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MINNESOTA
DEPARTMENT OF NATURAL RESOURCES

Feasibility Study

To Limit the Spread of Zebra Mussels From Ossawinnamakee Lake

Prepared by
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Consultant's Report

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Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

I. Introduction

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Section I

I. Introduction

Purpose

In 2003, zebra mussels *(Dreissena polymorpha)* were documented in Ossawinnamakee Lake (Crow Wing County, Minnesota). Subsequent sampling in 2004 indicated that the population had become established and that natural reproduction was occurring. Ossawinnamakee Lake has one outfall location that discharges into Pelican Brook, which is a small stream that flows approximately 5.5 miles (8.85 kilometers) before entering into the Pine River. The Pine River is a tributary of the Mississippi River. This flowing water path provides a means for zebra mussels, particularly veligers, to move from Ossawinnamakee Lake into the Mississippi River and causes a significant threat for dispersal of this harmful invasive species.

In 2004, a chemical treatment was applied to Ossawinnamakee Lake in an effort to reduce the risk of zebra mussel spread from the lake to Pelican Brook. The treatment was applied to one bay of the lake, Muskie Bay, on a weekly basis. Following this temporary treatment, there was a reduction in zebra mussels (MN DNR unpublished data). Although the treatment was effective, many other aquatic species were harmed in the process. As a result, it was important to explore alternative technologies that would control the established zebra mussel population.

According the Minnesota Department of Natural Resources (MN DNR) Staff, the zebra mussel population in Ossawinnamakee Lake is a threat that needs to be promptly addressed. The Minnesota Department of Natural Resources (MN DNR) has requested an evaluation of potential technologies that would prevent or limit the in-water transport of zebra mussels, with particular focus on peak veliger periods (May – September). This study, entitled **Feasibility Study to Limit the Spread of Zebra Mussels from Ossawinnamakee Lake**, has been developed in response to their request.

Scope of Work

This study evaluated potential and available technologies that may be effective in managing zebra mussel dispersal from both an environmental and engineering point of view. The specific goal was to provide the state with an objective analysis of the effectiveness of these technologies in preventing or limiting the in-water transport of zebra mussels from Ossawinnamakee Lake. This study includes an assessment of the potential impacts of zebra mussels, the effectiveness of each technology in limiting the invading species, the environmental impact of each technology on native species, the advantages and disadvantages of each technology, the time frames needed to implement each technology, the potential of the engineering task to be successfully completed, and an opinion of the cost of implementing each technology.

Prior Studies

There is an extraordinary amount of literature in relation to zebra mussels. Much of the available literature was developed in the early to mid-1990's, but there is some recent literature that evaluates proprietary control methods for zebra mussels. The literature that was utilized in the development of each section has been included in a works cited page at the end of the corresponding section. In addition, a complete list of literature that has been reviewed in the process of writing this report has been included in **Appendix D** of this report.

MN DNR and the U.S. Army Corps of Engineers have studied zebra mussel occurrence and treatment in relation to Ossawinnamakee Lake. MN DNR has written two informal reports that discuss the sampling and treatment efforts that have been carried out. The U.S. Army Research and Engineer Development Center has completed a technical report entitled **Final Report of the Effects of Cutrine®-Ultra and Cupric Sulfate on the Zebra Mussel, *Dreissena polymorpha*** that describes the effects of the chemical treatment that was utilized at Ossawinnamakee Lake. These three documents have been included in **Appendix E.**

The following agencies have been involved to varying degrees in prior studies:

- U.S. Fish and Wildlife Service
- U.S. Geological Survey
- U.S. Army Corps of Engineers
- U.S. Department of Agriculture
- U.S. Environmental Protection Agency
- MN Department of Natural Resources
- MN Office of the Revisor of Statutes
- WI Department of Natural Resources
- IA Department of Natural Resources
- SC Department of Natural Resources
- WA Department of Fish and Wildlife
- PN Department of Environmental Protection
- New Hampshire Department of Environmental Services
- Vermont Agency of Natural Resources

The type of prior and current studies include:

- Habitat – Biodiversity
- Spawning Activities
- Adaptation Parameters
- Monitoring – Detection
- Control Methods
- Life Stages
- Food Source & Food Chain
- Movement – Dispersal
- Impacts of Macrofouling/Infestation

Project Authorization

This Feasibility Study was authorized by the Minnesota Department of Natural Resources to FishPro/Cochran and Wilken, Inc. on January 3, 2005.

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

II. Executive Summary and Recommendations

Section II

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II. EXECUTIVE SUMMARY AND RECOMMENDATIONS

STUDY OVERVIEW

Ossawinnamakee Lake is a 644.0-acre (260.6 hectare) lake located in Crow Wing County, Minnesota. The lake has one outfall location that discharges into directly into Pelican Brook. The brook is a small stream that flows approximately 5.5 miles (8.85 kilometers) before entering into the Pine River. The Pine River is a tributary of the Mississippi River. In 2003, MN DNR documented the presence of zebra mussels (*Dreissena polymorpha*) in the lake. According the MN DNR Staff, the zebra mussel population in Ossawinnamakee Lake is a threat that needs to be promptly addressed. In response to the documented presence and threat of zebra mussel dispersal downstream, MN DNR requested a formal feasibility study of zebra mussel control technologies.

The primary goal of the report was to provide an analysis of the effectiveness of potential technologies in preventing or limiting the in-water transport of zebra mussels, particularly the veliger stage, in the outlet stream of Ossawinnamakee Lake. The report reviewed existing and new technologies that may be effective in limiting not only the downstream dispersal of zebra mussel veligers but also the established population of zebra mussels in Ossawinnamakee Lake.

FINDINGS AND RECOMMENDATIONS

The study provided an overview of Ossawinnamakee Lake (Section III) and reviewed the historical, physical, and life history traits of the zebra mussel (Section IV). A review of known treatments along with their advantages and disadvantages was provided in Section V. An overview of the current Ossawinnamakee Lake copper sulfate treatments was also provided in Section V. Section VI of the report evaluated potential treatment technologies and provided a recommended set of objectives to be pursued. The technologies presented were objectively analyzed based on environmental and scientific/engineering points of view. The three major evaluation criteria included overall effectiveness, economics, and environmental impacts.

A review of the technologies available for application to the Ossawinnamakee Lake zebra mussel population groups potential treatments into five categories including biological, acoustic, chemical, electrical, and physical controls that have been utilized for zebra mussel control in either laboratory or field applications. Although each treatment category has advantages and disadvantages, the evaluation revealed that a combination of treatments would yield a highly effective alternative that is environmentally friendly and targets all zebra mussel life stages. While chemicals are most widespread, other technologies are available that merit further consideration for planning, permitting design, and construction. These engineering solutions coupled with environmental operations and management solutions appear to have the most potential for success. This report recommends the following three objectives be considered for implementation:

Objective 1 – Continue Ossawinnamakee Lake and Pelican Brook veliger, and adult monitoring to determine location and densities of zebra mussels. Continue education and outreach programs to inform lake and brook users about the risk of downstream zebra mussel transport.

Objective 2 – Implement dispersal control strategies that limit zebra mussel dispersal from Muskie Bay into Pelican Brook. A variety of solutions may be possible to limit dispersal downstream. In particular, the report reviewed a passive solution that incorporated a permeable barrier stretched from the lake bottom to the surface and from bank to bank. The permeable barrier would allow water to pass through but would obstruct the movement of organisms from Muskie Bay into the area immediately downstream of the bay.

Objective 3 – Implement population control strategies that target reduction or limiting the growth of the zebra mussel population in Ossawinnamakee Lake. Several proactive treatments could be utilized including the use of various chemicals that have known efficiencies for reducing the presence of zebra mussels.

Treated as just one system, the lake and brook together represent a wide variety of physical characteristics. For this reason, two general treatment locations were considered for the treatment alternatives evaluated: the lake itself and the brook. For lake treatment, the combination of Objective 2 and Objective 3 provide the most promising strategy for limiting downstream dispersal and reducing the size of the population. The lake location would serve as the primary treatment location that incorporated year-round treatment strategies. A second tier treatment location would be the brook. Several of the treatments reviewed could be applied to any populations that are discovered in the brook. Used in this manner, these treatments would represent a reactive response to the presence of zebra mussels in the brook and would be applied on an as needed basis versus the proactive treatment of the population in the lake.

IMPLEMENTATION

Objective 1 is on-going and it is recommended that education, research and monitoring be continued and even expanded. Implementation of Objective 1 could be coordinated through existing education, research and monitoring protocols established within MN DNR.

It is recommended that appropriate funding be obtained to implement the planning, design, permitting, and ultimately the installation of a permeable barrier outlined in Objective 2 and the associated proactive population treatments outlined in Objective 3. Based on the risk of the existing population, this system needs to be in-place within the next 12 months (prior to spawning downstream dispersal in 2006). To limit the risk of downstream dispersal between now and the implementation of the permeable barrier, the current copper sulfate treatments may be necessary to reduce the densities of veligers in Ossawinnamakee Lake.

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III. Overview of Ossawinnamakee Lake and Pelican Brook

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Section III

III. OSSAWINNAMAKEE LAKE AND PELICAN BROOK OVERVIEW

The following section provides a brief overview of Ossawinnamakee Lake and the outlet stream from the lake, Pelican Brook. This overview is intended to highlight known characteristics of the lake and stream but is not intended to serve as an official, detailed assessment of the waterbodies. Official lake assessments and field surveys completed by Minnesota Department of Natural Resources (MN DNR) include the physical characteristics, water quality data, a review of the local flora and fauna for the lake and brook area. Copies of these MN DNR reports and surveys are provided in **Appendix C**.

MN DNR website and staff report that there are no known threatened or endangered mussel, fish, or plant species in Ossawinnamakee Lake or Pelican Brook.

Ossawinnamakee Lake Overview

Physical Characteristics

The primary uses of Ossawinnamakee Lake include fishing and general recreation. There is one area for public access provided at this lake and several points of private access. **Table III-1** provides an overview of characteristics for the lake while **Figure III-1** displays the location of Ossawinnamakee Lake relative to the State of Minnesota.

Table III-1. Physiological and Morphological Overview

Parameter	Description
Lake Name	Ossawinnamakee Lake
Lake ID Number	18-0352
County	Crow Wing
Location (legal)	Sections 2,3,4,5; T136N, R28W of the 3rd Principal Meridian
Coordinates	UTM 15, 410624E 5164695N
Watershed Name	Mississippi Headwaters 15
Lake Surface Acres	644.0 acres (260.6 hectares)
Maximum Depth	63.0 feet (19.2 meters)
Shoreline Length	13.1 miles (21.1 kilometers)

Source: MN DNR

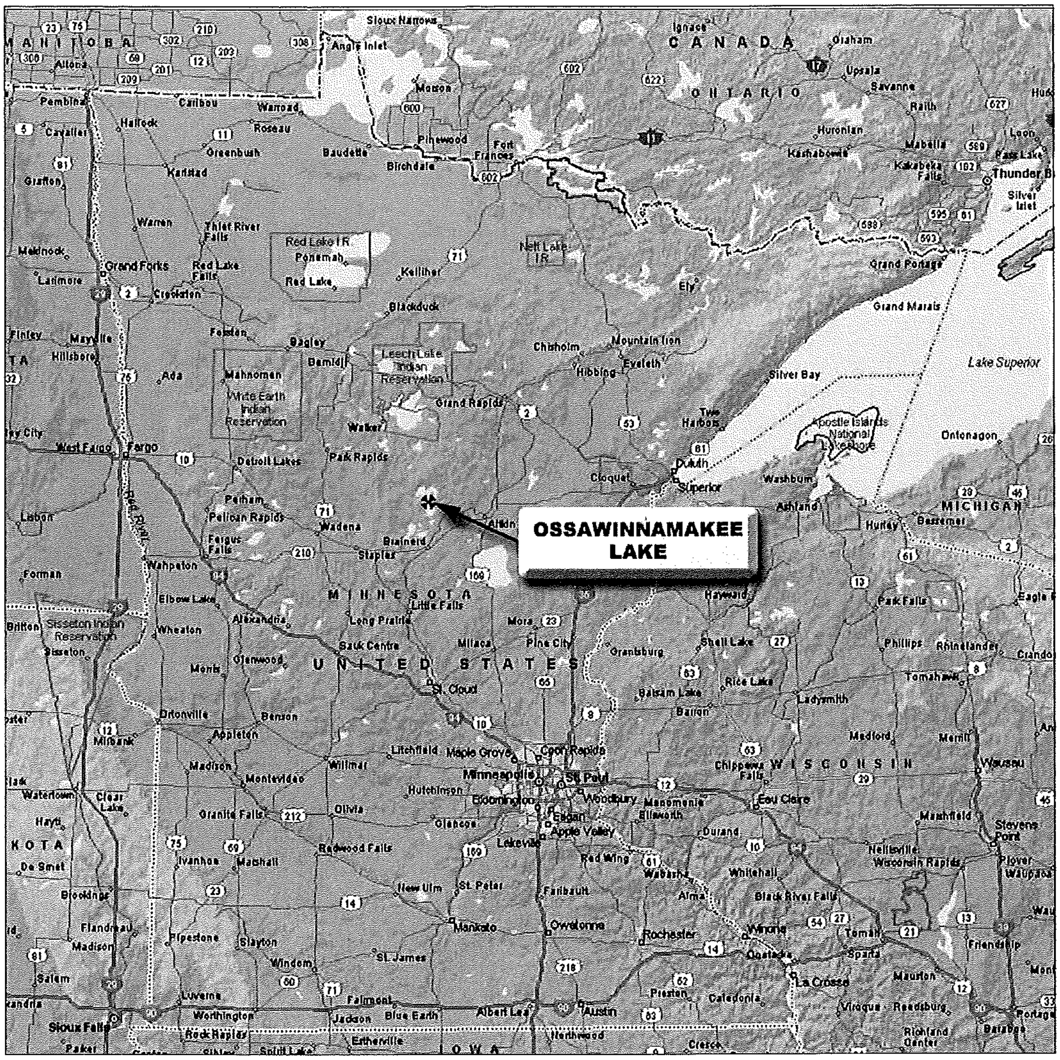


Figure III-1. Ossawinnamakee Lake Location

Hydrological Characteristics

Ossawinnamakee Lake has one main discharge point located in the southeastern portion of the lake. One primary inflow point exists in the northwestern portion of the lake, Kimball Creek. Under normal scenarios, Kimball Lake located to the north of Ossawinnamakee Lake, provides the only direct inflow into the lake. Under this condition, flows exiting Kimball Lake enter Kimball Creek, which MN DNR personnel indicate is a shallow creek of varying widths from 10.0 feet (3.0 meters) to 16.0 feet (4.9 meters). While water can flow from Kimball Lake to Ossawinnamakee Lake, boat traffic between the two lakes is physically restricted and prohibited by a County Board ordinance. A second potential inflow point exists, but according to MN DNR has never accounted for flow into Ossawinnamakee Lake. In the rare event that Pelican Lake elevations significantly rose, water could travel from Pelican Lake into Ossawinnamakee Lake through an outlet stream in Pelican Lake located south of Ossawinnamakee Lake. Records maintained by MN DNR since 1933 indicate that water has never exited Pelican Lake and entered Ossawinnamakee Lake. The emergency outlet structure elevation for Pelican Lake is 1,207.1 feet (367.9 meters), which is 0.9 feet (0.3 meters) above the highest recorded Ossawinnamakee Lake elevation of 1,206.8 feet (367.8 meters). Given these conditions, it is highly unlikely that water will exit Ossawinnamakee Lake and enter Pelican Lake. **Figure III-2** displays the relationship of Ossawinnamakee Lake to Kimball Lake to the north and Pelican Lake to the south.

The average water surface elevation Ossawinnamakee Lake is 1,205.5 feet (367.4 meters). The highest recorded elevation outlined above was 1,206.8 feet (367.8 meters) while the lowest recorded elevation was 1,205.0 feet (367.3 meters), which is an approximate 1.8 feet (0.55 meters) maximum elevation change. Under average conditions, the lake has a volume of 14,008 acre-feet (17,278,613 cubic meters) and a hydraulic residence time of six to seven years. The surrounding watershed is approximately 9,296.0 acres (3,761.9 hectares), which results in a watershed to lake surface areas ratio of approximately 14:1.

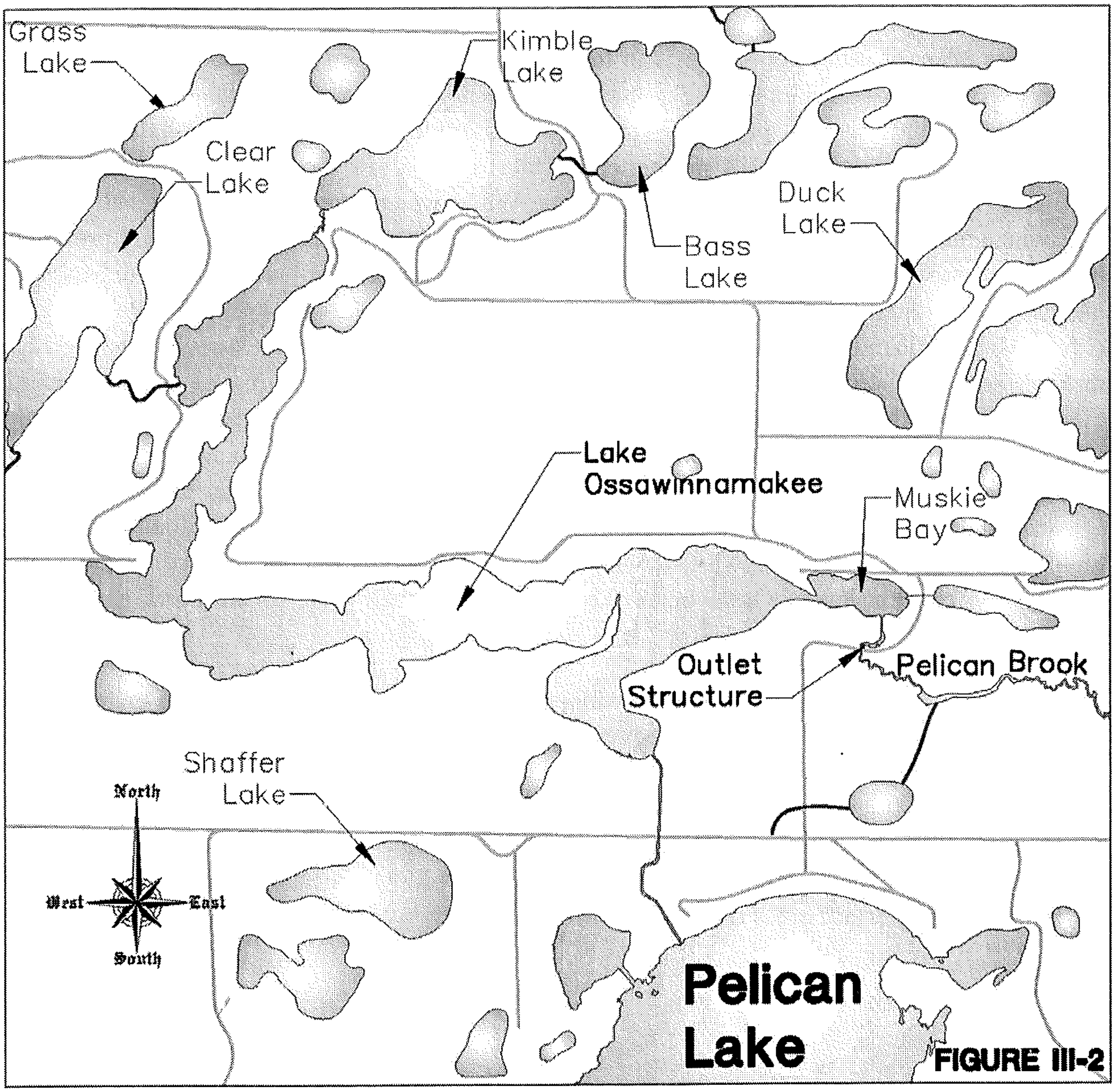


Figure III-2. Hydrologic Connectivity to Ossawinnamakee Lake

Outlet Structure

The Ossawinnamakee Lake outlet structure is displayed in **Figure III-3**. According to MN DNR, the spillway elevation of Ossawinnamakee Lake has been set since 1947 at 1,204.8 feet (367.2 meters). As outlined above, all water exiting the lake, with the exception of seepage and evaporative losses, discharges through this structure. MN DNR staff has recorded lake water level elevations, which are provided within excerpts taken from the *Lake Assessment Report for Ossawinnamakee Lake* (**Appendix C**). While the lake elevations have been noted, detailed flow measurements are not recorded. However, MN DNR has obtained some periodic measurements of flow. Communications with MN DNR staff indicates that the average discharge ranges from 40.0 cfs (1.13 cms) to 50.0 cfs (1.42 cms) for Ossawinnamakee Lake. Flow measured by MN DNR indicates discharge variability from 30 cfs (0.85 cms) to 85 cfs (2.41 cms).

