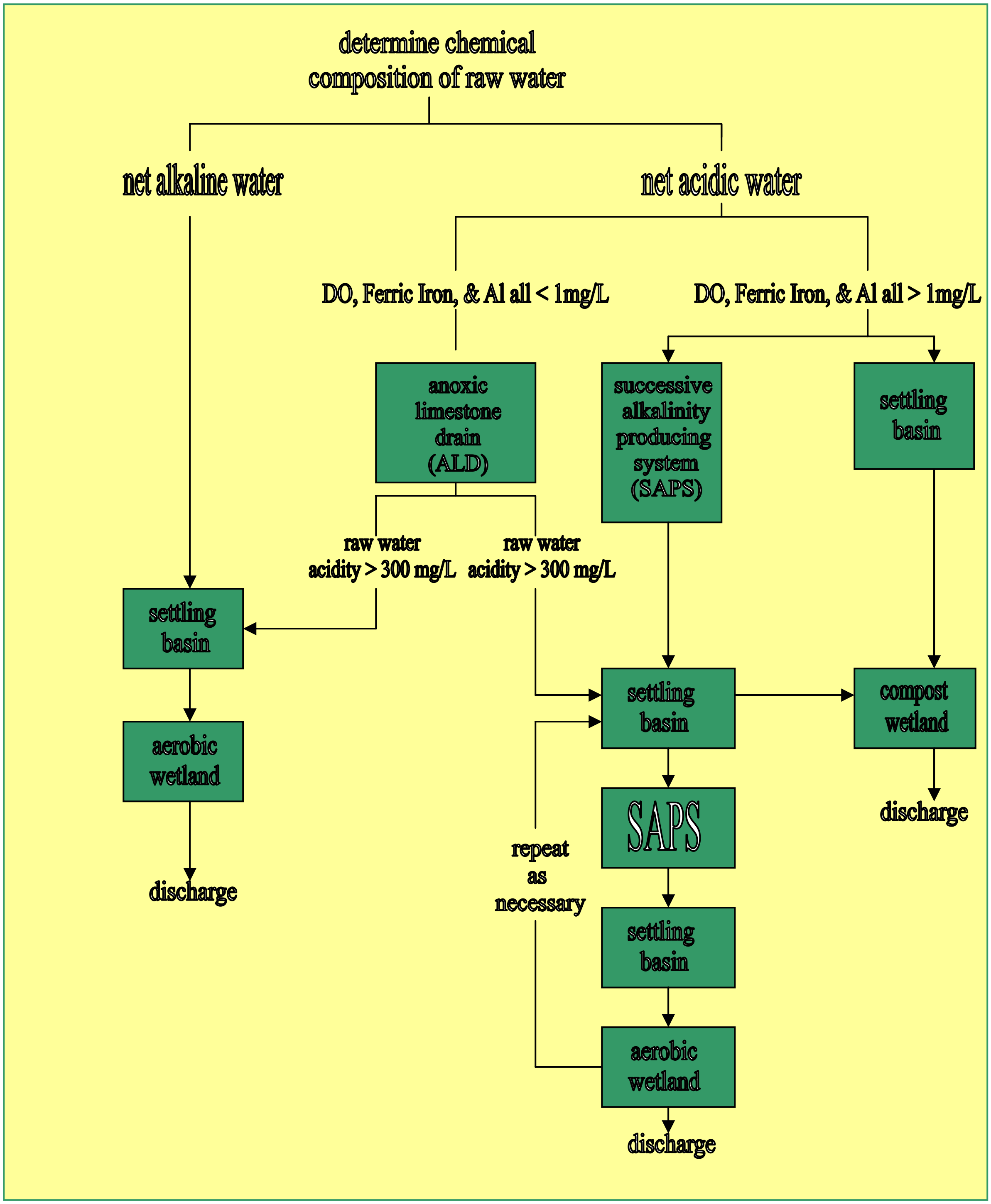


Figure 3. Passive Treatment System flow chart for selecting the appropriate treatment technology (modified from Hedin et.al. 1994).

Chapter 3. *Designs Parameters for each type of Passive treatment systems*

The appropriate design selection of all passive treatment systems begins and ends with an accurate characterization, both flow and chemistry, of the mine drainage to be treated. Prior to type of treatment selected this characterization is necessary to preclude "failure" of the system or an inordinate amount of operation and maintenance effort. The pre-selection criteria outlined in this section will help prevent such "failures" and unnecessary operation and maintenance.

Hedin (1994) summarized a treatment decision flow chart (Figure 3.) to be utilized when implementing passive treatment systems for mine drainage. This diagram was modified to included the types of treatment systems described within this manual.

Once accurate flow and chemistry measurements have been made, which generally include at least 12 months of data, to better characterize variation in flow and chemistry that typically occur with mine drainage. This characterization is crucial to the proper sizing and material requirements for the type of passive treatment selected. Water samples should be analyzed for pH (lab and field), ferric iron, ferrous iron, total iron, manganese, aluminum, sulfate, alkalinity, acidity, and dissolved oxygen. Measured acidity should be checked against calculated acidity to ensure that the chemistry is acceptable for design purposes. This is accomplished using specific values for ferris and ferric iron (1.8 and 2.7, respectively), aluminum (5.6), manganese (1.8), and pH (ranging from 0.1 at a pH of 7 s.u. to 158 at a pH of 2.5 s.u.; on a logarithmic scale); these numbers are then multiplied by the actual/specific metal concentration values and measured pH value; the resultant values are then summed to provide a total calculated acidity value. If this number is within 10% of the measured acidity value it is considered to be in "good" agreement, and the designer can then be relatively confident that the selected design is appropriate. Flow should be taken either with a weir or bucket and stop watch (estimates should not be used). Flows measured over the course of one season should be adequate for design purposes.

The water chemistry and flow data supply the conditions under which the treatment system can be designed for. Previous information suggests that the treatment system(s) should be designed for the “worst” case conditions. It is our contention that to do so, in the majority of cases, is neither cost or environmentally efficient. When the treatment system does not have to meet effluent criteria it is best to design the system for a high average flow and chemistry (elevated metals and depressed acidity/pH), as this would easily exceed the needs of the treatment system to effectively treat the mine drainage for the majority of the year; when the flow and/or chemistry are elevated the treatment system is designed such that a buffer exists which allows for effective treatment despite the higher loadings. Many times the worst case scenario includes data that is aberrant and/or non-indicative of the average loading values. If, for example, the flow of the discharge is typically 20 gallons per minute or less, but it has been “measured” as high as 100 gallons per minute - and you are required to build to encompass that level - then the cost of treatment has been increased several fold – to account for a very small percentage of the time the drainage requires treatment at this level. In cases like these it is imperative that the flows be examined closely to determine if this value is accurate or is an aberration caused by poor surface diversion or other such factors.

It is also imperative that the governor of the design be aware that all of these systems are site specific and the design can and must be adjusted accordingly. Many systems are currently being utilized for stream restoration activities, and in many of these cases the receiving streams are heavily polluted and biologically devoid of life. When this is the case, the design requirements would be much different than a system that is placed on a receiving stream that is only impacted by that specific discharge. In the former instance the systems should be designed to reduce as much acidity as possible (and the biologically significant metals – aluminum and iron) and elevate the pH. The latter condition would require that the alkalinity exceed the acidity, aluminum and iron are eliminated, and the pH is 5.5 or greater (typically streams in mined areas of Appalachia have background pH values in the 5.5 range). Manganese is not of great biological concern, and as such, need not be a design consideration for restoration activities. In regulated situations manganese is typically a design consideration but many of the more progressive states are currently modifying this requirement.

Passive Treatment System Selection

As mentioned the selection of the type of passive treatment system is governed by the water chemistry and the flow, or the loading of the acidity and metals present in the water. Figure 3. is a flow chart representation generally used to direct the designer to the appropriate passive treatment system.

The first decision that is required, based on the chemistry, is whether or not the water is net alkaline or net acidic. If the water is net alkaline then the metal concentration (iron in this case – typically) needs to be examined; if the alkalinity present in the source water is high enough to compensate for the proton acidity produced by the iron oxidation process then an adequately sized settling basin/aerobic wetland would be sufficient. If the oxidized iron acidity concentration is greater than the alkalinity present in the source water (net acidic), additional alkalinity must be created; in this case a SAPS is typically placed within the treatment system at a point when the source alkalinity is consumed and the additional alkalinity is needed.

If the water is net acidic then two options exist depending upon the concentrations of dissolved oxygen, ferric iron, and/or aluminum. The first option available is the use of an anoxic limestone drain, if the dissolved oxygen, ferric iron and/or aluminum numbers are low (typically less than 1.0 mg/L). When these parameters have been met the use of an ALD is typically area, treatment, and cost efficient. The use of an ALD as a pre-treatment alkalinity generator has been well documented and is effective in this role. ALDs are thus typically utilized when the water is net acidic and the major contaminant is iron (ferrous). The sequence for an ALD system is: ALD-settling basin/aerobic wetland-SAPS (if/as necessary).

The second option, when the acidity exceeds the alkalinity, and dissolved oxygen, ferric iron, and/or aluminum is greater than 1.0 mg/L, includes the use of a Successive Alkalinity Producing System (SAPS) or an Aluminator (a modified SAPS). The SAPS would be used similarly to an ALD as pre-treatment to generate alkalinity to remove the iron and aluminum components of the mine drainage. The SAPS, with it's integral organic layer, can remove dissolved oxygen prior to the mine drainage contact with the limestone. If aluminum is present then this metal typically is removed within the limestone layer of the *first* SAPS/Aluminator unit. Iron generally is accumulated within a receiving settling basin/aerobic wetland, and if sufficient iron (actually the proton acidity released when oxidized) exists within the mine drainage to exceed the alkalinity generated within the SAPS/Aluminator then at least one additional SAPS unit will be required. SAPS have been utilized successfully on net acidic discharges with high iron (ferrous or ferric) and/or aluminum. The typical treatment sequence when SAPS are utilized is: SAPS or Aluminator (if significant aluminum is present), settling basin/aerobic wetland, additional SAPS unit(s) as necessary.

