Title
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RESTORATION OF AN UPPER HEADWATERS COLDWATER ECOSYSTEM IN WESTERN MARYLAND UTILIZING PASSIVE TREATMENT TECHNOLOGIES

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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. The ultimate objective of the passive treatment was to initiate the recovery process of Lake Louise and its affected tributaries. Extensive water quality analyses, phytoplankton and zooplankton community assessment, fish bioassays, and fish repatriation commenced in 1997, and will be continued through 2005. The biological sampling has documented improvements in the lake phytoplankton and zooplankton communities, as well as survival and growth of rainbow trout (Oncorhyncus mykiss) and brook trout (Salvelinus fontinalis) stockings. Young-of-the-year brook trout were collected during 2002 in an impacted tributary, indicating the return of water quality and habitat conditions which support natural reproduction. Inflow, effluent, and biological monitoring completed to date have provided insight on the effectiveness and performance of these passive treatment systems for the restoration of the coldwater ecosystem.

Passive Treatment Technologies
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.

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. 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 the 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 7-year period of data collection, typical concentrations of chemical parameters of interest within these seeps have been total iron (0.8mg/L), total manganese (7.8mg/L), total aluminum (19.4 mg/L), and pH (3.74 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:

- **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- 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 #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 two areas of 1.5- to 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-foot deep holes of spent mushroom compost before being discharged.
a control. Numbers of organisms surviving in the various concentrations are enumerated after the 48-hour exposed to various dilutions of whole effluent, ranging from 100 percent effluent to 6.25 percent effluent and organisms exposed to several effluent dilutions over typically a 48-hour time period. Test organisms are organisms during a short-term exposure. Acute toxicity testing involves the measurement of lethality to aquatic discharges. Acute toxicity is broadly defined as the ability of a substance to cause deleterious effects to living organisms associated with NPDES permits typically issued to industrial and municipal wastewater includes the State of Maryland, employs the utilization of these invertebrate and vertebrate test species. The United States Environmental Protection Agency, Region Ill, whose jurisdiction is considered to be relatively sensitive to many toxicants and therefore a useful model for other freshwater the Cyprinidae family and is commonly found in lentic and slow moving Lotic freshwater habitats. The species 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 percent effluent to 6.25 percent effluent and a control. Numbers of organisms surviving in the various concentrations are enumerated after the 48-hour

Treatment System 002 is designed and configured in the following manner:

- **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 the 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.

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 seven-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 percent effluent to 6.25 percent effluent and a control. Numbers of organisms surviving in the various concentrations are enumerated after the 48-hour
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. Based on the seven-year period of data collection, typical concentrations of chemical parameters of interest within the effluent of Treatment System 001 have been total iron (0.4 mg/L), total manganese (4.0 mg/L), total aluminum (0.8 mg/L), and pH (6.33 S.U.). Typical concentrations of chemical parameters of interest within the effluent of Treatment System 002 have been total iron (1.5 mg/L), total manganese (9.2 mg/L), total aluminum (0.6 mg/L), and pH (6.86 S.U.).

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 have 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.

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 that 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 levels 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 levels (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 (U.S. EPA 1986). Total aluminum concentrations during biotoxicity testing have ranged from...
nondetectable levels (ND) to 2.80mg/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. 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 (U.S. EPA 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 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 that 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 from two successive alkalinity-producing passive treatment systems over the brief life-span of their existence. It is intended that these 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.

**Biological Restoration**

Phytoplankton samples were collected from three Lake Louise stations starting in 1997 (fig. 1). A 1000-ml sample was collected at a depth of one meter using a portable Masterflex pump to fill a 1-L polyethylene bottle at each station. Samples were preserved with 5 percent neutral buffered formalin in the field, with Lugol's solution added in the laboratory. Phytoplankton samples were shipped to aquatic analysts for identification and enumeration. Zooplankton samples were also collected from the same three Lake Louise stations (fig. 1). Samples were collected at a depth of one meter using a Schindler-Patalas plankton trap (12 L), preserved with 5 percent neutral buffered formalin in the field, and shipped to ZP’s Taxonomic Services for identification and enumeration.
Fish population estimates were done using gill net sampling in Lake Louise, and a backpack electroshocker in Tributary One. Lower reaches of each tributary entering Lake Louise were assessed for brook trout and rainbow trout, especially focusing on young-of-year fish, using backpack electroshockers.