A discharge curve was developed to estimate the volume of water being discharged over the outlet structure (CFS) at known lake water elevations (feet). The estimates were made using the following assumptions:

- Dam Crest Elevation: 1,204.8 feet (367.2 meters)
- Dam Weir Width: 22.8 feet (7.0 meters)
- Lowest Water Elevation Recorded: 1,205.0 feet (367.3 meters)
- Highest Water Elevation Recorded: 1,206.8 feet (367.8 meters)
- Average Water Elevation: 1,205.5 feet (367.4 meters)
- Water Elevation Delta: 1.8 feet (0.55 meters)
- $Q = CLH^{1.5}$ (Q=Discharge, cfs; C= Sharp Crest Weir Coefficient, 3.3; L=Weir Length, ft; H= Flow Depth, ft)

Based on these assumptions and personal communications with MN DNR staff, water has always overtopped the crest of the dam and entered Pelican Brook. There are currently no records that indicate a cease of discharge from Ossawinnamakee Lake.

Figure III-4 displays the estimated discharge in cfs for Ossawinnamakee Lake based on the above assumptions. These estimates should only serve as rough approximations. Discharge curves should be created with more model inputs and measured calibration; however, these approximations should represent conditions in a reasonable range of actual conditions.

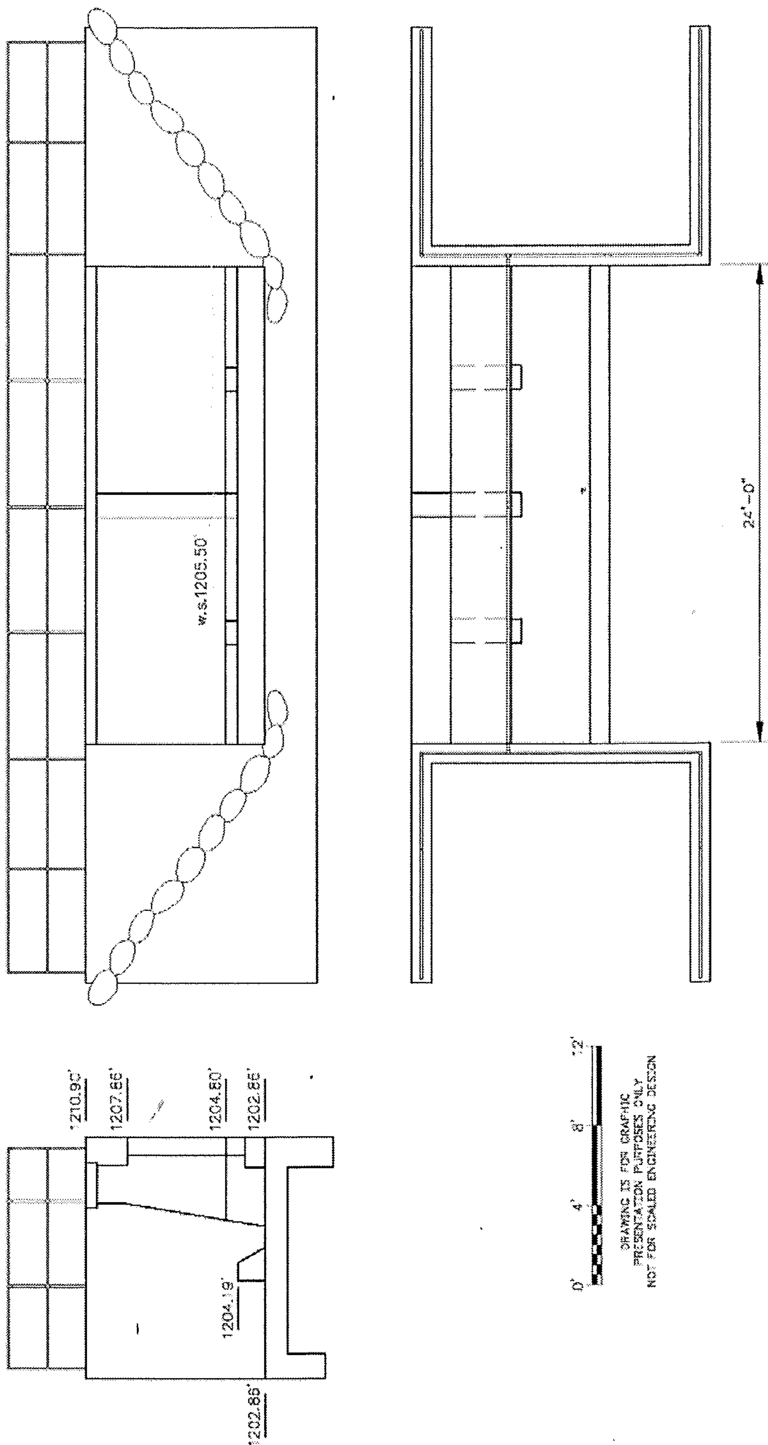


Figure III-3. Ossawinnamakee Lake Outlet Structure

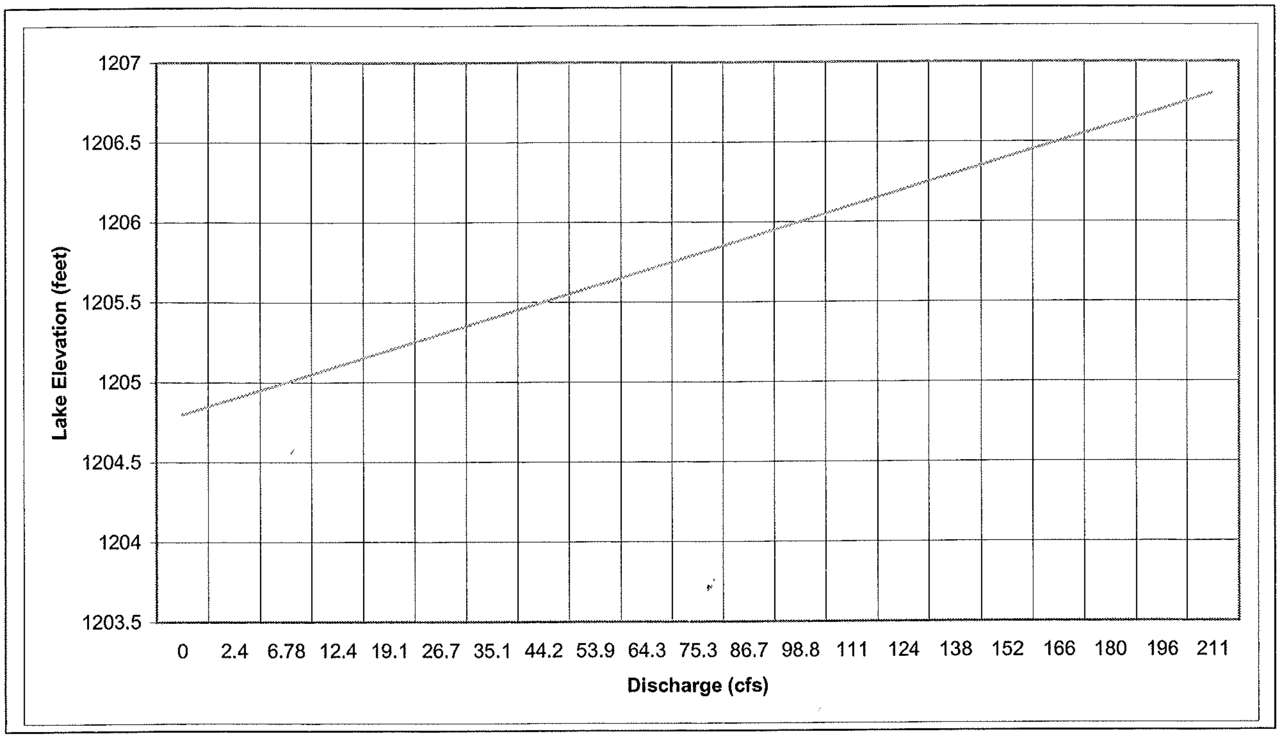


Figure III-4. Ossawinnamakee Discharge Curve (estimated)

Using the discharge curve and the known elevations outlined above, it is estimated that the average discharge from the lake is 44.2 cfs (1.25 cms). Similarly, the same discharge curve indicates that at the lowest elevation on record, the discharge would have been 6.8 cfs (0.19 cms) while the highest elevation on record would approach 211 cfs (5.1 cms) discharge.

Review of Water Quality Characteristics

Lake survey reports and water quality data collected by MN DNR is contained within **Appendix C**. Additionally, water quality data was obtained from the Minnesota Pollution Control Agency (MPCA) web site. In general, Ossawinnamakee Lake exhibits oligotrophic characteristics with high water transparencies and relatively low nutrient levels. The lake water quality is considered excellent but could be sensitive to nutrient changes (MPCA 1993). **Table III-2** provides summary water quality data for Ossawinnamakee Lake.

Table III-2. Ossawinnamakee Lake Water Quality Summary

Water Quality Parameters
Total Phosphorus Mean: 11 ppb (parts per billion)
Total Phosphorus Standard Error: 1 ppb
Total Phosphorus # of Observations: 4
Total Phosphorus Minimum: 10 ppb and Maximum: 13 ppb
Chlorophyll-a Mean: 3 ppb
Chlorophyll-a Standard Error: 0 ppb
Chlorophyll-a # of Observations: 4
Chlorophyll-a Minimum: 2 ppb and Maximum: 5 ppb
Secchi Disk Mean: 5 meters
Secchi Disk Standard Error: 0 meters
Secchi Disk # of Observations: 147
Secchi Disk Minimum: 4 meters and Maximum: 6 meters
Alkalinity Mean: 125 ppm (parts per million)
Alkalinity # of Observations: 4
Color Mean: 11 Platinum-cobalt Units
Color # of Observations: 4
Carlson Trophic Status for Total Phosphorus: 39
Carlson Trophic Status for Chlorophyll-a: 42
Carlson Trophic Status for Secchi Disk: 37
Overall Trophic Status: O
(O=oligotrophic, M=mesotrophic, E=eutrophic, H=hypereutrophic)

*Data for table obtained from the Minnesota Pollution Control Agency

Pelican Brook Overview

Physical Characteristics

Stream surveys conducted by MN DNR staff indicate that Pelican Brook is a shallow, warmwater stream that is approximately 8 miles (12.9 kilometers) in length. Pelican Brook connects Ossawinnamakee Lake to the Pine River. MN DNR reports the width near the upstream portion of the stream is approximately 29.8 feet (9.1 meters) while the downstream areas of the stream approach widths of 54.0 feet (16.5 meters). MN DNR staff has described the stream as having a mostly sand bottom with vegetation common throughout the stream. The stream is not known for sport fishing but contains a variety of fish species. The stream is navigable and canoeists have been witnessed traveling Pelican Brook in route to the larger Pine River. Copies of the more detailed field reports and surveys are contained in **Appendix C**.

As outlined above, flow from Pelican Brook enters the Pine River, which drains, into the Mississippi River. **Figure III-5** displays the length of the Pelican Brook and its geographical relationship to the Pine River and the Mississippi River.

Table III-3 lists the physical characteristics of Pelican Brook.

Table III-3. Physical Overview - Pelican Brook

Parameter	Description
Stream Name	Pelican Brook
Tributary Number	M-106-2
County	Crow Wing
Mouth Location	Sec. 8; T136N, R27W of the 3rd Principal Meridian
Length of Stream	5.5 miles (8.85 kilometers)
Watershed Name	Mississippi Headwaters 15

For sampling and data collection purposes, four stations have been established within Pelican Brook. Each sampling station is approximately 500 feet (152.4 meters), and varies in depth and width. In general, the widths ranged from 29.8 feet (9.1 meters) to 54.0 feet (16.5 meters). Average depths for the sampling stations ranged from 1.0 feet (0.3 meters) to 1.7 feet (0.52 meters). A variety of pools are present within each station length. The pools vary in depth from a minimum recorded depth of 2.6 feet (0.79 meters) maximum-recorded depth of 4.1 feet (1.25 meters). Erosion inspections at three of the sampling stations were documented as light, while one station was documented as moderate.

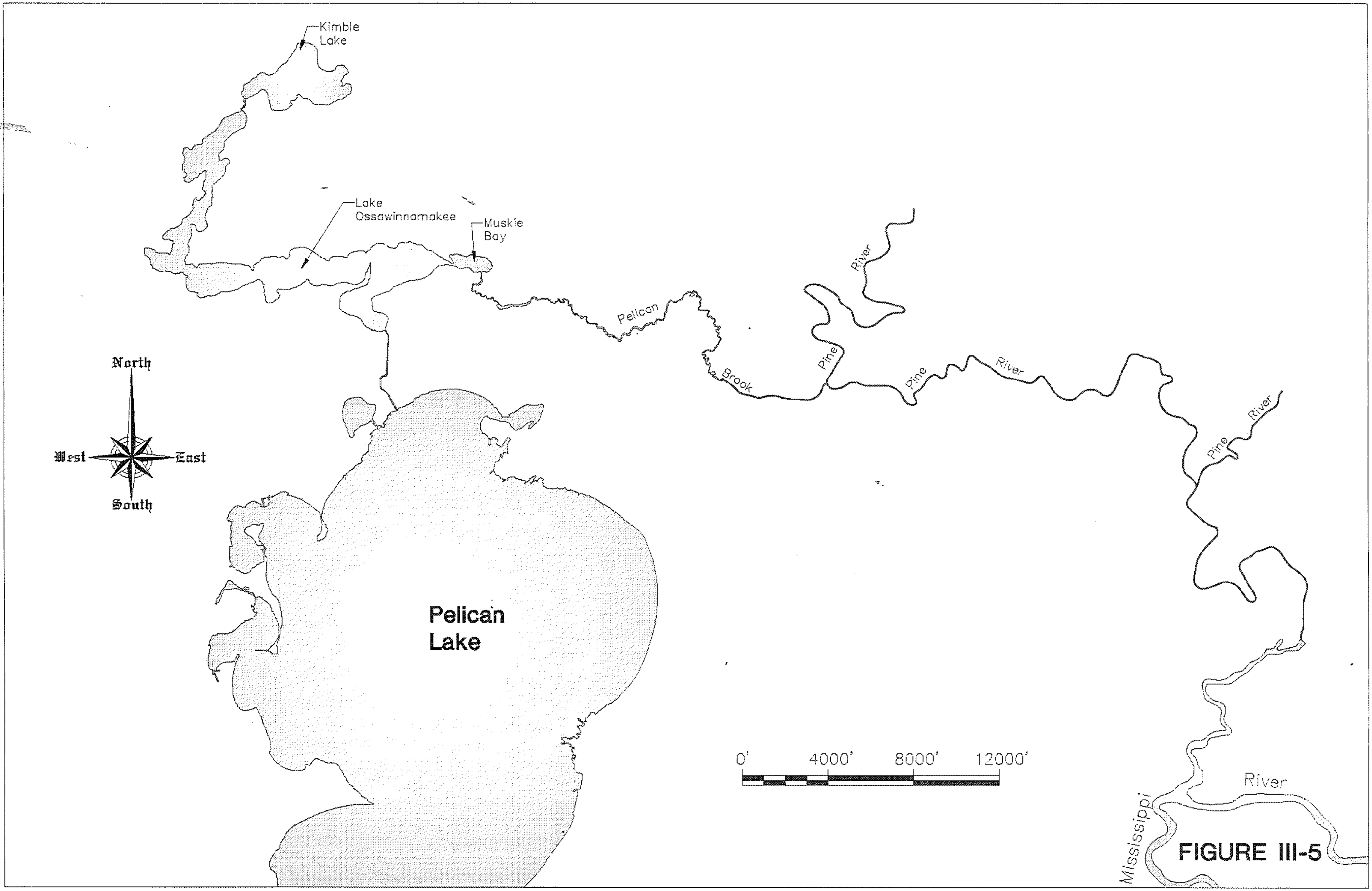
Water Quality Characteristics

Table III-4 lists water quality parameters for a single MN DNR sampling event in July of 2000.

Table III-4. Pelican Brook Water Quality Testing

Parameter	**Units**	**Results**
Water Temperature	C	25
Total Phosphorous	ppm	0.24
Color		clear
pH	SU	8.08
Chloride	ppm	1.8
Total Dissolved Solids	ppm	158
Conductivity	umho/cm	248

Note - The data reflects MN DNR testing conducted at the Hwy 39 bridge crossing on July 25, 2000


Kimble Lake
Lake Ossawinnamakee
Muskie Bay
Pelican Brook
Pine River
Pine River
Pine River
Mississippi River
North
West
East
South
Pelican Lake
0'
4000'
8000'
12000'
FIGURE III-5

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IV. Review of Zebra Mussel (*Dreissena polymorpha*) Species

Section IV

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IV. REVIEW OF ZEBRA MUSSEL (*DREISSENA POLYMORPHA)* SPECIES

This section provides a brief review of zebra mussel (*Dresissena polymorpha*) species that includes a historical overview, physical description and life history traits, ecological and physiological overview, impact of zebra mussels, and their status as an aquatic nuisance species.

Historical Overview

Russian scientist and explorer, Pyotr Simon Pallas, first described populations of zebra mussels (*Dreissena polymorpha*) in the Caspian Sea and Ural River in Russia (Pallas 1771). Native to Eastern Europe, including the Black, Azov, and Caspian seas, the species spread through Western Europe in the 19th century as canals and inland waterways were connected to facilitate trade during the Industrial Revolution (Nalepa and Schloesser 1993). The species was believed to be introduced to North America in 1985-86 by the release of larvae with ship ballast water in Lake St. Clair (Hebert et al. 1989, Griffiths 1993). Zebra mussels were first documented in North America in 1988 (Hebert et al. 1989).

Zebra mussels are nonindigenous, invasive macrofoulers that can quickly colonize new areas and rapidly achieve high densities. The success of the introduction and proliferation of the zebra mussel in North America can be partially related to the species' external fertilization and planktonic larval stages of its life history. These life stages are not typically found in indigenous, native freshwater mussels but are typically found in marine bivalves (Ackerman 1995). Furthermore, unlike native mussels that burrow in sand and gravel, zebra mussels spend their adult lives attached to hard substrates that can include rocks, logs, aquatic plants, and the shells of native mussels, as well as various man-made structures that contain plastic, wood, fiberglass, and iron surfaces. The ability to attach to these various natural and man-made substrates along with the species' high fecundity and passively dispersed planktonic veliger larval stage have allowed zebra mussels to significantly change ecosystem trophic dynamics and spread rapidly throughout the freshwater ecosystems. These changes have had various ecological and economic impacts throughout North America (Ram and McMahon 1996).