The other types of passive treatment systems described previously are marginally effective relative to aerobic wetlands, ALDs and SAPS and typically are relegated into service in certain "special" situations. When all things are equal aerobic wetlands, ALDs and SAPS are the most cost effective passive treatment currently available in terms of acid and metal loads removed per square foot (cubic feet in some instances).

Chapter 4. *Typical Treatment Components and Mechanisms of Commonly used Passive Treatment Systems*

The construction and the components that are placed within one of the passive treatment systems described are crucial to the long term performance of the system. This section examines that typical construction and components of the most commonly used passive treatment systems and the reasoning for certain construction and component selection.

Aerobic wetland and settling basins are typically constructed much like any type of pond, with the exception that aerobic wetlands are usually shallow units with an organic material (e.g. spent mushroom compost) added to facilitate wetland plant (cattails) growth. Typically no special structures are included in the design of these systems (settling basins), although curtains are sometimes added to facilitate the precipitation of iron (by better utilizing the total available volume).

Anoxic Limestone Drains are typically constructed at the source of the mine drainage. The drains are usually excavated into the existing ground, the limestone placed, piping installed, remaining stone placed and then covered with "clay" (quite often the material present at the site is the material used). The piping structure is constructed such that the pipe outlet is higher in elevation than the highest level of the limestone, to help prevent oxygen from entering the system. Typically these pipes are not valved, as flushing or maintenance is typically not a design issue; other than replacement of limestone when the longevity of the system has been reached. Figure 4. illustrates the general layout of a typical ALD system.

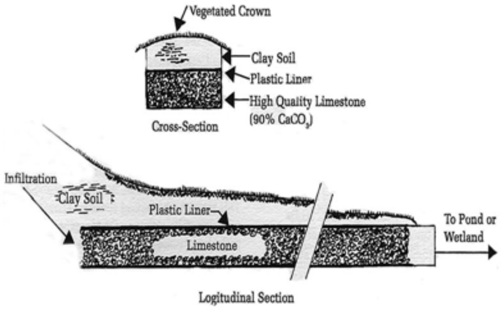


Figure 4. Generalized Schematic of Anoxic Limestone Drain

SAPS and Aluminators are similar to ALDs with the exception that no "impervious" cap is placed over the limestone – an organic layer and water are used as the "cap" material instead.

The piping layout can vary from simple (single collection units) to complex (multiple layer units and individual sub-systems); and ***all*** properly constructed piping systems are developed with a valve that can control flow (and thus elevation of the water in the SAPS) and the flushing/draining of the SAPS unit. Typical SAPS/Aluminator units (treatment systems placed on discharges with less than 500 mg/L of acidity) are being constructed with two to four discharge piping zones. Each of these zones, as mentioned, is controlled by a value that allows for control and flushing of that zone. In some cases flushing zones are kept separate from the normal flow zones to also help prevent preferential flow paths from developing. Figure 2. illustrates a typical SAPS/Aluminator design.

Spillways that are incorporated as a part of any of these treatment system designs are relatively standard. Typically they are lined with a filter fabric/cloth (to help prevent erosion from occurring under the spillway stone), underneath rip-rap sized stone (8-12 inch). The size of the stone placed in the spillway is dependant upon the flow and the slope of the spillway. The larger the flow and/or slope the larger the stone must be, that is placed in the spillway.

Chapter 5. *Operation and Maintenance Considerations for Various Passive Treatment Systems*

Because *effective* treatment of any mine drainage requires the removal of metals (iron, aluminum, or manganese or any combination of these metals) maintenance of the system to ensure continued effective treatment is a must. Since passive treatment inception the implication has been that this type of treatment, relative to chemical treatment, does not require regular maintenance. This could not be further from the truth; in actuality, relative to chemical treatment, the maintenance requirements are typically magnitudes less but they, to some degree (depending on the loading of the materials removed), remain as an integral part of the treatment.

The amount of monies that are being funneled towards watershed restoration projects, in mine drainage impacted areas, is growing exponentially; and is currently in the millions of dollars in Pennsylvania and the surrounding states. The vast majority of the treatment systems, implemented as a part of these restoration projects, are the one that have been described, especially SAPS/ Aluminator type systems. While generally these systems have performed to expectations initially, the lack of operation and maintenance (funds) built into the application of these systems, in the design phase, has compromised the overall integrity of the restoration efforts in this region. Entities that have implemented these systems in hopes of recovery of aquatic resources have been met with marginal success from two fronts: 1) improper design and implementation; and 2) lack of maintenance of properly designed systems. The improper selection of the appropriate treatment system, for a given mine drainage, and/or improper design of an appropriate design is beyond the scope of this manual.

However, if we assume that the appropriate design has been selected and implemented, the development of a more "standardized" operation and maintenance guidelines for these types of systems would encourage greater longevity ***and*** efficiency of these treatment systems - which would ultimately provide for the meeting of the goals and expectations of all of these watershed restoration projects. This chapter will discuss when, where, and how treatment of these systems should occur to maintain maximum treatment effectiveness of each of the commonly used passive treatment systems, discussed previously.

When, Where & How

When maintenance should occur is generally self-evident, from the standpoint that when effectiveness of the treatment system declines maintenance of some type is required. The types of maintenance varies with the type of system selected (*where* & *how*), each type of system will be examined along with their specific operation and maintenance requirements.

Aerobic wetlands/Settling Basins

When aerobic wetlands are chosen as a treatment mechanism for AMD, typically the major contaminant is iron; which is thus the major operation/ maintenance concern of these types of systems. Iron accumulation can be determined *a priori* by the theoretical removal rate (calculated removal) and *a posteriori* by the actual removal rate (measured removal). The calculated numbers can give one an approximation of the amount (in terms of mass) of iron that can be removed based on the alkalinity, oxygen, and detention time of the targeted mine drainage. To determine the actual amount of iron that the system is accumulating, one can use the measurement of the iron removed within the system as: ***total iron in – total iron out***. This measurement allows one to estimate the time that is needed before the detention time within the system is reduced to a level that the efficiency of the system is compromised. Typically, when the efficiency drops as a result of iron build-up, the amount of iron (actual measurement) removed within the system is noticeably decreased. As a “rule of thumb” when the removal efficiency drops below 60 percent of the previously established removal rate, the most likely cause is reduced retention time within the treatment unit. This is typically due to the build up of iron, but may not necessitate the clean-out of the entire treatment unit. Sometimes accumulation is preferential and certain areas accumulate differential amounts resulting in “short-circuiting” and a reduction in the removal rates. In either case the cause is typically self-evident upon visual inspection of the system.

Once the system has accumulated enough iron to affect the efficiency of the system then the iron needs to be removed. This can be done a number of ways but is typically pumped from the settling basin as a slurry and then transported to a suitable disposal area. If the water in the basin can be removed to the point that the iron can dry then the iron can be physically removed with a machine (tracked excavator, loader, etc…), loaded into a truck and then disposed of accordingly. Since iron is not currently classified as a hazardous waste, disposal is typically not a problem. In fact, the recovery of iron from passive treatment systems is currently being explored by Hedin Environmental, Incorporated. This iron, once recovered, can be used in various applications (paint pigment, iron supplements, aspirin, etc…).

The only other real concern within aerobic treatment systems is the buildup of organic material within the "wetland" portion of the system and the spillways. The accumulation of organic material within the spillways occurs relatively often and needs to be addressed when the system is monitored. Seasonally, the fall of the year (in Appalachia) is a time when the spillways need to be checked frequently as leaf accumulation is quite common. Blockage in spillways can cause erosion of the embankments adjacent to the spillway, if left unattended. Organic accumulation within the aerobic treatment system itself can, overtime, affect the detention time within the aerobic unit which can decrease system efficiency.

Other items of concern include muskrat infestation (draining ponds, eating cattails, etc…), vandalism (e.g. ATVs), and settling of embankments. These can and do occur but occur at different frequencies, depending on the location of the system. The solution to these different types of problems is site specific and quite variable in terms of effectiveness.

Primary Operation and Maintenance Concerns of Aerobic Systems/Settling Basins

1. insufficient detention time;
   Solution – restore detention time, usually caused by iron accumulation or re-examine system size.
2. short circuiting (associated typically with insufficient detention time);

Solution – correct short circuiting, also typically caused by iron accumulation in a specific location, creating a more direct flow path.

3. spillway constriction/blockage;
   Solution – remove constriction/ blockage, typically vegetative matter.
4. vandalism (ATV trails, etc…) & animal damage (muskrats, etc…);
   Solution – determine appropriate response for specific problem (i.e. muskrats, ATVs utilizing the treatment system as a trail, etc….)

Anoxic Limestone Drains (ALDs)

ALDs once constructed (assuming proper water chemistry), really have relatively little operation and maintenance concerns, as their primary purpose is to boost alkalinity. Thus, the consumption of limestone would be the major operation/maintenance concern. This entails the replacement of stone within the system when the alkalinity generation drops significantly from the established alkalinity values immediately post-ALD construction (values measured within one month post construction). It has been our experience that this typically occurs near the expected life of the ALD when the two following assumptions have been met: 1) the water chemistry is appropriate for an ALD – i.e. no aluminum or ferric iron; and 2) the drainage system is such that water from *throughout* the ALD can be collected, thus drawing water "uniformly" from the limestone bed within the ALD.

When these two assumptions have ***not*** been met is typically when ALD systems "fail". If the water has ferric iron, in significant quantities, the limestone can become coated and alkalinity from limestone dissolution is negligible. If the mine water has aluminum, the aluminum precipitates within the ALD, and over time (from a few weeks to years, depending on the loading) will plug the system and prevent, or greatly reduce, the flow from the ALD. Almost all of the "failed" ALDs that we have examined, were the result of metal accumulation within the ALD. In the remainder of cases, mine water was not obstructed from entering the piping system within the ALD (due to precipitated metals), but the collection system was insufficient to collect water from throughout in the ALD resulting in short circuiting and/or inadequate contact time with the limestone.

