THE EFFECTIVENESS OF UTILIZING PASSIVE TREATMENT SYSTEMS FOR ACIDIC LEACHATE DISCHARGES IN WESTERN MARYLAND[1]

by

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Abstract: The utilization of passive treatment systems to mitigate the effects of acid mine drainage and acidic leachate discharge is a recent innovation in the restoration of aquatic ecosystems. During the construction of U.S. Route 48 (presently Interstate Route 68) and the Maryland Route 219 Interchange in Garrett County, Maryland, in approximately 1973, sulfide-bearing rock material was utilized as valley fill and for embankments on the eastern side of Keysers Ridge. The placement of this material affected the headwater areas of two tributaries to Lake Louise, an impoundment of Puzzley Run. The movement of water through the material induced biological and chemical processes to occur, resulting in acidic leachate discharge to the tributary streams. Degradation of the aquatic ecosystems in the tributaries and Lake Louise was documented in 1975. Watershed studies have since identified aluminum leaching, an artifact of the acidic leachate, as the probable source of impairment. The Maryland State Highway Administration constructed two passive treatment systems in 1996 employing successive alkalinity-producing technology to remediate the effects of the acidic leachate discharge. Concurrent with the construction of the systems was the establishment of effluent limitations for selected chemical parameters and biological toxicity via the NPDES program. Inflow, effluent, and biological monitoring completed to date have provided insight on the effectiveness and performance of these passive treatment systems. The constructed treatment systems have demonstrated effectiveness for the reduction in concentrations of total metal parameters and total acidity and increased concentrations of total alkalinity and pH. Biological toxicity testing on the effluents of both treatment systems employing *Ceriodaphnia dubia* and *Pimephales promelas* test organisms has illustrated varying degrees of acute and chronic toxicity since the construction of the treatment systems. Further research into the causative agents of the biological toxicity is ongoing. The biological toxicity data provides new information to the scientific community on the potential effects of successive alkalinity-producing treatment technology on receiving aquatic ecosystems.

Additional Key Words: passive treatment systems, acidic leachate discharge, biotoxicity, *Ceriodaphnia dubia*, *Pimephales promelas*

Introduction

Aquatic ecosystems are dynamic assemblages supported by the interaction of physical, chemical, and biological features within the environment. Biota within these ecosystems exhibit specific tolerances and limitations to the various chemical and physical conditions of the environment they inhabit. When environmental conditions exceed these tolerances, toxicity to biota can result from acute or chronic exposure. The acidification of freshwater aquatic habitats and resultant mobilization of metals has been documented to be one of the principal causes of aquatic degradation throughout the eastern United States (Gagen and Sharpe 1987; Heard et al. 1997; United States Environmental Protection Agency 1997; Pennsylvania Department of Environmental Protection 1998). Acid mine drainage and atmospheric deposition are recognized as the two predominant sources of this type of aquatic impairment.

For approximately the past 15 years, passive treatment systems have been implemented throughout the eastern United States coal fields to mitigate the impacts of acid mine drainage discharges. Passive treatment systems employ naturally occurring chemical and biological reactions within a constructed habitat to improve inflowing

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water quality conditions prior to the subsequent discharge to the receiving environment. Passive systems have proven to be a cost-effective means of providing successful remediation and providing aquatic wildlife habitat in the form of palustrine wetlands (Davis 1995; Hedin et al., 1994; Kepler and McCleary 1994; McCleary and Kepler 1994).

Garrett County is the westernmost county in the state of Maryland, United States of America. A large portion of the U.S. EPA Central Appalachians ecoregion (Level III) encompasses this county, and in particular the Forested Hills and Mountains ecoregion (Level IV) (Woods et al., 1999). Physiographic land forms throughout the county are dominated by steeply sided mountain and ridge areas ranging in elevations from 2,000 to 3,000 feet above sea level with narrow valleys. Deciduous forest is the primary land cover/land use throughout the mountainous areas of the region, while livestock pasturing and agricultural cropfields are common in the valley reaches. Resistant sandstone and conglomerate of the Pennsylvanian Pottsville Group, sandstone of the Mississippian Pocono Formation, and sedimentary rocks of the Mississippian Mauch Chunk formations are commonly exposed at the surface in this region (Woods et al., 1999). The high, rugged topography also has a defining role on the climate of the region. Garrett County has a humid, continental climate and averages approximately 48 inches of precipitation yearly (United States Department of Agriculture, 1974). The elevation of this region limits the period between the last freezing temperature in the spring and first in the fall, defined as the growing season, to only 122 days on the average (United States Department of Agriculture, 1974).

The construction of U.S. Route 48 (presently Interstate Route 68) and the Maryland Route 219 Interchange in Garrett County, Maryland, in approximately 1973 by the Maryland State Highway Administration entailed the removal of sulfide bearing rocks from Keysers Ridge. The sulfide-bearing rocks are found in close association with many bituminous coal seams in the western Maryland region (Morgan et al., 1998). The rock material was placed as valley fill to support road construction on the eastern side of Keysers Ridge, and covered the origins of two headwater tributaries that flow into Lake Louise. Lake Louise is an approximate eight acre impoundment of Puzzley Run and its headwater tributaries. The removal and placement of these rocks allowed biological and chemical processes to occur within the fill resulting in the formation of acidic water. The acidic water, in turn, facilitated additional reactions that liberated constituents present in the rocks and overburden soils, most notably aluminum, iron, and manganese. Water contaminated with these elements and high acidity presently seeps from several locations near the toes of the fill slopes. The collection of these seep discharges by the headwater tributary streams has resulted in deleterious effects to aquatic environments downstream, including the tributaries and Lake Louise. Prior to highway construction, healthy aquatic ecosystems were documented in Puzzley Run and its tributaries, as well as Lake Louise (Brightwater 1991). Water uses within Puzzley Run are presently protected as Class III, Natural Trout Waters, capable of supporting self-sustaining trout populations and their associated food organisms by the Maryland Department of the Environment. Following construction of U.S. Route 48 and the Maryland Route 219 Interchange, a decrease in trout (*Salmonidae*) survival and reproduction rates occurred in Lake Louise. Elimination of the trout population is documented to have occurred in 1975 (Morgan et al., 1998). Historic aquatic sampling determined that the probable source of the aquatic degradation within the watershed could be attributed to aluminum toxicity, an artifact of the acidic leachate emanating from the constructed highway embankments (Brightwater 1991).