Physical Description and Life History Traits

Classification and Morphology

The classification or taxonomy of zebra mussels has been described as follows:

Class – Bivalvia, Subclass – Heterodonta

Order – Veneroida, Suborder – Dreissenacea

Superfamily – Dreissenoidea, Family - Dreissenidea

Genus – Dressiena, Subgenus – Dressiena s.l.

Species – D. polymorpha

Zebra mussels are taxonomically grouped in the class Bivalvia (bivalves) – molluscs that are characterized as having two shells or valves that are connected by ligaments. The common name "zebra mussels" is derived from the pattern of black stripes on the shell, and the Latin species name "*polymorpha*" refers to the many variations in shell color, pattern, and shape that can be found in zebra mussel populations (USACE 2005). **Figure IV-1** illustrates zebra mussel polymorphism and includes an assortment of variations of the zebra mussels. **Table IV-1** provides a summary of the diagnostic shell feature of North American zebra mussels (*D. polymorpha)*.

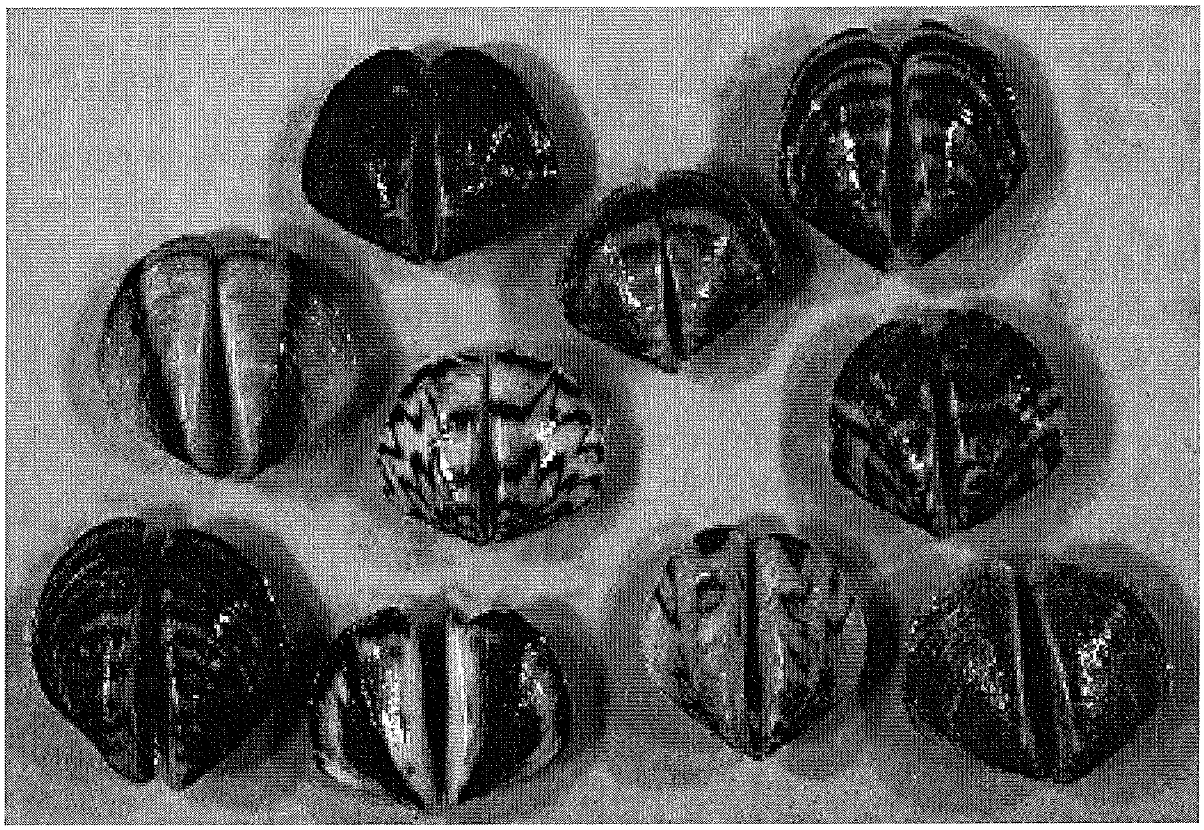

Figure IV-1. Examples of Zebra Mussel "Polymorphism"

Source: USACE 2005.

Table IV-1. Diagnostic Exterior Shell Features of *Dreisenna polymorpha*

Shell Feature	*Dreisenna polymorpha*
Shape and Color	Mytiliform, striped, all black or white
Ventral Margin	Arched, flattened, acute vento-lateral shoulder
Dorsal Margin	Rounded
Umbone	Pointed
Posterior Margin	Angled vento-posteriorly

Source: (Mackie and Schloesser 1996)

Mode of Life and Habitat

Mackie (1991) described the mode of life of *D. polymorpha* as epifaunal, which refers to living either on the sediment surface or on a firm substrate, such as a shell or other structure, on or above the sediment surface. Zebra mussels are known to inhabit freshwater lakes and rivers (Strayer 1991) but they also do well in cooling ponds, quarries, and irrigation ponds as well. Research within North America has demonstrated that zebra mussels are capable of living in brackish water or estuaries, where salinity does not exceed 8 to 12 parts per thousand (ppt) (Nalepa and Schloesser 1993).

Dispersal Mechanisms

Numerous potential dispersal mechanisms of larval and adult *D. polymorpha* have been reviewed in the literature. These dispersal mechanisms have been divided into natural mechanisms (e.g., water currents, birds, insects, and other animals) and human-mediated or anthropogenic mechanisms (e.g., artificial waterways, ships and other vessels, fishing activities, amphibious planes, and recreational equipment). Generally, dispersal of zebra mussels is believed to occur naturally primarily by currents that carry plankton veligers (Mackie et al. 1989, Carlton 1993).

The "foot" is an extendible muscular organ located in the mid-ventral region of the mussel, and its primary function is locomotion. Located within the foot is the byssal gland, which produces secretions that are used to form byssal threads. The zebra mussel uses the byssal threads for attachment to various substrates. As environmental conditions change, the zebra mussel has the ability to detach their byssal threads from the substrate and can "move" either directly via the "foot" or passively as water currents move the mussel to a more suitable location or substrate (Frisina and Eckroat 1992).

Geographic Distribution

As stated previously, zebra mussels were first observed within North America in Lake St. Clair in 1988 (Ram and McMahon 1996). From their apparent arrival in 1998 through the present, zebra mussels have spread throughout all the Great Lakes and St. Lawrence, Mississippi, Tennessee, Hudson, and Ohio River Basins (USACE 2005, US Department of the Interior 2000). **Figures IV-2 and 3** illustrate the initial infestation in 1988 and the subsequent spread of zebra mussel distribution in 1999 within North America.

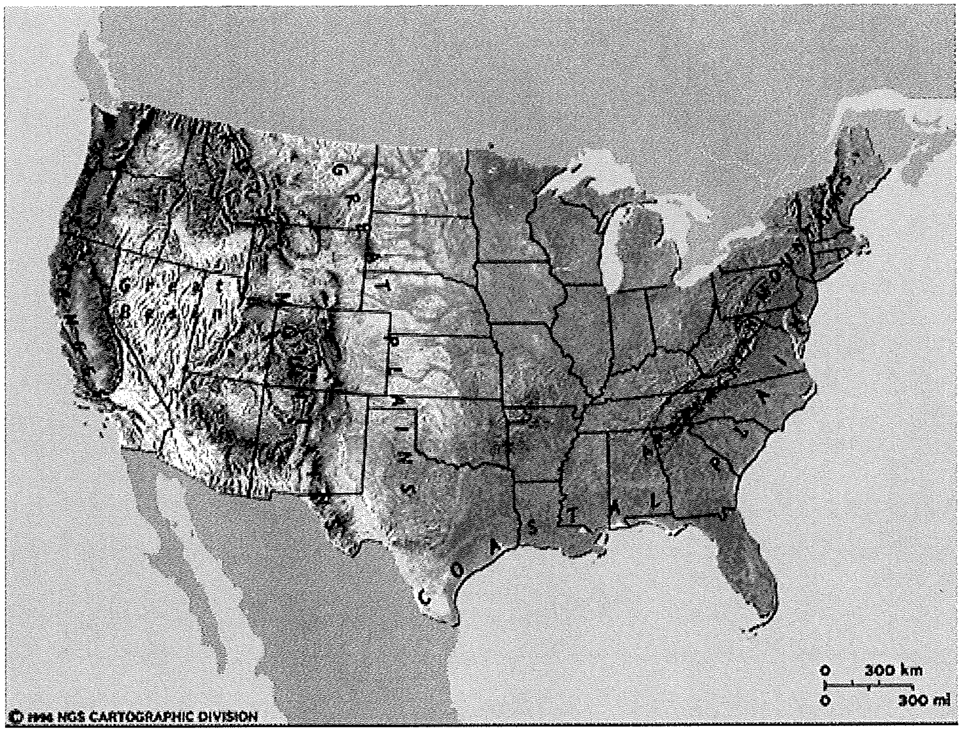

Figure IV-2. North American Zebra Mussel Distribution in 1988

Source: USACE 2005.

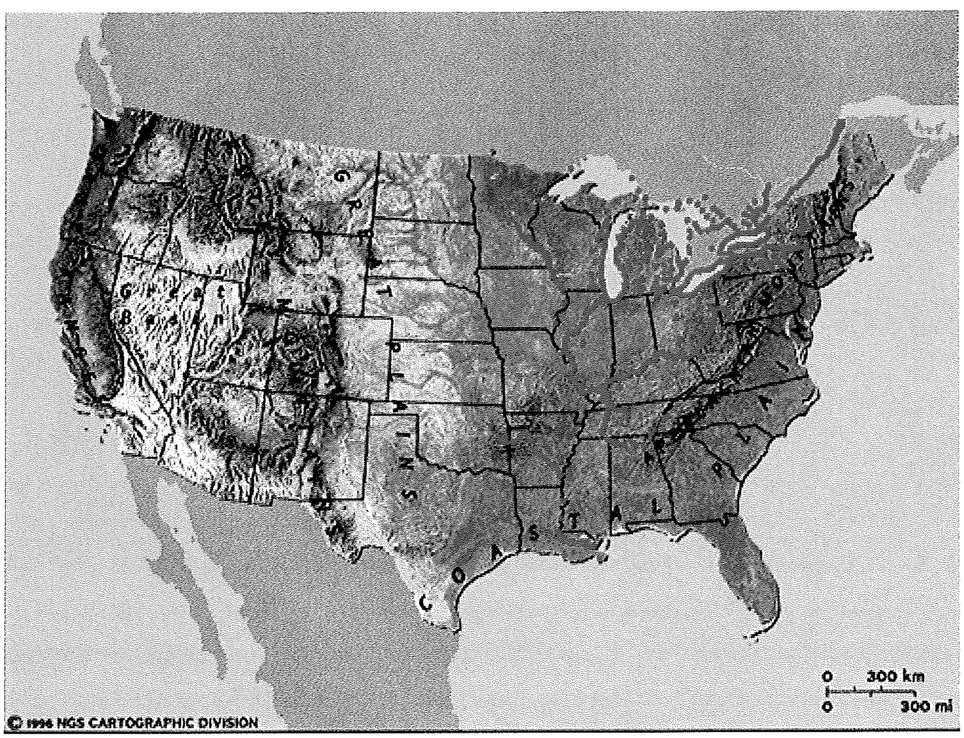

Figure IV-3. North American Zebra Mussel Distribution in 1999

Source: USACE 2005.

Habitat Distribution

Fraleigh et al. (1993) reported that wind driven currents can affect the vertical distribution of veligers throughout the water column and found that 95 percent of the veligers were encountered at depths varying from 2 to 6 meters (6.6 to 19.7 feet). Similarly, Mackie et al. (1989) found veliger abundance at depths from 3 to 7 meters (9.8 to 23 feet). Within temperate lakes, few veligers were found to occur below the thermocline (Mackie et al. 1989, Fraleigh et al. 1993).

Predators

The zebra mussel veligers have been consumed by crustacean zooplankton and larval fish; however, the relative importance of this prey on the mortality of veligers is unknown. The predation of juvenile and adult zebra mussels has been observed by crayfish, fish, and waterfowl (Mackie et al. 1989).

Fishes observed or expected to consume zebra mussels include: freshwater drum (*Aplodinotus grunniens*), redear sunfish (*Lepomis microlophus*), pumpkinseed (*L. gibbosus*), copper (*Moxostoma hubbsi*) and river (*M. carinatum*) redhorse, common carp (*Cyprinus carpio*), and blue catfish (*Ictalurus furcatus*) (MacIsaac 1996, Magoulick and Lewis 2002). Furthermore, adult zebra mussels have also been found in the digestive tracts of other fishes in the Great Lakes including yellow perch (*Perca flavescens*), white perch (*Morone americana*), walleye (*Stizostedion vitreum*), white bass (*Morone chrysops*), lake whitefish (*Coregonus clupeaformis*), lake sturgeon (*Acipenser fulvescens*), and the round goby (*Neogobius melanostomus*) (French 1993). In general, while fish prey on the mussels, it appears that fish do not limit the densities of zebra mussels (Mackie and Schloesser 1996).

Diving waterfowl are important zebra mussel predators in North America. The following species have been observed feeding extensively on zebra mussels in Ontario and throughout the Lake Erie region: greater scaup (*Aythya marila*), lesser scaup (*A. affinis*), common goldeneye (*Bucephala clangula*), and the bufflehead (*B. albeola*) (Wormington and Leach 1992, Hamilton et al. 1994). While bay diving ducks have been known to consume as much as the 57 percent of autumnal biomass of zebra mussels in Lake Erie and 90 percent winter zebra mussel biomass in Lake Constance, these reported predation events had little impact on mussel biomass the following spring. The regulation of zebra mussel biomass and abundance by waterfowl is unlikely in central North America because predation is limited to ice-off periods (Cleven and Frenzel 1993, Hamilton et al. 1994).

Productivity

Compared to European populations, the densities of zebra mussel veligers and adults in the Great Lakes are prolific and are among the highest reported to date (Mackie and Schloesser 1996). Leach (1993) found that Lake Erie averaged 126-268 veligers per liter, whereas the European waters averaged 10-100 veligers per liter (Fraleigh et al. 1993). Mean adult densities in Lake Erie ranged from 54,000 (Dermott et al. 1993) to 779,000 (Pathy and Mackie 1993) per square meter, compared to European densities of 5,000 to 115,000 per square meter (Mackie et al. 1989).

Life History

Mackie et al. (1989) and Ackerman et al. (1994) have reviewed the life history of zebra mussels. Generally, the zebra mussel life cycle (see **Figure IV-4**) has three main periods: larval, juvenile, and adult stages. The larvae are planktonic during their initial three life stages: trochophore, straight-hinged veliger, and umbonal veliger. As the planktonic larvae settle on a substrate, during the pediveliger stage, they develop into juveniles (Ackerman 1995). Mackie et al. (1989) and Nalepa and Schloesser (1993) report that the settling stages are the most sensitive zebra mussel life stages and high mortality rates have been observed, usually 90 to 95 percent.

Zebra mussels are considered adults when they reach sexual maturity, and populations within North America (unlike those in Europe) become sexually mature within their first year of life, usually 8 to 10 mm in shell length (Mackie et al. 1989). Zebra mussels have high fecundities that vary from 30,000 to 1,610,000 eggs per female (Borcherding 1992). Furthermore, zebra mussels are diecious (i.e., separate sexes) and are broadcast spawners, as fertilization occurs in the water column. Females and males have been known to produce over 1 million eggs and 10 billion sperm (Sprung 1991).

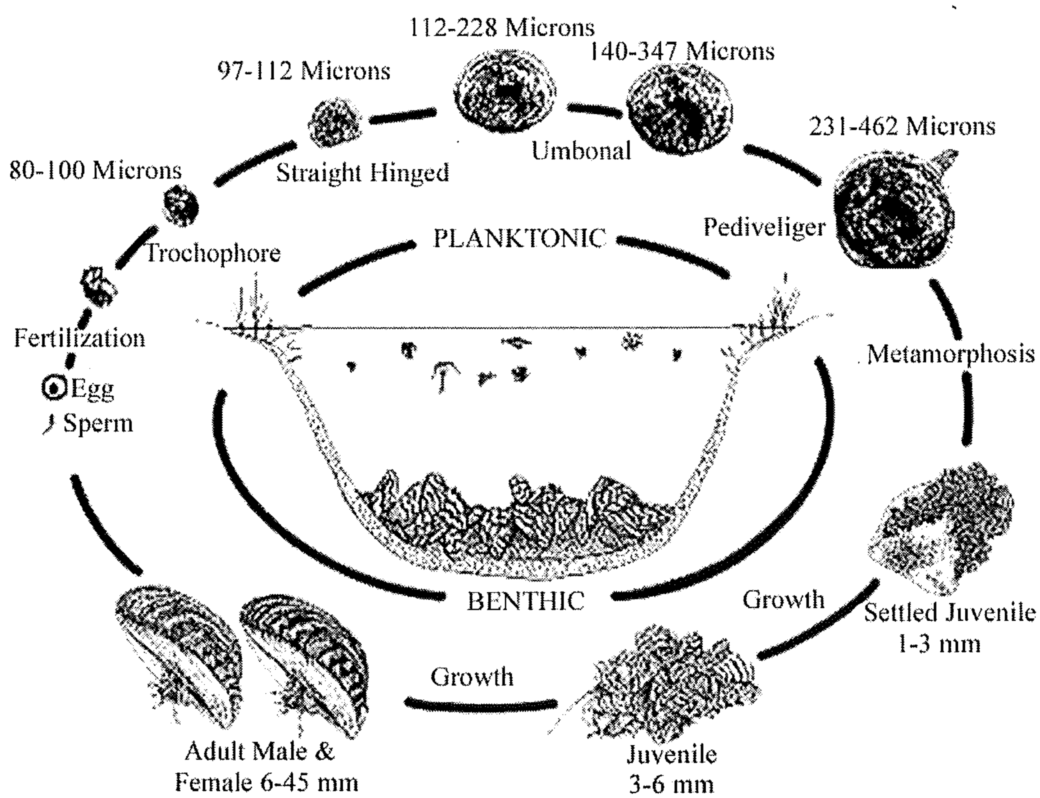

Figure IV-4. Zebra Mussel Life Cycle

Source: USACE 2005.

Age and Growth

The growth rate of larvae or veligers is highly variable and depends mainly on temperature (Mackie et al. 1989) and chlorophyll-a content (e.g., phytoplankton) (Smylie 1994). Within the Great Lakes, veliger growth and settlement rates appeared to be optimal between 15 and 17°C (Smylie 1994), and the temperature threshold for adult zebra mussel growth varied between 10 and 12°C (Mackie et al. 1989). Nichols (1996) reported that the time required for a fertilized gamete to develop (through the veliger stage) into a fully developed juvenile takes longer in colder water temperature and thus can range from 8 to 240 days.

The life span of zebra mussels is highly variable, but it appears that North American populations have a shorter longevity than European populations. The average life span of zebra mussels can vary from 3 to 6 years throughout Poland and Britain, to as many as 9 years in Russia (Mackie et al. 1989). However, in North America, most zebra mussel populations have a life span of about 1.5 to 2 years (Mackie 1991). Mackie et al. (1989) also found that zebra mussels inhabiting heated waters have life spans that are shortened by about 1 year compared to unheated lakes in the same geographic area.

Food and Feeding

Zebra mussels are filter feeders, and zebra mussel food sources vary from micro-algae, micro-invertebrates, bacteria, detritus, and other organic material. Zebra mussel food selection is performed by a variety of cilia, which generally select particles ranging from 15 to 40 μm for food but can filter out particles as small as 0.7 to 1.0 μm in diameter from the water (Mackie et al. 1989). The filtration of zebra mussels has been known to clarify the epilimnion and the littoral zones in lakes (Neumann and Jenner 1992). As zebra mussels ingest both organic and inorganic particles, the edible and nonedible portions are sorted. The rejected particles are bound in mucus, which are expelled as pseudofeces (Dean 1994).