In addition, if the outlet piping from an ALD is constructed such that the outlet water is exposed to oxygen within the outlet piping, iron can accumulate in this area, requiring removal to ensure unobstructed flows from the ALD unit. Depending on the amount of iron (ferrous) in the target water and the exposure to oxygen, this accumulation can occur rapidly, interfering with the flow from the ALD.

Primary Operation and Maintenance Concerns of Anoxic Limestone Drains (built for mine water with little or no aluminum and/or ferric iron)

1. Insufficient alkalinity production; ***Solution*** - replacement of limestone when alkalinity generation decreases significantly; examine design to ensure that water is being collected evenly throughout the ALD.
2. Iron build up in discharge piping; ***Solution*** - periodic visual inspection of outlet piping to assure unobstructed flows, if iron accumulation is observed remove iron precipitate constriction and install piping to ensure complete inundation of discharge opening (to prevent oxygen from entering discharge pipe).

SAPS and Aluminator type systems

These systems due to the type of water that they treat and the concomitant level of system complexity require more operation and maintenance than either aerobic wetlands/settling basins or Anoxic Limestone Drains. Because the water typically treated using these types of systems is high in acidity and metals (often both aluminum and iron) the concerns of both aerobic wetlands/ settling basins and ALDs apply to SAPS and Aluminators. The determination that maintenance is required is also similar to the other types of treatment in that a decrease in treatment efficiency triggers the maintenance response.

Maintenance response sequence for ***SAPS***

1. Determination that treatment efficiency has decreased, primarily a decrease in pH, alkalinity, and/or surface water elevation increase within the

SAPS unit. These systems should discharge an effluent at or near a pH of 6 s.u., although the pH can be lower (even around 4 - 4.5) if the aluminum/acidity is very high within the target water. Alkalinity can vary dramatically depending on the quality of the influent water(s) and no general range can be assigned as a target value. A noted decrease in alkalinity from the established values, immediately post SAPS construction, is a primary indicator that the system requires attention. Surface water elevations within the SAPS unit will also typically increase as flow constrictions increase in the organic/limestone layers of the SAPS. All of these are used as indicators that maintenance is immanent in the near future or required immediately;

Solution -

Upon determination that maintenance is immanent in the near future *or* required immediately then the first step is to "flush" the SAPS unit with the valve structures that are incorporated into the SAPS unit for this purpose. Flushing intervals are typically not pre-determined but are set post-construction following a year (typically) of treatment and water monitoring. Flushing consists of drawing the water from the underdrain system bedded within the limestone to remove metal accumulation, precipitated in the limestone layer, that interferes with normal flow and treatment. The flushing event can last from as little as 10 minutes to as long as 60 minutes, and is dependant on the flush water color – the flush should cease when the water appears relatively clear (see Figure 5 for comparative flush colors).

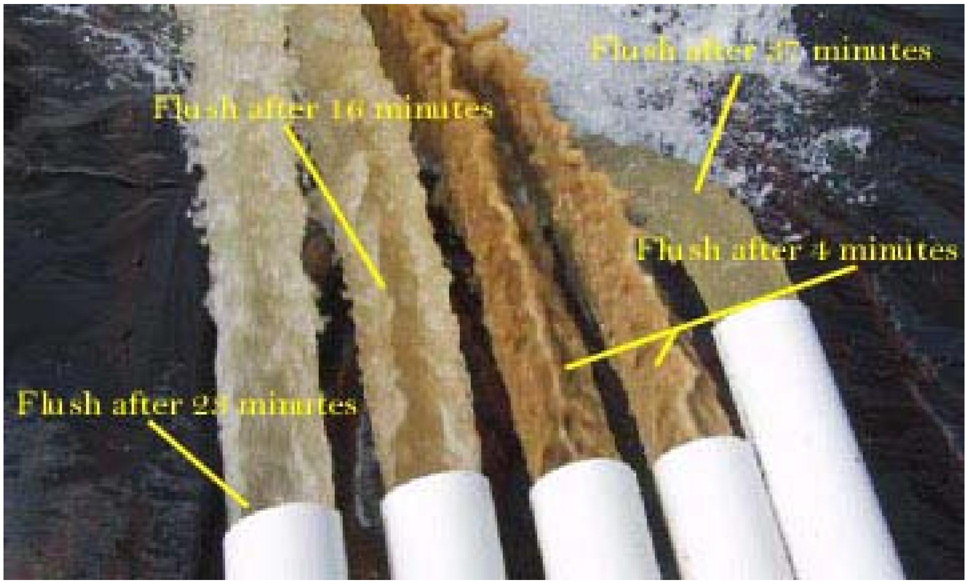


Figure 5. Various flush times (and associated colors) on a SAPS system in Somerset County, Pennsylvania (August 2002).

2. Flushing does not restore alkalinity production and/or pH values to levels immediately post-SAPS construction;

   Solution -

   Limestone and organic material can be replenished within these units when it has been determined that flushing cannot restore the efficiency of the system and/or the design longevity of the system has been approached or met. When the system has been properly designed, operated and maintained the time table for materials replacement should be relatively close to the projected longevity. If the system is not that old and flushing does not restore the alkalinity and/or pH values then examination of the original design to evaluate if short circuiting, aluminum retention, and/or ferric iron deposition could have occurred needs to be explored.

Successive Alkalinity Producing Systems (SAPS) & Aluminator Evaluations

Case Study 1

Background

Project Name: Tangascootack Watershed Rehabilitation Project
(No. 1 SAPS)

Location: Beech Creek Township, Clinton County, Pennsylvania
U.S.G.S. Quadrangle - Howard NW
Latitude 41° 08' 37", Longitude 77° 38' 47"
(*see* Figure T1.)

Funding: Western Pennsylvania Coalition for Abandoned Mine Reclamation

Design: Natural Resources Conservation Service, with support from:
the Clinton County Conservation District, and
the PA Department of Environmental Protection

Design Water Data Characterization (surface mine discharge):

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[4]	manganese[4]	sulfate[4]
40	3.3	0	300	4	25	67	1,700

---

[1]gpm; [2]s.u.; [3]$CaCO_3$ equivalent; [4]total, mg/L

Treatment Approach: Successive Alkalinity Producing System (SAPS)

Construction: June 1998

Statement of Problem: The effluent quality of the SAPS declined from a circumneutral, net alkaline flow during the initial months of system operation, to a net acidic discharge with a mid-4 pH range within roughly a six month period.

Design

The Clinton County Conservation District provided Damariscotta with design drawings for the Tangascootack Watershed Rehabilitation No. 1 SAPS project[1] as shown in Appendix 1. The "Original Contour Plan View" mapping indicates a collection of diffuse seepage flowing through a shallow pond/marsh area and into a settling basin prior to discharging to the receiving stream. The "Design Plan View" mapping develops a portion of the shallow pond/marsh area as a SAPS, and leaves the settling basin as is to receive the discharge of the SAPS. Figures T2 and T3 show the SAPS and settling basin; respectively, and are keyed to the design plan view mapping Appendix 1.

Figures T2 & T3. Photographs of the SAPS and settling basin as a part of the Tangascootack treatment system. Beech Creek Township, Clinton County, Pennsylvania.

The SAPS was designed with bottom dimensions of 30' x 120' and with 2:1 inslopes. The wetted area therefore encompasses roughly 66' x 156', or 0.25 acres. The as-built drawings (Appendix 1) show that 2.2' of No. 57 limestone[2] (500 tons) was placed on the bottom of the treatment unit, covered by 1.0' of mushroom compost, and roughly 6.0' of freestanding water.

The SAPS was designed with a collection pipe system placed directly on the bottom of the treatment unit. The pipes were 4" perforated, corrugated sewer pipe, placed on 5' centers and running the length of the unit. The six total pipes equaled 720' and were

---

[1] Hand written notations indicate "As Built" conditions, and therefore changes to the original drawings.

[2] Damariscotta was not provided with material specifications for the limestone other than being told it came from a Centre County quarry. We can assume that the limestone was of an acceptable $CaCO_3$ content (80^+ percent), knowing the general background of the limestone in this region. The No. 57 designation indicates that essentially all of the stone is smaller than 1 1/2" in diameter, that 60 percent of the stone is between 1/2" and 1 1/2", and that 40 percent of the stone is smaller than 1/2" in diameter.

connected to a common, perpendicular collection pipe at the discharge end of the unit. The discharge structure was a 6" diameter, solid SDR 26 pipe that angled upwards from the bottom elevation of the pond to a discharge invert equal to the design pool elevation of the SAPS. This pipe discharges into the settling basin.

The SAPS was subsequently retrofitted with a 6" solid PVC pipe at the bottom end of the unit opposite the discharge structure. This pipe was presumably connected to each of the six perforated pipes via a common manifold pipe, and was carried at this elevation to daylight within the woods adjacent to the treatment system. This pipe is valve controlled with the purpose of periodically flushing aluminum precipitates from the SAPS. The flush waters simply discharge into the woods without the benefit of a collection or settling pond.

Findings

The pH and aluminum components of the mine drainage to be treated, as shown in the background section, account for roughly 56% of the total acid load, and presumably were the main design concerns of the project. Iron treatment needs are minimal, at only 2% of the total acid load. Manganese contributes up to 42% of the total acid component of this flow, but did not appear to be directly addressed in the treatment design of the project.

Damariscotta was provided with water quality analyses from 15 sampling events pulled from the system, beginning immediately after construction in July of 1998 through August of 1999; the period of time when the system began to decrease in efficiency. Scatter plots of pH, acidity, alkalinity, and aluminum are provided in Figures T4 through T7; respectively. A consistent trend in the effluent quality of the SAPS is evident in these figures, with significant declines in treatment effectiveness for each parameter after roughly six months of system operation.

The pH of the source water is consistently between 3.3 and 3.5 s.u. The SAPS effluent showed a high pH of 6.7 s.u. the first month of operation, and a steady decline in value to a pH of 6.0 at seven months (July 1998 through January 1999). In early March, the pH of the SAPS discharge dropped below 6.0, and within two weeks, the value dropped below 5.0. The pH of the discharge maintained a value of roughly 4.6 through the remaining sampling (through August 1999). Even at these mid-4 pH range values, the SAPS' effluent pH remained elevated above the source values by roughly one magnitude.

