Lake Diagnostic Study
and Management Plan Development for
Lake Roaming Rock

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1.0 Introduction

EnviroScience, Inc. was contracted by the RoamRock Association, Inc. to evaluate current in-lake and watershed conditions in order to make long-term management recommendations for the improvement of Lake Roaming Rock. In recent years turbidity and the frequency of algal blooms have increased, while aquatic vegetation in the reservoir has dramatically decreased. Although the lake's fishing is generally considered good, the Association's board recognizes that changes in both water quality and the plant community have the potential for negatively impacting the fishery. Other threats to the fishery and long-term health of the lake include invasive species such as Azola and zebra mussels, and the introduction of white amurs (grass carp) to control aquatic vegetation.

As originally envisioned, the EnviroScience study is to focus on the following areas:

- Review of available historic information and consultation with the Association regarding goals and objectives of the Association and the community.
- In-lake sampling and analysis to document current water quality and condition of the plankton (zooplankton and algae) community. This information will be compared to past studies to document patterns and evaluate trends.
- An aquatic plant macrophyte (plant) survey to document changes in the plant community over the past decade.

Finally, as an option, EnviroScience suggested that the Association consider performing a fish survey to determine population characteristics and community trends.

Because the project was initiated in late summer, 2004, a decision was made to break up the sampling activities so that portions would be completed in both 2004 and 2005. The 2004 work involved the review of existing information, the first of three in-lake sampling events, and both wet weather and dry weather sampling of significant influent streams to the lake. Following submission of an interim report summarizing activities performed in 2004, EnviroScience was authorized to perform additional sampling during 2005. EnviroScience was also authorized to perform carp removal activities in the lake during 2005. This document will serve as the final report for the project and detail activities and findings from both 2004 and 2005.

2.0 Existing Data Review

Several past studies have been performed on Lake Roaming Rock and a review of the data from these studies may help identify long-term trends in water quality. These studies include:

- 1978 Water Quality Study conducted by G. Dennis Cooke, Kent State University (Cooke, 1978)
- 1990 Lake Management Consulting Study performed by ACRT, Inc. Kent, Ohio (ACRT 1990)
- 1991 Sediment Accumulation Study performed by James Wade (Wade, 1991)
- Ohio Lake Management Society's Volunteer Monitoring Program (CLAM)

Additionally, several other documents pertinent to the current study were reviewed including an undated project proposal which evaluated the feasibility of lake dredging and a draft study of the Rock Creek watershed prepared by Robert Carlson with Kent State University's Department of Biological Sciences.

The objectives, methods and findings from the studies by Dr. Cooke, James Wade and ACRT, Inc. are briefly summarized in the sections below.

2.1 1978 Trophic State Study by G. Dennis Cooke

The 1978 study by Kent State University's Dennis Cooke focused on determining the trophic state of Lake Roaming Rock. Trophic state is a measure of the overall productivity of a lake system and is widely measured using the Trophic State Index (TSI) developed by Carlson (1977). The TSI is based on the amount of algal biomass, which is directly related to Secchi Disc transparency. It is derived from the direct measurement of transparency, total phosphorus and total chlorophyll *a* in the surface water column.

Cooke measured these parameters three times at four locations over the course of the summer, along with an analysis of algal populations in various parts of the lake. He calculated mean TSI values for both the upper, shallow portions of the lake and for the deeper basins, including the area near the dam.

The results of this study revealed that lake was showing strong signs of eutrophication (a process akin to aging due to nutrient enrichment), particularly in the shallower basins. Levels of phosphorus in the upper waters were high enough (approximately 20 ug/L) to create algal blooms, with most of the phosphorus coming not from the lake sediments as is the case with many older reservoirs and lakes, but rather from the watershed. Phosphorus concentrations were at least two times greater at the upper end of the reservoir and this was reflected in much higher concentrations of algae and total chlorophyll in these areas. The algae (phytoplankton) community was dominated by blue-green algae, the type that are responsible for severe taste and odor problems in potable water supplies. The lake was found to be thermally stratified and anoxic, or nearly so, in deeper sections

Principal recommendations contained in the report included control of the aquatic weed Eurasian water milfoil with mechanical harvesting, reduction of both nutrients and sediment input to the lake, and development of an expanded monitoring program and lake budget for nutrients, water, and sediment.

2.2 1990 Lake Management Study by ACRT, Inc.

In response to frequent algal blooms, the Rome Rock Association contracted with ACRT in August 1990 to conduct a dissolved oxygen survey of the lake and analyze the phytoplankton present in the reservoir.

The DO survey revealed that throughout its length, the lake is anoxic below 15 feet in depth. In addition to being detrimental to aquatic life, very low oxygen levels at the sediment/water interface can result in metals and nutrients being released from the sediments into the water column. Once released to the water column, the resulting elevated phosphorus levels produce algal booms in the water column.

The algae analysis revealed that the phytoplankton community was dominated by blue-green algae, with *Aphanizomenon flos-aquae* being the most abundant species in the reservoir. This nuisance species produces endotoxins that have been known to cause both fish kills and harm to livestock and pets.

Overall, this study resulted in recommendations for additional monitoring in both the lake and the watershed, a macrophyte survey and control strategy, and evaluation of possible aeration methods applicable to the reservoir.

2.3 1991 Sediment Accumulation Study by James Wade

James Wade, identified as a geologist but with an unknown affiliation, performed a reconnaissance sedimentation survey in August 1991. The survey revealed that since 1968, the lake had lost approximately 6 percent of its volume. This value is relatively low compared to other Ohio lakes which typically lose up to 1 percent per year. Not surprisingly, the depth of accumulated sediment was highest at the upper end of the reservoir.

The report estimated sediment depths 25 and 50 years into the future based on current loading from the watershed which was estimated to be 0.7 tons of sediment per watershed acre per year. This totals approximately 668,000 tons or 32,000 yd^3 of sediment entering the lake per year. The report noted that shoreline erosion was being controlled fairly well, and this was unlikely to be a significant contributing factor to overall sedimentation of the reservoir.

2.4 Ohio Citizens Lake Assessment and Monitoring Program

Two of the major lakes in the watershed, Lake Cardinal and Lake Roaming Rock (Rome Rock) were early participants in the volunteer water quality monitoring program sponsored by the Ohio Lake Management Society. As a part of this program, Secchi disk transparency and an estimate of water color was measured throughout the summer. The average transparency and water color values are given in Table 2-1. The lower transparency and higher color values in Lake Cardinal suggest turbidity caused by non-algal material such as clay turbidity. Lake Roaming Rock is more transparent and has a color more indicative of an algae-dominated turbidity. However, it appears that its transparency fell throughout the years of monitoring, losing approximately half of its transparency (Figure 2-1). This would be indicative of a doubling of the amount of the limiting nutrient in the water. The single value taken in 2004 suggests this trend of decreasing transparency continues. However, in 2005 the transparency returned to values seen in the early 1990's. It remains to be seen if the lake has changed or whether this is natural variability being exhibited.

Figure 2-1 Trophic State and Secchi Depth in Lake Roaming Rock

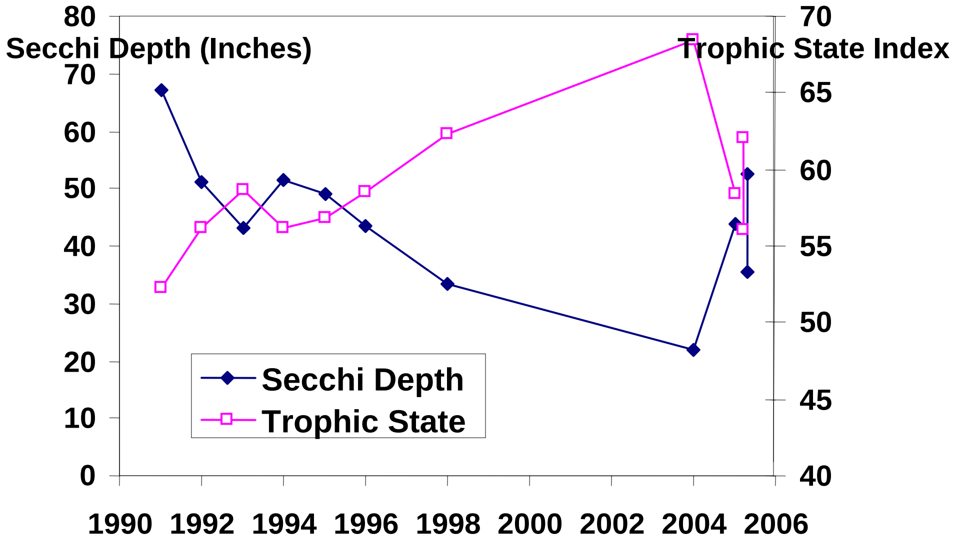


Table 2-1. Transparency and Color in two Grand River Reservoirs

Lake	Variables	1991	1992	1993	1994	1995	1996	1998	2004
Cardinal	Avg Secchi Depth (In)	22.1	19.3	19.4	18.4	15.3			
	Avg Watercolor	8.3	8.2	7.5	8.0	7.7			
Roaming Rock	Avg Secchi Depth (In)	67.3	51.2	43.1	51.4	48.9	43.5	33.5	22[1]
	Avg Watercolor	6.3	7.7	6.0	7.3	7.1	7.1	6.5	

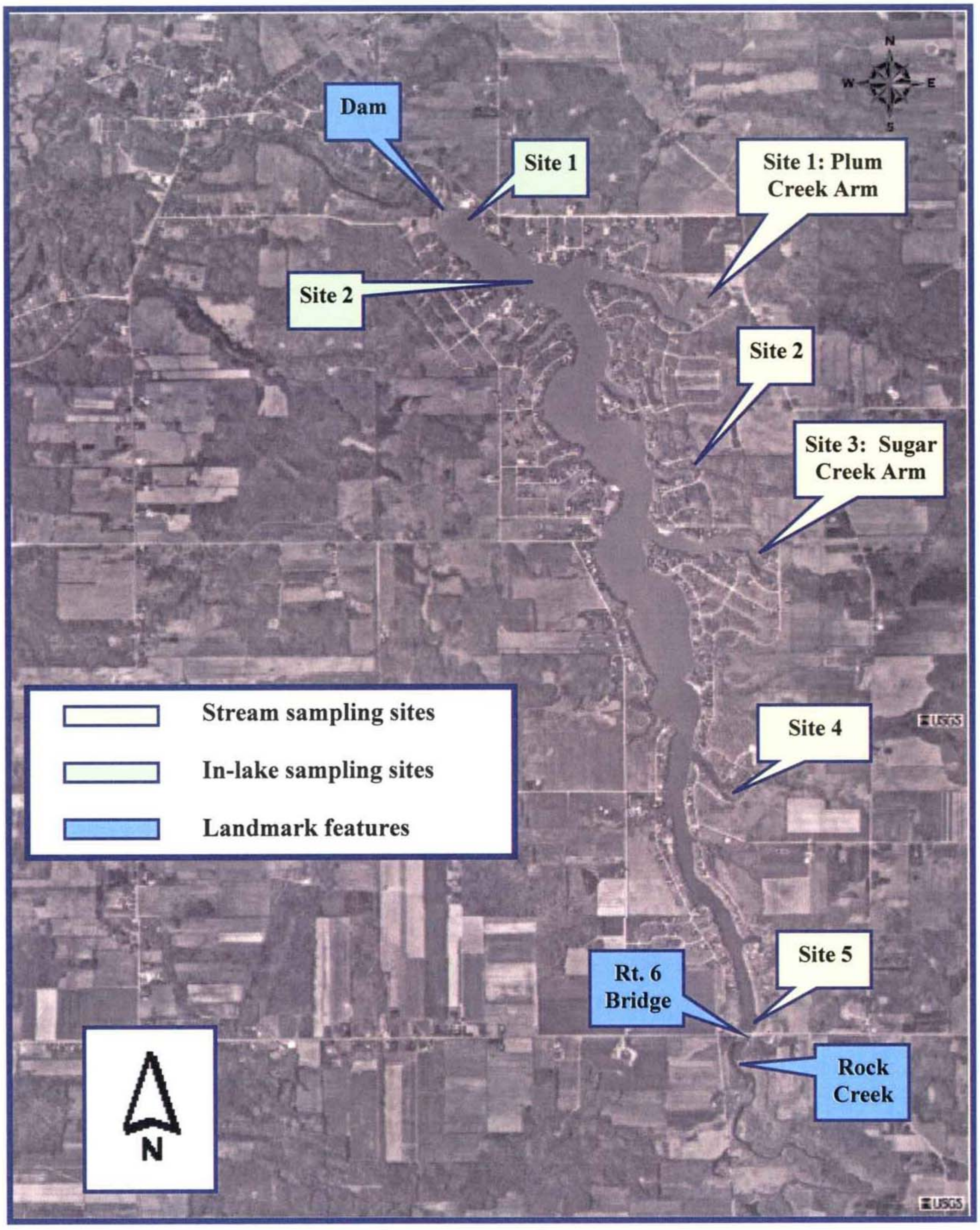
[1]Single sample

3.0 Methods

EnviroScience visited Lake Roaming Rock on three occasions during 2004. The first of these events (August 27th) was directed toward in-lake sampling at two locations. Sampling at five influent stream locations was conducted under dry weather conditions on September 24th, and under wet weather conditions on December 1st. For the purposes of this study, dry weather conditions were defined as being a period where no measurable precipitation had occurred within the past seven days and the influent streams were flowing at relatively low levels. Wet weather conditions were defined as periods where a minimum of 0.5 inches of precipitation had been recorded at a nearby National Weather Service monitoring station within the previous 24-hour period. Sampling locations are shown on Figure 3-1. Stream sampling locations were selected to provide information on what appeared to be the largest and most significant sources of flow to the reservoir.