Ecological and Physiological Overview

A summary of the following text describing zebra mussel resistance adaptation to physico-chemical parameters is provided on the following page in **Table IV-2** (McMahon 1996).

Table IV-2. Resistance Adaptation of Zebra Mussels to Physico-Chemical Parameters

Parameter	Life Cycle Stage	Environmental Tolerance Limit
Temperature Tolerance	Adult	Cannot survive above 30°C
	Veliger Larva	Fertilization 10 - 26°C; Development 12 - 24°C
Respiratory Response	Adult	O_2 uptake maximized at 30 - 35°C
	Veliger Larva	Unknown
Anoxia/Hypoxia Response	Adult	$pO_2 \geq 32 - 40$ torr at 25°C, poor O_2 regulator
	Veliger Larva	$pO_2 \geq 32$ torr at 18 - 20°C
Salinity Tolerance	Adult	Variable, <4 - 9 ppt, may acclimatize to higher levels
	Veliger Larva	<7 ppt for spawning, <6 ppt for development
Emersion Tolerance	Adult	Dependent on temp. and relative humidity, <8 days above 25°C
	Veliger Larva	Unknown
Freezing Air Temp. Tolerance	Adult	Single mussels <1.5°C, when clustered <-3°C
	Veliger Larva	Unknown
pH Limits	Adult	≥ 6.5, >8 for maximal growth
	Veliger Larva	7.4 - 9.4 for successful development, optimum = 8.4
Calcium Conc. Limits	Adult	Lower limit = 15 mg/l, ≥ 25 mg/l for good growth
	Veliger Larva	Lower limit = 12 mg/l, ≥ 34 mg/l optimum
Starvation Tolerance	Adult	LT_{50} = 118 days at 25°C, 352 days at 15°C, >500 days at 5°C
	Veliger Larva	100% mortality in 11-15 days at 12-24°C
Turbidity Tolerance	Adult	Upper limit unknown, lower limit >160 NTU
	Veliger Larva	Unknown
Organic Enrichment	Adult	Density decline with PO_4^{-3} and NO^{-3} enrichment
	Veliger Larva	Unknown
Food Particle Size Limit.	Adult	<1 µm up to planktonic rotifers and crustaceans
	Veliger Larva	Algae 1 – 4 µm in diameter

Source: McMahon 1996.

Temperature Reponses

Water temperatures impact and activate various phases in the seasonal life cycle and physiology of the zebra mussel (Claudi and Mackie 1994, Fong et al. 1995, McMahon 1996).

Effect of Temperature on Spawning and Fertilization

Zebra mussel spawning will not generally occur at temperatures below 12°C (Claudi and Mackie 1994). Sprung (1987) reported that successful fertilization and subsequent larval development of zebra mussels generally occurs between 10-26°C and 12-24°C, respectively. Within Lake Erie, initial spawning has been observed at temperatures ranging from 22-23°C. While veligers were first observed at 18°C, their abundance declined sharply after water temperatures fell below 18°C (Fraleigh et al. 1993, Garton and Haag 1993). While research suggests that zebra mussel spawning can occur at 12°C, the data suggests that it is maximized at 17-18°C (McMahon 1996).

Within temperate, freshwater lakes in North America, these water temperature thresholds typically occur between the months of June through September, which coincides with the typical time of year when veligers are typically found (Ackerman et al. 1994).

Effect of Temperature on Survival

Zebra mussels cannot withstand freezing temperatures and their lower temperature limit is 0°C (Paukstis et al. 1997). Although they can survive temperatures slightly above 30°C for short periods of time, optimum temperatures are generally less than 25°C (Karatayev et al. 1998). Temperature tolerance limits within zebra mussels is variable; generally, North American populations have a higher thermal tolerance than those found in Europe (Jenner and Janssen-Mommen 1989, Iwanyzki and McCauley 1992). North American zebra mussel populations are believed to have originated from the warmest and southern portion of the species' European range (Marsden et al. 1996), and therefore, it is possible that the North American populations have genetically elevated thermal tolerance (McMahon et al. 1994). Studies by McMahon (1996) indicate that zebra mussels can become acclimated to various temperatures and those populations acclimated to cooler ambient conditions have lower thermal tolerances than those seasonally acclimated to warmer conditions.

Effect of Temperature on Growth

Temperature has significant impact on zebra mussel larval development and adult growth rates (McMahon 1996, Sprung 1987). Studies by Sprung (1987) indicated that zebra mussel larval development occurs between 12-24°C, with 17-18°C being optimal. Temperatures for maximum adults growth falls within 10-15°C for optimal tissue growth (Walz 1978). Generally, high feeding rates correspond to high growth rates, and studies have shown that: 1) feeding rates of zebra mussels declined by 73 percent as temperature rose from 20 to 32°C, and 2) above 28°C, zebra mussels were unable to match energy expenditure with concurrent food intake and were forced to rely on stored fuels (Aldridge et al. 1995).

Respiration and Metabolism

Zebra mussel oxygen (O_2) consumption rates have been found to be similar to those of freshwater unionid and sphaeriid bivalves (Alimov 1975), which suggests that these groups have similar metabolic maintenance demands and requirements (McMahon 1996). Zebra mussels within Lake Erie have shown partial respiratory temperature compensation, where oxygen consumption rates from 5 to 30°C were decreased in individuals acclimated to 25°C, compared to those individuals acclimated to 5°C and 15°C (McMahon 1996).

Responses to Hypoxia/Anoxia

Studies within Europe and North America indicate that zebra mussels are relatively intolerant of hypoxia or anoxia. When held in sealed chambers depleted of oxygen, zebra mussels experienced 100 percent mortality within 144 hours at 17-18°C, 96 hours at 20-21°C, and 72 hours at 23-24°C (Mikheev 1964). Woynarovich (1961) suggested that while zebra mussels can survive for a period of time at very low oxygen concentration, these environmental conditions may not be conducive for growth or successful reproduction. Karatayev et al. (1998) indicated that zebra mussels require at least 25 percent oxygen saturation. Stanczykowska (1977) proposed that poor anoxia/hypoxia tolerance and oxygen regulatory ability may restrict zebra mussels to well oxygenated habitats and may account for their poor colonization success in eutrophic lakes (Stanczykowska 1984). Mackie et al. (1989) stated that these physiological characteristics may also prevent zebra mussel populations from extending into hypoxic, hypolimnetic waters.

Salinity Tolerances

Zebra mussels are freshwater organisms that possess a limited ability to tolerate brackish conditions, and research indicates that North American zebra mussel populations will tolerate salinity up to 5 ppt for a short period of time (McMahon 1996). When acclimated to freshwater, Lake St. Clair zebra mussels have been induced to spawn at ≤ 3.5 ppt at 12-27°C, but successful fertilization required ≤ 1.75 ppt (Fong et al. 1996). Early zebra mussel embryonic development occurs in salinities < 6 ppt (Kennedy et al. 1995). Salinity at < 8 ppt was required for development of zebra mussel larvae to D-hinge veligers and < 6 ppt for successful pediveliger settlement (Wright et al. 1995). McMahon (1996) stated the zebra mussel development stages have the same or slightly lower maximum salinity limits as adults with salinities below ≈ 6 ppt required for successful spawning, fertilization, settlement, and transformation to juvenile and below $\approx 7 - 10$ ppt for successful adult colonization.

Desiccation and Freezing Resistance

Zebra mussels are relatively emersion intolerant, and studies by (McMahon et al. 1993) in Lake Erie indicated that emersion intolerance (computed as LT_{50} values) in zebra mussels decreased exponentially with increasing air temperature and decreasing relative humidity. McMahon (1993) reported that based on LT_{50} values, zebra mussel emersion tolerance times above 25°C were less than 100 hours regardless of relative humidity and increased to 100 to 400 hours at 5°C. These levels of emersion tolerance are far less than those recorded among other freshwater bivalve species, many of which tolerate emersion for many months (McMahon 1991). Thus poor desiccation tolerance may be the reason juvenile zebra mussels that settle < 1 meter (< 3.3 feet) translocate (migrate) into deeper waters (Mackie et al. 1989). Mackie et al. (1989) also proposed that juveniles settling in shallow waters may translocate or migrate to deeper waters to avoid emersion in freezing winter air. Within North America, adult zebra mussels appear to be highly intolerant of aerial freezing (Clarke 1993).

Calcium Concentration and pH Limits

With calcium being essential in the development of the bivalve shell, zebra mussels do not survive well when there is low calcium concentration in water. McMahon (1991) reported that zebra mussels are less tolerant of low calcium concentrations and low pH than other freshwater bivalves (McMahon 1991). In North American populations, zebra mussels inhabit waters ≥ 15

mg/l Ca^{2+}, with dense populations developing in waters with ≥ 21 mg/l Ca^{2+} (Mellina and Rasmussen 1994). Calcium concentrations of 15 mg/l or less were found to limit zebra mussel development (Mellina and Rasmussen 1994). Negative zebra mussel shell growth was reported at levels less than 8.5 mg/l by (Hincks and Mackie 1997). Ca^{2+} at ≤ 12 mg/liter is required for successful zebra mussel veligers rearing (Sprung 1987). Generally, zebra mussel populations are positively correlated with Ca^{2+} concentrations and negatively correlated with PO_4^{-3} and NO^{-3} concentrations (Ramcharan et al. 1992).

The amount of hydrogen ions in the water, i.e., pH, impacts the ability of zebra mussels to survive and reproduce in a water body. Claudi and Mackie (1993) found that minimum pH limits are 6.5 for adult zebra mussels, 7.4 for veligers, and > 8.0 for moderate to maximal adult growth. Sprung (1987) found that a pH of 7.4 - 9.4 is required for successful veliger development.

Reponses to Starvation

Zebra mussels feed primarily on planktonic algae and zooplankton, with bacteria, detritus, and organic matter being alternate food sources. The availability of food sources has been shown to control zebra mussel populations (Sprung and Rose 1988). In high-density populations, adult zebra mussels have been known to compete with plankton algae for limited food resources, thus reducing the survival of the planktonic veligers (Strayer et al. 1996). Under laboratory conditions, Schneider et al. (1998) suggested that food quality may be a better indicator of environmental conditions suitable for zebra mussel growth than food quantity. These results suggest that zebra mussels do not thrive in an abundant suspended inorganic sediment environment, which is indicative of large, turbid rivers (McMahon 1996).

Generally, zebra mussels have a high starvation tolerance. For adult zebra mussels, Chase and McMahon (1994) reported 50 percent mortality (LT_{50}) occurred after 118 days at 25°C and after 352 days at 15°C with no source of food. One hundred percent mortality (SM_{100}) occurred at 143 and 545 days at 25°C and 15°C, respectively. In laboratory experiments, Sprung (1989) reported that zebra mussel veligers experienced 100 percent mortality within 11-15 days at 12-24°C when there was no food available.

Effect of Water Velocity on Settlement, Attachment, and Feeding

The speed of water movement, or velocity, impacts the settlement, attachment and feeding habits in zebra mussels. Juveniles will settle in internal piping and along any submerged area with a flow rate of less than 1.5 meters per second (4.92 feet per second) (Claudi and Mackie 1994). Adult zebra mussels have also been known to avoid high-velocity flow locations and typically detach from such a poor settlement location and move (e.g., crawl via the foot or float by detaching the byssal threads) to a more suitable site (Claudi and Mackie 1994).

Ackerman (1999) has shown in laboratory studies that the ability of zebra mussels to clear plankton can be impacted by water velocity. Increasing ambient velocity up to approximately 10 cm per second led to increased clearance rates, whereas high velocity rates of 20 cm per second resulted in reduced clearance rates.

Impacts of Zebra Mussels

The introduction and subsequent expansion of zebra mussel distribution into the inland waters of North America (see **Figures IV-2 and 3**) has caused and has the potential to cause significant direct or indirect abiotic and biotic changes to the environment (MacIsaac 1996).

Impacts on Infrastructure and Water Users

Biofouling is perhaps the greatest abiotic effect of zebra mussels to economic infrastructure within lakes, reservoirs, streams, navigation channels, and locks (MacIsaac 1996). Permanent structures including pilings, bridges, docks, and temporary structures including buoys, navigational aids, and fishing nets have all been biofouled by zebra mussels (Martel 1993). Carlton (1993) reported that zebra mussel infestation and fouling has also had economic impacts to recreational and commercial watercraft. While impacts are widespread, Claudi and Mackie (1994) reported that observed zebra mussel impacts within the Great Lakes are generally limited to structures submerged below a depth of 3.9 feet (1.2 meters).

Water intake structures for municipal, industrial, and hydroelectric plants are highly vulnerable to zebra mussel biofouling (MacIsaac 1996). Kovalak et al. (1993) and Claudi and Mackie (1994) report that the following components have all been adversely impacted through zebra mussel biofouling: crib structures, trash bars, screen houses, steam condensers, heat exchangers, penstocks, service water systems, water level gauges, and pipelines. High densities approaching 750,000 individual zebra mussels per square meter have been observed in Lake Erie (Kovalak et al. 1993). However, the intensity of zebra mussel biofouling depends upon and varies with substrate type (MacIsaac 1996). Kilgor and Mackie (1993) reported that zebra mussel colonization could vary greater than four orders of magnitude on substrates varying from copper to stainless steel. **Table IV-3** lists the reported zebra mussel colonization on various substrates. In addition to the water intake and control structures previously discussed, many of the materials listed are commonly used in the construction of dams, retaining walls, piers, and pipelines (MacIsaac 1996, Kilgour and Mackie 1993, Lewandowski 1982, Walz 1975).

Table IV-3. Zebra Mussel Colonization on Various Substrates (1)

Settling Substrate	Number of Zebra Mussels	Reference
Copper	0	Kilgour and Mackie 1993
Galvanized Iron	548	
Aluminum	2,324	
PVC	7,471	
Teflon	8,593	
Pressure-Treated Wood	15,255	
Polypropylene	17,554	
Stainless Steel	21,812	
Characeae (Green Algae)	1,727	(Lewandowski 1982)
Stones	61	
Sand	13	
Mud	13	
Polyvinylchloride	24	Walz 1975 (2)
Polypropylene	18	
Polyolefine	17	

(1) Methodological differences among studies limit comparisons to substrates within studies.
(2) Based on exposure of colonization plates for 93 days.

Source: MacIsaac 1996.

Other Abiotic Effects

A prominent and important abiotic effect of zebra mussel invaded ecosystems is enhanced water clarity (MacIsaac 1996). This trend has been observed in European and North American waters where zebra mussel infestations have been high. Where zebra mussel populations are plentiful, water clarity (measured as Secchi disk transparency) has been shown to be inversely related to the concentration of suspended sediments, detritus, and plankton (Preisendorfer 1986). Several potential reasons for this phenomenon have been suggested. First, zebra mussels are present year-around and filtering aspects are much less ephemeral than those of zooplankton (MacIsaac et al. 1992). Second, zebra mussels are capable of achieving population biomasses far greater than herbivorous zooplankton (MacIsaac 1996). Third, unlike most zooplankton that consume only a narrow size spectrum of foods, usually between 2 – 25 μm (Sterner 1989), zebra mussels filter a much wider range of particles. Ten Winkel and Davids (1982) demonstrated that zebra mussels have a positive selection for particles between 15 – 40 μm, though particles as large as 750 μm were ingested. Zebra mussels also appear to be capable of ingesting finer particles than those consumed by most zooplankton. Sprung and Rose (1998) observed zebra mussels ingesting particles as small as 0.7 μm, though at a low efficiency. Silverman et al. (1996) has demonstrated that zebra mussels are capable of ingesting bacteria that are ~1 μm in size.

Zebra mussels select particles for ingestion on the basis of size and possibly taste (Morton 1971, Ten Winkel and Davids 1982, Sprung and Rose 1988). When feeding, suspended clays and silts that can become entrained in the inhalant current are sorted within the mussel. These non-edible particles are then enveloped in mucous and are expelled as pseudofeces via the inhalant siphon (Walz 1978, Ten Winkel and Davids 1982). Studies by MacIsaac and Rocha (1995) indicated that zebra mussels increase feces and pseudofeces production when exposed to suspensions containing 25 – 250 mg/l of clay particles. Griffiths (1993) that reported Secchi disk transparency in Lake St. Clair increased from a range of 0.5 to 1.5 meters (1.6 to 4.9 feet) prior to zebra mussel invasion to a range between 1.8 to 2.8 meters (5.9 to 9.2 feet) in 1990. Field observations generally support the view that biodeposition of feces and pseudofeces associated with zebra mussel filtering can improve water clarity (MacIsaac 1996).

Biotic Effects

European and North American freshwater ecosystems have experienced profound changes as a direct and indirect result of zebra mussel invasion (MacIsaac 1996). The following short discussions describe some of the observed ecological responses to the increased presence of zebra mussels.

Phytoplankton

As filter feeders that primarily consume phytoplankton, it is not surprising that zebra mussels have been implicated in the reduction of phytoplankton biomasses. Reeders et al. (1993) reported a 46 percent decline in phytoplankton biovolume in a pond with zebra mussels, relative to a reference pond lacking mussels. Chlorophyll-a concentrations in Lake Erie and Saginaw Bay declined by approximately 60 percent between 1988 and 1991 subsequent to the establishment of zebra mussels within the region (Leach 1993, Fahnenstiel et al. 1995). Within Lake Erie, the depletion of phytoplankton was noted to be most severe directly over zebra mussel beds (MacIsaac et al. 1992).

Cyanobacteria

The data on the effect of zebra mussels on cyanobacteria (blue-green algae) are mixed. However, Reeders et al. (1993) reported that blue-green blooms of *Anabaena*, *Oscillatoria*, and *Aphanizomenon* developed in a reference pond but not in other ponds that contained zebra mussels. In another study, Birger et al. (1978) found that zebra mussels do not feed well on other blue-green species, and when exposed to *Mycrocystis* at 10-25 grams per liter, zebra mussels experienced between 30 and 100 percent mortality. Heath et al. (1995) also observed a negative response in zebra mussel filtering during cyanobacteria blooms.

Zooplankton

Zooplankton populations appear to be adversely impacted either indirectly (i.e., phytoplankton food source is reduced due to presence of zebra mussels) or directly (i.e., rotifers and other small zooplankton are ingested by zebra mussels) (MacIsaac et al. 1991 and 1995). In Lake Erie, rotifer abundance declined by 74 percent between 1988 and 1993, which coincides with the period of time in which zebra mussels became established (Leach 1993). In other Lake Erie findings, MacIsaac and Rocha (1995) reported that total copepod abundance (mainly nauplii) declined between 39 and 69 percent between 1988 and 1993. Generally, it is difficult to differentiate between suppression of zooplankton resulting from direct ingestion by zebra mussels and that caused from food limitation (MacIsaac and Rocha 1995).

Planktivorous Fish

The suppression of small zooplankton may reduce the food availability for fish that are planktivorous at some developmental stage; however, the actual field results have not been conclusive. While yellow perch recruitment and commercial harvest in Lake Erie declined during the time when zebra mussels invaded the region, the success of other fish species in the region such as the white perch may have contributed to the reduced numbers of yellow perch (OMNR 1994). Walleye populations within the region have also been variable (OMNR 1994). While the invasion of the zebra mussel within Lake Erie is believed to have increased water clarity and light transmittance, this phenomenon is thought to have altered the walleye's habitat. ONMR (1995) has reported that the returns on walleye have been reduced to mixed, as this light-sensitive species has been encountered at increased depths within the region.

Molluscivorous Fish

The invasion and proliferation of zebra mussels has served as an alternate food supply for those fish that contain upper and lower pharyngeal teeth and chewing pads (French 1993). Within the Great Lakes region, fishes known or expected to consume zebra mussels include freshwater drum, redear sunfish, pumpkinseed, copper and river redhorse, and common carp (French 1993). Adult zebra mussels have been found in the digestive tracks of yellow perch, white perch, lake whitefish, lake sturgeon, and the round goby (French 1993).