Acidity values followed this same trend, with the SAPS' effluent carrying no measurable acidity over the first four months of operation, and no net acidity through the first seven months. The discharge turned net acidic in March of 1999. The August 1999 sampling date showed a net decrease of roughly 50% in the acidity value of the treated flow.

Alkalinity concentrations at the source are consistently 0 mg/L, given the pH of the mine drainage. The early system data net alkalinity values were modest, at roughly 60 mg/L, but a net change in acidity of approximately 350 mg/L was realized over this same time period. Alkalinity values dropped to several mg/L with the decline of the system's effectiveness, and as noted above, the discharge became net acidic.

Aluminum values at the source sample location average 24 mg/L. The initial aluminum discharge concentrations were less than 0.5 mg/L, but increased to approximately 4-5 mg/L as the overall treatment efficiency of the system declined. This level of aluminum treatment remained fairly consistent through the last several months of data collection.

Iron values at the source averaged slightly less than 4 mg/L throughout the sample period, and were typically less than 1 mg/L in the effluent of the SAPS; remaining consistent over time.

Flows at the site ranged between 15 and 92 gpm, and did not show a correlation with treatment efficiency. It is difficult to ascertain the true effects of flow on treatment with the provided data because of the influence of stormwater at this site.

Discussion

The Tangascootack Watershed Rehabilitation Project No. 1 SAPS was constructed with the purpose of removing aluminum from the target mine drainage, whether or not that was the conscious intent of the designers. Aluminum is the prime acid producing component of the discharge(s), and is quite toxic to aquatic organisms at the reported concentrations. The design itself; however, was not consistent with the overall needs of aluminum treatment.

As background, aluminum removal from AMD is generally mediated by limestone dissolution and an increase in pH and alkalinity values. Aluminum removal from mine drainage is solely pH dependent, and not subject to oxidation/reduction reactions as is the case with iron removal. The extent of pH adjustment and alkalinity generation is partially dependent on the retention time of the AMD within the limestone.

As the pH of the flow reaches 5 s.u., aluminum will precipitate on and within the pore spaces of the stone, and both water to stone contact and residence time will decrease. Treatment efficiency will then decrease as well. The continued dissolution of the limestone is dependent on the ability of the water to contact the stone. Therefore, the key design consideration with an aluminum treatment system is to provide for an aluminum “removal mechanism" to maintain the effectiveness of the limestone treatment process. Not recognizing this need in the original Tangascootack design was a shortcoming of this treatment system.

It was reported through the PA DEP that the first flush of this system occurred in mid-March of 1999, eight months after the system was put into operation. At this point, the effectiveness of treatment had already significantly declined. Rough calculations of average flow and average aluminum removal over this time period show that the system had accumulated approximately 4,000 pounds of aluminum precipitate. Simply put, the abrupt decline in treatment efficiency was brought about by a physical "clogging" of the treatment system with aluminum precipitates as described above.

Initial declines in treatment effectiveness are expected from any limestone and organic compost based treatment systems. In fact, early water analyses (up to several months in some cases), should not be considered representative of the long-term functioning of these systems. Steady state conditions must be realized before treatment trends can be discussed.

It is not uncommon for individual SAPS, or the first SAPS in a series of several SAPS, to stabilize at an effluent pH in the low to mid 4 range. However, this system seemed to show the potential to stabilize in the low pH 6 range.

The overall design of this particular system was not sufficient for the quantity of aluminum that was present in the source water. The system would have required an assessment *a priori* concerning aluminum treatment and the necessary design modifications (in this case…piping and material changes) could have been incorporated to prevent the decrease in treatment efficiency that was noted for this system. In a properly designed system flushing activities would have likely been sufficient to maintain the treatment efficiency that was documented in the first few months of the system's operation.

The type of decrease in treatment efficiency that was noted for this system is typical of aluminum based systems; and the type of water chemistry trend that was noted in this case is indicative of maintenance initiation (i.e. flushing). Flushing likely was not successful in this instance because of piping layout and material (compost & limestone) thickness, and the time that was taken before any flushing activities were initiated.

Recommendations

The primary recommendations in this instance would be to reconstruct the system with an additional 1-2 feet of limestone and remove 6 inches of the compost. The piping system should be modified to have at least two separate zones (and limited to placement no closer than 10 feet from the edge of the limestone; to help prevent preferential flow paths) and a flush pipe that is at the same elevation as the piping within the limestone to facilitate flushing events. If these design modifications were incorporated the system should function at the highest levels of efficiency possible for the design (limestone) life of the system.

Damariscotta

Tangascootack Watershed Rehabilitation Project
(No. 1 SAPS & Aluminator)

Successive Alkalinity Producing Systems (SAPS) & Aluminator Evaluations

Case Study 2

Background

Project Name: Filson No.1 & No.2, Little Mill Creek Restoration Project
(Filson No.1 and Filson No.2 SAPS)

Location: Union Township, Jefferson County, Pennsylvania
U.S.G.S. Quadrangle - Corsica, PA
Latitude 41° 12'20.5", Longitude 79° 9'58.0"
(*see* Figure F1)

Funding: EPA 319

Design: Damariscotta

Design Water Data Characterization (surface mine discharge):

Filson No.1

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[4]	manganese[4]	sulfate[4]
35	3.6	0	250	25	20	45	1,200

---

[1] gpm; [2] s.u.; [3] $CaCO_3$ equivalent; [4] total, mg/L

Filson No.2

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[4]	manganese[4]	sulfate[4]
30	3.4	0	380	80	10	90	1,450

---

[1] gpm; [2] s.u.; [3] $CaCO_3$ equivalent; [4] total, mg/L

Treatment Approach: Successive Alkalinity Producing System (SAPS)/prototype Aluminator©

Construction: July 1995
Design Modified (SAPS/Aluminator© piping/water collection system was modified, and additional materials were added): May 1999

Statement of the Problem: Effluent from initial prototype Aluminator in both Filson 1 and Filson 2 declined in alkalinity and pH, while discharging elevated aluminum. Flow also began activating emergency spillway designed in to Aluminator.

Original Design (July 1995)

Filson #1 and Filson #2 are acid mine drainage discharges that emanate from the downslope “edge” of a 1970’s surface mine. This “edge” was mined in the 1940/1950’s and is consistent with contour mining of that era. The discharges are within 450 feet of one another and both flow into a large wetland that is/borders Little Mill Creek. The wetland was within 150 feet of the source and work area was available between the wetland/stream and the spoils left from the earlier mining. The provided design drawings show a site where the collection of each discharge flowed through initial (prototype) Aluminators, followed by a settling basin, and then a SAPS unit prior to discharging to Little Mill Creek.

The Filson #1 Aluminator© was designed with bottom dimensions of 30' x 65', the wetted area encompassed 30' x 70' (roughly 0.05 acres). Approximately 3' of No. 57 limestone (500 tons) was placed on the bottom of the treatment unit, covered by 6” to 1' of mushroom compost, and roughly 2.5' of freestanding water.

The Aluminator© was designed with a collection pipe (4” perforated, corrugated-flexible piping) system placed directly on 0.5’ of limestone at the bottom of the Aluminator© unit. The collection pipes were placed on approximately 5' centers and serpentined for the length of the unit. One roll (250’) of this collection pipe was placed in the Aluminator© and was connected to a solid collection pipe at the discharge end of the unit. The discharge structure was a 4" diameter, solid SDR 26 pipe that angled upwards from the bottom elevation of the pond to a discharge invert equal to the design pool elevation of the Aluminator. This pipe discharges into the settling basin; an additional pipe was placed inline with the discharge piping, and a valve added to allow for flushing/draining of the Aluminator.

The Filson #2 Aluminator© was designed with bottom dimensions of 30' x 65', the wetted area encompassed 30' x 70' (roughly 0.05 acres). Approximately 3' of No. 2B limestone (400 tons) was placed on the bottom of the treatment unit, covered by 6” to 1' of mushroom compost, and roughly 2.5' of freestanding water.

The Aluminator© was designed with a collection pipe (4” perforated, corrugated-flexible piping) system placed directly on 0.5’ of limestone at the bottom of the Aluminator© unit. The collection pipes were placed on approximately 5' centers and serpentined for the length of the unit. One roll (100’) of this collection pipe was placed in the Aluminator© and was connected to a solid collection pipe at the discharge end of the unit. The discharge structure was a 4" diameter, solid SDR 26 pipe that sloped downwards from the bottom elevation of the pond to a discharge invert that utilized a valve to control the level of the pool elevation of the Aluminator. This pipe discharges into a receiving settling basin; an additional pipe was placed inline with the discharge piping, and a valve added to allow for flushing/draining of the Aluminator.

Damariscotta
Little Mill Creek Watershed Rehabilitation Project
(No. 2 SAPS & Aluminator)

Damariscotta was not provided with material specifications for the limestone (for either Filson #1 or Filson #2) other than indications were that it came from a Centre County quarry. We can assume that the limestone was of an acceptable $CaCO_3$ content, knowing the general background of the limestone in this region and limestone used in adjacent systems. The No. 57 designation indicates that essentially all of the stone is smaller than 1 1/2" in diameter, and that 60 percent of the stone is between a 1/2" and 1 1/2" range. This also means that 40 percent of the stone is smaller than 1/2" in diameter.