A sphagnum bog was constructed by the Maryland State Highway Administration in 1982 to improve seep discharges prior to entering the tributaries (Brightwater 1990). However, design flaws limited the long-term capabilities of this treatment system to successfully complete its objective. A second area of acidic leachate discharge was identified in 1994 entering an additional headwater tributary to Lake Louise. This area of leachate was discovered along the mainline of Interstate 68. Hence, road fill discharges in the Lake Louise watershed presently occur in two separate locations.

Treatment Concept and System Designs

Background research and conceptual design studies completed for the Maryland State Highway Administration (Brightwater 1995) concluded that passive wetland treatment technologies offered the most cost-efficient and reliable means of ameliorating the impairment of Lake Louise and its tributary streams. The initial capital expenditures for constructing a passive treatment system were determined to be minimal in comparison to active chemical treatment.

Two discrete state-of-the-art passive wetland treatment systems were constructed during 1996 to ameliorate the toxic effects of the acidic leachate seepage. These treatment systems were designed utilizing the progressive technologies of SAPS, Successive Alkalinity-Producing Systems (Kepler and McCleary 1994; Brightwater 1995). These types of treatment systems were originally developed to treat acid mine drainage (AMD) from existing or abandoned coal mining operations. However, their applicability to this project was warranted by the similar nature of the acidic discharge (high acidity, high metals concentrations).

Theoretically, SAPS systems create alkalinity, raise pH values, and decrease metal concentrations by forcing water to flow vertically through a layer of rich organic wetland substrates, typically mushroom compost material, and into a bed of limestone. The discharge is subsequently moved into an aerobic open water wetland to enhance the removal of metals. The concept provides that the deep water of SAPS cells generates sufficient hydraulic head to drive water vertically through a substrate made up of a thick layer of mushroom compost placed over 1.5 to 2.0 feet of limestone gravel. The function of the compost material is to strip oxygen from the water, thereby reducing potential iron precipitation and coating of the limestone. The limestone dissolves and produces alkalinity. Water which has been leached through the succession of compost and limestone is collected by a system of perforated pipe placed at the bottom of the limestone bed. The discharge from this treatment is sequentially transported into an oxygenated, shallow pond area where the metals are to be removed through precipitation. Long-term removal of aluminum, manganese, and acidity could be achieved through the construction of a series of treatment cells which would integrate anaerobic treatment with aerobic processes. As alkalinity is added and the pH of the influent is raised through biologically induced chemical processes within selected treatment cells, concentrations of metal contaminants may be removed from solution.

Treatment System 001 is located immediately adjacent of the U.S. Route 219 exit ramp off of Interstate 68 to the north. The seeps at this location originate on a northeast facing fill slope that supports the interstate exit ramp. Some of the contaminated water is also collected from inside the cloverleaf interchange configuration and conveyed under the exit ramp via a concrete pipe. Collectively, these seeps typically comprise approximately 50 to 200 gallons per minute of discharge. Based on the 3-year period of data collection, average concentrations of chemical parameters of interest within these seeps have been total iron (1.01 mg/L), total manganese (7.69 mg/L), total aluminum (17.00 mg/L), total acidity (128.3 mg/L), and pH (4.01 S.U.). The *Sphagnum* bog was originally installed at this site in 1982 to treat the seep discharges. Data from the monitoring of this system revealed that it did not produce long-term treatment, and provided only metals retention capabilities for three months.

Treatment System 001 is designed and configured in the following manner (Figure 1).

- Forebay: A forebay is located at the northwest corner of the treatment system and functions as a mechanism for sediment removal. This area receives the seep discharge inflows which are transported to the forebay via two ditch systems from the Interstate 68 embankment. Inflow is transported from the forebay into the SAPS #1 cell through a riser inlet structure and PVC piping.

- SAPS Cell #1: SAPS Cell #1 functions as the initial area for passive remediation treatment. Flows entering the cell are distributed throughout with a perforated PVC level spreader pipe. The head provided by approximately 6.0 feet of water is driven sequentially through approximately 1.75 feet of spent mushroom compost and 2.0 feet of limestone. The leachate is collected in a series of perforated PVC laterals in the bottom of the limestone and discharged into Hybrid Pond #1. Flows between SAPS#1 and Hybrid Pond #1 can be regulated with a gate valve structure.

- Hybrid Pond #1: Hybrid Pond #1 receives the discharge from SAPS Cell #1 in a perforated PVC level spreader pipe. Shallow flow is induced throughout the cell across two areas of 1.5 to 2.0 feet deep holes filled with spent mushroom compost. Two berm areas are placed near the end of the treatment cell to provide an extended flow path for the precipitation of metals. Straw bales are also placed in this area to encourage the volunteer colonization of wetland vegetation. The discharge leaves Hybrid Pond #1 and is transported to SAPS Cell #2.

- SAPS Cell #2: SAPS Cell #2 functions as the second area for alkalinity addition. Flows entering the cell are distributed throughout with a perforated PVC level spreader pipe. The head provided by approximately 6.0 feet of water is driven sequentially through approximately 1.75 feet of spent mushroom compost and 2.0 feet of limestone. The leachate is collected in a series of perforated PVC laterals in the bottom of the limestone and discharged into Hybrid Pond #2.