The two in-lake stations were sampled once on August 27, 2004 and on May 17 and August 12, 2005 using a Kemmerer sampler capable of collecting discrete samples at various depths. A near surface sample was collected at each location at a depth of one meter. The surface sample was analyzed for nitrate, total organic nitrogen, total suspended solids, fecal coliform and total phosphorus. Mid-depth and near-bottom samples were also collected and analyzed for total phosphorus and each sample was also analyzed in the field for temperature, pH, conductivity and dissolved oxygen using a Hydrolab Quanta® multi-parameter water quality monitoring device. The device was calibrated according to the manufacturer's recommendations prior to each use. A standard plankton tow was used to collect plankton samples. These samples were analyzed by PhycoTech, Inc., St. Joseph, MI.

Figure 3-1. Lake Roaming Rock



Stream samples were collected mid-channel using a rinsed stainless steel bucket. These samples were analyzed in the field for temperature, pH, conductivity and dissolved oxygen using the Hydrolab Quanta® device. Turbidity was measured in the field using a turbidity stick. Each sample was also analyzed in the laboratory for nitrate, total organic nitrogen, total suspended solids, fecal coliform and total phosphorus.

Analytical samples were preserved and analyzed within prescribed holding times according to methods outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 1995). Analytical samples were analyzed by American Testing Company, Inc., Bedford Heights, OH.

In-lake samples were collected with the generous assistance of Mr. Bruce Bower.

Carp removal was attempted on three occasions during May and June, 2005. Sampling was performed using a boat mounted Smith-Root 5.0 GPP electrofisher. Shallow water areas where carp had been previously observed were sampled. Stunned fish were observed and species of interest (i.e. European and grass carp were netted and later sacrificed. Sampling was conducted as follows:

- May 23, 2005 for six hours between 6:00PM and 12:00AM,
- June 13, 2005 for eight hours between 1:00PM and 9:00PM,
- June 19, 2005 for six hours between 6:00PM and 12:00AM

A total of 58 man-hours were expended on this effort.

4.0 Results and Discussion

4.1 In-Lake Analytical and Field Chemistry

In-lake sampling of Lake Roaming Rock began in the August of 2004 and ended in August of 2005; one cohesive sampling project that expanded over a two year time frame. All data are presented and discussed below; the results of the 2004 in-lake chemistry samples taken during the late summer on August 27, 2004 are summarized in Table 4-1 and the 2005 in-lake chemistry samples taken during the early summer on May 17, 2005 and during the mid-summer on August 12, 2005 are summarized in Tables 4-2 and 4-3.

Table 4-1. In-Lake Sampling Results- Late Summer 08/27/2004

Date	Sample Location	Depth	Parameter	Result	Units
8/27/2004	Site 1-Near Dam	1 Meter From Surface	DO	11.9	mg/l
			Temp.	24.9	^{o}C
			Cond	0.164	μ mho/cm
			pH	8.57	S.U.
			Chl a	12	ug/l
			T. Phosphorus	130	ug/l
			TSS	14	mg/L
			T. Organic N	2	mg/L
			Coliform, Fecal	BDL*	cfu/100ml
			Nitrate, N.	0.25	mg/L
		4.6 m	DO	6.73	mg/l
			Temp.	22.6	^{o}C
			Cond	1.67	μ mho/cm
			pH	7.7	S.U.
			T. Phosphorus	230	ug/l
		9.4m	DO	0.37	mg/l
			Temp.	10.9	^{o}C
			Cond	0.224	μ mho/cm
			pH	7.03	S.U.
			T. Phosphorus	580	ug/l
8/27/2004	Site 2- Ctr. of Lake	1 Meter From Surface	DO	10.9	mg/l
			Temp.	24.8	^{o}C
			Cond	0.164	μ mho/cm
			pH	8.11	S.U.
			Chl a	45	ug/l
			T. Phosphorus	80	ug/l
			TSS	10	mg/L
			T. Organic N	1.1	mg/L
			Coliform, Fecal	BDL*	cfu/100ml
			Nitrate, N.	0.25	mg/L
		Mid-depth	DO	7.31	mg/l
			Temp.	23.4	^{o}C
			Cond	1.66	μ mho/cm
			pH	7.8	S.U.
			T. Phosphorus	240	ug/l
		1Meter From Bottom	DO	0.44	mg/l
			Temp.	10.72	^{o}C
			Cond	0.242	μ mho/cm
			pH	7.07	S.U.
			T. Phosphorus	880	ug/l
8/27/2004	Site 2		Secchi Depth	22	in.

*** BDL= Below Detectable Limits**

Table 4-2. In-Lake Sampling Results- Early Summer 5/17/2005

Date	Sample Location	Depth	Parameter	Result	Units
5/17/2005	Site 1-Near Dam	1 Meter From Surface	DO	9.98	mg/l
			Temp.	15.58	^{o}C
			Cond	0.159	μ mho/cm
			pH	7.77	S.U.
			Chl a	15	ug/l
			T. Phosphorus	0.015	ug/l
			TSS	BDL*	mg/L
			T. Organic N	BDL*	mg/L
			Coliform, Fecal	BDL*	cfu/100ml
			Nitrate, N.	0.62	mg/L
		4.6 m	DO	9.96	mg/l
			Temp.	15.45	^{o}C
			Cond	0.157	μ mho/cm
			pH	7.73	S.U.
			T. Phosphorus	0.016	ug/l
		9.4m	DO	6.43	mg/l
			Temp.	9.45	^{o}C
			Cond	0.149	μ mho/cm
			pH	7.68	S.U.
			T. Phosphorus	0.024	ug/l
5/17/2005	Site 2- Ctr. of Lake	1 Meter From Surface	DO	10.33	mg/l
			Temp.	15.92	^{o}C
			Cond	0.159	μ mho/cm
			pH	8.08	S.U.
			Chl a	17	ug/l
			T. Phosphorus	0.01	ug/l
			TSS	7	mg/L
			T. Organic N	BDL*	mg/L
			Coliform, Fecal	2	cfu/100ml
			Nitrate, N.	0.69	mg/L
		Mid-depth	DO	5.58	mg/l
			Temp.	9.66	^{o}C
			Cond	0.152	μ mho/cm
			pH	7.69	S.U.
			T. Phosphorus	0.018	ug/l
		1Meter from Bottom	DO	2.41	mg/l
			Temp.	7.37	^{o}C
			Cond	0.15	μ mho/cm
			pH	7.57	S.U.
			T. Phosphorus	0.057	ug/l
5/17/2005	Site 2		Secchi Depth	52.36	in.

*** BDL= Below Detectable Limits**

Table 4-3. In-Lake Sampling Results- Mid Summer 08/12/2005

Date	Sample Location	Depth	Parameter	Result	Units
8/12/2005	Site 1-Near Dam	1 Meter From Surface	DO	7.26	mg/l
			Temp.	26.44	°C
			Cond	0.207	μ mho/cm
			pH	8.06	S.U.
			Chl a	30	ug/l
			T. Phosphorus	0.061	ug/l
			TSS	BDL*	mg/L
			T. Organic N	BDL*	mg/L
			Coliform, Fecal	4	cfu/100ml
			Nitrate, N.	0.3	mg/L
		4.6 m	DO	2.08	mg/l
			Temp.	24.02	°C
			Cond	0.206	μ mho/cm
			pH	7.89	S.U.
			T. Phosphorus	0.059	ug/l
		9.4m	DO	0.63	mg/l
			Temp.	10.72	°C
			Cond	0.178	μ mho/cm
			pH	7.51	S.U.
			T. Phosphorus	0.101	ug/l
8/12/2005	Site 2- Ctr. of Lake	1 Meter From Surface	DO	7.41	mg/l
			Temp.	27.2	°C
			Cond	0.206	μ mho/cm
			pH	8.07	S.U.
			Chl a	35	ug/l
			T. Phosphorus	0.066	ug/l
			TSS	BDL*	mg/L
			T. Organic N	BDL*	mg/L
			Coliform, Fecal	11	cfu/100ml
			Nitrate, N.	0.2	mg/L
		Mid-depth	DO	1.33	mg/l
			Temp.	17.01	°C
			Cond	0.189	μ mho/cm
			pH	7.64	S.U.
			T. Phosphorus	0.059	ug/l
		1 Meter from Bottom	DO	0.65	mg/l
			Temp.	9.25	°C
			Cond	0.193	μ mho/cm
			pH	7.33	S.U.
			T. Phosphorus	0.323	ug/l
8/27/2004	Site 2		Secchi Depth	35.43	in.

*** BDL= Below Detectable Limits**

The results for temperature, conductivity and pH throughout the three sampled time periods were within expected ranges and are conducive to aquatic life. Surface dissolved oxygen at all locations was adequate, but as noted in earlier surveys by Cooke (1978) and ACRT, Inc. (1990), DO drops dramatically below 5 meters in depth and approaches zero near the bottom of the lake as the summer progresses (See Figures 4-1 and 4-2). However, the DO is observed as being the highest during the early summer and late summer samples taken on August 27, 2004 and May 17, 2005 and remains above 5 mg/L even at mid-depth. The DO during the early summer sampling continues to remain above 5 mg/L at 1 meter from the bottom in S1 and drops to 2.41 mg/L in S2. The additional DO levels recorded during the mid-summer and late summer samples reflect a similar decrease in DO levels from mid-depth to1 meter from the bottom, both dropping dramatically and reaching between 0.65 mg/L and 0.37 mg/L. The low DO conditions at the sediment/water interface result in a release of phosphorus and metals such as iron and manganese from the sediments to the water column.

DO profiles were collected at five different sites on two additional occasions (May 17, 2005 and June 28, 2005), in order to assess the DO levels at different depths using one meter increments. DO readings recorded on May 17, 2005, ranged from 10.33 mg/L to 9.88 mg/L at 1 meter in depth and reached a reading of zero mg/L between 6.5 to 10 meters in depth. In addition, all five sites were found to have a DO value of 5 mg/L or higher at a depths of 5 meters or less.

On June 28, 2005, DO readings ranged from 11.85 mg/L to 7.31 mg/L at 1 meter in depth and reached a reading of zero mg/L between 6 to 10 meters in depth. However, readings recorded at a depth of 5 meters were well below 2 mg/L. In fact, DO readings dropped dramatically after reaching a depth of 2 meters, decreasing an average of 6.4 mg/L from 2 meters to 3 meters in depth and then decreased slowly until finally reaching zero.