Macrophytes

In turbid, light-limited environments, the presence of zebra mussels may benefit macrophytes. Mussel production may enhance water clarity by reducing suspended sediments, which can promote macrophyte growth (Lewandowski 1982).

Piscivorous Fish

Zebra mussels may have an indirect beneficial impact on piscivorous fish. The increased abundance of muskellunge, northern pike, and bass in Lake St. Clair may be related to the increased presence of macrophytes and enhanced water clarity, which have been linked to the zebra mussel infestations (Griffiths 1993).

Benthic Invertebrates

The invasion of zebra mussels may shift energy from planktonic to benthic foodwebs, and this transition may increase benthic invertebrate communities (MacIsaac 1996). Unionid mussels have been adversely impacted directly by the colonization of zebra mussels (Schloesser et al. 1996). Conversely, other invertebrates including annelids, gastropods, amphipods, and crayfish have directly benefited from the increased presence of feces and pseudofeces associated with zebra mussel production (Stewart and Haynes 1994). Within Lake Erie (Dermott et al. 1993) and Lake St. Clair (Griffiths 1993), these populations of benthic invertebrates have increased proportionately with zebra mussels.

Diving Waterfowl

Diving waterfowl have been known to prey on zebra mussels within North America. The following species have been observed feeding extensively on zebra mussels in Ontario and throughout the Lake Erie region: greater scaup, lesser scaup, common goldeneye, and the bufflehead (Wormington and Leach 1992, Hamilton et al. 1994).

Aquatic Nuisance Species (ANS)

Nonindigenous species (NIS), also called exotic, alien or nonnative species, are generally referred to as those plants and animals that are found beyond their natural geographical ranges (US Congress, OTA 1993). It is estimated that as many as 50,000 nonindigenous species (plants, animals, invertebrates, microbes, etc.) have been introduced into the United States (Pimentel et al. 2000). Not all nonindigenous species are harmful; some are beneficial including many food crops (US Congress OTA 1993, Pimentel et al. 2000). In more specific terms, an invasive species is one category of nonindigenous species that is defined as 1) non-native (or alien) to the ecosystem under consideration and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112 1999). Invasive species can cause direct harm to species and habitat by directly competing for resources and competitively interacting with native, indigenous species. Additionally, invasive species can result in indirect impacts to species and the general ecology of a system such as the Upper Mississippi River Basin (UMRB). In either case, the impacts are often irreversible and costly. In a 1993 study produced by the United States Congress, Office of Technology Assessment, it was estimated that 79 nonindigenous species had caused approximately $97 billion in damages from a period of 1906 to 1991. However, more current estimates indicate that some nonindigenous species in the United States may cause as much as $137 billion of damage per year (Pimentel et al. 2000).

Most plant and vertebrate introductions were intentional, compared to invertebrate and microbe introductions that are mainly unintentional (Pimentel et al. 2000). Although intentional, not all introductions were malicious attempts to directly alter ecosystems but rather attempts to biologically control or enhance environments. Despite the introduction intentions, some nonindigenous species are spreading at alarming rates and threaten ecologically significant areas such as the Upper Mississippi River Basin.

A sub-classification of invasive species are the Aquatic Nuisance Species (ANS) described as nonindigenous species that threaten the diversity or abundance of native species; the ecological stability of infested waters; or commercial, agricultural, aquacultural and recreational activities dependent on waters (ANS 2000). The threat of ANS has prompted action at local, state and federal levels. In 1990, The Nonindigenous Aquatic Nuisance Prevention and Control Act created a Task Force with three primary goals aimed at stopping or slowing the spread of ANS. Reauthorized in 1996, the primary goals of the Task Force have remained:

1) To prevent introduction and dispersal of aquatic nuisance species

2) To monitor, control and study such species

3) To educate and inform the general public and program stakeholders about the prevention and control of these species

Regional panels of the ANS Task Force help coordinate ANS efforts and identify priorities in their respective regions. The increase in concern and need for prevention and control of ANS is exhibited by the establishment of state ANS programs and efforts. Minnesota, Wisconsin, Iowa, Missouri and Illinois all have established and/or expanding ANS programs.

The introduction of ANS (including zebra mussels) has the potential to alter ecosystems and food webs (Pflieger 1997) and cause extinction of some species (Taylor et al. 1984). Similarly, it is estimated that 44 species native to the Untied States are threatened or endangered by nonindigenous species (Wilcove and Bean 1994 in Pimentel et al. 2000). While some nonindigenous fish species have been associated with positive economic benefits, the majority of nonindigenous, exotic fish species are associated with an estimated $1 billion per year economic loss (Pimentel et al. 2000). Concern about the spread of ANS, including zebra mussels has been expressed by state (MN DNR Exotic Species Program 2002) and regional entities (MICRA River Crossings) for several years. The zebra mussel is among the 40+ nonindigenous species that pose a threat to waters in the United States.

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Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

V. Review of Potential Control Methods

Section V

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V. REVIEW OF POTENTIAL CONTROL METHODS

There are various control methods that could potentially be utilized to limit the spread of zebra mussels (*Dreissena polymorpha*) from Ossawinnamakee Lake. This section describes a number of technological, biological and physiological zebra mussel control methods that have been documented in scientific journals, government and state reports, and some on manufacturer websites. For the purpose of this study, technological methods have been divided into acoustic, chemical, electrical and physical controls. Biological and physiological methods include manipulation of water quality characteristics, exposure to bacteria, predation, and inhibition or reduction of spawning. Zebra mussel control methods tend to focus on one or more of the following techniques: 1) Prevention of settlement in particular locations, 2) Prevention of attachment to substrate, and/or 3) Mortality. Since the goal of the project is targeted toward the limitation of veligers from Ossawinnamakee Lake, it is important to note that some treatments may not apply to the veliger stage of zebra mussels and the definition of the veliger stage must be clear. For the purpose of this section, zebra mussel life stages will be divided into only three categories that are defined in the following way:

1) Veligers – any zebra mussel in a planktonic stage that has no means of attachment.
2) Juveniles – any zebra mussel that is seeking a location to attach or has recently attached.
3) Adults – any zebra mussel that is attached to a substrate and above the age of one year.

Table V-1 summarizes each of the control methods that are discussed in this section. The table includes categories such as control techniques, targeted ages, efficiencies, environmental impacts, probable costs and estimated implementation times. It is important to note that some of the specifications listed in the table only apply to veligers and the text should be referenced for clarification. For instance, many of the technologies affect all life stages, but the higher doses or frequencies are typically required for adult treatment. For clarity, the doses, efficiencies, and contact times that apply to veliger treatment have been included in the table and other specifications have been included in the text.

*The cost opinions included in **Table V-1** are believed to be good faith approximations of probable costs associated with each alternative. It should be noted that actual costs could vary after a preliminary design level or more detailed implementation strategy is developed for a particular alternative. In addition, management options such as monitoring, research, education and outreach, regulatory coordination, etc. have not been included in estimation of probable cost for this report. Additional analysis of selected alternatives beyond the evaluation in this report will be required in order to more accurately narrow these cost ranges.*

Aside from specific control methods, this section describes management and monitoring procedures that may aid in controlling the potential spread of zebra mussels from Ossawinnamakee Lake. In addition, a brief overview of the current treatment method has been included at the end of the section as a reference.

Table V-1. Methods Available for Control of Zebra Mussels

Technology	Specific Method	Purpose	Target Age	Efficiency	Contact Time	Environmental/ Toxological Impacts	Comments/Disadvantages	Range of Capital Costs*	Implementation Time*
Biological	Bacterial Exposure	Mortality	All	> 95%	6 hrs	None reported	Few treatments are required; Difficult to produce large quantities	Low	6 to 8 months
	Predation	Reduce biomass	All	Low	Not applicable	None	Not effective in producing mortality	Low	4 to 6 months
	Spawning Inhibition	Limit Spread	Veligers	95-100%	2 to 4 hrs	Similar species may be affected	Only proven in laboratory setting	Low	8 to 12 months
Acoustic	Cavitation	Mortality	Veliger/Juvenile	NA	< 60 seconds	May affect resident fish	Effectiveness is reduced in high flows	High	12 to 18 months
	Sound Treatment	Limit Spread	Juveniles	90%	4 to 12 minutes	None reported	Does not produce mortality	High	12 to 18 months
	Vibration	Prevent Attachment Mortality	Veliger/Juvenile	100%	NA	None reported	Only applicable for locations with structures that can subjected to vibration	Moderate	8 to 12 months
Chemical Oxidants	Chlorine	Mortality	Various	100%	2 hrs	High toxicity	Not viable for open water system due to EPA regulations	Moderate	10 to 12 months
	Ozone	Mortality	All	100%	5 hrs	May affect nontarget species	Very difficult to maintain oxidant	Moderate	10 to 12 months
	Potassium Permanganate	Prevent Attachment Mortality	All	90-100%	48 hrs	High toxicity	Must have high continuous dosage for mussel mortality	Low	6 to 8 months
	Hydrogen Peroxide	Mortality	Veliger/Juvenile	100%	6 hrs	High mussel toxicity	High doses required	Low	6 to 8 months
Chemical Nonoxidants	Activated Starch	Mortality	Veligers	100%	0 to 72 hrs	None reported	Not proven in open water system	Low	6 to 8 months
	Aluminum Sulfate	Prevent Attachment Mortality	All	50-100%	24 hrs	Low toxicity	High concentrations are needed; High solids loadings result	Low	6 to 8 months
	Chloride Salts	Mortality	Veliger/Juvenile	95-100%	6 hrs	Low toxicity	Very high doses required	Low	6 to 8 months
	Copper Ions	Prevent Attachment Mortality	Veligers	100%	24 hrs	High toxicity	Causes skin irritation	Low	6 to 8 months
	Potassium Salts	Mortality	Adults	95-100%	48 hrs	High mussel toxicity	Irritating to humans	Low	6 to 8 months
	Organic Molluscicides	Prevent Attachment Mortality	Various	95-100%	48 hrs	Very high toxicity	Difficult to handle (corrosive)	Low	6 to 8 months
Electrical	Cathodic Protection System	Prevent Attachment	Adults	75%	Immediate	None reported	Not effective in producing mortality	High	12 to 18 months
	Plasma Spark System	Prevent Attachment Mortality	Juvenile	90-100%	Several weeks	May harm other species	Designed for pipes; Difficult to implement	Moderate	12 to 18 months
	Pulse Power Electric Field	Prevent Attachment Mortality	Juvenile	80-90%	seconds	May harm other species	High voltages required	High	12 to 18 months
	Electro-magnetism	Limit Spread Mortality	All	90%	5 to 15 days	None reported	Long exposure time required	High	12 to 18 months
Physical	Disposable Substrates	Limit Spread Mortality	All	NA	Immediate	None	May have limited efficiency	Moderate	8 to 12 months
	Permeable Barrier	Limit Spread	All	NA	Immediate	None	Navigational/ migrational restrictions	Moderate	12 to 15 months
	Mechanical Cleaning	Prevent Attachment Mortality	Juvenile/Adult	95%	Immediate	None	Must periodically repeat process	Low	Minimal
	Mechanical Filtration	Limit Spread Mortality	All	95%	Immediate	May impact other species	Navigational/ migrational restrictions; Designed for a confined area	High	12 to 18 months
	Light Sources	Limit Spread	Juvenile	0-50%	Several hours	None reported	Effectiveness is very limited	High	12 to 18 months
	UV Radiation	Limit Spread Mortality	All	100%	4 min. to 4 hrs	May harm other species	High intensities are required	High	12 to 18 months

NA = Not available/ undetermined

References = The information included in this table is cited in the text.

*These ranges have been selected based on opinions and interpretations of available data.
Cost Ranges: Low = < $499,000 Moderate = $500,000 to $999,000 High = > $1.0 million

Technological Controls

As outlined above, technological control methods include acoustic, chemical, electrical, and physical treatments. Acoustic control methods can be utilized at high frequencies to induce mortality, or at lower frequencies to prevent settlement and typically affect all life stages. Electrical control methods have a similar effect at high and low frequencies, although most of these methods are most effective in controlling juvenile and adult mussels. Most of the physical control methods are utilized to prevent all zebra mussel life stages from spreading to particular locations, and subsequently induce mortality. Chemical control methods are generally utilized to induce mortality, but there are several that only prevent substrate attachment. Each of these control method categories and specific alternatives are described in detail below.

Acoustic Deterrents

Cavitation, sound treatment, and vibration are three acoustic treatments that can be utilized to control zebra mussel populations. The impacts and effectiveness of these treatments are not fully proven, especially in high-flow areas, but they are fairly low maintenance technologies that have a low likelihood of harming nontargeted organisms. There is a possibility that resident fish may be affected by cavitation, but migratory fish should not be affected at short exposure times. In addition, acoustic control methods are environmentally friendly and do not have associated safety issues. Although acoustic technology is still under investigation, there is evidence suggesting that sound energy could be an attractive alternative to chemical or electrical treatment. In order to implement acoustic treatment options, site considerations are required for constructability and periodic maintenance access. In addition, electrical service is required for signal generation and amplification. **Figure V-1** demonstrates a conceptual view of a cavitation or sound treatment deterrent system.

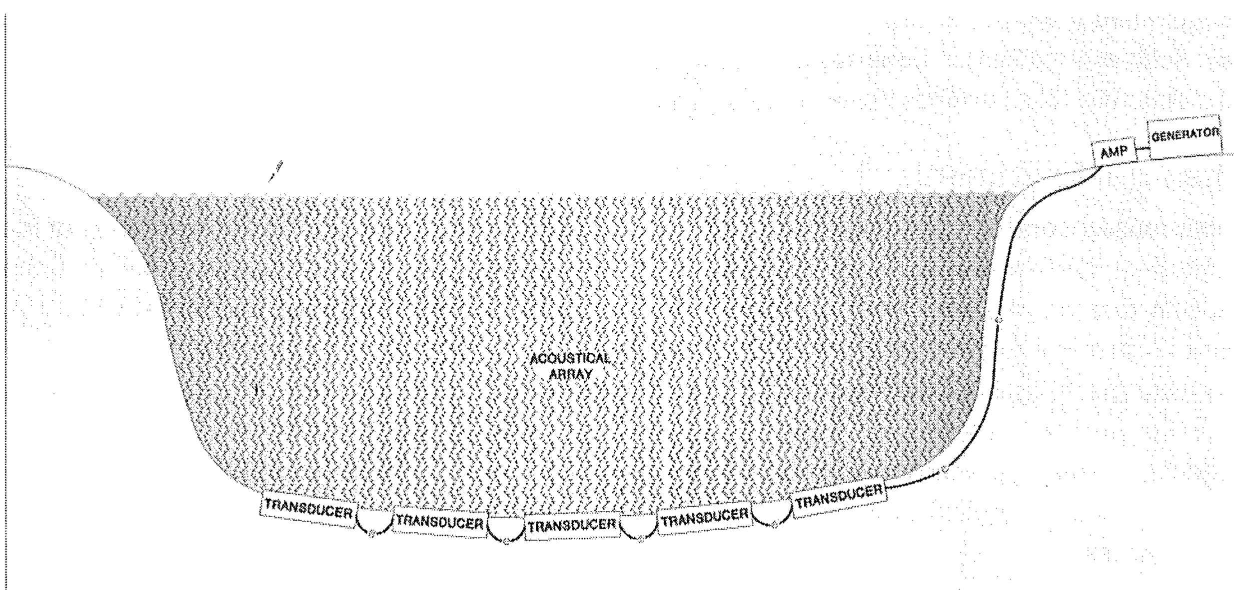

Figure V-1. General Schematic of an Acoustic Deterrent System

Cavitation

Cavitation is a form of acoustic energy that initiates the formation and collapse of microbubbles. The bubble formation occurs in the region of decreased density and pressure in an intense ultrasonic wave or high velocity turbulent water flow (Donskoy and Ludyanskiy 1995). At frequencies between 10 and 380 kHz, this type of energy has demonstrated mortalities of veliger, juvenile, and adult zebra mussels (Nalepa and Schloesser 1993). Exposure times are ranges of seconds for veligers, minutes for juveniles, and hours for adults.

Sound Treatment

Low frequency sound energy has demonstrated prevention of settlement by translocating zebra mussels and could be a valid option to reduce the spread of zebra mussels. Sound treatment utilizes water-borne acoustic energy in the form of sound waves (20 Hz to 20 kHz) or ultrasound waves (above 20 kHz) to disrupt the settlement of zebra mussels (Donskoy and Ludyanskiy 1995). This type of acoustic energy is effective against veligers at frequencies below 200 Hz by causing them to become stressed and immobilized, resulting in detachment and subsequent sinking in the water column. At frequencies between 39 and 41 kHz, ultrasound acoustic energy can fragment veligers within a few seconds and can also kill adults within 19 to 24 hours. Two reports prepared for the Empire State Electric Energy Research Corporation (ESEERCO) document that frequency of 20 kHz or 42 kHz fragment or dissolve veligers in under 30 seconds (Sonalysts and Aquatic Sciences 1991, Sonalysts 1993).

Vibration

Vibration refers to the use of solid-borne acoustic energy in mechanical structures. This type of treatment requires that the zebra mussels be settled on a structure that can be subjected to vibration, such as pipes or water intakes. Vibrational energy is effective in killing zebra mussel veligers and juveniles at just below 200 Hz and between approximately 10 and 100 kHz (Nalepa and Schloesser 1993). Long-term effects of vibration may include structural deterioration of infrastructure (e.g., bridges, water intakes, etc.).

Chemical Treatments

Zebra mussel control technologies are sometimes categorized as chemical or non-chemical in the literature. They are commonly categorized in this fashion due to the environmental or toxic impacts that are a factor with chemical additions, but not with other technologies. For this reason, chemical treatments are very feasible for public facilities that can control the amount of chemical discharge, but they remain less practical for open water systems. If there is a concern of environmental impacts or harm to aquatic life, non-chemical treatments are sometimes targeted. Although many researchers have developed non-chemical strategies for control of zebra mussels, chemical alternatives remain the most common treatment due to their proven effectiveness.

There are two main categories of chemical treatments: oxidants and nonoxidants. Oxidizing agents are very effective in controlling zebra mussel populations; however, many of them also target other aquatic species. Nonoxidizing agents are less harmful to aquatic species such as fish, but some of them are very toxic to native mussel species. Due to the high toxicity of chemical additions in general, it is important to survey all chemicals to determine which one will be the most effective and least harmful for each particular water system. **Table B-1** in **Appendix B** lists variations of the chemicals discussed in this section and their potential environmental impacts. In addition, various Material Safety Data Sheets (MSDS) have been included in **Appendix B.**

All chemical treatment options require site considerations for constructability, periodic maintenance access and supply/chemical storage. The issue of chemical storage is dependent on the frequency of treatments, which can range from continuous dosing to one dosing per year. If the chemicals are administered through a pumping station, electrical service will also required. Furthermore, since these treatment options involve introduction of chemicals into raw water, a discharge permit may be required.

Oxidants

Chlorine, bromine, hydrogen peroxide, ozone, and potassium permanganate are oxidants that facilitate zebra mussel mortality when administered properly (i.e., doses and contact times). These oxidizing agents are efficient; however, some of them target organisms other than zebra mussels. In addition, adult zebra mussels can detect the presence of oxidants and subsequently close their valves. Since the mussels are capable of remaining closed for up to two weeks, longer and more frequent treatment times may be necessary to induce mortality of adults.

Chlorine/Bromine

Chlorination is the most common method of treatment for zebra mussel infestation in public facilities, but it is not commonly used in treatment of open waters. This is partially due to high environmental impacts (i.e., generation of trihalomethanes), but mainly due to high toxicity toward other aquatic species. As a rule, dechlorination is required to neutralize any residual chlorine that may come into contact with aquatic life. Dechlorination is typically performed with sodium bisulfite and administered at concentrations of 1.8 to 2.0 mg/L (Sprecher and Getsinger 2000).