- Hybrid Pond #2: Hybrid Pond #2 receives the discharge from SAPS Cell #2 in a perforated PVC level spreader pipe. Shallow flow is induced throughout the cell across 2 areas of 1.5- to

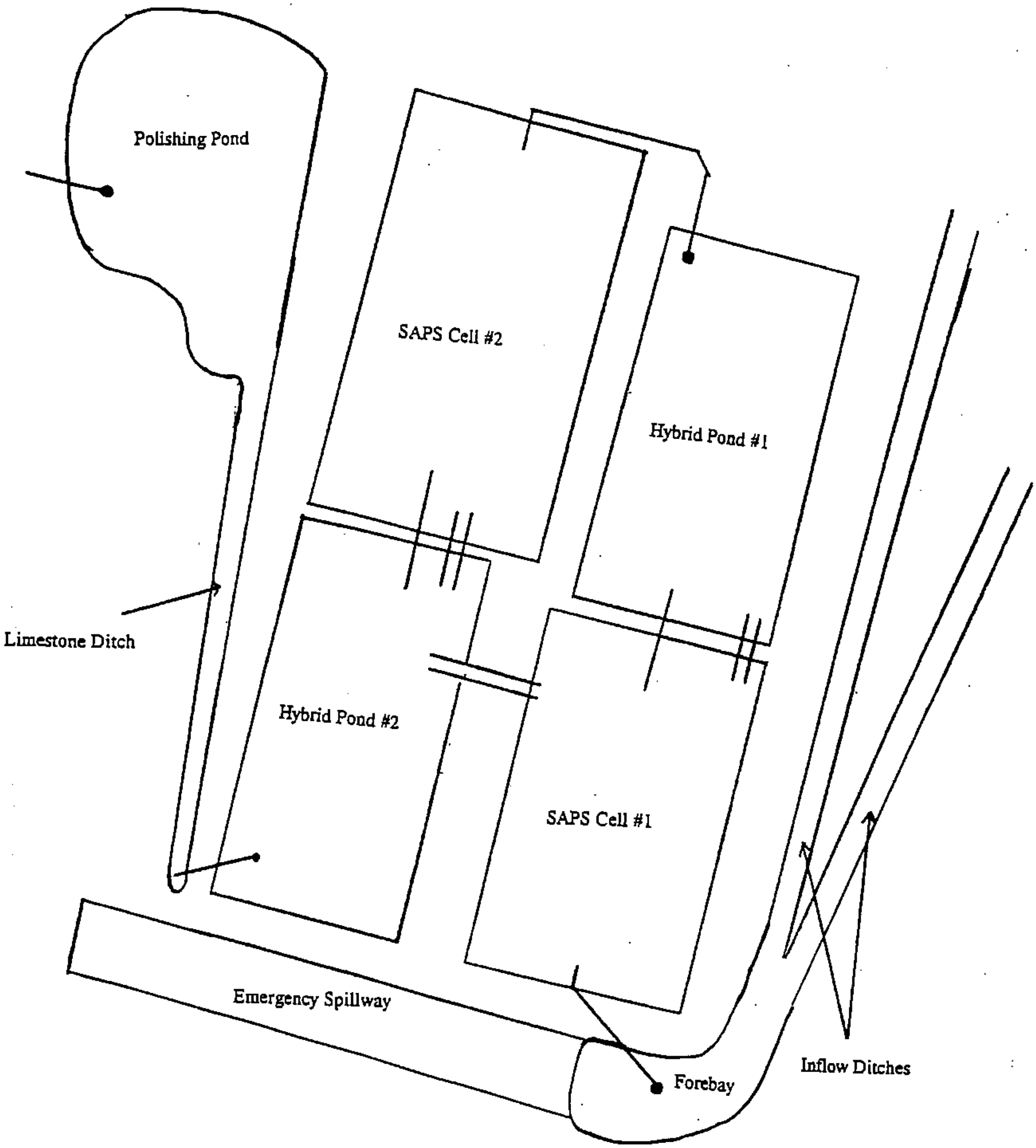

Figure 1. Schematic Diagram of Treatment System 001

2.0-foot deep holes filled with spent mushroom compost. Two berm areas are placed near the end of the treatment cell to provide an extended flow path for the precipitation of metals. Straw bales are also placed in this area to encourage the volunteer colonization of wetland vegetation. The discharge leaves Hybrid Pond #2 and is transported to a final Polishing Pond in an open limestone channel.

- Polishing Pond: After being exposed to atmospheric oxygen in the open limestone channel, flow enters the Polishing Pond. The Polishing Pond functions as a location for final treatment before being discharged through an outlet into the receiving unnamed tributary stream of Lake Louise. Shallow flow is facilitated across three 1.5 feet deep holes of spent mushroom compost before being discharged.

Treatment System 002 is located immediately adjacent the westbound lanes of Interstate 68, approximately one-half mile east of System 001. The seep zone at Site 2 originates from a north facing fill slope of the highway. Treatment System 002 is much smaller and less complex than the System 001 due to the lower flow rates of the discharge seeps in the range of 5-10 gallons per minute. Based on the three-year period of data collection, average concentrations of chemical parameters of interest within these seeps have been total iron (1.25 mg/L), total manganese (35.19 mg/L), total aluminum (18.92 mg/L), total acidity (152.7 mg/L), and pH (3.90 S.U.).

Treatment System 002 is designed and configured in the following manner (Figure 2).

- Forebay: Inflow from the embankment seeps are transported to the forebay via a french-drain collection system. This small area provides sediment removal. Inflow is transported from the forebay into the SAPS #1 cell through a riser inlet structure and PVC piping. Flows between the collection system and forebay can be regulated with a gate valve.