Figure 4-1 Early Season Temperature and Dissolved Oxygen Profiles

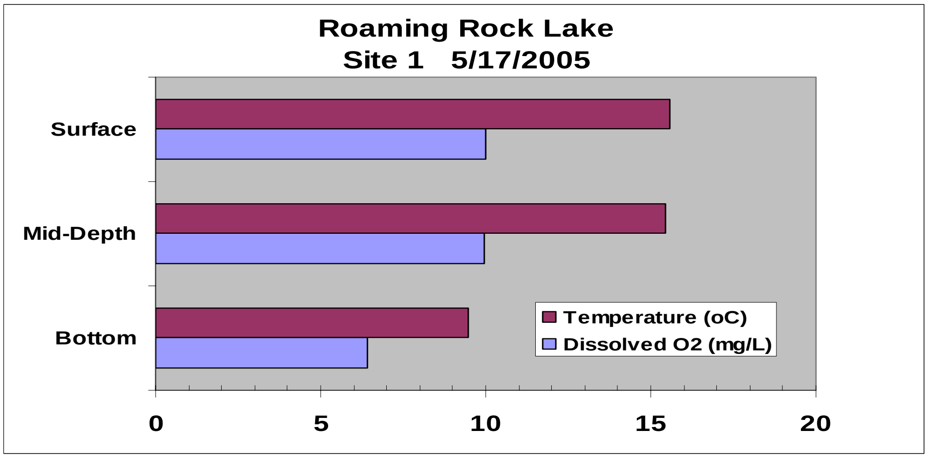


Figure 4-2 Late Season Temperature and Dissolved Oxygen Profiles

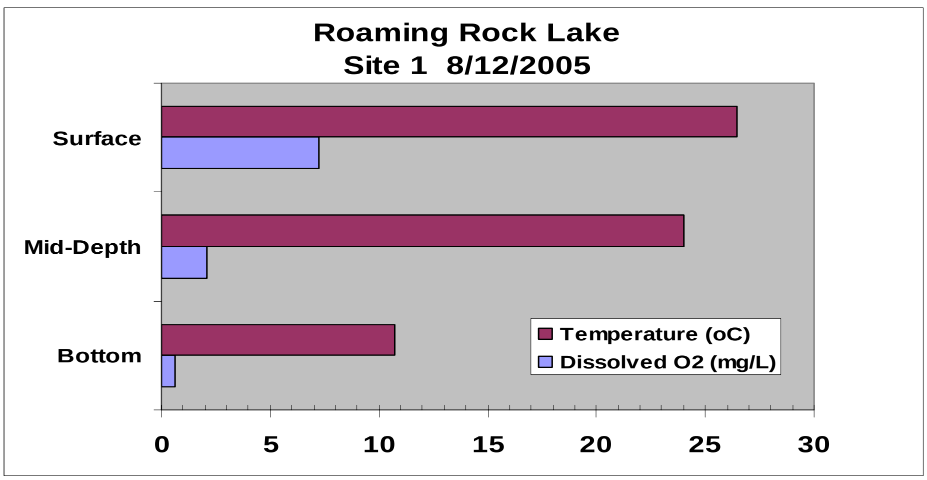
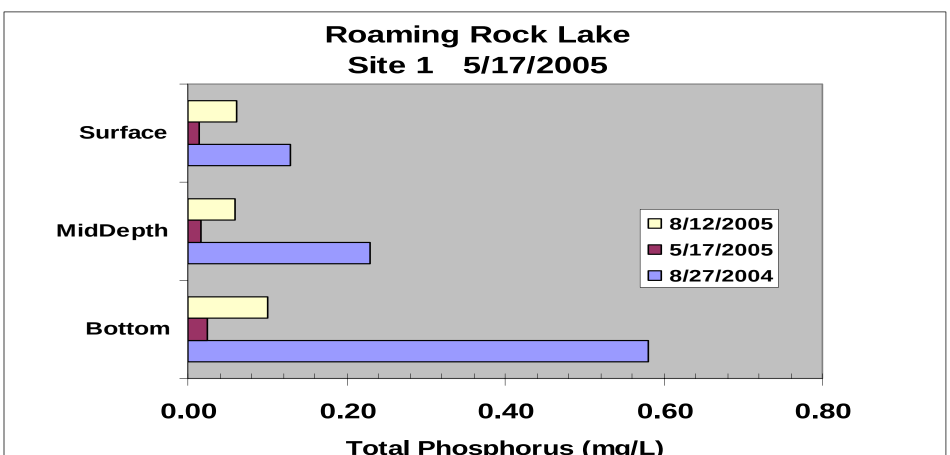


Figure 4-3 Total Phosphorus Concentrations at Depth



A dramatic increase in total phosphorus concentrations were recorded during the late and mid-summer samples, increasing an average of 0.62 mg/L in the late summer sampling and an average of 0.148 mg/L in the mid-summer sampling. The greatest increase noted between the mid-depth sample and 1 meter from bottom sample. The total phosphorus levels recorded during the early summer sampling remained relatively constant throughout the depth changes, increasing an average of only 0.028 mg/L.

During each sampling period, a dramatic increase in total phosphorus concentrations were noted at both sample locations in the samples collected one meter from the bottom. Figure 4-3 provides an example of this trend. As is typical for many lakes, Lake Roaming Rock becomes thermally stratified during the summer months resulting in relatively little interchange between the upper and lower reaches of the lake. This stratification breaks down in the fall resulting in this nutrient and metal rich water becoming distributed throughout the water column. It is during this turnover period that biologically important nutrients such as phosphorus become available to algae in the photic zone of the lake. This internal release of phosphorus from the sediments is often one of the most important factors ultimately responsible for nuisance algal blooms. The effects of the spring turnover can be observed here during the early summer sampling conducted on May 17, 2005, based on the relatively high amount of DO throughout the entire water column of the lake, as well as having similar phosphorus, conductivity and pH values throughout the water column.

In addition to the taste and odor problems that may result from nuisance algal blooms and iron and manganese, low or no DO in the water column can pose a threat to the aquatic life in the reservoir.

4.2 Trophic Status and Calculation of the TSI

In any given lake system, the trophic state of the lake can be defined as the total amount of living material (biomass) present in the water column at a given time. Trophic state is generally accepted as a biological response to factors such as nutrient addition, with phosphorus being the primary growth-limiting nutrient for algae and macrophytes in lakes (Horne and Goldman, 1994). Eutrophication, although a natural process over time, is often accelerated by human activities, namely those that increase plant nutrients (i.e. phosphorus) in the lake. Nutrients enter the lake through run-off or direct input from fertilizer rich agricultural soils, sewage, or other wastewater. Enrichment of the nutrients in the water results in increased algal densities (algal "blooms") which in turn may produce a host of undesirable effects including discoloration, taste and odor problems, low DO conditions, changes in fish species abundance, and toxicity problems. Toxicity is of concern with increasing awareness that some strains of algae produce toxins at doses that are lethal to animals and humans.

Due to its importance in lake dynamics, monitoring of total phosphorus was an important part of the current study. Samples of Chlorophyll *a* provided an estimate of the amount of algae present. The more chlorophyll *a* that is present the larger the algal biomass, and the more eutrophic the lake is. Additionally, the clarity of the lake, as measured with by Secchi disc transparency, is a function of the density of varying algal concentrations and other suspended material.

Carlson's Trophic State Index (TSI) (Carlson, 1977) is a relatively simple way of comparing these three measurements. Chlorophyll *a* (CHL), Secchi depth (SD), and total phosphorus (TP) are used in the TSI calculations to independently estimate algal biomass. Each individual measurement is converted to an index value ranging from 0 to 100 using the following equations:

$$TSI_{(SD)} = 60 - 14.41\ln(SD)$$

$TSI_{(CHL)} = 9.81 \ln(CHL) + 30.6$

$TSI_{(TP)} = 14.42 \ln(TP) + 4.15$

Based on its TSI values, a lake can be placed into one of four categories of trophic status: oligotrophic, mesotrophic, eutrophic, and hypereutrophic. **Oligotrophic** lakes (TSI <40) are typically clear, well oxygenated throughout, with little phytoplankton and low nutrient levels. **Mesotrophic** lakes (TSI between 40-50) are intermediate between oligotrophic and eutrophic lakes and are characterized by moderate clarity and nutrient levels, and increasing probability of anoxic conditions at depth during the summer. **Eutrophic** lakes (TSI between 50 and 70) are often characterized by a disappearance of oxygen (anoxia) in the deeper parts of the lake and nuisance levels of macrophytes and blue-green algal scums during the summer. **Hypereutrophic** lakes (TSI >70) have algal densities so high that light rather than nutrients becomes limiting to plant growth. Macrophytes often disappear because there is insufficient light to support their growth. Fish species shift towards roughfish that can tolerate low oxygen levels. In extreme hypereutrophic situations, winter and summer fish kills will occur.

TSI values calculated for Lake Roaming Rock are as follows:

In-Lake Sampling Results – Late Summer 8/27/2004

Site 1

$\mathbf{TSI_{CHLA}}$ = 55

$\mathbf{TSI_{TP}}$ = 74

Site 2

$\mathbf{TSI_{CHLA}}$ = 68

$\mathbf{TSI_{TP}}$ = 67

$\mathbf{TSI_{SD}}$ = 68

In-Lake Sampling Results – Early Summer 5/17/2005

Site 1

$\mathbf{TSI_{CHLA}}$ = 57

$\mathbf{TSI_{TP}}$ = 43

Site 2

$\mathbf{TSI_{CHLA}}$ = 58

$\mathbf{TSI_{TP}}$ = 37

$\mathbf{TSI_{SD}}$ = 56

In-Lake Sampling Results - Mid Summer 8/12/2005

Site 1

$\mathbf{TSI_{CHLA}}$ = 64

$\mathbf{TSI_{TP}}$ = 63

Site 2

$\mathbf{TSI_{CHLA}}$ = 65

$\mathbf{TSI_{TP}}$ = 65

$\mathbf{TSI_{SD}}$ = 62

These values place Lake Roaming Rock near the high end of the eutrophic range and indicate that the lake is approaching hypereutrophic conditions. These values are among the highest values found by Cooke (1978) in a survey of ten Northeast Ohio lakes. Possibly more troubling is the fact that the TSI values calculated in the current study are significantly worse than those found by Cooke in 1978. In that study the maximum $TSI_{(SD)}$ was 60 (current study = 68), the maximum $TSI_{(CHL)}$ was 56.4 (current study = 68), and the maximum recorded $TSI_{(TP)}$ was 58.3 (current study = 74). It should be noted that the current study uses a very limited data set; additional data would allow for more meaningful comparisons.

The fact that the three indices tend to be very similar on the same dates is indicative that there is little non-algal turbidity in the water and that the transparency is being largely affected by algae concentrations. The similarity of the phosphorus and the chlorophyll indices suggests that the nutrient, phosphorus, is probably limiting the growth of the algae in the lake. This has implications on what nutrient should be targeted for control.

4.3 Stream Analytical and Field Chemistry

Sampling results from major influent sources to Lake Roaming Rock are presented in Table 4-4.

Table 4-4. Stream Sampling Results

Site No.	Stream Description.	Parameter	Result- Dry Weather 9/24/04	Result- Wet Weather 12/01/04	Units
1	Plum Creek Arm	DO	6.53	6.61	mg/l
		Conductivity	0.185	0.126	μ mho/cm
		pH	7.01	7.4	S.U.
		Temp.	14.2	5.65	^oC
		Turbidity	36/34	8/8.5	in.
		T. Phosphorus	5.0	0.1	mg/l
		TSS	<2	28	mg/l
		T. Organic N	<0.2	0.7	mg/l
		Coliform, Fecal	82	TNTC	cfu/100ml
		Nitrate, N.	0.01	0.47	mg/l
2	Unnamed Trib.	DO	8.08	5.92	mg/l
		Conductivity	0.16	0.124	μ mho/cm
		pH	7.55	7.36	S.U.
		Temp.	18.1	5.56	^oC
		Turbidity	8.25/8.5	15/15.5	in.
		T. Phosphorus	0.41	0.09	mg/l
		TSS	53	17	mg/l
		T. Organic N	3.2	0.7	mg/l
		Coliform, Fecal	25	TNTC	cfu/100ml
		Nitrate, N.	0.32	0.05	mg/L
3	Sugar Creek Arm	DO	7.43	6.19	mg/l
		Conductivity	0.214	0.131	μ mho/cm
		pH	7.44	7.38	S.U.
		Temp.	15.1	5.68	^oC
		Turbidity	34.25/35	10/9.0	in.
		T. Phosphorus	0.07	0.21	mg/l
		TSS	<2.0	35	mg/l
		T. Organic N	0.5	0.4	mg/l
		Coliform, Fecal	77	TNTC	cfu/100ml
		Nitrate, N.	0.07	0.48	mg/L

Table 4-4. Stream Sampling Results

Site No.	Stream Description.	Parameter	Result- Dry Weather 9/24/04	Result- Wet Weather 12/01/04	Units
4	Unnamed Trib.	DO	8.2	7.54	mg/l
		Conductivity	0.39	0.164	μ mho/cm
		pH	7.67	7.47	S.U.
		Temp.	14.72	5.6	°C
		Turbidity	28.75/28.75	3/3.5	in.
		T. Phosphorus	0.07	0.37	mg/l
		TSS	<2.0	100	mg/l
		T. Organic N	0.6	0.9	mg/l
		Coliform, Fecal	33	TNTC	cfu/100ml
		Nitrate, N.	0.03	1.89	mg/L
5	Rock Crk. Inlet	DO	6.55	6.95	mg/l
		Conductivity	0.171	0.198	μ mho/cm
		pH	7.56	7.39	S.U.
		Temp.	19.8	5.98	°C
		Turbidity	19/18.75	4.0/4.0	in.
		T. Phosphorus	0.13	0.35	mg/l
		TSS	6	80	mg/l
		T. Organic N	0.7	0.9	mg/l
		Coliform, Fecal	22	TNTC	cfu/100ml
		Nitrate, N.	0.3	1.31	mg/L

Stream sampling results summarized in Table 4-4 confirm that significant levels of nutrients, particularly phosphorus are entering the lake from the surrounding watershed. As expected, concentrations of nutrients are two to three times higher and suspended solids concentrations are as much as an order of magnitude higher under wet weather conditions. The only exception to this trend is the un-named tributary identified as Site 2. At this location, both nutrients and suspended solids were significantly higher under dry, low-flow conditions than during wet weather. Limited investigation of this sub-watershed should be conducted to determine whether this anomaly is a recurring event. If so, high suspended solids and nutrient inputs occurring during dry weather may indicate the presence of point source discharges that need further investigation to determine the source and whether these pollutants can be readily abated.