Chlorine variations include hypochlorites, sodium chlorite, chlorine dioxide, and chloramines. Direct chlorination via hypochlorite, sodium chlorite or chlorine gas targets adult zebra mussels at a concentration of 2.0 mg/L and results in a 90% mortality rate after several weeks. Periodic or continuous treatment is usually needed to eliminate adult mussels, although less frequent treatment will be effective against veligers. A lower concentration of 0.5 mg/L is effective toward veligers and results in 100% mortality after two hours (Sprecher and Getsinger 2000). As a reference, the maximum effluent concentration for discharge of chlorine is typically 0.2 mg/L and is only allowed for two hours per day. If this concentration of chlorine were utilized for zebra mussel control, low efficacy would result.

Chlorine dioxide targets veligers at a concentration of 0.5 mg/L and produces 100% mortality rates after a twenty-four hour period. Periodic treatments that last four days at a time can produce 70-100% mortality in adults at a concentration of 0.6 to 1.0 mg/L (Sprecher and Getsinger 2000). Chlorine dioxide offers advantages in terms of exposure time for adult mortality, but it is a stronger oxidant and produces higher human risks associated with handling.

Chloramine administration produces 100% veliger mortality after twenty-four hours at a concentration of 1.2 mg/L (Boelman et al. 1997). The adult exposure times and lethal concentrations have not been reported. If there is high nitrogen content in the water, administration of chlorine or hypochlorite will naturally produce chloramines.

Bromine produces effects similar to chlorine and is typically administered concurrently with chlorine treatment in order to reduce the environmental impacts of chlorine, as specified above. In the presence of chlorine, bromine concentrations between 0.1 to 0.5 mg/L for one to three weeks will produce 60% mortality of veligers. A 90-100% mortality of adult mussels can be achieved after approximately thirty days (Sprecher and Getsinger 2000).

Hydrogen Peroxide

Hydrogen peroxide is less common for zebra mussel control, possibly due to the relatively high dose needed for treatment. Although, it is toxic to veligers in a relatively short time and it is nontoxic to many fish. After six hours at a concentration of 100 mg/L, 100% veliger mortality was observed and 26% juvenile mortality was observed (Waller and Fisher 1998).

Ozone

Ozone is another oxidant that is toxic to zebra mussel veligers, juveniles, and adults at relatively low concentrations. A concentration of 0.5 mg/L has demonstrated 100% veliger mortality after five hours, and 100% adult mortality after seven to twelve days (Boelman et al. 1997). Disadvantages of ozone include its sometimes explosive nature and rapid dissipation in surface waters. Dissipation will decrease the amount of exposure time per dosing and essentially lead to higher costs to sustain the treatment. On the other hand, it is nontoxic to many aquatic organisms at low levels and demonstrates low environmental impacts, due to dissipation.

Potassium Permanganate

Potassium permanganate is effective in reducing or eliminating zebra mussels when administered at high doses for extended periods of time. Mortality rates have been observed at 90-100% for adults at dosing rates of 2.5 mg/L. Reports also suggest that dosing rates of 1.0 mg/L have been effective for preventing juvenile settlement, but direct toxicity has not been observed (Sprecher and Getsinger 2000).

Separately, the toxicity of this chemical has been examined for nontarget fish and unionids. Waller et al. (1993) determined that the concentration required to produce zebra mussel mortality within forty-eight hours (40 mg/L) would also produce fish mortality. As a result, potassium permanganate may only be advantageous in closed systems or other systems that can tolerate a continuous dose of potassium permanganate.

Nonoxidants

Activated starch, aluminum sulfate, chloride salts, potassium salts, copper ions, and organic molluscicides are examples of nonoxidizing agents that can be utilized to promote zebra mussel mortality. The major advantage of nonoxidizing agents over oxidizing agents is that adult zebra mussels cannot detect them.

Activated Starch

Barkley Distribution, LLC. has developed a starch product that they feel is very effective for zebra mussel control. The activated starch reagent has demonstrated 100% mortality of veliger and adult zebra mussels at concentrations between 3.0 and 6.9 mg/L (Smythe 2003). Mortality can be achieved immediately in some cases, but may take up to seventy-two hours in other cases. The large variation most likely results from differences in acute concentration and zebra mussel life stages. Barkley reports that the activated starch reagent has shown zero percent toxicity thus far and causes no known adverse environmental impacts. In fact, the reagent undergoes breakdown via bacterial oxygen demand within several hours. Although this reagent has been studied and proven in the laboratory and in closed-systems, the only open water system it has been applied to is an open water discharge area.

Aluminum Sulfate (Alum)

Alum is commonly used in the drinking water industry to remove suspended particles from the water. Researchers have determined that alum can also be utilized to remove zebra mussel veligers via toxicity and flocculation. Veligers suffer from 50% mortality rates at alum concentrations of 126 ppm for twenty-four hours (Boelman et al. 1997). This may be a valid method to prevent growth of zebra mussel populations; however, a relatively large concentration is needed to produce only 50% mortality. In addition, a large solids loading could be produced if TSS levels are high and phosphorus reduction could occur due to coagulation. If 100% mortality of veligers and adults is desired, other chemical additives are much more efficient.

Chloride Salts

Various chloride salts have been utilized to induce zebra mussel mortality and are safe for most fish species. These salts are advantageous because they are less harmful to the person handling the chemical and the exposure time needed to induce mortality is under twenty-four hours, unlike some of the other treatments. The major disadvantage is the high concentration needed for 100% mortality. Calcium chloride ($CaCl_2$) and sodium chloride ($NaCl$) produce 100% veliger and juvenile mortality after six hours at concentrations of 10,000 and 20,000 mg/L, respectively. With respect to native mussel species, $NaCl$ is less toxic than $CaCl_2$ (Waller and Fisher 1998).

Potassium Salts

Potassium concentrations of approximately 50 mg/L are effective in preventing the settlement of zebra mussels, but higher concentrations (between 88 and 288 mg/L) are necessary to produce mortality. At high concentrations, 100% mortality can be achieved in forty-eight hours. Unfortunately, many native mussels have potassium tolerance levels that are lower than that of zebra mussels (Sprecher and Getsinger 2000). Potassium salts are toxic to zebra mussels and other freshwater mussel species, but they are nontoxic to fish (Waller et al. 1993).

Copper Ions

Copper ions have shown distinct toxicity toward zebra mussels. One hundred percent veliger mortality can be achieved after twenty-four hours at 5 mg/L (Sprecher and Getsinger 2000). Separately, Waller and coworkers (1993) reported that copper sulfate levels between 5 and 40 mg/L were effective in adult zebra mussel control, but fish and other mussel species were more sensitive than zebra mussels at these high concentrations. There is also evidence that very low levels of copper ions can produce zebra mussel mortality if a constant residual level is maintained. Specifically in Ossawinnamakee Lake, cupric sulfate (as cutrine-ultra) has exhibited positive results at low concentrations; however, this chemical also affects nontarget organisms (Steevens et al. 2004). A further discussion of this treatment is presented at the end of **Section V**.

MacroTech, Inc, has developed a device that distributes copper and aluminum to water at a low concentration. The aluminum encourages copper ions to settle and cover surfaces, which consequently prevents zebra mussels from settling (Sprecher and Getsinger 2000). Furthermore, veligers are targeted by flocculation and direct toxicity. The ZM-Series devices developed by MacroTech, Inc. could alleviate disadvantages associated with the use of aluminum and copper alone due to the low concentrations needed when utilized together. This device would most likely be effective in small or closed systems.

Organic Molluscicides

Some organic molluscicides are chemicals that are commercially manufactured specifically for zebra mussel control. Many of these compounds are registered with the US EPA as effective control agents, but they are mostly utilized in closed systems or systems that have the ability to decontaminate the water before it encounters aquatic life (Sprecher and Getsinger 2000). These chemicals are very effective for zebra mussel control, but they are also toxic to many fish and other aquatic species. In addition, they can be corrosive and harmful to humans. As a result, they are not highly recommended for use in open water systems. Regardless of the system, an NPDES permit must be obtained prior to use due to their harmful impacts. Please refer to **Table B-1** for a list of these chemicals as well as lethal concentrations and exposure times.

Aside from commercially manufactured molluscicides, various organic compounds have been targeted for zebra mussel control. Cope et al. (1997) tested forty-seven chemicals to determine their ability to prevent the attachment of zebra mussels. Butylated hydroxyanisole (BHA), *tert-*

butylhydroquinone, and tannic acid were chosen for further testing after an analysis of chemical cost, solubility in water, anticipated treatment concentrations, and potential hazards to humans and the environment. *Tert*-butylhydroquinone was the only chemical that was nontoxic to fish species. At a concentration of 5.8 mg/L for forty-eight hours, 90% of zebra mussels were prevented from attaching to the substrate. *Tert*-butylhydroquinone must be administered continuously to control zebra mussel attachment. Approximately 90% of mussels tend to reattach within forty-eight hours after exposure to *tert*-butylhydroquinone (Cope et al. 1997). The major disadvantage of this chemical is its inability to produce zebra mussel mortality.

Electrical Deterrents

Electrical fields can be utilized to proactively or reactively control zebra mussel populations. The literature collectively documents that low-voltage electric fields are capable of preventing zebra mussel settlement, and high-voltage electric fields are capable of producing zebra mussel mortality (Smythe and Dardeau 1999). The rate of mortality resulting from high-voltage fields depends on the intensity of the voltage, the length of time it is applied, and the age of the mussel. Cathodic protection systems produce a continuous low-voltage electrical field that deters settlement of adult mussels. Plasma-pulse systems generate sonic waves, as a result of an electrical discharge, that induce high adult mortalities and reasonable veliger mortalities. Pulse-power systems generate an electric field through a series of electric pulses and generally target the zebra mussels in the settling stage. Low-frequency electromagnetism produces an electromagnetic field that leads to zebra mussel mortality by decreasing the amount of calcium available to the mussel for development.

Similar to the previous technologies, all electrical treatment options require site considerations for constructability, periodic maintenance access and supply storage. Also, electrical service is crucial for implementation of this control method. In addition, it is very important to post signs that alert the public of potential electric shock in the area of the electrical fields.

Cathodic Protection System

Cathodic protection systems control zebra mussel settlement by creating a continuous low-voltage electric field and they are not intended to induce mortality (Smythe and Miller 2003). Adult mussels are irritated by the low-voltage and tend to avoid settlement in the area of the electric field, but veligers and juveniles remain relatively unaffected. A study conducted by Fears and Mackie (1995) demonstrated that settlement of zebra mussels could be completely prevented with an 8-volt A-C current and partially prevented with a 6-volt A-C current (Fears and Mackie 1995).

Plasma Spark System

Sparktec Environmental, Inc. has developed plasma pulse technology that has proven to be efficient in controlling zebra mussels when implemented in pipes. The system works by releasing stored energy that subsequently causes an intensive shockwave, a steam bubble, and ultraviolet light (Mackie et al. 2000). Field and laboratory studies were conducted to determine the ability of the plasma sparker to limit biofilm biomass and composition, kill adult zebra mussels, detach settled mussels, and prevent settlement of new zebra mussels. Results from the study demonstrated that this technology could effectively prevent settlement of zebra mussels. The number of zebra mussels that settled in the control pipe was 10,000 times that of the pipe that was exposed to the electric energy. The electric field also affected the attachment and survival of adult mussels. After five weeks of plasma pulse pressure waves, approximately 20% mortality was observed when accounting for mortality observed in the control group. At this rate, 100% adult mortality would be achieved in just over nine weeks. Overall, the study proved that plasma-pulse technology is an efficient electrical method that can be utilized to control zebra mussels both proactively and reactively when utilized in intake pipes, but it would probably not have merit in an open water system (Mackie et al. 2000).

Pulse Power Electric Field

Pulse-power devices can be utilized to create an electric field that is confined between two electrodes. The electrical field must span the entire width of the area it is intended to protect. In comparison to the previous electrical methods, the pulse-power electric field is much stronger than a cathodic protection system, and covers a greater surface area than a plasma spark system. The electric field generated by the electrodes is essentially designed to stun or kill juvenile mussels. Very small veliger zebra mussels are typically not killed due to their tolerance of the amount of electric energy they come in contact with, whereas larger mussels with a larger biomass are killed because they contact a greater amount of electric energy as they pass through the electric field. Furthermore, pulse-power electric fields are sometimes utilized as graduated electric fields and would not apply to veligers because they have no free-swimming abilities.

Pulse-power electric field studies conducted by Smythe and coworkers in the mid-1990's have demonstrated that this technology can prevent zebra mussel settlement at an efficiency of 78-88% (Smythe and Miller 2003). The literature also suggests that this type of system can be adjusted in order to establish a system that would routinely control zebra mussel settlement at an efficiency of 80-90% (Smythe and Miller 2003). Studies conducted in the late 1990's showed that mussel settlement downstream of the electrical test device was reduced at an efficiency of approximately 40-90%, but there is speculation that variable results were obtained due to equipment malfunction and low mussel densities.

Although this technology is designed to target juvenile zebra mussels, a study conducted in 2000 demonstrated that veligers are also affected by the pulse-power electric fields. The mortality rates for umbonal stage veligers consistently ranged from 21-40% with a mean of 31%. The low mortality rate is likely due to the small size of the mussel, which decreases the electrical exposure. It is important to note that this study was only conducted to determine the consistency of zebra mussel control utilizing an electric field. The study utilized a Megapulse electrical system and results confirmed that a pulse-power electric field would effectively prevent long-term zebra mussel settlement and macrofouling (Smythe and Miller 2003).

Low-Frequency Electromagnetism

Low-frequency electromagnetism has demonstrated zebra mussel mortality at frequencies under 300 Hz (Ryan 1998). Zebra mussels utilize calcium for growth, shell development, reproduction, and regulation of metabolic functions. This technology increases the solubility of calcium carbonate and consequently affects survival of zebra mussels by removing calcium from the water column and removing calcium from zebra mussel shells and tissues (Ryan 1998). Low-frequency electromagnetism has obvious affects on zebra mussels; however, there are limited reports that describe these effects. Current reports suggest that zebra mussel mortality only occurs after exposure to calcium deficient waters for five to fifteen days. This treatment may eventually demonstrate utility in a variety of systems, but it would ultimately be most efficient in a closed system.

Physical Treatments

Physical treatments are typically effective methods for prevention of zebra mussels in particular areas. In addition, many of these methods indirectly cause mortality. All physical treatment options require site considerations for constructability, periodic maintenance access and possibly supply storage. Electrical service is also required for all options except possibly disposable substrates and mechanical cleaning. Some of these options (mechanical filtration backwash, mechanical cleaning, etc.) also require solids handling to some extent, which could require a permit.

Disposable Substrates

Disposable substrates can be utilized to limit the spread of zebra mussels but apply only to juvenile and adult translocating mussels (Miller and Wells 1993). These substrates are constructed of materials that encourage zebra mussel settlement. The substrate is immersed in the problematic area to attract zebra mussel populations and then removed and disposed of after a designated time period has passed. Disposable substrates are typically placed in the infested area for approximately one year before being removed. These substrates offer advantages such as low maintenance and easy implementation, but they may not be as effective as other methods.

Permeable Barrier

A permeable geotextile barrier with a small mesh size (e.g., $<50\ \mu m$) could extend from the floor to the surface of the water column in order to prevent passage of zebra mussels (**Figure V-2**). Gunderboom, Inc. manufactures fabrics that are utilized as exclusion systems in marine settings and may be efficient in controlling the spread of zebra mussel veligers. A potential downside to this treatment option is that migration of non-target species and some recreational activities may be impacted, but efficiencies of limiting veligers are very high.

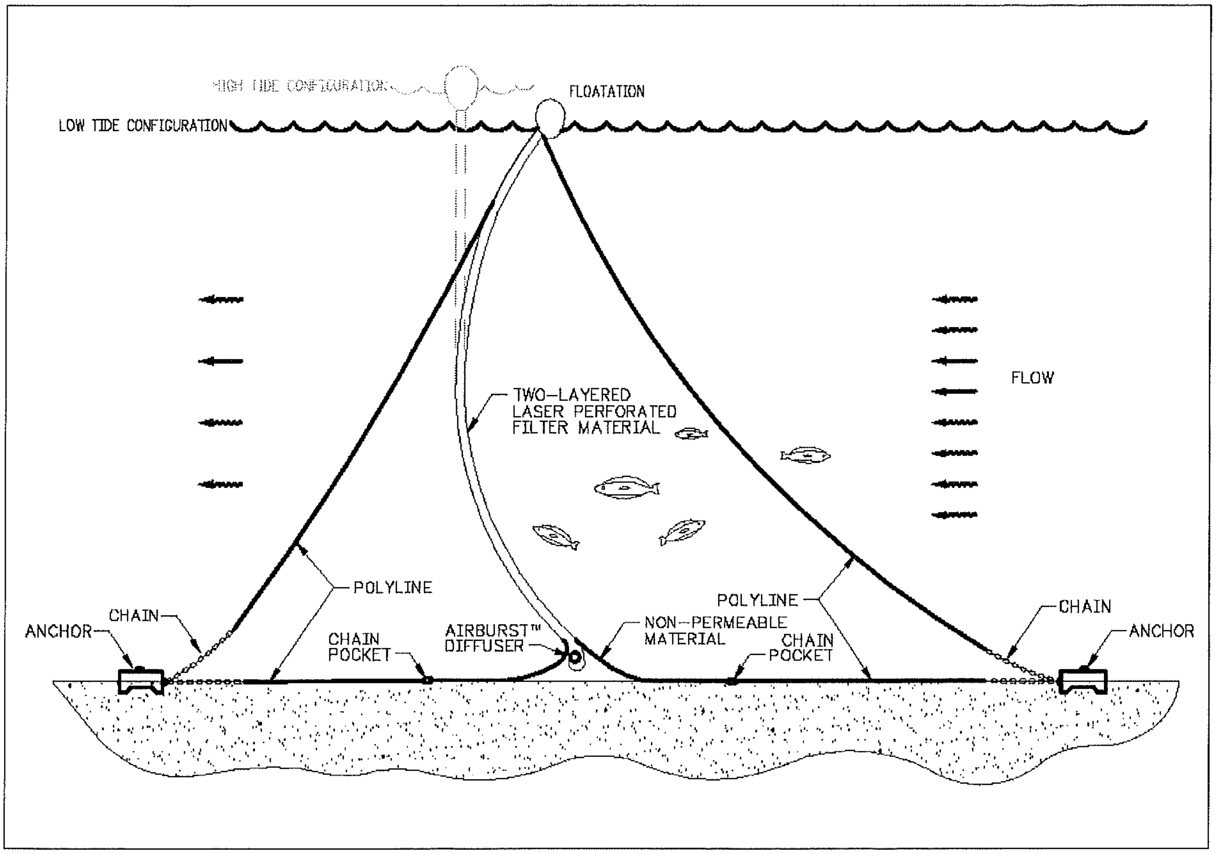

Figure V-2. Conceptual View of Permeable Barrier

Courtesy of Gunderboom, Inc.

Mechanical Cleaning

Adult zebra mussel populations can become large and dense; they thrive by attaching to hard surfaces with byssal threads. If the population is easily accessible, juvenile and adult mussels can be removed from large hard surfaces via scraping, carbon dioxide pellet blasting, and other variations of high pressure cleaning. Although this method is effective for removal of mussels from accessible infested substrates, cleaning must be periodically repeated in order to keep the zebra mussels removed. In addition, zebra mussel veligers are not targeted with this method and small mussels may avoid removal if they are located in crevices.

Mechanical Filtration

Zebra mussels in all developmental stages can be contained with filtration systems. Screens with small mesh sizes (40 µm) or filters with granular media are both efficient for containing zebra mussel veligers (Boelman et al. 1997). Common granular media include sand, anthracite coal, activated carbon, resin beads, and garnet. Since the filters collect a large amount of suspended solids in addition to 100% of zebra mussel veligers, they typically require periodic back washing.