- SAPS Cell #1: SAPS Cell #1 functions as the initial area for passive remediation treatment. Flows entering the cell are distributed throughout with a perforated PVC level spreader pipe. The head provided by approximately 6.0 feet of water is driven sequentially through approximately 1.75 feet of spent mushroom compost and 2.0 feet of limestone. The leachate is collected in a series of perforated PVC laterals in the bottom of the limestone and discharged into the Precipitation Pond.

- Precipitation Pond: Flow enters the Precipitation Pond and flows over a 1.25-foot bed of spent mushroom compost before being discharged into an aeration channel to the treatment pond. Metals in solution are to precipitate as shallow flow over the compost material is facilitated.

- Treatment Pond: The Treatment Pond receives the discharge from the Precipitation Pond through an aeration pond and rock level spreader. Shallow flow is induced throughout the cell across 3 areas of 1.5-foot deep holes filled with spent mushroom compost. Two berm areas are placed in the treatment cell to provide an extended flow path for the precipitation of metals. Straw bales were also placed near the end of the cell to encourage the volunteer colonization of wetland vegetation. Discharge water leaves the cell and is transported through a rock level spreader into a natural wetland habitat immediately downslope.

Corrective Actions

Following construction in the period of 1996 through 1999, corrective actions have been necessary at both treatment systems to improve performance and collect additional seep areas. Corrective actions were taken during 1997 at both treatment systems. Activities at Treatment System 001 concentrated on correcting a malfunction which allowed a portion of the inflowing impaired water to completely bypass the system and exit via the emergency spillway into the unnamed tributary to Lake Louise, as well as clean out accumulated sediment in the forebay. The bypass of impaired hydrology through the emergency spillway was believed to have been caused by sediment and straw material blockages in the T-level spreader pipe which connects the forebay with SAPS Cell #1.

Activities at Treatment System 002 centered on correcting a malfunction which allowed a portion of the inflowing impaired water to completely bypass entering the french drain collection area and flowing directly into

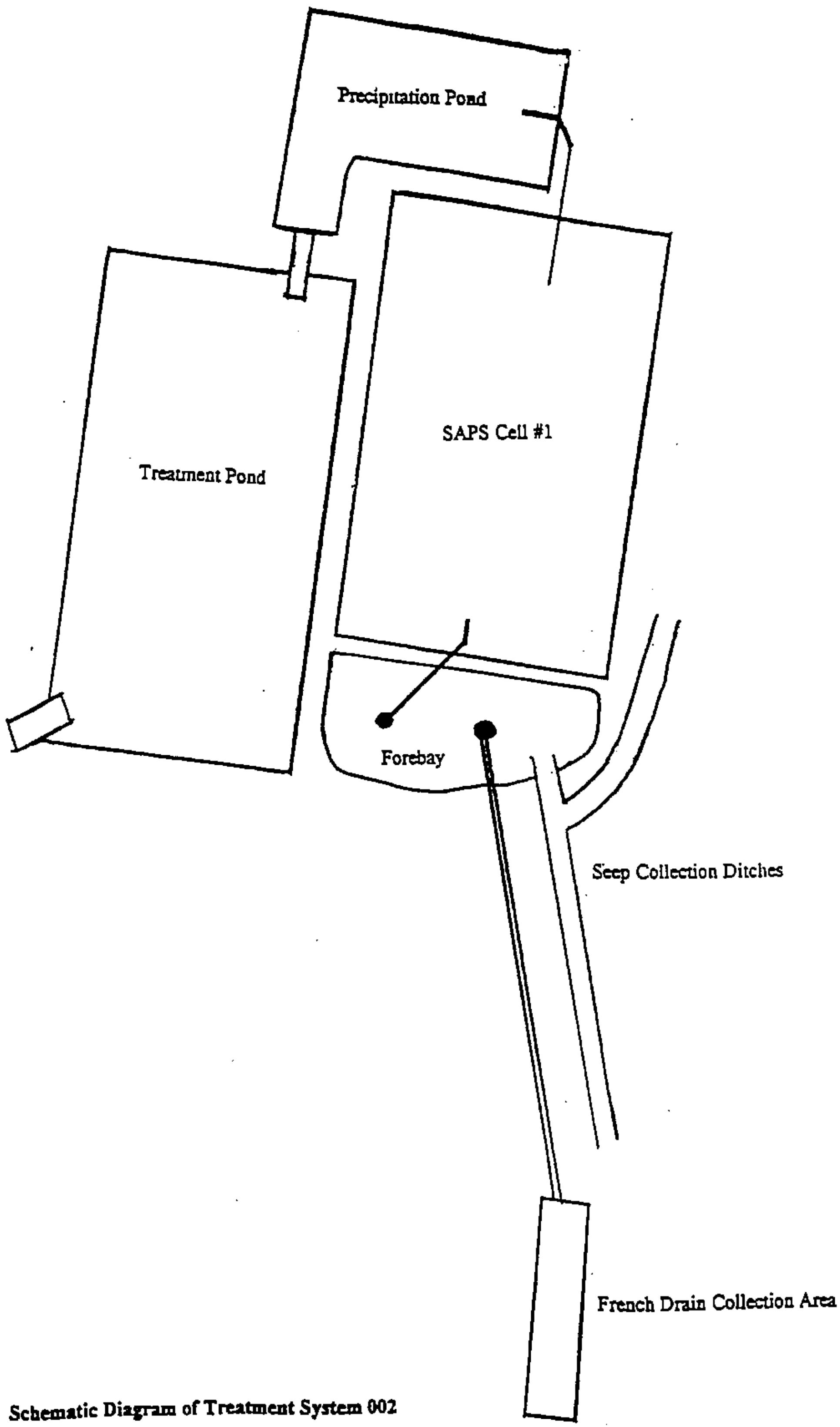

Figure 2. Schematic Diagram of Treatment System 002

the unnamed tributary to Lake Louise. The bypass of impaired hydrology was believed to have been caused by tire ruts above the french drain collection system which permitted the groundwater seep to flow above ground and into the stream without percolating into the collection area. The situation was corrected by constructing a larger rock french drain system which forced the groundwater seeps to percolate directly into the collection system.