4.4 Biological Sampling and Analysis

The results of the phytoplankton (algae) analysis are provided in Appendix A. The algae community is largely dominated by blue-green algae, with *Anabaena flos-aquae*, *Microcystis aeruginosa*, and *Coelosphaerium naeglianum* being the most dominant species. These species are common in nutrient-rich surface water and generally do well in warm temperatures and in high light levels. However, some species such as *Aphanizomenon flos-aquae* are able to increase their population size in every season of the year if conditions are right and they have been known to make significant blooms in fall, winter and spring. Many water treatment problems stem from blue-green algae in reservoirs used as water supplies. These include:

- Poor taste and odor associated with algal blooms
- Possible toxicity to domestic animals and humans from toxins produced by common bloom-forming blue-green algae
- Production of potential carcinogenic byproducts such as trihalomethanes when algal matter is treated with chlorine disinfectant.

Although some of the blue-greens found in Lake Roaming Rock such as *A. flos-aquae*, and *M. aeruginosa* have often been implicated when toxic blooms are reported, most occurrences of these species are not toxic and should not be cause for concern merely because of their identification in the phytoplankton community of the lake.

However, the presence of these species and the abundance of blue-green algae (>32,000 cells/ml) relative to other algal divisions (<2,500 cells/ml) are indicative of eutrophic conditions.

The results of the zooplankton analysis are presented in Appendix B. Overall, the zooplankton community of Lake Roaming Rock was not very diverse, comprised mainly of two groups, the rotifers and the cladocerans (daphnids). Of these, the community is dominated by the rotifers, very small multi-cellular animals that filter planktonic algae for food. The relative dominance of rotifers in the lake is likely related to the abundance of blue-green algae. Rotifer abundance is often positively correlated with high levels of blue-green algae because rotifers seem to be able to feed on toxin-producing blue-green algae more successfully than cladocerans or other zooplankton.

One of the more startling observations made at the time of the in-lake sampling involved the near total lack of aquatic macrophytes (rooted plants) in the lake. This contrasts sharply with past surveys by Cooke in 1978 and ACRT in 1999. Both surveys reported that macrophytes were present in the lake at levels considered to be a nuisance and requiring control. At the time of Cooke's survey the dominant plant was reported to be milfoil (*Myriophyllum sp*.). The plant was presumably Eurasian watermilfoil (*M. spicatum*), an aggressive and invasive exotic species that once established usually dominates the plant community of infested lakes. Domination by milfoil is usually undesirable because milfoil 1) forms dense floating mats which interfere with boating and swimming, 2) provides poor fish and wildlife habitat, and 3) generally reduces the overall biodiversity of a lake.

In recent years, Lake Roaming Rock was reportedly infested and (within the past five years) dominated by *Azola*, an unusual floating non-native aquatic plant more commonly recognized as a water garden plant. Despite being extremely abundant as recently as three years ago, Azola had virtually disappeared from the lake at the time of the 2004 survey.

Aquatic plants are important and natural components of most lake communities and provide many benefits to fish wildlife, and people. Aquatic plants serve many important functions including:

- Providing food for fish- More food for fish is produced in areas having aquatic plants than in areas without plants. Insect larvae, snails, and a variety of crustaceans inhabit plant beds. Sunfish, an important component of the lake's fishery, eat aquatic plants in addition to insects and crustaceans.
- Providing fish shelter- Plants provide shelter for young fish and they are areas frequently used for spawning and nesting by bass sunfish and pike.
- Improving water clarity and quality- Aquatic plants help maintain water clarity by stabilizing and preventing the re-suspension of sediment. Moreover, nutrients used by the plants are nutrients that aren't available to algae. The loss of aquatic plants in Lake Roaming Rock is likely aggravating the lake's algae problems.
- Providing food and shelter for waterfowl- Many submerged plants produce seeds and tubers which are eaten by waterfowl. Submerged plants also provide habitat and food for many insects and invertebrates that are, in turn, important foods for resident and migrating waterfowl such as ducks.

The almost complete absence of aquatic plants in the lake has the potential to dramatically affect both water quality and the lake's fishery. The removal of aquatic plants may negatively impact water quality by both increasing turbidity and by making additional nutrients available for nuisance algal growth. As noted above, removal of aquatic plants has the potential to disrupt the fishery by removing an important component at the base of the food chain and by removing important nesting areas and shelter for young fish.

It should be pointed out that not all aquatic plants provide equal value to the lake. Domination by one or two species (especially exotic ones) is not a desirable situation. A diverse the plant community provides better habitat and will support a healthier and more diverse fishery. Diversity in these communities is important because they are both critical components of a healthy lake and are inseparably related to the ongoing algae problems experienced in recent years.

One possible explanation for the absence of aquatic vegetation in Lake Roaming Rock may be the introduction of large numbers of white amur (grass carp) over the past twenty years. According to records available from the Association, approximately 1,000 small grass carp were stocked in 1988. Since that time, 100 15"-20" grass carp were stocked in 2001, 200 were stocked in 2002, and an additional 100 were stocked in 2003.   Grass carp are non-native fish capable of consuming large quantities of aquatic vegetation. Although they are usually considered generalist feeders, they exhibit strong preferences and unfortunately, tend to avoid milfoil, one of the most common nuisance plant species.

European carp also considered generalist feeders are abundant in Lake Roaming Rock accordingly to members of the Fishing Club. Although not usually as disruptive to the plant community as grass carp, European carp also uproot vegetation and contribute to high suspended solids through their feeding activities and excrete nutrients into the water column.

4.5 Carp Removal Activities

A total of 58 man-hours of effort were expended electroshocking various bays and near-shore habits, but very few roughfish were captured. The first of three night electroshocking efforts conducted on May 23, 2005 produced many stunned bass and panfish (which recovered with no adverse effect within minutes), but no common European carp or grass carp.   The second of these efforts on June 13th captured 10 European carp and the final effort on June 19th collected six European carp.

Despite 58 man-hours of effort collecting in areas known to be good carp habitat, very few roughfish were collected. Because larger fish tend to be more sensitive to electrical current, it may be that the fish were able to sense the pulsed current from a greater distance and escape into deeper water where the current was insufficient to stun them. Although the precise reason for this poor collection efficiency is unknown, ample evidence exists that large numbers of both varieties of carp remain. It is also clear that electroshocking is not an efficient means of roughfish collection in a relatively deep lake like Roaming Rock. As will be discussed in Section 6.4 below, more aggressive techniques will be needed to harvest a meaningful number of these fish.

5.0 Summary of Current Conditions and Management Issues

The results gathered to date indicate that Lake Roaming Rock is in a highly eutrophic state and this trend has worsened over the past two decades. Steady inputs of phosphorus from what are likely agricultural sources in the watershed, coupled with increasingly significant internal loading of phosphorus from the sediment under anoxic conditions, steadily contributes to the increasing eutrophication of the lake. This has resulted in more frequent blooms of nuisance and noxious blue-green algae. These blooms are not only aesthetically unpleasing, but may also pose a number of problems if not addressed. These include:

- a reduction of sunlight in the water column making it more difficult for aquatic macrophytes to become established and grow;
- a general depression in dissolved oxygen levels caused by decomposition of algae as they decay;
- the bluegreen algae are a less desirable food source for many zooplanktivorous fish, and finally;
- a direct threat to human health from algal toxins sometimes produced by these blue-green algae.

If not addressed, the severity and frequency of blue-green algal blooms in Lake Roaming Rock is likely to worsen in the coming years. The rapid disappearance of aquatic vegetation in the lake is likely contributing to the nuisance algal blooms and, in fact, making them worse.

At present, Lake Roaming Rock supports a healthy and diverse sport fishery. Electroshocking performed during May and June, 2005 revealed abundant and good sized panfish and bass. Years of judicious stocking complemented by placement of artificial habitat and a catch and release program promoted by the community's fishing club has produced one of the best sport fisheries in the region.

There is reason for concern, however, due to the disappearance of the aquatic vegetation throughout the lake. Because of the many important functions that a balanced vegetation community holds for the fishery, we believe the lack of aquatic plants in the lake poses a significant threat to the long-term stability and health of the fishery in Lake Roaming Rock.

In addition to negative impacts caused by a lack of macrophytes, the fishery may be increasingly threatened in the future if there are overabundant populations of roughfish such as European (common) carp, grass carp and bullheads. The impact of roughfish on the sport fishery may be direct (e.g. out-compete sport fish for food) or indirect (increase turbidity or reduce habitat by reducing macrophytes).

The following sections will outline restoration and management techniques that may be used address these related problems.

6.0 Algae Control

In discussions with the community and the project sponsors, the most frequent complaint regarding the lake was the frequent blooms of algae, including mat-forming blue-green algae. A large number of management options exist for control of algae in lakes. These can be broadly categorized as 1) nutrient control techniques, 2) physical controls, 3) chemical controls, and 4) biological controls. A number of control techniques may overlap one or more of these categories. Similarly, some of the techniques may be useful in addressing other problems in addition to nuisance algae, and in fact, this was a primary criterion when selecting potential management options and technologies for further consideration below.

6.1 Nutrient Control Techniques

6.1.1 Watershed Source Reduction

Because algal growth is fueled by high nutrient levels, primary consideration should be given to identifying and controlling the external sources of these nutrients first. Although a formal nutrient budget was beyond the scope of the current project, sampling data collected to date reveals that significant amounts of nutrients are entering the lake from the surrounding watershed, in particular from Rock Creek. The nutrient responsible for excess algae growth appears to be phosphorus. Watershed sources of phosphorus may be varied and may come from distant points of the watershed as well as from property along the lake shore. Because most nutrients usually enter waterways or the lake via overland runoff (as opposed to sewers and other man-made conveyances), they are referred to as non-point source pollution.

Non-point sources of biologically important nutrients can be difficult to control, particularly when they originate in distant parts of the watershed and in different political subdivisions. For this reason, the Association should consider becoming an active participant in regional watershed organizations such as the Grand River Partners (www.grandriverpartners.org). By working in a cooperative manner with state agencies and local conservation districts, regional organizations like the Grand River Partners can help develop and encourage the use of best management practices by landowners in the watershed.

In addition to long-term controls in the watershed, several techniques can be readily implemented by Association members and lake residents to reduce the influx of nutrients from property bordering the lake. These include:

- reducing the use of fertilizer on lawns;
- requiring the use of phosphorus-free fertilizers;
- raking up and removing fallen leaves from the shore, and
- naturalizing the lake shore and providing buffers along the shoreline to slow runoff into the lake and increase infiltration into the soil.
- Regular checks of septic tanks for leakage

Despite being a worthwhile long-term objective, source reduction of the external nutrients in the watershed is unlikely to effect desirable short-term changes in the lake.

6.1.2 Restorer Technology

One innovative and ecologically sound technique developed by the nonprofit Ocean Arks Institute of Burlington, VT may be worth further evaluation for use in Lake Roaming Rock. This technology involves construction and placement of floating artificial islands designed to support a complex and balanced ecology which removes nutrients from the water column. Termed Restorers, these islands incorporate both artificial and living substrates. Plants growing on the artificial substrates provide a large underwater surface area to which beneficial microorganisms can attach themselves. According to the designers, the microorganisms feed off the nutrients in the water column, turning the entire body of water into a treatment engine.