Modified Design (May 1999)

Each of the Filson systems performed as designed initially, but declined in *overall* treatment system efficiency with time (*see **Findings***). This decline, in part, was the result of: 1) sediment loading from a flood in June of 1996; 2) lack of consistent flushing of the aluminum precipitates; 3) increased flows (above the initial design levels), which likely resulted in some preferential flow path development; and 4) the "dated" piping system which accentuated the preferential flow concerns. The original piping systems (one discharge pipe), that consisted of black corrugated-flexible piping serpentined within the limestone layer, over time was unable to carry the design flow (which, as noted, was larger than designed for). Thus, while the water that went through the SAPS/ Aluminator© unit was "treated" much of the water simply "bypassed" the system via emergency spillway resulting in an overall system discharge that, over a few years, was lessening in quality (i.e. lower pH and elevated aluminum concentrations). Data for pH, acidity, alkalinity, and aluminum are included for the start-up and initial decrease in treatment system effectiveness to illustrate the type of trends in water chemistry one would expect in systems of this type (*see* Figures F2-F5).

Even though the quality of the overall system effluents decreased with time, because of these concerns, it is key to note that the systems continued to improve the water quality over a four year span with very little maintenance and in the presence of considerable concentrations of aluminum. A summary of the 1999 modifications are as follows:

The Filson 1 Aluminator© was drained and the compost layer was pushed to the source end of the system. The original 6" layer of compost (which compressed to roughly 4" when wetted) was still intact and measured roughly 3". The compost did not migrate into the limestone, remaining segregated over the four years between 1995-1999. There was a 3-4" layer of iron precipitate and some leaf debris overlying the compost layer.

The top 2-3" of limestone had a relatively complete coating of aluminum around the individual stone pieces and within the pore spaces. The remaining limestone was free of any visible sign of aluminum across its entire depth. The corrugated piping system was also essentially free of any signs of aluminum accumulation, although one section of the pipe was "sealed" with silt that had washed into the pond during the previously noted 1996 flooding.

The limestone, except for a bottom layer of approximately 6" was pushed to the opposite end of the pond from the compost to prepare a bed for the new piping system. The piping system (*see* mapping in Appendix 2) was then installed and connected to the existing discharge pipe. The pipe was covered with the original stone, and then an addition several inch layer (approximately 6", totaling 30 tons) of stone was added to the system. It was estimated that each of the Filson systems has utilized between 30 and 40 tons of limestone since implementation. The compost was re-spread and the system was allowed to refill.

The Filson 2 system had the same appearances and was modified in the same manner as the Filson 1 site, with one exception. The Filson 2 system was originally constructed with "2B" rather than "3A" limestone because the 3A was not available at the time. When examined, the aluminum did migrate slightly further into this stone than with the 3A, but only by a few inches. The new piping system was covered with (approximately 30 tons) of 3A limestone, and the 2B stone was then used to cover the 3A stone.

Findings

For the Filson #1 discharge; the aluminum and manganese components of the mine drainage to be treated, as shown in the background section, account for roughly 80% of the total acid load. The aluminum and iron were the main design concerns of the project. Iron treatment needs are less, at approximately 20% of the total acid load but were addressed again primarily because of treatability of iron in mine drainage. Manganese contributes up to 35% of the total acid component of this flow, but was not directly addressed because of the available treatment area, topography (the area was limited and the slope in the available work area was less than 3 percent), and the overall effect of manganese on biota (at these concentrations).

For the Filson #2 discharge; the iron and manganese components of the mine drainage to be treated, as shown in the background section, account for roughly 85% of the total acid load. However, as with the Filson #1 discharge, the aluminum and iron components were the main design concerns of the project because of their respective treatability in mine drainage. Aluminum in this discharge accounts for approximately 15% of the total acid load; and manganese contributes up to 40% of the total acid component of this flow, but again was not directly addressed because of the available treatment area, topography, and lack of significance of biological impact.

Damariscotta was provided with water quality analyses for sampling events from September 1995 through June 2000. Scatter plots of pH, acidity, alkalinity, and aluminum are provided in Figures F2 through F5 (for both Filson 1 and Filson 2). A consistent trend in the effluent quality of the SAPS is evident in these figures, with declines in treatment effectiveness for key indicating parameters after roughly three years (1995-1998).

No measurement of the source water chemistry was made after the original construction (on either Filson #1 or Filson #2) as the source was incorporated into the bottom of the SAPS/Aluminator© system and no collection point was physically available for sampling. Thus, the first sampling location was the effluent pipe of the SAPS/Aluminator©, for both Filson #1 and Filson #2. The SAPS/Aluminator© effluent did not vary dramatically for any of the data (with a few exceptions). The main reason that this occurred was the fact that the flows were controlled by either; 1) "allowing" certain levels of flow through the treatment unit (via valve), as in the case of Filson #2; or 2) self regulation via the standpipe, as in the case of Filson #1. This would explain the overall uniformity of the data for the outfalls of these treatment units. The cases where the pH was low at the Filson #1 SAPS/Aluminator© discharge piping were likely a result of higher than normal flows. The aluminum in these instances was typically less than 1 mg/L, which indicates that the treatment unit is functioning as intended (i.e. removing aluminum); while the pH indicates that the flows are large enough to prevent the necessary contact time to elevate the pH to more elevated levels. After the Filson #1 system modification the piping system within the treatment unit was able to handle a larger flow; the system, however, was not maintained at an optimum flow (financial constraints with maintenance), and a larger flow than desired was allowed through the treatment system, resulting in a degraded effluent.

Acidity values followed this same trend, with the Filson 1 & 2 SAPS' effluent carrying some, to no measurable acidity over the first years of operation, and little, to no net acidity through the first year or so. Towards the end of 1999, the discharges turned more net acidic, and by the last sampling value in December of 1999, both of the SAPS' were decreasing the net acidity of the flow by roughly 50 percent. After the systems were retrofitted the water quality data returned to the values that were obtained immediately after the systems were constructed in 1995. Pertinent data is illustrated on the scatter plots Figures F6-F9, for pH, Acidity, Alkalinity, and aluminum.

Discussion

This system was designed to remove as much acidity loading as possible to help recover the biota in the Mill Creek watershed (which Little Mill Creek is a part of); *and* as a prototype Aluminator. The piping discharge system that was utilized was consistent with earlier designs that incorporated one perforated pipe (black flexible 4") that was serpentined throughout the limestone. This type of piping system has several inherent flaws that include: 1) difficulty to lay flat, depressions will eventually fill with aluminum and/or limestone fines that can create flow constrictions; 2) can be crushed if care is not taken when laying the pipe; and 3) slits in pipe tend to become restricted quicker than ½ inch holes drilled in solid pipe. With these flaws this system began to decline in treatment efficiency, primarily as a result in loss of contact time with the limestone.

Damariscotta

Little Mill Creek Watershed Rehabilitation Project
(No. 2 SAPS & Aluminator)

The reconstruction that took place in 1999 was an attempt to address the inherent flaws, associated with the piping, in the original design. This was addressed by utilizing a piping bed constructed of perforated (non-flexible) SDR 26 4" pipe. In addition, with the flooding that introduced significant sediment loads to Filson 1 and the limestone that was utilized over the four years of operation, additional limestone was added for both system efficiency and longevity. These modifications, and the allowance for more timely flushing activities, carried out by the Mill Creek Coalition have, to date, result in an overall more consistent treatment system (*see* Figures F6-F9).

Successive Alkalinity Producing Systems (SAPS) & Aluminator Evaluations

Case Study 3

Background

Project Name: REM Orcutt/Smail, Little Mill Creek Restoration Project

Location:	Union Township, Jefferson County, Pennsylvania U.S.G.S. Quadrangle - Corsica, PA Latitude 41° 12’27.3”, Longitude 79° 11’2.2” (*see* Figure R1)
Funding:	Bond Forfeiture - Handled through the Pennsylvania Department of Environmental Protection & Bonding Company
Design:	Initial 1992 Design - Damariscotta; 2002 Redesign – NRCS (conceptual – Damariscotta)

Design Water Data Characterization (surface mine discharge):

REM (Northern Discharge)

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[5]	manganese[4]	sulfate[4]
35	3.5	0	1000	425	5	110	1,600

[1]gpm; [2]s.u.; [3]$CaCO_3$ equivalent; [4]total, mg/L; [5]estimated

REM (Southern Discharge)

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[5]	manganese[4]	sulfate[4]
28	4.9	7.0	200	50	<5	50	800

[1]gpm; [2]s.u.; [3]$CaCO_3$ equivalent; [4]total, mg/L; [5]estimated

Treatment Approach: Anoxic Limestone Drains (ALD) and Successive Alkalinity Producing System (SAPS).

Construction: February/March 1992
Design Modified (SAPS/Aluminator© piping/water collection system was modified): 2002

Damariscotta
Little Mill Creek Watershed Rehabilitation Project
(No. 3 SAPS & Anoxic Limestone drain)

Original Design (February/March 1992)

The REM Orcutt/Smail acid mine drainage discharges emanate from small abandoned "punch mines" and are recharged by surface mines. These small mines were developed in the early 1900s and surface mining took place in the 1970s and 1980s. The discharges enter an unnamed tributary to Little Mill Creek and were the treatment responsibility of the coal operator until his bankruptcy and subsequent bond forfeiture. The Pennsylvania Department of Environmental Protection (then Department of Environmental Resources) worked with the bonding company to develop passive treatment at this location. Damariscotta developed the initial passive treatment system at this location which entailed anoxic limestone drains, prototype SAPS systems, settling basins, and aerobic wetlands. The attached design drawings and aerial photograph (Appendix 3) show the treatment system location and layout.