A second instance of remediation was required on both treatment systems during 1998. Activities at Treatment System 001 centered on ensuring proper treatment sequencing. Deficiencies arose from a portion of the flow bypassing Hybrid Pond Cell #1 and SAPS Cell #2. Corrective actions included the removal of a geotextile material which separated the layer of mushroom compost material from the limestone bed in SAPS Cells #1 and #2. The removal was warranted by the speculation that the geotextile material had acted like a filter and clogged, thereby reducing the ability of hydrology to move downward into the limestone bed. Due to the decreased permeability at the compost/limestone interface, water levels rose in SAPS Cell #1 and began to discharge through a bypass channel between SAPS Cell #1 and Hybrid Pond Cell #2. Cleanout extension pipes were also added to the PVC piping in the bottom of SAPS Cells #1 and #2. This piping, which receives the product of the mushroom compost/limestone treatment, conducts the hydrology into the Hybrid Pond Cells. The extensions would provide a means to quickly clean out this piping system should blockages arise. Emergency spillway ditches were also constructed in the berms between each of the SAPS Cells and Hybrid Pond Cells to function as emergency overflow channels should hydrology not be able to be conveyed through the connective piping. These emergence spillway ditches maximized water treatment opportunities by directing water to the next cell in progression instead of bypassing multiple cells and also reduced chances for a SAPS Cell #2 berm failure.

Corrective actions completed at Treatment System 002 during 1998 entailed the construction of additional limestone channels to collect new seep areas which had arisen from the Interstate 68 highway embankment. The new seeps were collected in the channels and routed to the forebay of the treatment system.

NPDES Industrial Permitting

The Maryland Department of the Environment (MDE) issued a National Pollutant Discharge Elimination System (NPDES) Permit for the two passive treatment systems in 1996 due to their point source discharges into unnamed tributaries to Lake Louise. These tributaries are regarded as regulated waters of the United States and the State of Maryland. Special conditions within this permit included the establishment of discharge effluent limitations and monitoring requirements. Monthly monitoring is required for the amount of discharge, field pH, total iron, total manganese, total aluminum, total cadmium, total copper, total zinc, and total acidity. Quarterly monitoring is required for total lead, total silver, total nickel, total mercury, total selenium, total chromium, total arsenic, and total hardness. The Maryland State Highway Administration initiated monitoring of inflowing seep quality conditions shortly after completion of the treatment systems to provide an evaluation of passive system performance. The Administration has monitored for all parameters contained within the conditions of the NPDES Permit and additionally monitored total alkalinity in the seep discharges and treatment system effluents.

The permit conditions also require the performance of biotoxicity testing on the discharges of both treatment systems to evaluate acute and chronic biological toxicity. The permit mandates definitive 7-day chronic testing utilizing *Ceriodaphnia dubia* survival and reproduction protocols and the *Pimephales promelas* larval survival and growth protocols. *Ceriodaphnia dubia* is a small planktonic invertebrate which is ubiquitous in temperate lentic freshwater habitats. These cladocerans are noted for their sensitivity to various environmental toxicants and therefore function as a bioindicator for aquatic invertebrates (United States Environmental Protection Agency 1985). *Pimephales promelas*, commonly referred to as the fathead minnow, is a member of the Cyprinidae family and is commonly found in lentic and slow moving lotic freshwater habitats. The species is considered to be relatively sensitive to many toxicants and therefore a useful model for other freshwater fishes (Palmer et al., 1989). The United States Environmental Protection Agency, Region III, whose jurisdiction includes the State of Maryland, employs the utilization of these invertebrate and vertebrate test species for biomonitoring associated with NPDES permits typically issued to industrial and municipal wastewater discharges. Acute toxicity is broadly defined as the ability of a substance to cause deleterious effects to living organisms during a short-term exposure. Acute toxicity testing involves the measurement of lethality to aquatic organisms exposed to several effluent dilutions over typically a 48-hour time period. Test organisms are exposed to various dilutions of whole effluent, ranging from 100% effluent to 6.25% effluent and a control. Numbers of organisms surviving in the various concentrations are enumerated after the 48-hour period and a statistical estimate of the lethal concentration is derived. Chronic toxicity is broadly defined as the ability of a substance to cause deleterious effects to living organisms during a long-term exposure. Chronic toxicity testing of effluents typically involves the measurement of survival, growth, and reproduction of aquatic organisms exposed to several different effluent dilutions over a 7-day period. Test organisms are again exposed to various dilutions of whole effluent from 100% effluent to 6.25%

effluent and a control. Evaluations of the particular test organism are completed over the course of the 7-day test and statistical estimates of chronic effects are assembled.

A Toxicity Reduction Evaluation (TRE) consistent with United States Environmental Protection Agency protocol is required should biotoxicity testing indicate unacceptable acute or chronic effluent toxicity. The objective of the Toxicity Reduction Evaluation is to determine those actions necessary to reduce the effluent's toxicity to acceptable levels. The general study approach to Toxicity Reduction Evaluations has been developed based upon the design and performance of these protocols at an industrial discharge facility. Fundamentally, the Toxicity Reduction Evaluation is a multiple phase investigation conducted to identify the causative agents of effluent toxicity, isolate the source(s), determine the effectiveness of control options, implement the necessary control measures and then confirm the reduction in toxicity.

Results

Effluent discharges from both passive treatment systems have been monitored since the completion of their construction in October 1996. The Maryland State Highway Administration initiated monitoring of inflowing seep quality conditions in February 1997 to provide insight on treatment system performance and efficiency. A comparison of inflowing seep conditions and treatment system effluent conditions is provided in Tables 1 and 2.