Restorer technology has been in use worldwide for more than twenty years and has reportedly been used to control algal communities, reduce turbidity and levels of both phosphorus and nitrogen in a wide variety of eutrophic lakes. In addition to being ecologically sound, this technology uses little energy and has low operating costs, requires little ongoing maintenance, and is simple to construct. In Lake Roaming Rock, these structures could be placed near the lake inlets to intercept much of the incoming nutrients and sediments. In these locations there would be minimal, if any, impact on recreation.

Additional information on the Restorer technology developed by Ocean Arks is provided in Appendix C.

6.2 Physical Control Techniques

A wide variety of physical algae control techniques exist, with these ranging from aeration to dredging. Table 6-1, adapted from the North American Lake Management Society (2001), provides a brief overview of these technologies.

Table 6-1. Physical Control Options for the Control of Algae

Option	Mode of Action	Advantages	Disadvantages
1. Aeration or oxygenation	• Addition of air or oxygen at varying depths to create oxic conditions throughout the water column • May break stratification	• Oxic condition promote binding/ sedimentation of phosphorus- less phosphorus in the water column = less algae • Oxic conditions improve habitat for fish and invertebrates	• Capital intensive • Relatively high ongoing operating and maintenance (O&M) costs • May promote supersaturation with gases harmful to fish.
2. Circulation and destratification	• Similar to aeration but may involve use of water or air to keep water in motion • Generally driven by	• Reduces surface buildup of algal scums • May disrupt growth of some algae • Similar benefits to	• May spread locally troubling impacts • Capital intensive • Relatively high O&M costs

Table 6-1. Physical Control Options for the Control of Algae			
	mechanical force	aeration when oxic conditions are created	
3. Dilution/Flushing	• Addition of higher quality water can dilute nutrients • Addition of water helps flush system to minimize algae buildup	• Dilution reduces nutrient concentrations without altering load.	• Diverts water from other uses • Flushing may wash desirable zooplankton from the lake • Possible downstream impacts
4. Drawdown	• Lowering of water allows desiccation, oxidation, compaction and freezing of sediments • Nutrients may become unavailable resulting in reduction of algae	• May reduce available nutrients affecting algal biomass • Opportunity for shoreline and structure maintenance • May provide limited rooted plant control	• Possible impacts on contiguous wetlands • Possible impacts on overwintering reptiles and amphibians • Alteration of downstream flows
5. Dredging	• Sediment is physically removed by wet or dry excavation with deposits placed in a containment area for dewatering • Nutrient stores are removed and algal growth can be limited by nutrient availability	• Can result in good algae control if internal cycling is main nutrient source • Increases water depth • Can reduce sediment oxygen demand • Can improve spawning habitat for many fish species • Allows complete renovation of the system	• Very expensive undertaking • Temporarily removes benthic invertebrates • May eliminate current fish community • Large nearby area needed for containment area • May interfere with recreation during dredging
6. Dyes	• Water-soluble dye is mixed with lake water limiting light penetration and inhibiting algal growth • Dye remains in system until flushed out	• Inert dye is non-toxic	• May be impractical in larger lakes or those with rapid flushing • May not control surface bloom-forming species or shallow water algal mats
7. Mechanical Removal	• Collection of floating sums or mats with harvesters, booms, nets, or other devices	• Algae and associated nutrients can be removed from system • Surface collection may be done on an "as needed" basis • Collected algae dry to minimal volume	• Very labor intensive unless a mechanized system is used, in which case it becomes capital intensive • Many algal forms not amenable to collection by net or boom

6.2.1 Aeration/circulation

Of the physical control techniques listed in Table 6-1, lake aeration/circulation is probably the most widely used technique to control algae and probably holds the greatest potential for application to Lake Roaming Rock. This technique functions by reducing the amount of phosphorus released from the lake sediments. The basic concept of an aeration system is to maintain oxygen at the bottom of the lake so that iron- which binds up phosphorus- will remain in a solid form and out of the water column (McComas, 2003). Under anoxic conditions iron dissolves and releases phosphorus. Secondarily, aeration helps control algae by creating an increased space for zooplankton to avoid predation. By oxygenating the bottom water, zooplankton (which prey on algae) are able to swim deeper into the dark bottom water during the day. They come up to feed on algae at night.

The most common type of aeration- termed artificial circulation- introduces air bubbles at the bottom of the lake or pond. Rising air bubbles push oxygen-poor bottom water to the surface where it is re-aerated though contact with the atmosphere at the surface. This type of aeration system works best in lakes that are 15 feet deep or greater.

Conventional subsurface aeration systems typically utilize one or more shore-based compressors with air lines running out to devices called diffusers on the bottom of the lake. In general, an air flow rate of approximately 1.3 cubic feet per minute per acre is required to control algae and maintain a recommended minimum DO concentration of 5 ppm.

Figure 6-1. Aeration Diffusers and Compressor Assembly (from Vertex Water Features, Deerfield Beach, FL). Note: Fountain in background is a water feature unrelated to the aeration system shown in the foreground.

To be effective, aeration systems must be appropriately sized and powered. Systems with inadequate power may bring up nutrient-rich water without re-oxygenating the lake, resulting in algae becoming an even greater nuisance. Once begun, the system must be continuously operated. If turned off, algae may rapidly reappear because phosphorus will be rapidly released from the sediment under anoxic conditions. These systems can also be operated during the entire year to improve water quality. This type of system is considered safer than the other some floating aerators and fountains due to the fact no electrical cords are used in the water. A subsurface aeration system appropriately sized for Lake Roaming Rock is estimated to cost between $200,000 and $400,000.

Other types of aeration systems include fountain surface units and horizontal spray units. Surface units are best used in less than 12ft/4m depth and in irregularly shaped lakes. Surface units also are generally more expensive, often primarily decorative, use more horsepower, and contain electrical cords that could create safety hazards. Horizontal spray units are best used for long, narrow bodies of water due to the directional spray pattern it ejects.

More than 100 different aeration/circulation systems are on the market in various sizes and configurations. Among these are both solar and wind-powered aerators. Although they may be well-suited to small lakes where electricity is not available, solar and wind-powered in-lake units are generally deemed unfeasible for Lake Roaming Rock due to 1) the large number that would be required, 2) concerns about their ability to circulate water effectively in a lake as deep as Roaming Rock, and 3) the large surface profiles these units typically have which would pose a hazard to boat traffic on the lake.

6.2.2 Other Physical Control Techniques

A brief review of the remaining physical control options listed in Table 6-1 indicates that they are largely unsuitable in Lake Roaming Rock due to environmental constraints (dilution/flushing, drawdown), very high cost (dredging), or impracticality due to the large size of the lake (dyes and mechanical removal).

6.3 Chemical Control Techniques

Two major types of chemical controls are used to control nuisance algae and they vary greatly in both their mode of action and in their effectiveness over time. They are algaecides and phosphorus inactivation.

6.3.1 Algaecides

Algaecides kill algae in the lake. The most common and widely used algaecide is copper, a cellular toxicant that comes in a variety of forms. Copper sulfate ($CuSO_4$) is the most common and basic form and can be used in potable water, though restrictions apply in most states. In alkaline water, hard water, or water having high organic content copper can be quickly lost from solution. In these cases, liquid chelated form is used to allow the copper to remain in solution long enough to kill the algae.

Most algae will be killed by doses of 1 to 2 mg $CuSO_4$ /L, however many blue-green algae- including those nuisance species abundant in Lake Roaming Rock- are resistant to copper. Repeated use of use of copper over time may actually aggravate algal problems by not affecting these nuisance species and by reducing other more desirable algal species (North American Lake Management Society, 2003).

Copper application can release taste and odor agents into the water column. In killing certain species of the blue-greens, algaecides may release cellular toxins that can cause human illness. Some doses of copper may also be toxic to fish (Cooke, et al., 2005). Zooplankton are particularly sensitive to copper and loss of them eliminates food for many fish as well as grazing control of algae. Finally, long-term use of copper results in significant accumulation in the sediments. In many lakes that have used copper over a period of decades, the sediment concentration of copper has reached levels where dredged material is deemed a hazardous waste under EPA regulations.

Although relatively inexpensive, a major limitation for use of copper-based algaecides in Lake Roaming Rock is its short period of efficacy. To provide good control of algae (including blue-green species), application may need to be repeated as often as every two weeks and ever larger doses will likely be required over time. Despite these drawbacks, copper application may be the most cost-effective, short-term, treatment approach. Estimated cost per acre for copper-based treatment is between \$200 and \$300.

Not many alternatives to copper-based algaecides exist. Hydrothol® and diquat are used on hard-to-kill blue-greens, but water use is restricted for multiple days after application, and diquat is moderately toxic to lake invertebrates. Although probably not significant, herbicide use may also have unintended downstream impacts.

In the past few years, considerable interest has arisen regarding the use of barley straw as a natural alternative for control nuisance blue-green algae. Relatively little peer-reviewed literature exists to confirm reports of the effectiveness of this technique. There is also little understanding about the underlying control mechanisms at work, although inhibiting agents produced by microbial agents involved in breaking down the straw are believed to play an important role.

Barley straw is typically applied in small 6 to 10 pound bags and appears to inhibit algal growth for 30 to 90 days. After that time, the decomposition of easily digestible organic compounds in the straw is finished and production of the inhibiting compound slows down. At that point the bags can be replaced, or if the summer is nearly over, they can be removed from the lake.

Although inexpensive (as low as $5 per 40 pound bale), barley straw is rarely used in larger lakes such as Roaming Rock. In general, successful control of nuisance algae with barley straw appears to be somewhat spotty. More carefully controlled experiments are needed to confirm the long-term effectiveness of this approach. Although it may be possible to conduct some barley straw experiments in one or more of Lake Roaming Rock's coves, it does not appear to be a suitable management alternative for Lake Roaming Rock as whole due to the large amount of labor required to place and remove the straw.

6.3.2 Phosphorus Inactivation

Phosphorus inactivation controls algae by limiting phosphorus availability. This is accomplished by using chemicals to precipitate phosphorus from the water column and by adding a binder to the lake to prevent release of phosphorus from the sediments. The most commonly used chemical for this purpose is aluminum sulfate (or alum). Often applied in a buffered form at the water surface at a rate between 100 and 500 pounds per acre, alum forms a nontoxic precipitate that scavenges phosphorus as it settle through the water column. When used in an appropriate dose, a thin layer of aluminum hydroxide will cover the sediments and continue to tie up phosphorus as it is released from lake sediments.

Nutrient inactivation has received increasing attention over the last decade as long lasting results have been demonstrated in many projects (North American Lake Management Society, 2001). Longevity of alum treatments has been generally excellent where external inputs of phosphorus have been controlled. Good candidate lakes for alum treatment are those with low external nutrient loads and high internal phosphorus release from the sediment. Where significant nutrient inputs from the watershed exist, algal blooms may still result. For this reason, alum treatment may not be a preferred control technology at the present time for Lake Roaming Rock. If the external nutrient inputs from the watershed can be controlled, or if further studies demonstrates that the external nutrient loading is relatively small compared to internal loading, alum treatment may prove to be a viable treatment option. Costs for alum treatment ranges from a few hundred dollars per acre to one thousand dollars per acre.

6.4 Biological Control Techniques

As indicated, the boundary blurs between several of these techniques, and at least two discussed so far- Restorers and barley straw- are in essence biological techniques. Other biological management techniques to be considered include bacterial addition, roughfish removal and biomanipulation.

6.4.1 Bacterial Addition

A number of products on the market claim to use microbial components to reduce algae in lakes. The concept is that with some assistance, natural populations of bacteria can gain a competitive advantage and out-compete algae for nutrients. With less available nutrients, algae should decline according to theory. In practice, however, current scientific literature has been unable to verify that these products actually do decrease algal growth.

6.4.2 Roughfish Removal

Roughfish is a category that includes bottom feeding fish such as carp and bullheads. Browsing activities of these fish involve their rooting through the sediments which results in significant releases of nutrients into the water column. In addition to this direct effect, other negative consequences of these fish include uprooting aquatic plants (and consuming them in the case of white amurs), their excretion which contributes to phosphorus loads, and an increase in turbidity in the water column.

As noted previously, removal of as many of these fish as possible from Lake Roaming Rock is a desirable goal. Removing roughfish may allow the re-establishment of aquatic plants which would help maintain clear water. By reducing excretion-related phosphorus sources, a reduction in roughfish may also result in a decrease of nuisance algal production. Unfortunately, electroshocking was found to be an inefficient removal technique for both European and grass carp in Lake Roaming Rock. Other techniques that may be considered include:

- Spring archery tournaments
- Carp fishing derbies
- Use of trap nets or hoop nets for bullheads
- Commercial baits and traps
- Hiring commercial fishermen

6.4.3 Biomanipulation

Biomanipulation is another type of fish management, but one that works at a different trophic level than roughfish removal.   This technique involves a set of procedures which manipulate the natural biological components of a lake to produce desired conditions. In most cases, the objective is to increase zooplankton numbers because, at times, grazing zooplankton and not the quantity of nutrients control the amount of algae in the water column (McQueen et al., 1986).