This system has two discharges (referred to as the "northern" and "southern" discharges) that are combined part way through the treatment system. An anoxic drain 25'X100'X4', containing approximately 550 tons of No. 57 limestone, was developed on the somewhat smaller, "southern", discharge. An anoxic limestone drain was also developed on the "northern" discharge that was roughly 40'X100'X4' and contained approximately 900 ton of limestone. A perforated collection pipe (***one*** pipe approximately 20 feet long – not a piping bed typically placed in drains today) was placed at the discharge end of the system and angled upward for discharge and to prevent air from entering the anoxic drain. Aerobic wetlands and settling basins were established immediately following each of these drains that encompassed approximately 0.1 acres, (7,380 ft^3) for the southern discharge, prior to combining with the flow from the northern discharge; and 0.17 acres (5,100 ft^3) for the northern flow prior to combining with the southern flow. Both flows were then combined in a prototype SAPS system similar to the designs used at the Filson and Howe Bridge sites. This SAPS system was 50'X75' on the bottom with 2:1 inslopes, approximately 3' of No. 57 limestone, and 0.5' of spent mushroom compost. The collection pipe (4" perforated, corrugated-flexible piping) system was placed directly on 0.5' of limestone on the bottom of the SAPS unit. The collection pipes were placed on approximately 5' centers and serpentined for the length of the unit. One roll (250') of this collection pipe was placed in the SAPS unit and was connected to a solid collection pipe at the discharge end of the unit. The discharge structure was a 4" diameter, solid SDR 26 pipe that angled upwards from the bottom elevation of the pond to a discharge invert equal to the design pool elevation of the SAPS. This pipe discharged into an aerobic wetland cell (number 2 of the 5 aerobic cells present); a flush (drain) pipe was also established that had the outlet placed in the aerobic wetland cell number 3 (of 5). The flow (combined) from the first SAPS unit was discharged into the second (of five total) aerobic wetland cell, were it proceeded through the next three aerobic units (No.'s 3, 4, & 5) before entering the last SAPS (and treatment cell) in the entire system. This SAPS was constructed in a similar fashion to the first SAPS system; however, the size of the system was approximately 50'X100'(bottom dimensions) and two pipes were placed in this system instead of one. The two, primary, discharge pipes were angled upwards to control the elevation within the SAPS system; and the flush (drain) pipes were placed to discharge into the unnamed tributary to Little Mill Creek (*see* Figure R2, for a general schematic of the system layout).

Modified Design (2002)

The REM Orcutt/Smail systems performed as designed initially; however, it did not meet effluent criteria numbers (primarily pH – which was less than 6, iron and acidity which were both greater than allowable by law) and was considered a "failure" by the Knox Department of Environmental Protection. In contrast, it was considered a success by scientists that had been trying to treat acid mine drainage passively (specifically the United States Bureau of Mines and West Virginia University). The primary reason for the excitement was the fact that this system, in the early years following implementation, was consistently removing 80-90% of the acidity load (with concomitant metal removal). To date this was the most degraded acid mine drainage that was treated effectively, with a passive treatment system. The PA DEP abandoned the system after it became apparent to them that the system would not meet effluent criteria required for acid mine drainage discharges. The system continued to decline in effectiveness, due to the lack of operation and maintenance, until very little "treatment" occurred within the system.

The redesign of this system took place in 2002, with the actual construction planned for 2003. This redesign, like those at Filson, was an attempt to address the inherent flaws and outdated technology that were in the original design. The redesign addressed updating of the piping systems in the SAPS, adding additional SAPS units, and/or expanding the SAPS that are there, and adding additional settling basins. A copy of the redesign, as envisioned by the NRCS is included in Appendix 3.

Findings

For the REM Northern Discharge; the aluminum and manganese components of the mine drainage to be treated, as shown in the background section, account for roughly 23% of the total acid load. The aluminum and iron were relatively minor design concerns of the project. Iron treatment needs were the primary focus, at approximately 77% of the total acid load. Manganese and iron were the only two metals of concern in the REM Southern Discharge, both contributing roughly 50%(each) of the total acid component of this flow.

The primary focus of treatment at this location was to remove the iron to effluent standards (3.5 mg/L), increase pH to between 6-9, and maintain net alkalinity.

Damariscotta was provided with water quality analyses for sampling events from May 1992 through June 2002. Scatter plots of pH, acidity, alkalinity, and aluminum are provided in Figures R3 through R6 (for the combined final discharge). A consistent trend in the effluent quality of the system is evident in these figures, with declines in treatment effectiveness happening relatively quickly (less than one–year) and then stabilizing for key indicating parameters.

Similar to the Filson sites, no measurement of the source water chemistry was made after the original construction, as the source was incorporated into the bottom of the Anoxic Limestone Drains (ALDs) and no collection point was physically available for sampling. Thus, the first sampling location was the effluent pipe of the ALDs, for both the Northern and Southern discharges. The final effluent did not vary dramatically for any of the data for the first several months; after which the pH values started to decline as did the alkalinity values, while the metals and acidity increased proportionally. The pH values were typically 5.5 or higher leaving the ALDs and near 5.5 discharging the treatment system for the first few months (greater than 6 in the first month or two). After approximately 6 months the final discharge dropped in pH to near or below pre-treatment values (less than 3.5). The first SAPS system that collected the combined flows from both the Northern and Southern discharges, did not operate as expected due to the design of the outlet discharge structure that was required (by the state regulatory agency) to have an invert elevation at the same elevation as the surface water in the SAPS. Without the ability to adjust this outfall to compensate for head differences, the surface water merely discharged via the emergency spillway receiving no treatment from the limestone/compost layer of the SAPS. The same thing happened with the final SAPS. Enough alkalinity was introduced through the ALDs on the Northern and Southern discharges that iron oxidation was facilitated, even though the SAPS failed to operate as designed, which resulted in pH values that were suppressed below the values of the source waters. Alkalinity followed a similar trend to that of pH, with values staying relatively elevated at the ALD discharge, up to five/six years after installation but falling quickly after that; primarily due to the failure of SAPS systems.

Acidity values and metal followed this same trend, with the REM Orcutt/Smail effluent carrying some measurable acidity, and metals (i.e. iron) over the first years of operation, while over time these values increased, nearing original source values. This type of trend is common in systems that receive little or, in this case, no operation and maintenance attention. The modifications to this system are an attempt to try and return the water quality to the values that were obtained immediately after the systems were constructed in 1992.

This system was designed to meet the state of Pennsylvania's and the Federal government's mining effluent criteria (and did so on occasion, initially), and to remove as much acidity (and associated metals) loading as possible to help recover the biota in the Mill Creek watershed (which Little Mill Creek is a part of). However, overtime the overall system efficiency declined to the point where little or no treatment occurred. Some of this was due to design, while the remainder was related to lack of care of the system. Thus, while there were many reasons for the overall effectiveness of this system, they can be reduced to basically two that are primary, interrelated issues and are outlined as follows: 1) preliminary design of this type of system; and 2) regulatory oversight of initial design and budgeting concerns.

Preliminary Design

The designs that were utilized for this system were prototype and as such, in retrospect, had several design "flaws", that limited the systems ability to treat *this type* of water to the level required by the Pennsylvania Department of Environmental Protection and the Federal government's standards. We know today that given an appropriate design that this system would most likely have met the effluent standards required by law, and done so consistently. The technology that was employed, at that time, was technologically appropriate and overall sound. Time, however, has shown that the modification of the original/basic design would have allowed for greater efficiency and longevity. The "flaws", that have become clear over time are:1) the lack of a more complete piping system (black flexible piping (250 feet per SAPS unit) was utilized in this system, similar to that used in both Howe Bridge and Filson) – greater zone of influence; 2) establishment of an Aluminator type system on the "northern" discharge, instead of an Anoxic Limestone Drain (although the anoxic drain at this location lasted over five years with approximately 5 mg/L of aluminum in the source water); and 3) slightly larger SAPS systems (although this was limited by funding).

Regulatory oversight of initial design and budgeting concerns

An additional part of the problem, associated with the initial design of the REM site came from regulatory oversight and budgeting constraints. Primarily the oversight was restrictive due to the fact that this agency did not have the staff that was familiar with this type of passive treatment technology and was skeptical of the ability of this type of system to function given the water chemistry (some of these concerns were legitimate, others were not). This was developmentally restrictive, from the standpoint that new design approaches were not "allowed" because the reviewing engineer was unfamiliar with the approach/technology. Thus design features were compromised, which ultimately turned out to be detrimental to the system's ability to function. An example of this was the requirement to establishment the discharge pipe in the SAPS system to the ***exact*** elevation of the surface water level in the SAPS, with no allowance for head differences (i.e. the ability to adjust the discharge piping to compensate for head differences). This design feature alone limited the operation effectiveness of the SAPS to about six months.

The budgeting constraints, however, were the largest factors in limiting this system's ability to function properly. The initial design estimate of $130,000 was reduced to slightly under $70,000, which limited the amount of materials, size, and *any* continued operation and maintenance of the system. This constraint, in retrospect, has illuminated the fact that the SAPS and ALDs systems were undersized and that problems encountered in the field (e.g. lack of a suitable bottom to place stone on - in the final SAPS systems) were not dealt with appropriately because the funds were not present to do so. When the system did not meet the criteria required by the PA DEP the system was abandoned. With no operation and maintenance funds allocated the system declined in efficiency to the point that very little treatment occurred (over the last ten years). This was despite the fact that at peak operation efficiency this system removed more acid load from the Mill Creek Watershed than five other passive systems that were established in the watershed that met effluent criteria (although these systems were not required to do so).

Over the last several years, the Mill Creek Coalition pursed funding through the Natural Resource Conservation Service (NRCS) located in Clarion, PA and Headwater Charitable Trust to upgrade and modify the design to compensate for some of the original design problems. The design was redone in 2002, conceptually by Damariscotta for the NRCS. The regional engineer for the NRCS utilized our conceptual design for a basis of the modifications/upgrades and finalized the design in early 2003, for implementation in 2003. Upon review of the design, several features were identified that would limit the new system's ability to function at peak levels that include: 1) improper pipe sizing and placement in both ALDs and SAPS; 2) improperly sized settling basins; 3) routing of untreated water around systems treatment components, and then placing this water back into the system at a downstream point; 4) fix discharge outlets in SAPS units; and 5) improper material quantities and depths. While these types of shortcomings have been illuminated to the NRCS, some of these were not changed in the final design and will likely result in the revised system's inability to operate at maximum efficiency.

This case study is used to illustrate that when an improper design is implemented that will ultimately not operate at maximum design effectiveness ("fail"), speculation can be thrown on the treatment system components rather than on the improper design. All most all of the cases of "failed" passive treatment systems, that we have examined, were the result of situations similar to this. The overall approach to passive treatment systems in the form of ALD, SAPS, Aerobic Wetlands, Settling Basins, and Aluminators has lead many to believe that these types of approaches are simple and that little design knowledge (science behind the approach), beyond the basics is necessary; and that standard engineering principles can be applied to implement effective systems. This coupled with the fact that any type of standard design approach, for passive treatment systems, does not exist has led consumers to the erroneous conclusion that certain types of passive treatment are not effective.