For purposes of this paper, we concentrate only on three primary elements of the lake ecosystem – phytoplankton, zooplankton, and the restored fish community. A number of other factors were evaluated at Lake Louise during the study, including stream and lake chemistry, stream habitat, stream and lake benthos, sediment chemistry, and aquatic vegetation – these will not be discussed further.

**Phytoplankton**

The phytoplankton community in Lake Louise was surveyed from 1997 to the present, with three more future study years planned from 2003-2005 (Morgan et al. 1999, 2000, 2001, 2002). *Cyclotella stelligera* was the dominant phytoplankton species collected at all stations in June 1997, comprising 69 to 87 percent of the algal community and reflected in overall low algal diversities in June 1997 (fig. 1). By 1998, the percent contribution of this species dropped to 41-49 percent of the summer algal community. Moreover, by June 1999, it ranged from 5.6-7.2 percent of the algal community – a huge drop from earlier values for this species. *Cyclotella* is an indicator diatom commonly found in ponds and lakes receiving runoff from mining wastes, and is very metal tolerant. *Cyclotella stelligera* remains as a key species in the phytoplankton community temporally, but at levels far lower than observed before SAPS operation.

For the most recent phytoplankton samples (25 samples from 2000-2002), the following algae were most common (as relative density): Glenodinium sp. (12 percent), Chlamydomonas sp. (11 percent), Cosmarium sp. (10 percent), Cyclotella comta (9 percent), Cyclotella stelligera (6 percent), Gloeocystis ampla (6 percent), Dinobryon sertularia (6 percent) and Synedra radians (6 percent). All other algal species were present at less than 5% relative density. Total densities ranged from 104 to 7,069/ml (mean = 1,959), total biovolumes from 55,505 to 4,008,716 μM³/ml (783,810), and trophic state indices from 28.4-59.9 percent (43.1 percent).

The trophic state index, based on the total algal biovolume, ranged from about 28 to 60. This places Lake Louise into a lower mesotrophic status, indicating some nutrient addition, probably from limited agricultural practices in the watershed. The continuing presence of a metal tolerant algal species, *Cyclotella stelligera*, indicates that Lake Louise is often still dominated by algal species tolerant of metals and acidic conditions. However, this species continues to show an overall significant decline in the lake, and may be a minor species eventually.

Fig. 1. Phytoplankton and zooplankton sampling stations on Lake Louise.
Summer period algal diversities increased significantly in Lake Louise after the summer of 1997 (Fig. 2), following improving water quality in the lake due to SAPS operation. From 1998 to 2002, the phytoplankton diversity was over 2.0 (mean diversity in June 1997 = 1.3), with a corresponding linear increase from 1998 to 2002. This change in diversity indicates overall improvement in lake water quality, as effected by the SAPS.