Although some algae are immune to grazing, continued strong grazing can reduce algae abundance and increase clarity. An adequate population of large bodied zooplankton depends on their being protected from zooplanktivorous fish such as small panfish and minnow-sized fish. The management goal is to either reduce the number or zooplanktivorous fish or to create a refuge for the zooplankton.

If fish habitat is adequate and anglers cooperate through catch and release programs, a healthy and balanced game fish population will help control the planktivores. The reduced number of zooplanktivorous fish then allows more zooplankton to survive. A semi-quantitative fish survey conducted in the spring would be useful in determining the relative balance of the fish community.

The almost total lack of macrophytes in Lake Roaming Rock severely limits the ability of zooplankton to find shelter and produces poor conditions for zooplankton survival. Although not widely used in the U.S., McComas (2003) reports the use in Europe of dense brush piles having openings too small for fish entry, thereby providing refuge for the zooplankton.

While discussing the importance of zooplankton, it should be noted that populations of large-bodied zooplankton may also be negatively impacted by:

- Low oxygen conditions near the lake bottom. As mentioned, deeper, darker areas of the lake can serve as an important refuge for zooplankton. Anoxic conditions eliminate this refuge.

- copper sulfate used for temporary algae control can also kill zooplankton, and this may be a primary mechanism responsible for the commonly observed rebound of algae following a copper treatment (Cooke et al., 2005)

7.0 Re-establishment of Aquatic Macrophytes

As noted, a balanced and healthy native plant community is critical to the ongoing health of Lake Roaming Rock. The almost total lack of these plants is arguably the most serious and immediate problem facing the lake. The benefits associated with promoting a healthy plant community are numerous and include:

- stabilizing bottom sediments
- oxygenating water
- provide refuge for zooplankton, aquatic insects and small fish
- provide food and habitat for waterfowl and other wildlife

Additionally, because aquatic plants compete for and tie up substantial amounts of nutrients in the lake, a healthy plant community can help control nuisance algae problems.

Although a long list of possible factors may prevent the growth of desirable plants in the littoral zone of a lake, relatively few possible explanations exist for the lack of macrophytes in Lake Roaming Rock because, until recently, rooted aquatic plants were all-too abundant in the lake. The most likely cause of vegetation disappearing from the lake over the past few years is the action of roughfish, and grass carp in particular.

One technique that could be used to demonstrate the impact that these fish are having on the plant community would be to construct several "exclosures" or shallow water pens that exclude fish from an area. If, over the course of the summer, plants grow within the exclosure and nowhere else, then fish are the most likely culprit in the disappearance of the macrophytes from Lake Roaming Rock.

Once the cause is verified and corrective measures implemented, several opportunities exist to promote re-establishment of native macrophytes. In addition to transplanting plants using wetland nursery stock or by digging up plants from other water bodies, winter drawdown has reportedly been used to help stimulate the existing seedbank (McComas, 2003).

It should be noted that these recommendations remain valid despite reports of limited re-growth of Eurasian watermilfoil in some areas of the lake during the fall of 2005. The invasive and exotic Eurasian watermilfoil is common in highly disturbed systems where it forms dense monocultures that interfere with recreation and provide poor fish habitat. Although a rebound of milfoil may be arguably preferable to no vegetation from a biologist's perspective, it should not be considered a sign of improvement in the lake's overall condition. Establishment of a healthy and diverse ***native*** plant community where no species dominate to the point where control is required, should be the goal for Lake Roaming Rock.

8.0 Conclusions and Recommendations

Lake Roaming Rock is an outstanding recreational resource and serves as the centerpiece for the RoamRock community. It currently provides excellent opportunities for swimming, boating, and fishing.

Despite these positive features, several related water quality problems exist. Owing to the agricultural setting of the community, the lake has historically received a relatively high and steady influx of nutrients such as nitrogen and phosphorus from the watershed. Large amounts of these nutrients- in particular, phosphorus- accumulate in the sediments of Lake Roaming Rock where they are seasonally re-entrained into the water column due to anoxic conditions resulting from stratification of the lake.

Data generated as part of the current study indicate that the lake has become significantly more eutrophic since the early 1990's and is approaching a hypereutrophic condition. Under such conditions, recreational activities important to the community such as swimming, skiing and fishing will likely be negatively affected.

Regardless of the progress which may be made with long-term nutrient source reduction in the watershed, the internal phosphorus cycling which occurs as a result of these anoxic condition is likely to result in ongoing and worsening nuisance algae blooms for the foreseeable future unless in-lake treatment options are implemented.

The problem of high nutrient levels in the water column is aggravated by the steady release of nutrients from the sediment due to 1) a lack of rooted aquatic plants which can help stabilize near shore sediments and compete with algae for available nutrients, and 2) an overabundance of roughfish, including European and grass carp. Because the aquatic macrophytes fulfill a number of important functions with regard to the lake's fishery, the near total lack of plants also does not bode well for the near-term health of the fishery, a critical part of the overall ecosystem. Although almost any plant is better than none, the reported limited resurgence of Eurasian watermilfoil in some parts of the lake this past fall is not necessarily good news since milfoil provides poor wildlife habitat and tends to form dense monocultures that may interfere with recreational uses of the lake.

Rooted plants in the lake provide shelter for young-of-the-year fish and the near total lack of plants over the past several years may have seriously impacted recruitment. It may take three or four years before this decreased recruitment shows up as a general decrease in the quality of the fish community, and sport fishing in general. In an attempt to identify warning signs and track changes to the fish community, the project sponsors should consider implementing an annual fish monitoring program. This program would minimally involve a spring electrofishing survey and would provide information on age distribution and the density of roughfish in the lake, as well as help in their control by removing any that are encountered during the survey.

Although several management options for dealing with these problems are discussed above, it is difficult and likely inadvisable to make definitive recommendations here for long-term management without considerable input from and discussion among the community. Having stated this, the Association and the Roaming Shores community will need to choose between several options for long-term management, and in short, these are:

- the no action, or "do nothing" approach
- a seasonal "band-aid" approach involving periodic algaecide application to control blooms
- comprehensive strategies to address the summer stratification, roughfish and macrophyte issues.

Although the no action alternative is clearly the easiest and least expensive in the short-term, there is ample evidence to indicate the nuisance algae problem will likely worsen over time and may reach a level where the problem begins to depress property values. Additionally, a significant decline in the sport fishery can be expected if no efforts are made to address the lack of aquatic plants in the lake.

A short-term palliative approach using herbicides may be able to keep the worst of the nuisance algal blooms in check, but this approach does nothing to remedy the problem of no macrophytes and the resultant impact on the fishery. As mentioned, the lack of macrophytes not only threatens the long-term health of the fishery, it likely aggravates the algae problem.

More comprehensive approaches which address the summer stratification, roughfish and macrophyte issues will be both longer-term and more costly, but have potential to improve water quality and help ensure the lake sustains a healthy sport fishery.

Short-term or "next step" recommendations include:

1. Schedule a community meeting to disseminate information gathered from this study and solicit input from Association leadership and members regarding their priorities for future action. EnviroScience is prepared to support and/or facilitate such a meeting in early 2006 to conclude activities under the existing contract.
2. Continue <u>limited</u> in-lake and stream monitoring efforts in 2006 to further assess the amount of nutrients and algae present and how these relate to the amount and concentration of nutrients entering the lake. Early and late-season monitoring will help confirm the internal phosphorus dynamics of the lake and provide information useful in the design of an aeration system. EnviroScience can help design such a sampling program, but we

recommend that this sampling be performed by trained volunteers from the community to minimize costs.

3. Given recent concerns about high bacteria levels following rain events, bacterial monitoring should be expanded to include major tributaries to the lake. A limited study of possible sources in the watershed may be needed.
4. Conduct a synoptic surveillance of the Rock Creek watershed and identify locations where it appears that high concentrations of nutrients are found, and collect repeated samples. It is important to locate any obvious nutrient sources within the watershed since it may be possible using existing regulations and cooperative efforts of the local Soil and Water Conservation District Offices to lessen the loading to the lake.
5. Develop an accurate bathymetric map of the lake to aid in macrophyte re-establishment efforts and design of other lake restoration techniques.
6. Perform an early-season fish survey to evaluate likely changes to the sport fishery and measure the density and control of roughfish in the lake.
7. With data generated from the fish survey, develop an active plan for annual removal of roughfish from the lake. As discussed, this could include fishing derbies, bow hunters, and/or baited traps.
8. Construct several fish exclosures to demonstrate the impact of the roughfish on aquatic vegetation and to verify the viability of the existing sediment seed bank. This will help determine whether or not active planting activities may be needed to re-establish an aquatic plant community around the lake.

9.0 References

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Appendix A- Algae Analysis

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Algae Analysis
Report and Data Set

Prepared for: 144
Calc Type: Phytoplankton - Grab

Tracking Code:	040001-144	**Sample ID**	.
Job:	144	**Replicate #**	1
Job Number:	1	**Level**	Epi
System:	Roaming Rock Lake	**Depth**	0
Date:	8/27/2004	**Preservative**	Glutaraldehyde
Station:	.		
Site:	.		

Report Notes .

Taxa Id	*Genus*	*Species*	*Subspecies*	*Variety*	*Form*	*Morph*	*Structure*	*Concentration* NU/ ml	*Relative Concentration*	*Algal Cell Concentration* Cells/ml	*Relative Algal Cell Concentration*
Division:	**Bacillariophyta**										
1432	*Aulacoseira*	*granulata*	.	.	.	*straight*	Vegetative	19.474	0.15	115.625	0.33
☑ 9072	*Navicula*	*cryptotenella*	.	.	.	.	Vegetative	19.474	0.15	19.474	0.06
							TOTAL Bacillariophyta	**38.947**	**0.30**	**135.098**	**0.39**
Division:	**Chlorophyta**										
2686	*.	*spp*	.	.	.	.	Cyst	19.474	0.15	19.474	0.06
2683	**Chlorococcaceae*	*spp*	.	.	.	*2-9.9 um spherical*	Vegetative	19.474	0.15	19.474	0.06
1000031	*Ankistrodesmus*	*falcatus*	.	.	.	*straight*	Vegetative	19.474	0.15	19.474	0.06
2080	*Chlamydomonas*	*spp*	.	.	.	.	Vegetative	19.594	0.15	19.594	0.06
2211	*Dictyosphaerium*	*pulchellum*	.	.	.	.	Vegetative	58.421	0.45	934.734	2.68
☑ 2280	*Gloeocystis*	*spp*	.	.	.	.	Vegetative	3.919	0.03	62.699	0.18
2371	*Pandorina*	*morum*	.	.	.	.	Vegetative	3.919	0.03	62.699	0.18
8396	*Scenedesmus*	*bijuga*	.	*alternans*	.	.	Vegetative	3.919	0.03	15.675	0.04
							TOTAL Chlorophyta	**148.191**	**1.14**	**1,153.822**	**3.31**
Division:	**Cyanophyta**										
4331	*Anabaena*	*macrospora*	.	.	.	.	Vegetative	11.756	0.09	94.049	0.27
4012	*Anabaena*	*flos-aquae*	.	.	.	.	Vegetative	195.935	1.50	3,232.921	9.28