Damariscotta
Little Mill Creek Watershed Rehabilitation Project
(No. 3 SAPS & Anoxic Limestone Drain)

Successive Alkalinity Producing Systems (SAPS)

Case Study 4

Background

Project Name: Howe Bridge, Mill Creek Restoration Project

Location: Union Township, Jefferson County, Pennsylvania
U.S.G.S. Quadrangle - Corsica, PA
Latitude 41° 13’42.3”, Longitude 79° 11’10.3”
(*see* Figure H1)

Funding: Abandoned; Trout Unlimited, Pennsylvania’s Growing Greener, In kind United States Army National Guard

Design: Initial 1991 Design - Damariscotta; 2002 Reconstruction - Damariscotta

Design Water Data Characterization (bore hole discharge):

Howe Bridge

flow[1]	pH[2]	alkalinity[3]	acidity[3]	iron[4]	aluminum[4]	manganese[4]	sulfate[4]
35	3.5	0	540	275	<1	20	1,200

---

[1] gpm; [2] s.u.; [3] $CaCO_3$ equivalent; [4] total, mg/L;

Treatment Approach: Anoxic Limestone Drains (ALD) and Successive Alkalinity Producing System (SAPS).

Construction: November 1991
Design Modified/System Reconstructed (original SAPS reconstructed - piping/water collection system was modified; a new SAPS unit was installed): 2002

Original Design (November 1991)

The Howe Bridge acid mine drainage discharges emanate from small abandoned United States Geological Service exploratory bore hole and is recharged by surface mines that are located upslope. Many of the small mines upslope were developed in the early 1900s and additional surface mining took place in the 1970s and 1980s. The discharge entered Mill Creek directly and was abandoned for twenty years, and additional flow from an abandoned gas well (early 1900’s) also was incorporated into the system. Damariscotta

Damariscotta
Mill Creek Watershed Rehabilitation Project
(No. 4 SAPS & Anoxic Limestone Drain)

developed the initial passive treatment system at this location which entailed one anoxic limestone drain, settling basin, aerobic wetland, and the first full scale (prototype) SAPS system. The attached design drawings and aerial photograph (Appendix 4) show the treatment system location and layout.

This system has one primary discharge from the abandoned USGS exploratory drilling, and a smaller discharge that emanates from an abandoned gas well. Both sources were diverted into separate Anoxic Limestone Drains which discharge to a common settling basin (approximately 20'X20'X2'). The anoxic drain for the USGS discharge is 25'X100'X4' and contains approximately 500 tons of No. 57 limestone. The ALD on the gas well discharge is 25'X30'X3' and contains approximately 125 tons of No. 57 Limestone. After he common small settling basin the flows were directed into a large settling basin (65'X65'X8'), prior to entering an aerobic wetland (approximately 75"X150'X1') and then the SAPS unit (125'X70'X8'- 3' of limestone, 0.5' of compost, and 3' of water). Perforated collection pipes (two) were placed on 0.5'-1' of limestone then covered with 18" to 24" of limestone. This was black flexible piping and approximately 250 feet were utilized for each collection/discharge pipe. These collection pipes (4" perforated, corrugated-flexible piping) were placed on approximately 5' centers and serpentined for the length of the unit. A standpipe was established through the embankment of the SAPS pond, and standpipes were erected that were adjustable for elevation to help account for head pressure changes in the SAPS when these changes occurred. Flush lines were also established to flush/drain the system when either of these activities became necessary. The discharge and flush line structures were 4" diameter, solid SDR 26 pipe that were placed at the same elevation as placed on the limestone, through the breastwork, then a 90 degree connector was placed on the pipe and a standpipe to control the elevation in the SAPS pond was placed in the 90 degree connection. A valve was placed downflow of the 90 degree connector to allow for the flushing/draining activities (*see* Figure H2 in Appendix 4, for general system layout).

Modified Design/Reconstruction (2002)

The Howe Bridge system is likely the most studied AMD passive treatment system in the world, having been examined by the U.S. Bureau of Mines, Clarion University, Bucknell University, West Virginia University, Pennsylvania State University, Pennsylvania Department of Environmental Protection, and a host of consultants. This system has performed within the limitations of the original design (i.e. size and prototype design) for over ten years. The value of this system to Mill Creek has been well documented by the Mill Creek Coalition, and the Fish Commission actually stocked this portion of Mill Creek for the first time in over fifty years in 1994. This system would consistently discharge pH greater than 5 s.u., net alkalinity or only slightly acidic water, with a significant portion of the iron removed (typically <50 mg/L, often less than 20 mg/L) for these ten years. However, in recent years these numbers had been getting progressively "worse", indicating a need to revisit the system and incorporate more recent technology to revitalize this system.

Damariscotta

Mill Creek Watershed Rehabilitation Project
(No. 4 SAPS)

The original SAPS that was placed at the end of the system was reconstructed by: 1) removing the accumulated iron precipitate; 2) removing compost and stockpiling compost that could be reused; 3) removing the old black flexible piping system; 4) installing new piping system with perforated SDR 26 - 4” pipe; 5) adding additional limestone, approximately 500 tons; 6) replacing compost that could be reused and adding additional new compost; and 7) installing new discharge pipes at a new location to pool water before discharging into Mill Creek (a precaution to remove any additional iron if present). Photographs of this reconstruction can be seen in Figures H3 and H4, as well as Figure 2.

Figure H3 & H4. SAPS reconstruction at Howe Bridge in 2002, Corsica, Pennsylvania.

In addition a new SAPS was constructed to help boost alkalinity in the system for additional iron removal. This unit was placed in a portion of the former aerobic wetland treatment unit. This SAPS unit was 75’X75’ on the bottom with roughly 3 feet of limestone, and 0.5 feet of compost. Four inch SDR 26 perforated piping (two separate zones) was placed on 0.5 feet of limestone and solid SDR 26 4” pipe was placed through the breast work; and a standpipe was placed on the outslope of the SAPS pond to discharge into the aerobic wetland prior to the final SAPS. Approximately 1,000 tons of No. 57 limestone was utilized in this SAPS system and 50 tons of compost.

Lastly, flow restriction curtains were placed in the original sedimentation basin (that receives water from the two ALDs) to help precipitate as much iron as possible in this basin and, thus, preventing iron from entering the aerobic wetland and first SAPS unit. This would also help in utilizing all of the available alkalinity prior to entering the first SAPS, which would increase the efficiency of the system. These curtains were 60 feet long and 3 feet high, they had floats incorporated into the top portion of the curtain and chains incorporated into the bottom portion. The ends of the curtains were secured/ anchored to the edge of the settling basin.

Damariscotta
Mill Creek Watershed Rehabilitation Project
(No. 4 SAPS)

Findings

For the Howe Bridge discharge; the iron component of the mine drainage to be treated, as shown in the background section, accounts for nearly 92% of the total acid load. The manganese and pH were considered minor design (from an acidity contribution standpoint) concerns of the project. Thus, iron treatment needs were the primary focus for the design of this system.

Damariscotta was provided with water quality analyses for sampling events from March 1992 through December 1998. Scatter plots of pH, acidity and alkalinity are provided in Figures H5 through H7. A consistent trend in the effluent quality of the system is evident in these figures, with declines in treatment effectiveness happening over a longer period of time than the other systems examined. The system gradually increased in iron and acidity at the discharge point, while gradually decreasing in pH and alkalinity over the ten years prior to the reconstruction and addition of treatment units.

Similar to the Filson & REM sites, no measurement of the source water chemistry was made after the original construction, as the source was incorporated into the bottom of the Anoxic Limestone Drains (ALDs) and no collection point was physically available for sampling. Thus, the first sampling location was the effluent pipe of the ALD. The final effluent did not vary dramatically for any of the data over the ten years that this system was in operation. The pH early in the system life, typically discharged near 6 s.u., while roughly between 1997 and 2002 this value was slightly lower, and nearer to 5.5 s.u.. The pH of the effluent from the Anoxic Limestone Drain has been incredibly consistent, typically greater than 6.2 s.u. and generating in excess of 170 mg/L of alkalinity. The alkalinity that was generated in the ALD was typically consumed in the spillway of the settling basin, where the pH dropped from near 6 s.u. to the low 3's. The amount of iron however, was usually in the 150-200 mg/L range and was reduced slightly prior to final discharge from the SAPS unit (typically the final effluent iron was in the 50-90 mg/l range). The alkalinity generated in the final SAPS was typically in the 80 mg/L range, while acidity was in the 160 mg/L range. These values varied little from 1991 through 2002, with slight increases in metals/acidity, and slight decreases in pH and alkalinity. In the years preceding the redesign it became apparent that the flow from the SAPS was becoming affected, both in terms of flow and quality. Based on the experiences at other similar sites (e.g. Filson 1&2, and other installed in the same time period), it was apparent that the SAPS needed to be reconstructed. In addition, the water chemistry was such that a new SAPS unit, immediately following the settling basin would be appropriate and would likely result in this system discharging net alkaline water with little iron.

Discussion

This system was the first SAPS/ALD system that was designed on a full scale, and was designed to reduce the acidity (and associated metals - iron) loading as possible to help recover the biota in the Mill Creek watershed. This system has proven very valuable over the years from both an application and information standpoint. The system was a large reason why the Pennsylvania Fish & Boat Commission resumed stocking of Mill Creek in 1994 and was the basis of several research studies in passive treatment system design and function. The primary reasons for system treatment efficiency decline can be attributed to age of the system, original system design, and technology at time of original system implementation. The necessity for additional alkalinity to remove the remaining iron, restoring the original SAPS by reconstruction the drainage pipe system, and adding limestone for that which has been consumed over the last 10 years, and removing iron that had precipitated over the compost of the original SAPS was apparent in the water quality data obtained from this system. The restriction in flow, caused primarily by the iron precipitates over the compost (*see* Figure H8) and the black flexible perforated piping system (with it's inherent flaws) reduced the contact time and the quantity of water contacted in the limestone layer. This obviously caused a decrease in alkalinity production, resulting in a decrease of pH and an increase in iron in the final effluent.