**Zooplankton**

The second component of the Lake Louise ecosystem to be tracked was the zooplankton community (Morgan et al. 1999, 2000, 2001, 2002). Over time, more zooplankton species have appeared in the lake following SAPS installation. For example, more species of zooplankton were collected in 2001-2002 than were ever found in Lake Louise. The same six species of planktonic crustaceans first found together in 2000 were present, along with a new seventh planktonic species present at all stations in both December 2001 and May 2002, suggesting that a major improvement in water quality, first noted in 2000, continues. Six species of cladocerans (four euplanktonic), four copepods (three euplanktonic), fifteen rotifers (six new), and two protozoans were observed in 2002. The four species of crustaceans that were common in 1997 through 2001, *Diaphanosoma birgei*, *Bosmina longirostris*, *Mesocyclops leuckarti*, and *Tropocyclops prasinus*, were again relatively common as was the small daphnid, *Daphnia parvula*, first found in 1999, and the new cyclopoid copepod, *Diacyclops thomasi*. 
Zooplankton abundance in Lake Louise presented an interesting pattern (fig. 3). Initially, the 1997 samples showed a high density of zooplankters, but represented by only a few species. Over time, more species appeared in Lake Louise, but density fluctuated. In part, zooplankton densities observed in Lake Louise after SAPS follow patterns observed in small lakes, where densities are closely tied in with phytoplankton abundance (Sorano et al. 1993). However, zooplankton densities do show significant increases (over 400,000/m$^3$) in spring/summer periods following SAPS treatment (fig. 3).

The initial assessment made of Lake Louise based upon the 1997-1999 zooplankton data suggests that it was apparently a rather stressed eutrophic to hypereutrophic ecosystem. As noted in 1999, both the low species richness and lack of large edible forms for trout as well as the high total zooplankton numbers supported such a conclusion. Data from 2001 and 2002, however, definitely support the observation that there has been an improvement in the water quality (though not necessarily in trophic status). For example, the discovery of *Dacyclops thomasi*, a planktonic crustacean found in all but the most polluted or most oligotrophic, North American lakes (i.e., it is absent only from the extremes), suggests that the water quality of Lake Louise is starting to become more tolerable. Likewise, observing a water mite and *Ploesoma* for the first time, along with the absence of *Keratella taurocephala*, suggests that conditions seem to be improving.

This improvement, unfortunately, has not yet lead to the realization of the 2000 prediction, namely, that colonization by large cladocerans should occur with sufficient water quality improvement. Furthermore, such a colonization event ought to provide a positive feedback loop on water quality as well (Carpenter and Kitchell 1993), further improving Lake Louise. Such an introduction would be accompanied by changes in the rotifer species composition due to interference competition (Gilbert 1988a,b). However, although this colonization has not occurred yet, it is still too early to suggest that it will not occur in Lake Louise, given the decennial nature of past crustacean colonization events (Keller and Yan 1991; Keller, et al. 1992; Vogel, et al. 2000). In summary, the 2001-2002 samples point toward a consistently improved condition among the zooplankton assemblage, implying an improvement in Lake Louise water quality. With three years of steady improvement, it is starting to appear that 1999 marked the beginning of a long-term positive trend.

**Fish Community**

Based on positive bioassay results, fish stocking of Lake Louise started in 1999 (Morgan et al. 1999, 2000, 2001, 2002). We delayed the initial planting of brook trout into Tributary One because of 1999 drought conditions – this stocking was then done in 2000. On May 19, 1999, we stocked 490 rainbow trout (*Oncorhynchus mykiss*) into Lake Louise (table 1). These trout were from the Laurel Hill Trout Hatchery in Osterberg, PA, and were transported to the field site in a hatchery truck. The mean length of stocked rainbow trout was 172mm, with a mean weight of 58 g. On October 19, 1999, we stocked an additional 290 rainbow trout, with mean length = 202mm and mean weight = 75g. In 2000, we completed one stocking (290 fish) of rainbow trout into Lake Louise followed by 290 more rainbow trout in June 2001. An additional stocking of 250 rainbow trout was done in June 2002 (table 2). Total stocked fish to date number 1,620 rainbow trout into Lake Louise over four years. In October 2000, we planted 100 brook trout into Tributary One. Fish size was mixed; 35 brook trout were stocked from the SAPS downstream, and 75 from the bridge upstream. Table 1.

Summary of rainbow trout releases and recaptures in Lake Louise (2001 and 2002). Three brook trout were captured by gill nets in 2001 (mean length = 210mm); one brook trout was captured in 2002 (338mm).