The disadvantage of this control method is the difficulty associated with implementation in an open or high-flow water system. On the other hand, this method is very effective in preventing the spread of zebra mussel veligers and offers a nontoxic, environmentally friendly alternative to other treatment methods that can be harmful to humans and aquatic species.

Light Sources

There are several reports that suggest zebra mussels prefer to settle in dark places or within shadows. In general, studies show that adult mussels are more likely to reside in shadowed areas and tend to settle on substrates more often in the dark. Some studies have demonstrated that large mussels prefer darkness, and small mussels do not show significant preferences to light or dark environments (Kobak 2001). Other studies have demonstrated that small mussels not only preferred dark/dim places, but their growth rates are accelerated as well. It is important to note that the dark areas of this system were also the low-flow areas, which could also be the reason that mussels preferred the dark areas (Zhang et al. 1998). Strobe lights were utilized in laboratory and field settings to determine the direct effects of light on zebra mussel movement and settlement. The results showed that the mussels regularly move away from light in laboratory experiments, but when applied in the field there was no affect (Coons et al. 2004).

It appears that zebra mussels prefer to settle in dark places, but there are inconsistent results when direct correlations are examined. There are a number of other factors that also affect the settlement and movement of zebra mussels, such as substrate color, flow, and depth. As a result, there is a lack of conclusive evidence that supports the use of light sources as a method to control zebra mussel settlement.

UV Radiation

UV radiation is typically an effective method for controlling zebra mussels in all life stages, although veligers are more sensitive than adults. Complete veliger mortality can be obtained within four hours of exposure to UV-B radiation, and adult mortalities can also be obtained if constant radiation is applied (Boelman et al. 1997). On the down side, UV-B radiation is observed at wavelengths between 2800 and 3200 Å and is sometimes harmful to resident aquatic species. Furthermore, the effectiveness of UV radiation may be decreased by turbidity and high suspended solid loads.

Separately, Wright and coworkers examined the efficiency of UV radiation as a method for zebra mussel control. Using an 1800W medium pressure mercury lamp, veligers were exposed to UV radiation for up to four minutes and results showed that 100% mortality was reached within 24 hours after exposure (Wright 1995). It is important to note that their experiments were conducted using quagga mussels, but UV radiation should have very similar effects on zebra mussel populations.

Biological and Physiological Methods

Zebra mussels are sensitive to a number of environmental factors that can be manipulated to induce mortality of various life stages. Aerial exposure, calcium deficiency, acute or chronic heat exposure, oxygen deprivation, parasitism, predation, and starvation are all natural control methods that could potentially reduce the size of zebra mussel populations. There is potential for increasing the salinity or decreasing the calcium concentration of the infested environment without major environmental impacts, but parameters such as dissolved oxygen, pH, and temperature are difficult to manipulate at levels that would affect zebra mussels. In addition, most of these factors cannot be manipulated in an open water system without serious repercussions. Since these biological and physiological control methods have been discussed in the previous section, they will not be discussed in great detail here. Please refer to **Table IV-2** (Resistance Adaptation of Zebra Mussels to Physio-Chemical Parameters) in **Section IV** for an overview of these tolerances. Bacterial exposure and inhibition of spawning are additional biological treatments that could potentially be implemented in an open water system. These biological control methods are well documented, but they have not been widely implemented.

Bacterial Exposure

Research findings by Molloy (1998) have shown that a natural bacterial toxin found in the CL0145A strain of *Pseudomonas fluorescens* is lethal to zebra mussels by destroying the mussel's digestive tract (Molloy 2001). Molloy also found that alive and dead bacterial cells were equally effective against the zebra mussel, suggesting that the biotoxin is likely found in the cell walls of the bacterium. Unlike some biocides and other chemical treatment methods, the ingestion of CL0145A did not elicit an immediate adverse response in zebra mussels (i.e., closing off siphons to adverse conditions). Therefore, it is likely that fewer and shorter treatments would likely be required with CL0145A. All zebra mussel sizes (1 to 25 mm shell length) appeared to be equally susceptible to CL0145A, and unlike other treatment technologies, there are no known adverse effects of CL0145A to non-target species such as ciliates, other bivalves, or fish. Case studies at power plants conducted by Molloy indicated that kill rates of >95% were accomplished at a concentration of 100 ppm of dry bacterial mass per unit volume for duration of 6 hours (Molloy 2002).

Spawning Inhibition

Zebra mussel spawning can be inhibited with various chemicals that target serotonin reuptake. Selective serotonin reuptake inhibitors can be blocked by receptor antagonists, such as cyproheptadine and mianserin (Fong et al. 2003). Fong and coworkers (2003) have shown that low concentrations of these inhibitors can be utilized to block both spawning and parturition in males and females. Other antagonists such as tricyclic antidepressants have been studied in relation to zebra mussel spawning. Hardege and coworkers found that imipramine and desipramine can inhibit male spawning and clomipramine can inhibit both male and female spawning (Hardege et al. 1997).

Overview of Current Ossawinnamakee Lake Treatment Process

The current treatment information outlined below represents a summary of information provided by MN DNR that is included in **Appendix C**.

Chemical Treatments Using Copper Sulfate

Based on the findings of field sampling and the threat of zebra mussel dispersal, Minnesota Department of Natural Resources (MN DNR) contracted a private aquatic pesticide applicator to administer copper sulfate packaged as Cutrine Ultra to approximately 26-acres of Ossawinnamakee Lake's Muskie Bay on a weekly basis from mid-June through September 2004. The treatments were intended to address the threat of downstream veliger transport from Ossawinnamakee Lake to Pelican Brook. Application rates were reported at 0.6 mg/l (ppm) of Cutrine Ultra, with 400-gallons applied per treatment via subsurface injection. Following the chemical treatments, the MN DNR monitored residual copper levels, zebra mussel veliger densities, and the benthic invertebrate communities in Pelican Brook (Montz et al. 2004).

Efficacy

Following the copper sulfate treatments, MN DNR collected samples and found veliger densities in the bay and brook to be low or at undetectable levels (often less than 0.1 per liter). MN DNR concluded that the copper treatments were successful in reducing veligers in Muskie Bay, thus reducing downstream transport of zebra mussel larval stages (Montz et al. 2004). In a separate study, the U.S. Army Corps of Engineers (USCOE) Research and Development Center determined that administered concentrations at 0.6 ppm within Ossawinnamakee Lake was 10x greater than the suggested LC_{100} for zebra mussel veligers (Steevens et al. 2004).

Environmental Impacts

MN DNR also sampled various sites within Pelican Brook for aquatic invertebrates prior to and after the copper sulfate treatments. Pre-treatment samples were collected in May 2004 and post-treatment samples were collected in September 2004 to help determine what impact the treatments had on the benthic invertebrate communities. In general, the MN DNR observed post-treatment declines for the following benthic invertebrate populations within Pelican Brook: Ephemeroptera (mayflies), Trichoptera (caddisflies), and Amphipoda (crustaceans). Additionally, populations of mayflies, stoneflies, and crayfish were not found in the post-treatment samples (Montz et al. 2004).

Management and Monitoring

There are various management and monitoring procedures that can aid in reducing the risk of zebra mussel dispersal from Ossawinnamakee Lake into the Mississippi River. A summary of the following management alternatives is included in **Table V-2**: prevention through education and public outreach, detection and monitoring, rapid response alternatives, tolerance of ANS, and the implementation of control methods. While this section lists general management and monitoring procedures, specific objectives that relate to management of the current lake population are recommended in **Section VI**.

Table V-2. Summary of Potential Management Alternatives

Type of Management Alternative	Impletmentation and/or Maintenance Issues
Prevention through Education and Public Outreach	It is important to educate the public and recreational users about the impacts of zebra mussels and guidelines that can be followed to aid in prevention of spreading.
Detection and Monitoring	Proper equipment and training must be provided for appropriate personnel to facilitate early detection and regular monitoring procedures.
Rapid Response Alternatives	A coordinated rapid response plan must be developed that can aid management personnel in the event of detection or establishment of zebra mussels.
Tolerance of ANS	Management plans must address the systems tolerance of zebra mussels in order to determine if prevention or elimination procedures are required.
Implementation of Control Methods	Specific technological, physiological, or biological control methods can be implemented to control the spread of zebra mussels.

Prevention through Education and Public Outreach

It is important to promote public awareness and understanding of zebra mussels and their potential impacts to the ecological and economic health of Ossawinnamakee Lake, Pelican Brook, Pine Brook, and the Upper Mississippi River. Outreach programs that promote commercial and recreational practices to prevent the spread of zebra mussels are also important. These practices include the proper disposal of live bait, inspection of any boats or other equipment that is placed in infested waters, and proper cleaning procedures for removal of zebra mussels. In addition, frequent boaters should be educated on anti-fouling paints and coatings that can be utilized to prevent zebra mussel attachment.

The ANS Task Force public awareness campaign in an effort to control recreational spread of aquatic nuisance species has initiated the program entitled "Stop Aquatic Hitchhikers." This program encourages recreational users to not only identify ANS present in their surroundings, but also follow a short list of guidelines every time they leave a lake, stream or coastal area. **Figure V-3** gives a short description of these guidelines.

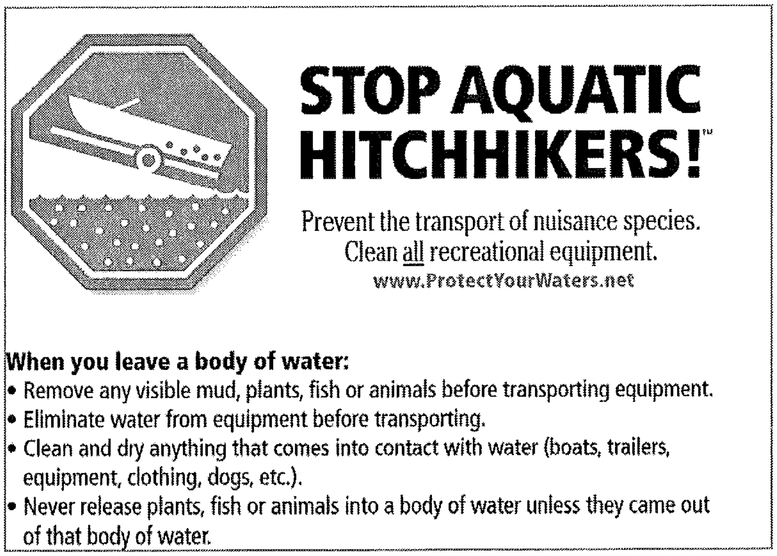

Figure V-3. Stop Aquatic Invaders Graphic
(courtesy of www. protectyourwaters.net)

The ***Model Rapid Response Plan for Great Lakes Aquatic Invasions*** (Draft: July 17, 2003) represents the development of a model rapid response plan for Great Lakes aquatic invasions. The goal of this project was to develop a model rapid response plan as part of an overall regional effort to enhance ability to anticipate, prevent and respond to new aquatic invasions of non-indigenous species in the Great Lakes-St. Lawrence region and could be modified and adapted for limiting the movement of zebra mussels into the Upper Mississippi River System.

Integral to rapid response planning is a communication and organizational structure that determines how to disseminate information, as well as authority and leadership roles, coordination, cooperation and partnerships. Legislative authority and policy also need to be taken into consideration under this component. A clearly defined communication structure will facilitate timely information exchange among the appropriate entities in the rapid response network. If a rapid response is deemed appropriate, information needs to be communicated to appropriate stakeholders to engage them in the process. Other states, provinces, agencies, the media and the public need to be made aware of the situation and associated activities as appropriate.

Detection and Monitoring

Early detection and monitoring efforts are critical to the discovery of new introductions of zebra mussels and in accurately tracking the spread of existing invasions. Detection of this non-indigenous aquatic species is essential because zebra mussels have rapid dispersal and growth rates that could inhibit control strategies if not implemented promptly. Monitoring can be utilized to determine the specifications for developing control methods, such as frequency and urgency of necessary treatments. Efforts related to early detection and monitoring may include such activities as identifying at-risk sites; routinely monitoring certain areas (LTRMP-Long Term Resource Monitoring Program may need to be supplemented with additional monitoring sites); prevention and containment efforts; surveillance, detection and reporting activities including data collection and management; the collection, identification and storage of voucher specimens; and training volunteers and professionals in detection, identification and removal techniques.

Rapid Response Alternatives

In order to carry out the rapid response process, a compilation of management options that can be utilized in response to a zebra mussel invasion is necessary. In addition to mechanical/physical, biological and chemical responses, the process should provide direction on how to obtain pre-approval and permitting for control measures, quarantine establishment and enforcement, and an assessment of specific control measures and management tools for high priority species. Several of the most common control measures that are applicable to zebra mussels should be pre-approved for specific situations. Management tools should be assessed based on the species, location and extent of the infestation. Some of the tools for response include control methods discussed earlier in Section V.

Implementation efforts need to be highly coordinated to limit redundancy and to ensure that the appropriate stakeholders are involved and informed of actions. It is particularly important that this coordination and planning is incorporated into the state and federal ANS management plans. Because authority and leadership roles are critical to the implementation of a rapid response, the communication and organizational structure described above should be well developed on a state and federal level. Implementation of a response to zebra mussels would most likely be conducted by the agency with the authority to respond or the agency with jurisdictional responsibility/rights over the infested area. Securing and appropriating adequate funding for the implementation of a rapid response may be the largest potential obstacle to overcome.

An adaptive management scheme is crucially important to the implementation of a rapid response. Ideally, adaptive management will include an evaluation of plan effectiveness, mitigation and/or restoration of treatment areas, an assessment of re-introduction risks, and post-procedure monitoring. Additionally, education and outreach efforts should continue during the adaptive management phase of the rapid response plan. The evaluation of the chosen management option should determine if the desired outcomes have occurred and whether or not the goals and objectives set during the initial phases of plan implementation were met. If the preferred management option is not producing the desired outcomes and meeting goals, there needs to be a mechanism in place to make the decision quickly to move to another option. The adaptive *Model Rapid Response Plan for Great Lakes Aquatic Invasions* (Draft: July 17, 2003) management phase of the plan allows for the assessment of what strategies worked and those that did not.

Tolerance of Aquatic Nuisance Species

There is a wide range of systems that may become infested with zebra mussels and some systems can temporarily tolerate macrofouling, while others cannot. A management plan must address the extent of control necessary to provide an adequate tolerance level. In other words, the goal of the control method must be categorized as prevention or elimination of zebra mussels. If the infested system can tolerate minor zebra mussel populations, or if the goal is to prevent the spread of zebra mussels into a certain area, control methods that do not result in mortality can be implemented. Many of the control methods target particular life stages of zebra mussels. Once the tolerated zebra mussel population has been established, particular life stages can be targeted depending on the focus of the control method (i.e., prevention or elimination).

Implementation of Control Methods

Technological, physiological, and biological control methods have been discussed previously. These methods can be utilized to control zebra mussel populations via limitation or eradication, but should be evaluated closely in order to determine a control method that will cause the least harm and environmental impact.

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Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VI. Alternative Analysis and Recommendations

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Section VI

VI. ALTERNATIVES ANALYSIS AND RECOMMENDATIONS

Field sampling conducted by MN DNR has confirmed adult zebra mussels within Ossawinnamakee Lake and the upper portion of Pelican Brook, near the lake outlet structure. While zebra mussels have not been encountered in other downstream areas of Pelican Brook, it is possible that downstream dispersal could occur. Thus zebra mussels could eventually enter the Pine River and disperse into the upper waters of the Mississippi River. Based on this possible migration and the known life history and behavior of the zebra mussel, the project team determined that treatment alternatives should address the growing size of the zebra mussel population in the lake, and movement of zebra mussel larval stages in both the lake and brook.

This section ultimately provides an analysis of the treatment alternatives previously described in **Section V**. Alternatives have been grouped into five categories, ranging from biological control to physical control, and analyzed collectively. A numerical rating system that includes items such as efficiency of the alternative, cost implications, constructability and impacts to native species was utilized to evaluate each alternative. Furthermore, the feasibility of treatment alternatives is discussed relative to location in Ossawinnamakee Lake and Pelican Brook. The section concludes with a list of objectives that could be utilized to limit the spread of zebra mussels from the infested area.

Analysis of Potential Treatment Methods

As previously mentioned, the treatment alternatives discussed in **Section V** and listed in **Table V-I** were individually analyzed and scored with a numerical ranking system. In addition, several combinations of alternatives were evaluated. **Table VI-1** contains the results from the analysis. Three major evaluation criteria including effectiveness, economics, and environmental impacts were used to make general inferences as to whether a particular treatment alternative could be applied and capable of achieving the overall project objective. The scoring system utilized numerals 1 through 6 to evaluate the overall effectiveness of each alternative, with "1" designating the highest effectiveness and "6" designating poor effectiveness due to low efficiency or high feasibility concerns. For simplicity, the remaining categories were rated as a 1, 2, or 3 with "1" being the best and "3" being the worst. The categories utilized to evaluate treatment alternatives are outlined below.

Effectiveness

Reported Efficiency - Theoretical treatment effectiveness as suggested by case, field, and laboratory studies. Additionally, any efficiency claims made by product manufacturers were considered.

Site Application/Implementation - Predicted treatment effectiveness and feasibility as suggested by site-specific characteristics or limitations (e.g., implementation, contact time, flow rates, and potential design requirements).

Overall Effectiveness - Objective rating based on a combination of reported efficiency and site application. This category is weighted differently than the other categories in order to emphasize its importance in relation to the other categories.

Economics

This study demonstrates the relative difference in cost between alternatives; however, very broad ranges were given because the exact location of the potential treatment alternative will need to be confirmed in schematic level design. The actual costs may require adjustment depending criteria and site specific information outlined during the design phases.

Capital Costs - Opinions of capital costs required for construction and/or implementation of treatment alternatives.

Operation & Maintenance Costs - Manpower hours, utility costs, repair and consumable material costs. This value is highest for chemical applications due to the cost of the chemical.

Environmental Impacts

Recreational Impacts & Public Perception - The probability that treatment alternatives would alter or impact activities such as swimming, fishing, and boating, and subsequent public perception or willingness to accept the potential outcomes of the treatment alternatives.

Impacts to Non-Target Species - Potential environmental impacts and toxicological impacts to other species (e.g., plants, benthic invertebrates, and fish).

Other

Permitting Issues - Probability that treatment alternatives will require local, state, or federal permits including, but not limited to, construction, NDPES, 401 Water Quality, and 404 permits.

Study Rating - Overall rating of each treatment alternative relative to its application in Ossawinnamakee Lake or Pelican Brook. This numerical value is meant to provide an *estimated* ranking for each treatment. The study rating is weighted so that effectiveness is the highest priority and can be qualitatively utilized to determine which technologies would most likely be highly effective, economically feasible, and environmentally friendly.