The results of biotoxicity testing completed on the effluent discharges of both treatment systems is provided in Tables 3 and 4. Descriptive biotoxicity statistics are defined as follows for chronic toxicity: NOEC (No Observed Effect Concentration)-the highest test concentration that causes no observable adverse effects on the test organisms; and LOEC (Least Observed Effect Concentration)-the lowest test concentration that causes observable adverse effects on the test organisms. The descriptive biotoxicity statistic for acute toxicity is the LC (Lethal Concentration)-the toxicant concentration which causes death in a given percentage of the test population. The 48-Hour LC50 is the effluent concentration that would cause death to 50% of the test population in 48 hours.

Discussion

Passive treatment is a tool rapidly being employed throughout impaired watersheds for the remediation of acid-related impairments. Habitat acidification and the associated mobilization of metals attributed to acid mine drainage alone is estimated to have impacted more than 7,500 miles of stream throughout West Virginia, Pennsylvania, Maryland, Virginia, Ohio, Tennessee, Kentucky, and Alabama according to a 1997 Progress Report prepared by the U.S. Department of the Interior, Office of Surface Mining and United States Environmental Protection Agency (United States Environmental Protection Agency 1997). The optimal applicability of passive treatment systems for watershed restoration will be fully realized as the scientific community gathers further information on their performance and efficiency.

In terms of passive treatment, the concept of successive alkalinity-producing systems is a recent achievement. Hence, the collection and publication of treatment performance information and particularly biotoxicity monitoring data will provide further information to assess and evaluate the merits of this approach. Since the completion of their construction in October 1996, Treatment Systems 001 and 002 have illustrated variability in chemical constituent concentrations in the discharge effluent. The effluents of both treatment systems have demonstrated elevated levels of total alkalinity and pH, and predominantly decreased concentrations of priority metals, particularly aluminum, in comparison to inflow quality. Treatment System 002 has, however, illustrated occurrences of elevated total iron concentrations in the effluent. Several important observations have been documented on these passive systems in their approximate three-year life span. Alkalinity generation, pH elevation, and metals removal in the effluent of both treatment systems has been observed to decrease with shifts to colder ambient weather conditions in the region, especially during the winter period between November and April. These changes may be attributed to increased amounts of hydrology entering the systems from prolonged winter precipitation events and annual snowpack runoff as well as decreased microbial activity within the passive systems with the climate change. This observation should be considered for future siting of these types of passive systems in locations with limited growing season durations and substantial snowpack accumulation/runoff. Both treatment systems have also struggled to meet the effluent limitations imposed in the NPDES Permit for total manganese (4.0 mg/L Daily; 2.0 mg/L Quarterly). Volunteer colonization of the treatment systems by wetland vegetation is ongoing and has not been fully achieved during the life of these systems. Treatment performance is expected to benefit by full colonization of the treatment systems in the future.

TABLE 1
COMPARISON OF TREATMENT SYSTEM 001 INFLOW AND EFFLUENT CONDITIONS OBSERVED DURING THE PERIOD OCTOBER 1996 - NOVEMBER 1999

Parameter	Maximum Concentration Observed	Minimum Concentration Observed	Average Concentration Observed	Number of Samples Collected
Total Iron	(3.50 mg/L) 4.90 mg/L	(0.06 mg/L) 0.09 mg/L	(1.01 mg/L) 0.76 mg/L	(34) 38
Total Manganese	(13.00 mg/L) 27.00 mg/L	(4.20 mg/L) 0.62 mg/L	(7.69 mg/L) 4.94 mg/L	(34) 38
Total Cadmium	(0.019 mg/L) 0.37 mg/L	(ND) ND	(0.009 mg/L) 0.01 mg/L	(34) 38
Total Copper	(0.11 mg/L) 0.04 mg/L	(0.02 mg/L) ND	(0.06 mg/L) 0.002 mg/L	(34) 38
Total Zinc	(1.90 mg/L) 3.50 mg/L	(0.51 mg/L) ND	(1.05 mg/L) 0.22 mg/L	(34) 38
Total Aluminum	(32.00 mg/L) 4.20 mg/L	(3.60 mg/L) ND	(17.00 mg/L) 0.80 mg/L	(34) 38
Total Arsenic	(0.003 mg/L) 0.002 mg/L	(ND) ND	(0.0006 mg/L) 0.0008 mg/L	(5) 6
Total Chromium	(0.005 mg/L) 0.003 mg/L	(ND) ND	(0.002 mg/L) 0.0005 mg/L	(5) 6
Total Lead	(0.013 mg/L) 0.003 mg/L	(ND) ND	(0.006 mg/L) 0.0002 mg/L	(12) 13
Total Mercury	(ND) ND	(ND) ND	(ND) ND	(5) 6
Total Selenium	(ND) ND	(ND) ND	(0.002 mg/L) ND	(5) 6
Total Silver	(0.003 mg/L) 0.003 mg/L	(ND) ND	(0.0006 mg/L) 0.0005 mg/L	(5) 6
Total Hardness	(410.0 mg/L) 348.0 mg/L	(135.0 mg/L) 230.0 mg/L	(232.7 mg/L) 285.6 mg/L	(11) 13
Total Acidity	(220.0 mg/L) 28.0 mg/L	(55.0 mg/L) ND	(128.3 mg/L) 4.20 mg/L	(29) 29
Total Alkalinity	(10.0 mg/L) 161.0 mg/L	(ND) ND	(0.65 mg/L) 87.1 mg/L	(34) 36
Field pH	(4.93 S.U.) 7.56 S.U.	(3.13 S.U.) 5.30 S.U.	(4.01 S.U.) 6.69 S.U.	(34) 38
Discharge	(NA) 805 gpm	(NA) 2 gpm	(NA) 110 gpm	(NA) 38

* Inflowing concentrations expressed in parenthesis ( )
** ND - Concentration below the detectable limitations of laboratory instrumentation
*** NA - Not Assessed
**** Total Acidity concentrations expressed reflect Analytical Method ASTM 2310B.
***** Total Hardness, Total Acidity and Total Alkalinity concentrations expressed reflect mg/L of calcium carbonate equivalents.