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Table 1.
A total of 14 rainbow trout were collected in gillnets on October 23, 2001, (overnight set starting on October 22, 2001) and two fish were caught on October 11, 2001 in a trial set (table 1). Interestingly, only one rainbow trout released in October 1999 was captured. Twelve rainbow trout were collected in gillnets on September 23, 2002 (table 1). Fishes from cohort 1 were not collected in 2002 – this may be due to the gill net mesh size limitations since cohort 1 fish may now be too large to be effectively captured by the largest mesh in our gill nets. In both years, we did not collect the newest cohort introduced into the lake (cohort 4 in 2001, and cohort 5 in 2002) – this may be due also to the gill net mesh used. Interestingly, again only one rainbow trout released in October 1999 was captured. All cohorts had good growth rates.

Through electroshocking in Tributary One during fall 2001, we collected a total of six brook trout (out of 100 stocked in the stream). However, we also caught three brook trout in the lake (two males - 198 and 209mm; one gravid female - 224mm), indicating movement out of Tributary One into Lake Louise. With low buffering capacity in Tributary One, there is a strong possibility that more brook trout have moved out of this stream, and now reside in Lake Louise. Low buffering capacity may also indicate that there is likelihood that rainbow trout may not be able to successfully reproduce.

In October 2002, we collected 28 young-of-year (YOY) at Lake Louise (23 in Tributary One), indicating that successful spawning occurred during fall 2001. More encouraging was the fact that we found brook trout YOY in the lower end of presumably tributaries 3 (1 YOY), 4 (2 YOY), 5 (1 YOY), and 7 (1 YOY), near the lake. We do not know if spawning occurred in these tributaries since they were not surveyed for redd formation in the fall (this would be very difficult because of dense vegetation in the lakeside stream reaches). The general case is that upon emergence from redds, a rapid movement of YOY takes place away from a redd, and brook trout YOY may move significant distances. The mean YOY size was 89.7mm (SD = 9.0; range = 70-110mm). We also collected nine adult brook trout. These fish were all collected from Tributary One, and ranged from 118 to 276 mm (x = 190.4; SD = 48.0). Four were males, four were females, and one was not sexed.

Successful reestablishment of brook trout into Tributary One indicates that the SAPS has improved water quality to the point where brook trout reproduction is successful, and a viable population of rainbow trout exist in Lake Louise. Monitoring will continue through 2005 to determine long-term restoration of Lake Louise.

Future monitoring with Lake Louise may also need to evaluate potential land use changes due to land development within the watershed. The Tributary One watershed of Lake Louise is dominated by 40 percent forest (deciduous and evergreen), although the forest in Tributary One (and the entire Lake Louise watershed) has been subjected to numerous, and continuing, timber harvests. Approximately 12.3 percent is in agricultural use, with another 28.4 percent present as open field. Water (0.1 percent) is a very minor component of the watershed.

The most critical concern hinges on the amount of impervious surface (17.2 percent) and other urban landuse (1.9 percent) in the Tributary One watershed. Currently, the watershed contains a large amount of total impervious surface (19.1 percent), especially surfaces associated with Route 68, and the Keysers Ridge interchange. In addition, there are other areas of impervious surface connected with business, especially the area in the northern segment of the watershed.

Based on models developed to assess the relationship of stream quality with the percentage of impervious surface, Tributary One is currently classified as being impacted [Center for Watershed Protection (CWP) 2003]. The basic, general model, with some assumptions and caveats, developed by the CWP indicates that there are breakpoints in stream quality and impervious surface, with 10 percent as being the initial cutpoint for stream sensitivity, followed by an interval of 10-25 percent where a stream becomes impacted. Impervious surface in a watershed over 25 percent usually results in stream quality becoming non-supportive for aquatic life. Some of these impacts may be seen in the increased sediment loadings observed in Tributary One. Future development in the watershed of Tributary One may result in pushing impervious surface to over 25 percent, resulting in significant damage to Tributary One, and consequent long-term effects on Lake Louise.

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