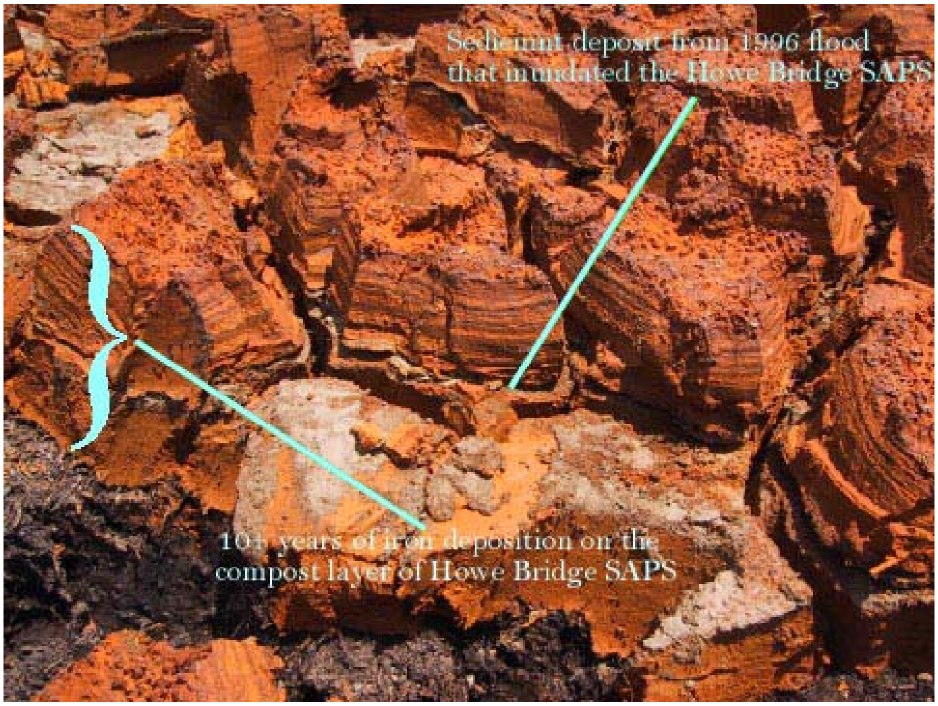
The fact that the alkalinity generated in the ALD(s) at Howe Bridge was consumed by the time the water entered the aerobic wetland, rendered the aerobic wetland relatively useless (although suspended iron did precipitate in this unit). This system was design to allow for maximum iron precipitation, a reaction mediated by alkalinity and oxygen. Without alkalinity the aerobic wetland and the original SAPS pond (hydrologically one unit) became an iron sink for the iron that was left in solution (suspended) discharging from the settling basin. This would not have been deleterious to the system, if it were not for the fact that both the aerobic wetland and the SAPS were hydrologically the same. Over the ten years of operation this lack of separation caused a relatively large amount of iron (approximately 4 inches, *see* Figure H8) to be deposited in the SAPS; which was augmented by a flood of the SAPS system that occurred in 1996, when an additional layer of silt was deposited over iron and the compost/limestone layer.

It was thought in the redesign, that if the settling basin were more efficient at iron retention the additional SAPS added in the area of the aerobic wetland would create enough alkalinity to precipitate any remaining iron prior to final discharge. This will likely, over time, lead to the same scenario that created the 2002 reconstruction of the Howe Bridge original SAPS. However, the addition of the new SAPS, and the more advanced discharge piping system (even with the area limitations) it is felt that an additional 7-10 years should be received from the new system.

The anoxic drain continues to discharge water chemistry that is similar to values obtained early in the system's operation. At some point (calculated at 20 years) the limestone will need to be replaced to continue alkalinity production. No signs of reduced flow and/or plugging have been documented at this site. In addition, flow reduction curtains were added to help slow the water in the settling basin to retain as much iron as possible to prevent excess iron from entering the first (new) SAPS system. The curtains were added in May of 2003.

Damariscotta
Mill Creek Watershed Rehabilitation Project
(No. 4 SAPS)

Figure H8. Iron deposition on the compost of the SAPS at Howe Bridge, Corsica, Pennsylvania. Photograph taken during the SAPS reconstruction in 2002.



The original design for this system were prototype (much like REM and Howe Bridge) and as such, had similar design “flaws”, that limited the systems ability to treat *this type* of water to the level that was set for the treatment goal of this system. This goal was to remove as much iron, and it’s associated acidity, while increasing the pH prior to discharge into Mill Creek. This was, for the most part was accomplished at this system, given the area and the technology at the time. With the improvements in technology the redesign in 2002 has proven, thus far to be meeting the original design goals (*see* graph H6, for the limited data collected to date). In reality the“flaws” of this system that become apparent during the course of operation were are:1) larger settling basin or flow restriction added; 2) establishment of an additional SAPS unit for alkalinity generation; and 3) more complete piping system in the original SAPS unit.

This system actually performed at or near the same level as the REM site (while it was being tended) but has enjoyed far more “success” than the REM site. This is not entirely clear, the REM system was held to more stringent standards, in terms of effluent criteria – being a regulated site. However, when both systems were operating as effective as the technology allowed at that time, the REM system was actually removing more pollution load from the receiving stream. Thus the *a priori* goals or standards set prior to the system implementation dictates how the system’s operation will be perceived. While the intent of effluent standards is intended to reduce contaminant loading, many times just the opposite occurs. In the case of REM, if the system would have been maintained and upgraded as necessary when the technology allowed, this system would have been removing contaminates to this day – similar to what occurred at Howe Bridge. REM, however, when the regulatory agency realized that effluent standards could not be met consistently, abandoned the site and the contamination load to the receiving stream increased accordingly. While effluent standards are present for a reason, these reasons are often times lost when sites are not examined on a case by case scenario. Many of the passive treatment systems, that are currently being installed, are placed in watersheds that are biologically devoid of normal (pre-mining) aquatic life. The necessity to remove acidity loading in these instances is far more important than meeting effluent standards; in that passive treatment systems are much more effective at reducing total maximum daily loads than meeting effluent criteria (although it can be done if properly designed and funded).

Damariscotta
Mill Creek Watershed Rehabilitation Project
(No. 4 SAPS)

Chapter 7 - Dichotomous Operation and Maintenance Key for Mine Drainage Passive Treatment Systems.

1a. Passive treatment system's efficiency is declining/has declined. ***go to 2(a,b,&c).***

1b. Passive treatment system's efficiency meeting expectations. ***excellent.***

2a. Passive treatment system receives mine water that is net alkaline. ***go to net alkaline treatment systems – page 21.***

2b. Passive treatment system receives mine water that is net acidic with less than 300 mg/L of acidity. ***go to 3a.***

2c. Passive treatment system receives mine water that is net acidic with more than 300 mg/L of acidity. ***go to 4a.***

3a. Source mine water with little to no ferric iron, aluminum, and dissolved oxygen (less than 1 mg/L for each parameter). ***go to anoxic limestone drain – page 22.***

3b. Source mine water with ferric iron, aluminum, and dissolved oxygen (greater than 1 mg/L for ferric iron and/or dissolved oxygen and less than 1 mg/L aluminum). ***go to successive alkalinity producing treatment systems – page 23.***

3c. Source mine water with ferric iron, aluminum, and dissolved oxygen (greater than 1 mg/L for aluminum). ***go to aluminator treatment systems – page 23.***

References

Hedin, R.S., R.W.Nairn, and R.L.P. Kleinmann. 1994a. Passive Treatment of Coal Mine Drainage. Bureau of Mines Information Circular 9389. US Bureau of Mines, Pittsburgh, PA 35 pp.

Hedin, R.S., and G.R. Watzlaf. 1994. The effects of anoxic limestone drains on mine water chemistry. Pp 185-194 *in* Volume 1 of the Proceedings of the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

Hendricks, A.C. 1991. The use of an artificial wetland to treat acid mine drainage. *In* Proceedings of the International Conference on the Abatement of Acidic Mine Drainage. Montreal, Canada. September 1991.

Kepler, D.A., and E.C. McCleary. 1994. Successive alkalinity-producing systems (SAPS) for the treatment of acidic mien drainage. pp 195-204 *in* Volume 1 of the Proceedings of the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

McCleary, E.C. and D.A. Kepler. 1994. Ecological benefits of passive wetland treatment systems designed for acidic mine drainage: with emphasis on watershed restoration. pp 111-120 *in* Volume 3 of the Proceedings of the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

Skousen, J. 1997. Overview of passive systems for treating mine drainage. Green Lands 27(4):34-43.

Skousen, J.G., A.J. Sexstone, P.F. Ziemkiewicz. 2000. Acid mine drainage control and treatment. Chapter 6. *In* Reclamation of Drastically Disturbed Lands. American Society of Agronomy and American Society for Surface Mining and Reclamation. Madison, WI

Weider, R.K., G.E. Lang, A.E. Whitehouse. 1985. Metal removal in Sphagnum-dominated wetlands: experience with a man-made system. *In* Wetlands and Water Management of Mined Lands: proceeding of a conference Oct. 23-24, 1985. The Pennsylvania State University. Pp 353-364.

Weider, R.K. 1989. A survey of constructed wetlands for acid coal mine drainage treatment in the eastern United States. Wetlands 9(2):299-315.

Weider, R.K., M.N. Linton, and K.P. Heston. 1990. Laboratory studies of Fe, Al, Mn, Ca, and Mg dynamics in wetlands. Water, Air and Soil Pollution 51:181-196.

Ziemkiewicz, P.F., J. Skousen, D. Brant, P.Sterner, R. Lovett. 1997. Acid mine drainage treatment with armored limestone in open limestone channels. J. Environ. Qual. 26:1017-1024.