☑ = Identification is uncertain
* = Family level identification

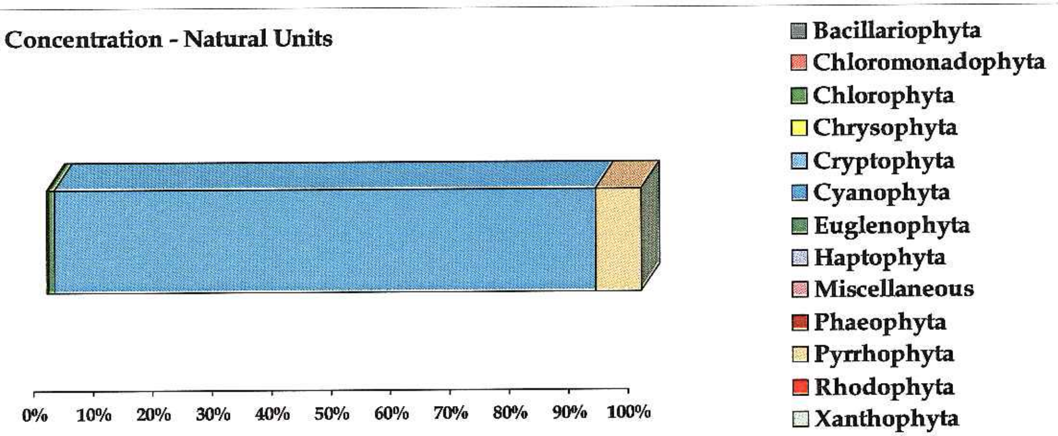
	4018	*Anabaena*	*planctonica*	.	.	.	.	Vegetative	70.537	0.54	705.365	2.02
	4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	11.756	0.09	188.097	0.54
	4041	*Aphanizomenon*	*flos-aquae*	.	.	.	.	Vegetative	11.756	0.09	182.873	0.52
	4091	*Coelosphaerium*	*naegelianum*	.	.	.	.	Vegetative	172.422	1.32	14,075.948	40.41
	4092	*Coelosphaerium*	*naegelianum*	.	.	.	.	Vegetative	1,655.259	12.68	1,655.259	4.75
	4261	*Microcystis*	*aeruginosa*	.	.	.	.	Vegetative	19.594	0.15	1,434.241	4.12
	4264	*Microcystis*	*aeruginosa*	.	.	.	.	Vegetative	9,639.448	73.87	9,639.448	27.67
☑	4290	*Nostoc*	*spp*	.	.	.	.	Vegetative	43.106	0.33	977.062	2.80
	4183	*Oscillatoria*	*agardhii*	.	.	.	.	Vegetative	7.837	0.06	164.585	0.47
	4460	*Pseudanabaena*	*spp*	.	.	.	.	Vegetative	19.474	0.15	194.736	0.56
								TOTAL Cyanophyta	**11,858.879**	**90.88**	**32,544.584**	**93.42**
Division:		**Euglenophyta**										
	5047	*Trachelomonas*	*volvocina*	.	.	.	.	Vegetative	3.919	0.03	3.919	0.01
								TOTAL Euglenophyta	**3.919**	**0.03**	**3.919**	**0.01**
Division:		**Pyrrhophyta**										
	6011	*Ceratium*	*hirundinella*	.	.	.	.	Vegetative	999.267	7.66	999.267	2.87
								TOTAL Pyrrhophyta	**999.267**	**7.66**	**999.267**	**2.87**

☑ = Identification is uncertain
* = Family level identification

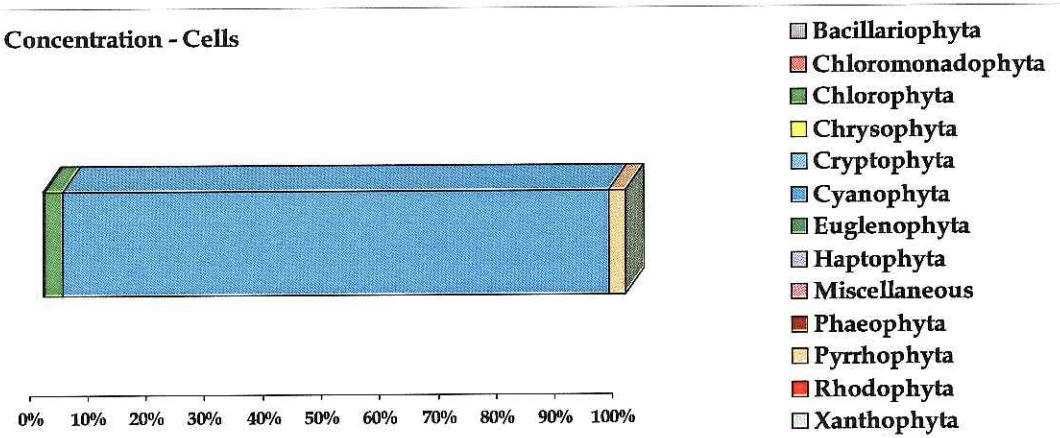
Summary Graphics

Total Sample Concentration	Total Sample Cell Concentration
13,049.203	34,836.689

Sample Concentration - Natural Units



Sample Concentration - Cells



☑ = Identification is uncertain

* = Family level identification

Species List

Taxa Code	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
Division: Bacillariophyta								
1432	*Aulacoseira*	*granulata*	.	.	.	*straight*	Vegetative	(Ehrenb.) Simonsen
9072	*Navicula*	*cryptotenella*	.	.	.	.	Vegetative	Lange-Bert.
Division: Chlorophyta								
2686	.	*spp*	.	.	.	.	Cyst	N/A
2683	*Chlorococcaceae*	*spp*	.	.	.	*2-9.9 um spherical*	Vegetative	N/A
1000031	*Ankistrodesmus*	*falcatus*	.	.	.	*straight*	Vegetative	(Corda) Ralfs
2080	*Chlamydomonas*	*spp*	.	.	.	.	Vegetative	Ehrenberg
2211	*Dictyosphaerium*	*pulchellum*	.	.	.	.	Vegetative	Wood
2280	*Gloeocystis*	*spp*	.	.	.	.	Vegetative	(Kuetzing) Lagerheim
2371	*Pandorina*	*morum*	.	.	.	.	Vegetative	(O. Muller) Bory De St Vincent
8396	*Scenedesmus*	*bijuga*	.	*alternans*	.	.	Vegetative	(West and West) Chodat
Division: Cyanophyta								
4010	*Anabaena*	*spp*	.	.	.	.	Vegetative	Bory
4012	*Anabaena*	*flos-aquae*	.	.	.	.	Vegetative	(Lyngbye) de Brebisson
4331	*Anabaena*	*macrospora*	.	.	.	.	Vegetative	Klebahn 1895
4018	*Anabaena*	*planctonica*	.	.	.	.	Vegetative	Brunnthaler
4041	*Aphanizomenon*	*flos-aquae*	.	.	.	.	Vegetative	(L.) Ralfs
4091	*Coelosphaerium*	*naegelianum*	.	.	.	.	Vegetative	Unger
4092	*Coelosphaerium*	*naegelianum*	.	.	.	.	Vegetative	cells Unger
4261	*Microcystis*	*aeruginosa*	.	.	.	.	Vegetative	(Kutzing) Lemmermann
4264	*Microcystis*	*aeruginosa*	.	.	.	.	Vegetative	Kutzing
4290	*Nostoc*	*spp*	.	.	.	.	Vegetative	Lyngby
4183	*Oscillatoria*	*agardhii*	.	.	.	.	Vegetative	Gomont
4460	*Pseudanabaena*	*spp*	.	.	.	.	Vegetative	Lauterborn
Division: Euglenophyta								
5047	*Trachelomonas*	*volvocina*	.	.	.	.	Vegetative	Ehrnb
Division: Pyrrhophyta								
6011	*Ceratium*	*hirundinella*	.	.	.	.	Vegetative	Dujardin

☑ = Identification is uncertain
* = Family level identification

☑ = Identification is uncertain

* = Family level identification

Appendix B- Zooplankton Analysis

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http://www.phycotech.com

Zooplankton Analysis
Report and Data Set

Prepared for: 144

Calc Type: Zooplankton - Tow Volume Calculated (Field Method)

Tracking Code:	040002-144	**Sample ID**	.
Customer ID:	144	**Replicate #**	1
Job Number:	1	**Level**	Epi
System:	Roaming Rock Lake	**Depth**	0
Date:	8/27/2004	**Preservative**	Glutaraldehyde
Station:	.		
Site:	.		
Report Notes:	.		

Taxa ID	*Genus*	*Species*	*Subspecies*	*Variety*	*Morph*	*Structure*	*Concentration* Animal/ ml	*Relative Concentration*
Phylum: Arthropoda								
Order:	**Calanoida**							
1000344	*.	spp	.	.	CI-CIV	Whole Animal	92.14	4.92
131852	*.	spp	.	.	.	nauplius	261.06	13.93
						TOTAL Calanoida	353.20	18.85
Order:	**Diplostraca**							
1000146	Daphnia	galeata	mendotae	.	Female	Whole Animal	15.36	0.82
						TOTAL Diplostraca	15.36	0.82
Phylum: Protozoa								
Order:	**Arcellinida**							
1000425	Difflugia	spp	.	.	.	Whole Animal	506.77	27.05
						TOTAL Arcellinida	506.77	27.05

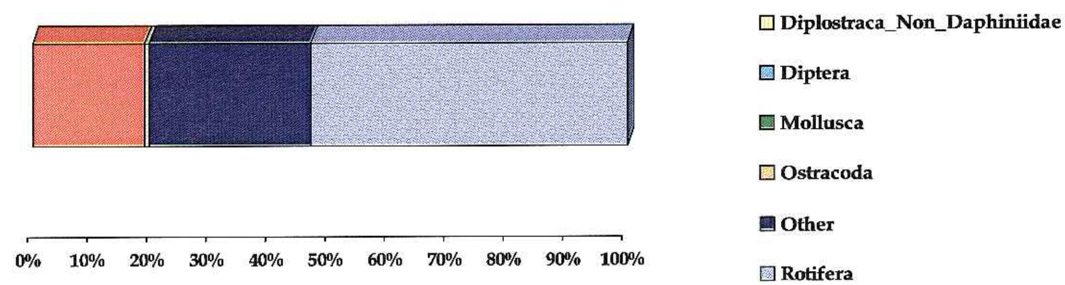
☑ = Identification is uncertain
= = Subclass level identification
* = Family level identification
040002-144

Phylum: Rotifera

Order:	**Flosculariaceae**							
125617	Filinia	longiseta	.	.	.	Whole Animal	30.71	1.64
						TOTAL Flosculariaceae	30.71	1.64
Order:	**Ploima**							
1000423	Gastropus	spp	.	.	.	Whole Animal	92.14	4.92
125281	Keratella	cochlearis	.	.	.	Whole Animal	138.21	7.38
126153	Polyarthra	vulgaris	.	.	.	Whole Animal	92.14	4.92
126258	Trichocerca	pusilla	.	.	.	Whole Animal	644.98	34.43
						TOTAL Ploima	967.46	51.64

Total Sample Concentration
1,873.50

Sample Concentration



☑ = Identification is uncertain
= = Subclass level identification
* = Family level identification
040002-144

Species List

Taxa Code	Genus	Species	Subspecies	Variety	Form	Morph	Structure	Authority
Order : Calanoida								
131852	.	spp	.	.	.	.	nauplius	Esterley 1911
1000344	.	spp	.	.	.	CI-CIV	Whole Animal	Sars, 1903
Order : Diplostraca								
1000146	Daphnia	galeata	mendotae	.	.	Female	Whole Animal	Birge
Order : Arcellinida								
1000425	Difflugia	spp	.	.	.	.	Whole Animal	Unknown
Order : Flosculariaceae								
125617	Filinia	longiseta	.	.	.	.	Whole Animal	(Ehrenberg 1834)
1000423	Gastropus	spp	.	.	.	.	Whole Animal	.
125281	Keratella	cochlearis	.	.	.	.	Whole Animal	(Gosse 1851)
126153	Polyarthra	vulgaris	.	.	.	.	Whole Animal	Carlin 1943
126258	Trichocerca	pusilla	.	.	.	.	Whole Animal	(Lauterborn 1898)

☑ = Identification is uncertain
= = Subclass level identification
* = Family level identification

Appendix C- Restorer Systems from Ocean Arks

Restorer Technology

Introduction to Natural Treatment Systems and Restorer Technology

All wastewater treatment processes are a combination of physical, chemical and biological activities. Improving performance of a given system is accomplished by enhancing one or more of these basic processes. Typically this is accomplished by the addition of more oxygen with the goal of oxidizing carbon and nitrogen compounds. A less common approach is to enhance the biological processes.

In relying on enhanced biological processes for treatment, the design engineer recognizes that most of the wastewater treatment process relies on attached growth microbial communities which require a substrate. In complete mix aerated lagoons or activated sludge systems, the substrate is the microbial floc. In natural systems, substrate is usually provided by plant roots, stems, and leaves, and inorganic substrates such as sand, gravel, or fabric media.

Natural systems, such as ponds, wetlands, floating islands, or grasslands have their engineering equivalents in wastewater stabilization lagoons, aerated lagoons, constructed wetlands, Restorer technology and overland flow. The design principles for these types of systems have been developed over many years of observation and are based on the concepts of biological unit processes described in wastewater engineering textbooks. However, the energy requirements in natural systems are generally significantly less than for mechanically enhanced treatment such as activated sludge or sequence batch reactors (SBR). Applied natural systems such as constructed wetlands can be designed for 98% removal of BOD without any energy input. Restorer technology also has a small energy footprint. The exchange is land for energy. However Restorer technology can be applied in substantially smaller footprints than constructed wetlands. Reducing electricity consumption minimizes the release of greenhouse gases and pollution. For every kWh of energy used, 0.78 pounds of carbon enter the atmosphere to generate the electricity (energy conversion factors courtesy of Rocky Mountain Institute).