TABLE 2
COMPARISON OF TREATMENT SYSTEM 002 INFLOW AND EFFLUENT CONDITIONS OBSERVED DURING THE PERIOD OCTOBER 1996 - NOVEMBER 1999

Parameter	Maximum Concentration Observed	Minimum Concentration Observed	Average Concentration Observed	Number of Samples Collected
Total Iron	(13.00 mg/L) 4.00 mg/L	(ND) 0.19 mg/L	(1.25 mg/L) 1.76 mg/L	(25) 24
Total Manganese	(62.00 mg/L) 16.00 mg/L	(13.00 mg/L) 1.90 mg/L	(35.19 mg/L) 6.94 mg/L	(25) 24
Total Cadmium	(0.007 mg/L) ND	(ND) ND	(0.015 mg/L) ND	(25) 24
Total Copper	(0.06 mg/L) 0.04 mg/L	(0.02 mg/L) ND	(0.038 mg/L) 0.003 mg/L	(25) 24
Total Zinc	(3.10 mg/L) 0.51 mg/L	(0.78 mg/L) ND	(1.79 mg/L) 0.06 mg/L	(25) 24
Total Aluminum	(36.00 mg/L) 2.90 mg/L	(7.40 mg/L) ND	(18.92 mg/L) 0.71 mg/L	(25) 24
Total Arsenic	(ND) 0.01 mg/L	(ND) ND	(ND) 0.006 mg/L	(6) 6
Total Chromium	(0.015 mg/L) 0.010 mg/L	(ND) ND	(0.004 mg/L) 0.002 mg/L	(6) 6
Total Lead	(0.045 mg/L) 0.004 mg/L	(0.007 mg/L) ND	(0.019 mg/L) 0.0006 mg/L	(10) 9
Total Mercury	(ND) ND	(ND) ND	(ND) ND	(6) 6
Total Selenium	(0.03 mg/L) ND	(ND) ND	(0.008 mg/L) ND	(6) 6
Total Silver	(0.005 mg/L) 0.003 mg/L	(ND) ND	(0.0008 mg/L) 0.0005 mg/L	(6) 6
Total Hardness	(516.0 mg/L) 270.0 mg/L	(253.0 mg/L) 888.0 mg/L	(422.8 mg/L) 538.7 mg/L	(9) 9
Total Acidity	(240.0 mg/L) 76.0 mg/L	(55.0 mg/L) ND	(152.7 mg/L) 4.75 mg/L	(20) 16
Total Alkalinity	(14.0 mg/L) 65.0 mg/L	(ND) ND	(0.56 mg/L) 878.0 mg/L	(25) 22
Field pH	(4.44 S.U.) 7.65 S.U.	(3.53 S.U.) 6.48 S.U.	(3.90 S.U.) 6.91 S.U.	(25) 24
Discharge	(NA) 22 gpm	(NA) 0 gpm	(NA) 3 gpm	(NA) 38

* Inflowing concentrations expressed in parenthesis ( )
** ND - Concentration below the detectable limitations of laboratory instrumentation
*** NA - Not Assessed
**** Total Acidity concentrations expressed reflect Analytical Method ASTM 2310B
***** Total Hardness, Total Acidity, and Total Alkalinity concentrations expressed reflect mg/L of calcium carbonate equivalents.

TABLE 3
SUMMARY OF BIOTOXICITY RESULTS OBSERVED AT TREATMENT SYSTEM 001 DURING THE PERIOD OCTOBER 1996 - NOVEMBER 1999

	1997 (2 Test Events)	1998 (4 Test Events)	1999(4 Test Events)
No Observed Effect Concentration			
Ceriodaphnia dubia	Not Observed	25% Effluent	6.25 -50% Effluent
Pimephales promelas	50-100% Effluent	100% Effluent	12.5 - 100% Effluent
Lowest Observed Effect Concentration			
Ceriodaphnia dubia	6.25 % Effluent	50% Effluent	12.5 - 100% Effluent
Pimephales promelas	100% Effluent	Not Observed	25% - Not Observed
48-Hour LC50 - Lethal Concentration			
Ceriodaphnia dubia	10.9% - 21.9% Effluent	90% - >100% Effluent	72% - >100% Effluent
Pimephales promelas	73.5% - >100% Effluent	>100% Effluent	74% - >100% Effluent

TABLE 4
SUMMARY OF BIOTOXICITY RESULTS OBSERVED AT TREATMENT SYSTEM 002 DURING THE PERIOD OCTOBER 1996 - NOVEMBER 1999

	1997 (2 Test Events)	1998 (1 Test Event)	1999 (4 Test Events)
No Observed Effect Concentration			
Ceriodaphnia dubia	6.25 -12.5% Effluent	6.25% Effluent	6.25 -50% Effluent
Pimephales promelas	6.25 - 25% Effluent	100% Effluent	12.5 - 100% Effluent
Lowest Observed Effect Concentration			
Ceriodaphnia dubia	12.5 - 25% Effluent	12.5% Effluent	12.5 - 100% Effluent
Pimephales promelas	12.5 - 50% Effluent	>100% Effluent	25% - >100% Effluent
48-Hour LC50 - Lethal Concentration			
Ceriodaphnia dubia	14.4% - 70% Effluent	33.75% Effluent	88% - >100% Effluent
Pimephales promelas	24.6% - 76.7% Effluent	>100% Effluent	>100% Effluent