Natural systems rely on the complex ecologies of the pond, marsh, and meadow to convert carbon and nitrogen to gaseous forms (CO_2, CH_4, N_2) or to redistribute the C, H, O, N, and P into more ecologically acceptable forms such as plant biomass (e.g. hayfields, woodlands) or animals (fish, ducks) rather than sludge. Application of natural treatment technologies is desirable due to high performance standards, energy efficiency, elimination of chemical additions, ease of operation, system robustness, and associated capital and operational cost savings.

In the design of any wastewater treatment facility, there are certain desirable characteristics that should be the basis of any design. The following is a partial list of what most engineers would consider as a basis for design:

Simple to construct: local equipment and contractors should be able to build the system without resorting to specialized equipment;
Simple to operate: the system should require minimal operator involvement;
Avoid high rate processes and rely where possible on low-energy or passive technologies with longer detention times;
Simple to maintain;
Minimize energy requirements: utilize gravity and high oxygen-transfer rate technology whenever possible, minimize equipment requirements;
System must meet discharge permits: it must be robust and capable of handling variations in flows and mass loading.

Ocean Arks International and its licensees have completed over 80 ecological waste treatment projects worldwide. We have experience treating diverse waste streams from breweries, cosmetic manufacturers, food processors, community developments, municipalities, agriculture, etc.. For over a decade, we have worked to develop an array of natural treatment strategies, cumulating in the highly economical Restorer technology. Restorers have been used to reduce the impact of eutrophication, or nutrient enrichment, on ponds, and most recently have been designed to treat lagoons heavily impacted by organic waste. They have the capability, when integrated with other natural systems technologies, to treat sewage and industrial wastewater to the demanding standards necessary for reuse.

Physical Components and Systems

There are five basic physical components to Restorers: a floating structure, media to support attached growth bacterial communities, an aeration system, energy system, and biological components.

1. Floating Structure
   The floating structure and associated cells support media, air distribution systems, and specially fabricated racks which support and protect dense plantings of higher plants including shrubs and trees. They have been built of high-density polyethylene (HDPE) floatation cubes, while the largest Restorers are fabricated from welded HDPE pipes. The HDPE pipe-based floatation technologies have been adapted from the offshore marine fish farming industry.

2. Media
   The media provides the surface area that supports diverse biological communities. In some Restorers the media is comprised of semi buoyant materials housed within chambers through which oxygenated water circulates. In others, suspended curtains provide biologically friendly surfaces throughout the full water column below the Restorer. Gentle aeration circulates large volumes of water throughout the Restorer.

3. Air Distribution System
   The air distribution system provides oxygenation and controlled water movement throughout the whole complex. Aeration may be provided through airlift pumps or efficient fine bubble diffusion systems tailored to lagoons.

4. Energy System
   The energy system is required to provide electrical power to blowers and compressors that distribute the air. Several Restorers have been "unplugged" from the grid and powered by wind and solar energy systems. For high strength organic wastes, where larger amounts of energy are required, the conventional solution to meeting the power requirements is through a shore-based grid connection.

5. Biology and Ecology
   Finally there is the biology and ecology of the Restorer. The Restorer provides the foundation and the substrate to support a diversity of life forms from many different phylogenetic kingdoms. These include the bacteria, fungi, algae, protozoa, annelids, mollusks, insects, vertebrates (including frogs and turtles), and higher plants. This multitude of life forms, in concert, has the capability to treat wastes, pathogens and toxins. The basic technological and scientific principles governing the design of natural treatment systems have been articulated and subjected to scientific review.

Wastewater Treatment Restorers
Linear design: Used for canals, rivers and lagoons

Click for more information

Restorers designed for lagoons and canals are typically 4 m to 10 m wide by any manageable length. Lagoon treatment design often involves the creation of cells in the lagoon using floating baffles. Each cell has at least one Restorer. Multiple cells offer enhanced treatment performance and control over a single cell system and allow for diverse ecosystems to establish throughout the treatment process. Fabric baffles also provide a large area of attached growth treatment.

The areas of the lagoon, outside of the Restorer itself, are gently aerated with fine bubble diffusion aeration set on the bottom or suspended from the Restorer. This type of aeration has a high "field transfer rate" of oxygen to water and a correspondingly low energy requirement when compared to other aeration technologies. In addition to adding oxygen to the water, this system circulates water towards the Restorer's reactors. The water then flows through the open water channels between the Restorers and is circulated past biological surfaces including fabric media and plants. Aeration blowers, normally located in sound insulated enclosures on the lagoon banks, provide the air.

on the Baima Canal Restorer in China.

Plants are grown in racks at the surface of the water. Planted ecologies establish a symbiotic relationship between plant roots and vast populations of attached and free-swimming bacteria. The bulk of the treatment is carried out in these planted areas. Ocean Arks International has carried out extensive research into the characteristics of over 500 species of botanicals for treatment purposes. The plants are typically native to the local area.

Often, the Restorer and the water body are bioaugmented. The bacteria added are all naturally occurring organisms (nothing in Restorer Technology is genetically engineered). The intention is to ensure that the right bacteria are present in the water. Fine powdered minerals and trace elements may also be added to the engineered ecologies. Once the Restorer ecology is fully established the addition of supplemental bacteria and minerals may be reduced or eliminated.

Restorers of this design are normally fabricated from diameter high-density polyethylene (HDPE) pipes to provide structural support and floatation. The planted systems are fabricated off site and seeded on site. The central reactor uses manufactured media and fine bubble aeration and circulation. Air is supplied to the sub-surface aeration pipes through the floatation pipes. A walkway provides excellent access to the system.

Restoration and Maintenance of Lakes and Ponds
Often Square/Circular Designs

Circular Restorer at Bush residence in Kennebunkport.

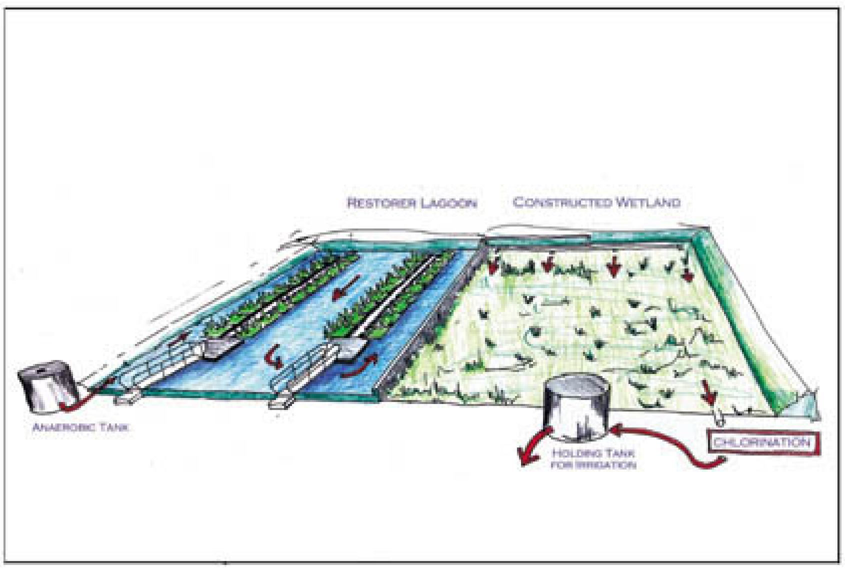
The concept of 'floating island' is visually apparent in this Restorer Design. HDPE cubes or pipes, some with wood frames, are used for structure. The HDPE provides long life and well tested floatation and strength for the process components of the Restorer. This configuration is typically square, rectangular or circular with dimensions of 15 ft to 30 ft (5 to 10 meters). Manufactured media is located in the center of the Restorer and plants are racked on the outside of the floating dock to a width of 5 ft to 10 ft (2 to 3 meters). Alternatively, fabric media hangs below the Restorer and plants are planted in the center. fueled by oxygen delivered to the ecosystem by the vascular structure of the higher plants. Bioaugmentation is used when necessary. Large Restorers can be built to handle substantial pollution loadings.

Water and sediments from the pond are airlifted up into the center of the Restorer through a large diameter airlift pump, suspended vertically in the center of the media filled square. Airlift technology can move large amounts of water with minimum energy, also adding oxygen to the water.

In the oxygen rich root zones below the Restorer, biosolids from the sediments are consumed by a multitude of grazing organisms, including zooplankton, snails, and fish. A symbiotic relationship between the native fauna and the plant roots rapidly develops.

Restorer Treatment Processes

Restorer technologies support a wide spectrum of biological treatment processes. They can reduce organic loading measured as Biochemical Oxygen Demand (BOD), improve water clarity through the reduction of Total Suspended Solids (TSS) and fats, oils and greases (FOG) in the water. They have the capability to reduce pathogens and priority pollutants. They also can reduce nutrient levels, including nitrogen and phosphorus. Nitrification and denitrification can be incorporated into Restorer designs. If metal contamination is an issue, Restorers can be designed to recover and remove many heavy metals using attached algae sub-systems and plants. Restorers enhance the dynamic ecological cycles within the lagoons, ponds, lakes and canals in which they reside.



Restorers influence water quality in five interlocking ways:

Oxygenation and circulation.

Air lift pumps and curtains of fine bubble aeration circulate water through the cells and the different segments of the Restorer. Water can be mixed in a way that prevents stratification in the bottom sediment zone. In this configuration the bottom sediment-water interface has enough oxygen tension to support the establishment of a diverse and dynamic benthic or bottom animal community. Grazing populations of zooplankton, whose populations might normally be restricted by low oxygen, can be maintained at high population levels by aeration and circulation.

Biofilm reactors.

The Restorers utilize artificial media surfaces to support rich microbial, algae and animal communities. Nitrification of ammonia to nitrates occurs in the reactor's biofilms. Most nitrifiers are chemoautotrophs, organisms that can only thrive in a carbonate-rich and aerobic environment. The biofilms that form on Restorers provides such an environment. Adjacent areas on the films and under the Restorer walkways provide low oxygen (anoxic) zones for the denitrification of nitrates to nitrogen gas, which then escapes the system into the atmosphere. The root zones of the higher plants play a central role in this process and provide the endogenous sources of carbon that drive it. Biofilms in the Restorers are made up of extremely complex and diverse communities of bacteria, fungi, attached algae and protozoa living in thin films that favor material exchange by diffusion. They take up nutrients from the water column, shifting the system to one that is dominated by bacteria. Such an influence can limit the numbers of suspended micro-algae in a pond or reservoir. These same biofilms have a high degree of physiological plasticity, and typically maintain anoxic layers under aerated conditions.

Chemostat and Incubator.

One of the principal contributions of a Restorer to a water body is that it functions as a chemostat, incubating and releasing large numbers of bacteria and associated microorganisms into the aquatic environment. Sub-components in the system are designed to be mineral and nutrient rich zones that are optimal for microbial production. These organisms subsequently enter the surrounding water body and aid in its own metabolism. As a consequence beneficial effects initiated by the Restorer can extend beyond its immediate sphere of influence or contact. This can speed up the rate of sediment digestion and nitrification over a large area.

Benthic Community - For Bioremediation Projects

The Restorer can allow benthic communities to become established in bottom areas that were once oxygen poor. Similar communities can also become established in the root zones of the higher plants on the Restorer itself. The establishment of a strong benthic community has the potential to trigger a water body into a higher state. Bivalves, benthic arthropods and many other invertebrates consume organic matter. Many detritus feeders hasten bacterial and fungal breakdown of the sediments by shredding them. Benthic filter feeders, such as bivalves, can filter out a significant amount of biomass from the water column.

Higher Plants.

Studies over the last decade or two have begun to recognize the multiple roles and the critical importance of higher plants in wastewater treatment. Restorers have areas devoted to the culture of higher plants on the water surface. These include water tolerant grasses, flowers, shrubs and trees. Their roots extend well down into the water column. The extensive root network, or rhizosphere, provides the structure and nutrient support for diverse microbial communities. There is a close association between the plants and their root zones. Materials from the plant roots are exuded into the surrounding rhizosphere. Although it varies from species to species, approximately forty percent of the production of a plant goes into root saps that enter the root zone community. These materials include hormones, antibiotics, metal chelators, nutrients, humic compounds and polysaccharide glues. Another benefit of higher plants is that they provide refuges for large populations of microcrustacean zooplankton. The higher plants also provide shade and produce chemical compounds that can suppress algae.

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