Effluent biotoxicity testing conducted at both treatment systems has revealed acute and chronic toxicity during approximately the first three years of operation. Consequently, the Maryland Department of the Environment requested that a Toxicity Reduction Evaluation (TRE) consistent with United States Environmental Protection Agency be performed due to unacceptable acute and chronic effluent toxicity. The objective of the TRE is to determine those actions necessary to reduce the effluent's toxicity to acceptable levels. The Maryland State Highway Administration has continued to monitor the effluent toxicity from each system and evaluate potential causes during the TRE. Recent monitoring data collected during 1999 does suggest that acute toxicity has improved dramatically over the three-year period. Chronic toxicity remains present, although it varies among the two test organisms and temporally based upon sample collection. Several potential causes of the toxicity have been hypothesized including, the presence of lethal concentrations of aluminum despite passive treatment, the presence of lethal concentrations of metals which are not being routinely monitored as part of the NPDES Permit, synergistic effects of various concentrations of metals, leachate from the mushroom compost, and osmotic stress related to elevated ionic levels of hardness, salinity, and dissolved solids within the effluent. However, none of these scenarios has been definitively proven to date.

Historic investigations have attributed the aquatic degradation of Lake Louise and select tributaries to aluminum toxicity. Aluminum is well documented at pH's below 4.0 S.U. for its acute and chronic effects on aquatic biota, although some literature suggests that deleterious effects may also occur at higher pH's (Call et al., 1984; McCauley et al., 1986; Palmer et al., 1989). The remediation of depressed pH and elevated metal concentrations, particularly aluminum is the goal and purpose of the two constructed passive treatment systems. Published U.S. EPA freshwater aquatic life criteria for aluminum (pH 6.5-9.0 S.U.) lists criterion maximum concentration (cmc) at 0.75 mg/L and criterion continuous concentration (ccc) at 0.087 mg/L (United States Environmental Protection Agency 1986). Total aluminum concentrations during biotoxicity testing have ranged from nondetectable levels (ND) to 2.80 mg/L. This potentially suggests some correlation, however, as noted toxic effects were observed even when total aluminum concentrations were below the detection limitations of the laboratory instrumentation.

Metal parameters also monitored under the NPDES permit included iron, manganese, cadmium, copper, and zinc. Total manganese concentrations have been elevated in the effluents of both treatment systems over the three-year monitoring period (average total manganese concentration: Treatment System 001 - 4.94 mg/L; Treatment System 002 - 6.94 mg/L). Research conducted by Cumming and Hill (1971) on freshwater fish species suggested that manganese concentrations from 7 to 60 mg/L were not toxic to the select species. Manganese toxicity thresholds have also been observed to be dependent on the sample hardness (Grizzle, 1981), as other metals such as cadmium, copper, and zinc (Hoffman, et al., 1995). Average concentrations of hardness observed in the effluents of both treatment systems have been elevated as well (Treatment System 001 - 285.6 mg/L; Treatment System 002 - 538.7 mg/L). These concentrations are the result of biological and chemical processes within the treatment systems.

In freshwater environments, water hardness is attributed to metal ions, primarily calcium and magnesium, dissolved in solution. The effects of hardness on freshwater fish and other aquatic life appear to be related to the specific ions contributing to the hardness (United States Environmental Protection Agency, 1986). It has been theorized that increased hardness may aid aquatic life in reducing metals toxicity because it decreases metal uptake into the organism and may facilitate its excretion as well (Hoffman, et al., 1995). The effects of hardness on osmoregulation could suggest another source of test organism mortality and reduced reproduction in the bioassays completed for this project. Given the elevated concentrations of hardness and presumed calcium and magnesium ions, the test organisms, particularly the *Ceriodaphnia*, may be experiencing osmotic stress. The continuous effort of these organisms to excrete these ions and maintain homeostasis with the surrounding solution may be stressing to the point of mortality and/or reduced reproductive success. This theory bears further recognition and testing.

An integral component of the SAPS treatment systems is the use of mushroom compost to facilitate hydrogen sulfide production through sulfate reduction. The principal components of spent mushroom compost are reported to be hay and a bedded animal manure. Studies conducted on a comparison of materials utilized for sulfate-reducing wetlands substrate indicated that labile BOD and ammonia-nitrogen leaching from these substrates in a constructed wetland could initially cause water quality degradation (Gross et al., 1993; Skovran and Clouser, 1998). A large volume (approximately 3,900-9,000 cubic feet) of spent mushroom compost has been placed within the primary treatment cells of these systems. Large amounts of organic staining and color attributed to leaching of the mushroom compost have been noted in the effluents of both treatment systems since construction. This artifact of the treatment process may also have a pronounced effect on the biomonitoring study species. Acute toxicity of the effluents has appeared to decrease with the maturation of the treatment systems. This could suggest the toxic effect is attributable to a product of the mushroom compost leachate which is being diluted and removed over time.

The intent of this paper was to present conclusions and data collected by the Maryland State Highway Administration made at two successive alkalinity-producing passive treatment systems over the brief life-span of their existence. It is intended that this data may provide valuable insight into the function, performance and effects of these systems on the receiving watersheds and aquatic ecosystems. The initial data obtained from these treatment systems illustrate their effectiveness for generating alkalinity, raising the pH of the sample, and decreasing concentrations of metal parameters, particularly aluminum. Acute and chronic toxicity of the effluents to the *Ceriodaphnia dubia* and *Pimephales promelas* test species has been documented, however, this toxicity appears to be decreasing as the treatment systems mature. The toxicity observations should be taken into consideration prior to placing the discharge of these types of treatment systems into small-order watercourses which may lack sufficient dilution capacity to assimilate any imparted toxicity. Future monitoring of successive alkalinity-producing systems should also include a component of effluent biotoxicity to evaluate this potential effect.

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