Table VI-1. Prioritization Matrix for Treatment Alternatives

Technology	Treatment Alternative	Effectiveness: Reported Efficiency	Effectiveness: Site Application/ Implementation	Effectiveness: Overall Effectiveness	Economics: Capital Costs	Economics: Operation & Maintenence Costs	Environmental Impacts: Recreational Impacts & Public Perception	Environmental Impacts: Impacts to Non-Target Species	Permit Issues (Y or N)	Study Rating
Biological	Bacterial Exposure	1	3	4	1	3	1	1	Y	14
	Predation	3	3	6	1	1	1	1	N	16
	Spawning Inhibition	1	3	4	1	2	1	1	Y	13
Acoustic	Cavitation	2	2	2	3	1	1	2	N	13
	Sound Treatment	2	2	2	3	1	1	1	N	12
	Vibration	1	3	6	2	1	1	1	N	15
Chemical Oxidants	Chlorine and Bromine	1	3	4	2	2	3	3	Y	18
	Ozone	1	1	1	2	2	1	1	Y	9
	Potassium Permanganate	2	3	5	1	2	1	3	Y	17
	Hydrogen Peroxide	1	2	2	1	2	1	3	Y	12
Chemical Nonoxidants	Activated Starch	1	2	2	1	2	1	1	Y	10
	Aluminum Sulfate	3	3	6	1	2	1	1	Y	17
	Chloride Salts	1	3	4	1	3	1	1	Y	14
	Copper Ions	1	1	1	1	3	1	3	Y	11
	Potassium Salts	1	1	1	1	1	1	3	Y	9
	Organic Molluscicides	1	3	4	1	2	2	3	Y	16
Electrical	Cathodic Protection System	3	3	6	3	1	2	2	N	20
	Plasma Spark System	2	3	6	2	1	2	1	N	17
	Pulse Power Electric Field	2	2	4	3	1	3	2	N	17
	Electro-magnetism	2	3	5	3	1	2	1	N	17
Physical	Disposable Substrates	3	3	6	2	2	1	1	N	18
	Permeable Barrier	1	1	1	2	1	1	1	Y	8
	Mechanical Cleaning	1	3	4	1	1	1	1	N	12
	Mechanical Filtration	1	3	4	3	2	1	2	N	16
	Light Sources	3	3	6	3	1	1	2	N	19
	UV Radiation	1	2	3	3	1	3	2	Y	15
Combined Treatments	Ozone and Permeable Barrier	1	1	1	3	3	1	1	Y	11
	Ozone and Sound Treatment	1	1	1	3	3	1	1	Y	11
	Activated Starch and Sound Treatment	1	1	1	3	2	1	1	Y	10
	Activated Starch and Permeable Barrier	1	1	1	3	2	1	1	Y	10

Rating Criteria
Reported Efficiency: 1 = 95-100%; 2 = 80-95%; 3 = <80%
Overall Effectiveness: 1 = High Efficiency; 2 - 5 = Moderate Efficiency; 6 = Low Efficiency
All other Criteria: 1 = Low (Best); 2 = Moderate; 3 = High (Worst)

These rankings are based on opinions and interpretations of available data and should only be utilized as approximations that represent actual situations.

Table VI-1 and the following text demonstrate that there are many advantages and disadvantages to each treatment alternative. The table first and foremost provides a list of treatment alternatives that is rated according to the *overall effectiveness* of the treatment at the specific site under consideration. Secondly, the table incorporates key factors, such as costs and environmental impacts, that may be critical in determining which treatment alternative is most advantageous for this project. The study rating in the last column of the table is a numerical summation of the effectiveness and the other key factors that were considered when each alternative was evaluated. **Table VI-1** shows that biological, electrical, and some physical technologies have attractive characteristics, but they have low overall effectiveness in relation to preventing dispersal of zebra mussel veligers from Ossawinnamakee Lake. For this reason, they have the worst study ratings. In relation to the table, treatment alternatives with a study rating of 16 or over can be considered poor options for this project due to low mortality rates or implementation difficulties. The technologies that received the best ratings (~ 9 to 12) include various acoustic treatments, chemical treatments, and physical treatments. The treatment alternatives in these categories that received the best study ratings are the most effective, mainly due to high reported efficiencies and ease of application. Further analysis of each treatment alternative listed in the table is provided in the following discussion.

Biological Controls

The biological treatment alternatives as a whole have minimal recreational impacts, low capital costs, and limited impacts to non-target species. However, success with these treatment alternatives is unlikely due to the inability to produce sufficient numbers of bacteria required to treat open water systems, the inability of natural predators to reduce zebra mussel population densities to acceptable levels, and the inability to successfully implement a spawning inhibition program outside of laboratory conditions. Due to these factors, operation and maintenance costs may be high as well. For instance, the amount of bacteria needed to control zebra mussels in such a large area is not readily available and extra expense may be required in order to supply sufficient numbers. Overall, biological controls in both the lake and the brook would likely be limited by scalability from laboratory settings to field settings and by the size of the proposed treatment areas.

Acoustic Deterrents

The acoustic deterrents collectively have high efficiencies, low operational costs, and low recreational impacts. The acoustic treatment of zebra mussels at Ossawinnamakee Lake using cavitation or low frequency sound treatment is dependent on the ability of the system to effectively control zebra mussel populations in field settings. Although reports suggest efficiencies are high, these systems have not been proven in open water systems, to our knowledge. This system could be provided in point specific areas of the lake, such as the entrance or exit of Muskie Bay; however, the large area may prohibit its application. Implementation in the brook may be more feasible due to a smaller volume of water, but the flow would reduce contact time and thus reduce effectiveness. It would be extremely difficult to implement a vibration system in either the brook or the lake because there are few structures that can be subjected to vibration.

Overall, acoustic deterrent systems have relatively high capital costs and may be feasible for certain areas in Ossawinnamakee Lake, but efficiencies of these systems have not been proven in open water settings. In fact, research pertaining to acoustic deterrents for control of zebra mussels in water intakes was documented as long as thirty years ago primarily for intakes, but there are no cases to our knowledge of acoustic systems that have been implemented in open water systems.

Chemical Controls

Chemical treatments have some advantages over the other treatment alternatives because they have high efficiencies and are relatively easy to implement within open water systems such as the lake and/or brook. Specifically, Muskie Bay could be utilized as a potential treatment area and the brook may benefit from residual chemical levels, as exhibited by the current treatment. Capital costs for chemical treatments are generally reduced due to the limited equipment needed to implement chemical dosing; however, operational and maintenance costs (i.e., man hours and chemicals) may be higher than some other treatment alternatives. Overall, the major disadvantages for chemical treatments include environmental impacts to non-target organisms and health and safety of the operators that handle the chemicals. With these considerations in mind, a brief statement is provided (within the subdivided categories) to explain why or why not each chemical would be advantageous for zebra mussel control in the lake and/or the brook. Aside from toxicology, chemical treatments are a viable option for implementation in Muskie Bay or Pelican Brook, although implementation may be more difficult in the brook due to higher flows.

Oxidizing Agents

The oxidizing chemicals discussed in **Section V** are generally effective in reducing zebra mussel populations; however, this class of chemicals is best suited for application within controlled, closed water systems. The use of oxidizing chemicals in natural, open water systems is limited due to toxicity and impacts to non-target organisms, potential occupational safety issues, and the regulatory permitting issues/restrictions. In addition, there could potentially be higher operational costs (in comparison to non-oxidizing agents) associated with administration of oxidizing agents because juvenile and adult zebra mussels can detect chemical oxidants and subsequently close their shells to protect themselves from the harsh environment.

Toxicity is a major disadvantage to several of these chemicals. Chlorine is harmful to the environment due to release of trihalomethanes and it is toxic to many species other than zebra mussels. Hydrogen peroxide is not advantageous because it must be utilized at a high concentration to produce mortality and it is also toxic to native mussels species. Potassium permanganate is not advantageous because it must be continuously administered in order to produce high mortality rates and may also be toxic to fish species at the concentration required for zebra mussel control.

Comparatively, ozone is advantageous due to its low toxicity toward non-target species, but it dissipates very quickly. There may be high capital and operational costs associated with maintaining the proper ozone concentration for zebra mussel control.

Overall, most of the disadvantages of oxidizing chemicals (e.g., toxicity) outweigh the advantages of utilizing these chemicals to control zebra mussels. Out of the four chemicals discussed, ozone would be the most advantageous if cost were not a factor.

Non-Oxidizing Agents

The non-oxidizing chemicals discussed in **Section V** have one major advantage over oxidizing chemicals: zebra mussels cannot detect them and will not exhibit avoidance behavior when exposed to most non-oxidizing agents. Non-oxidizing chemicals have varying levels of toxicity and may present more of a risk for operator handling the chemical. Although most of these chemicals rank similarly to oxidizing chemicals as far as efficacy, there are generally higher requirements for dosing amounts and contact time.

Most non-oxidizing agents offer disadvantages. Aluminum sulfate is effective for preventing attachment of zebra mussels, but low efficacy has been obtained in relation to veliger mortalities. Chloride salts are effective in relatively short time periods, but these alternatives appear to be relatively infeasible for use in an open water system due to the high concentrations required to effectively reduce zebra mussel populations. Copper ions are effective when applied at low, continuous doses, but toxic to many non-target species, as illustrated within the MN DNR sampling reports. Potassium salts are toxic to native mussel species and require high concentrations for long periods of time in order to induce mortality. Most organic molluscicides are toxic to aquatic life and generally harmful to the operator. For use in closed water systems, molluscicides require deactivation or neutralization of discharge to limit impacts to non-target species and to reduce the corrosiveness of these agents. It follows that these chemicals are not highly recommended for open water systems.

Activated starch is a novel alternative that is very promising, but unproven in treating large volumes of water. According to the manufacturer claims, results from laboratory tests, and experience in closed systems and open water discharges, this product should be effective in eliminating all zebra mussel life stages, but specific field studies need to be conducted in order to prove its efficiency in open water systems.

Overall, these chemicals tend to have high toxicities toward non-target species, which is a major disadvantage for application in an open water system. If the activated starch reagent were feasible for an open water system, it would be the most advantageous of the non-oxidizing chemicals due to low toxicity to non-target species.

Electrical Deterrents

While electrical deterrents have been used to limit the dispersal and migration of other aquatic invasive species, these treatment alternatives appear to only prevent zebra mussel attachment or settling and may not limit downstream movement of veligers. In the instance that veliger mortality is achieved, very high frequencies are required. Overall, research suggests that these technologies might be better served in small-controlled applications such as water intakes or pipelines. Like acoustic deterrents, electrical barriers or deterrents could be constructed within the brook or the riverine area of the lake, but with the high flow velocities, effectiveness would likely be diminished with reduced exposure time. These treatment alternatives would not be feasible in Muskie Bay due to issues with implementation and overall scale. Aside from low efficacy and difficult implementation, the capital costs to construct electrical deterrents systems coupled with the public perception of the electrical barrier would likely outweigh any benefits.

Physical Treatments

Physical treatments are generally environmentally friendly and may not require permits; however, many of them are not feasible for lake and brook applications. For treatment in Muskie Bay, implementation and scale present problems with most of the evaluated physical treatment alternatives; however, the treatments could be applied in areas downstream of the bay under controlled scenarios such as a fixed water flow rate. These treatment alternatives could technically be applied to the brook, but under the high flow conditions, the volume of water would present significant engineering challenges. For instance, the treatment of the large continuous volume of water would impact overall effectiveness of strobe lights or UV radiation by limiting the exposure or contact time. Similarly, the efficiency of mechanical filtration would be reduced when treating such a large volume of water.

Aside from the previously mentioned alternatives, disposable substrates are a viable treatment option for specific areas of the lake, but they are not highly efficient in controlling dispersal of zebra mussel veligers. Mechanical cleaning is not largely applicable to the lake or the brook, but could be utilized as a spot treatment in areas that contain hard surfaces infested by juvenile or adult zebra mussels. Separately, a physical barrier could be implemented near the riverine area downstream of Muskie Bay. This alternative will limit navigation and migration, but it would be highly effective in limiting veligers.

Overall, high capital costs and low efficiencies are disadvantages to many of the evaluated physical alternatives. It is also believed that many of the difficulties in implementing and maintaining these alternatives may outweigh the benefits gained by utilizing them. The permeable barrier, however, is an exception in terms of low efficiencies and limitations with implementation. If the disadvantage of navigation and migration impacts and high capital costs can be outweighed, this may be a good alternative for limiting the spread of veligers out of Muskie Bay.

Combined Treatments

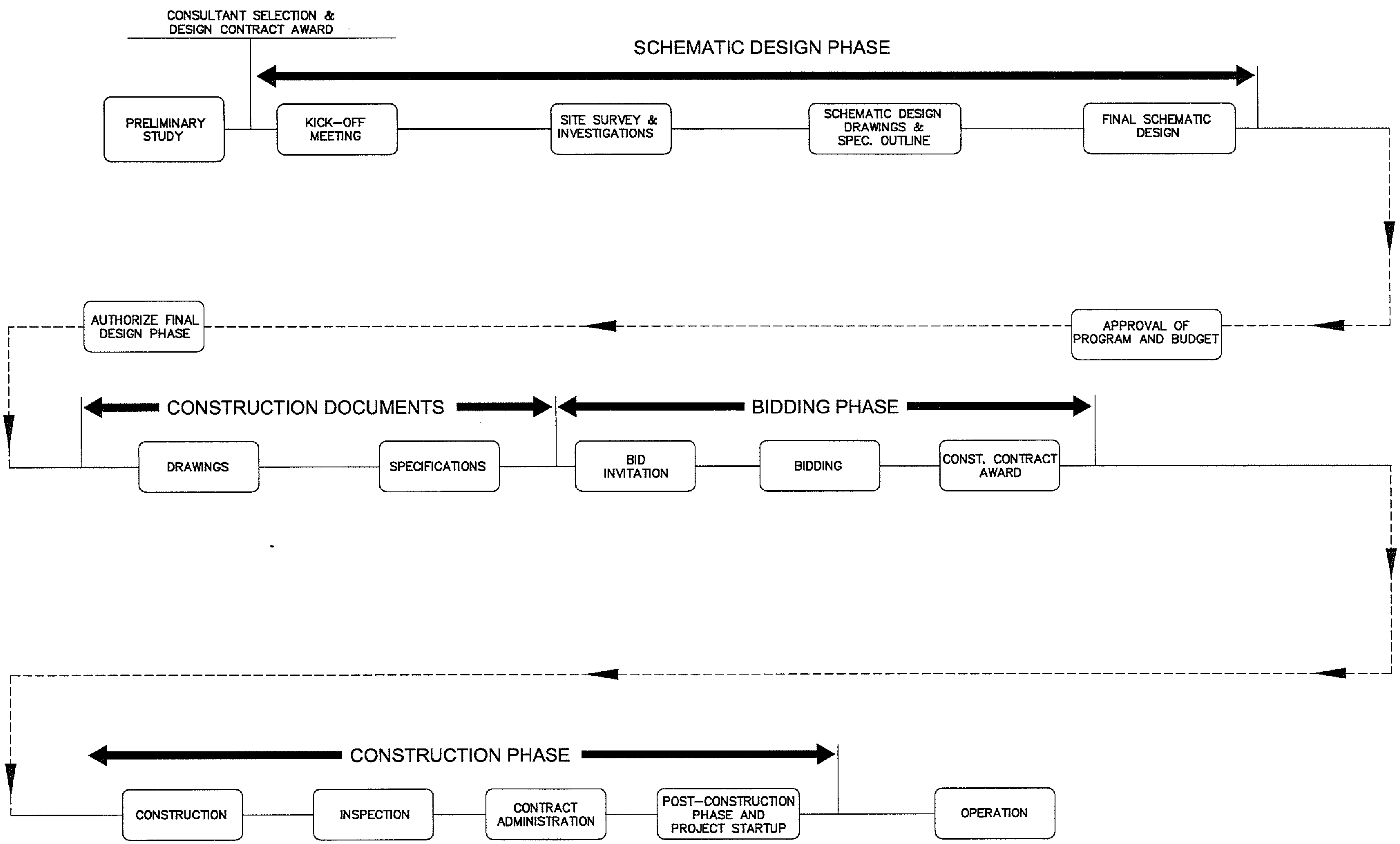
Although some of the treatment alternatives appear to be highly efficient, the best option for this project may be a combination of treatment methods. The combined treatment methods would probably be the most advantageous because they target all life stages and have very low environmental impacts in addition to very high overall effectiveness. The treatment alternatives that were combined in this category were among the best rated treatments for this study. Other combinations may also be feasible and could be considered, but evaluating combinations of every alternative was outside the scope of this study.

The only disadvantage with the combined treatments is the higher cost that results from implementing and operating two treatment systems. Specifically, combining the cost of maintaining ozone and installing a permeable barrier or a sound system with high capital costs gives these categories a lower rating in comparison to other combinations. The cost of applying activated starch is much lower than ozone administration, which lowers the overall cost of a combined treatment. Overall, these alternatives are advantageous because a combination of treatments will give the highest efficiency and target a range of life stages at the same time.

Other Considerations

Section V briefly mentioned implementation issues and estimated time periods of implementation but the elements of design and construction have not been discussed. Some of the treatment alternatives require design and construction of a specialized system for Ossawinnamakee Lake. For example, acoustic, electric and some physical technologies would require installation of a structure that would encompass the entire water column in which it is designed to protect. While similar systems may have been utilized elsewhere, the morphology of the treatment area must be utilized to design a site-specific system. For treatment alternatives that may not require extensive construction, a design phase is still important in order to assess the site and provide specifications for proper treatment. An estimate of the time it may require to implement each treatment alternative has been included in **Table V-1** in the previous section. In addition, the **Chart VI-1** provides an outline of several phases that may be included in the implementation of a specialized treatment alternative and tasks that may need to be completed for each phase. This flow chart may not specifically apply for all treatment alternatives, due to the large variation in technologies, but it serves as a representative example for the purpose of this study.

Chart VI-1 Example Phases for Implementation of A Specialized System



Treatment Alternative Recommendations

Treatment Locations

Limiting the downstream movement of zebra mussels could occur at several locations, including areas of Muskie Bay and possibly Pelican Brook. While similar treatment alternatives may be applied to each system, the physical implementation of the alternatives differs greatly. For example, the hydrologic characteristics of Muskie Bay with its slow moving water provides ample contact time for exposure to many of the chemical treatment alternatives. In contrast, the lacustrine environment of the bay may present physical implementation obstacles due to the size and volume of the treatment area. Conversely, the more riverine areas of the system (i.e., near the outlet structure downstream of Muskie Bay and Pelican Brook) present other implementation and contacting issues due to the continuous volume of moving water.

Given the wide variety of characteristics within the system (i.e., various water depths and flow velocities), two general treatment locations are most likely advantageous for the limit of zebra mussel veligers from Ossawinnamakee Lake. Since the main goal of the project was to limit the spread of zebra mussels from Ossawinnamakee Lake, the lake represents the primary treatment location. Within the lake, some type of barrier or deterrent may be feasible at the exit of Muskie Bay, as this area is constricted by width. In addition, chemical treatment alternatives could be applied in the greater portion of the bay, as seen in previous treatments. It is likely that two treatment alternatives working concurrently would result in the greatest efficacy to confine the current zebra mussel population and reduce downstream dispersal. These alternatives are described in further detail below.

Based on the observed field accounts outlined above, the known life histories of the organism, and the accounts in the literature of environments and locations of where the organisms are typically found, it is likely that the hydrologic characteristics of Pelican Brook (i.e., shallow water with high flow velocities) may provide a natural defense that is not conducive for zebra mussel populations to become established. In addition, many of the treatment alternatives are not feasible in high-flow applications, such as the brook. However, a contingency plan is recommended and should be developed in the event that sampling events identify areas of established populations in the brook. This plan could outline the steps necessary to target eradication of adults in Pelican Brook when discovered. Several point application alternatives could be employed from **Table VI-1**.

Treatment Objectives

As stated previously, the primary goal of this evaluation was to provide an analysis of the effectiveness of potential technologies in preventing or limiting the in-water transport of zebra mussels, particularly the veliger stage, in the outlet stream of Ossawinnamakee Lake. For the purposes of discussion and general treatment application, two distinct control categories have been developed. These are dispersal control and population control. **Dispersal Control** is defined as limiting downstream movement of any or all zebra mussel life stages. **Population**

Control is defined as limiting the growth of zebra mussel populations by primarily targeting adults. While specific treatment alternatives for population control and dispersal control will vary depending on location, both types of control strategies can be employed in the lake and in the brook. In other words, it may be possible to limit the growth of the population while also limiting the downstream dispersal of the species within both locations.

To limit the downstream movement of zebra mussels from Ossawinnamakee Lake, the following zebra mussel management objectives are recommended.

> **Objective 1** – Continue Ossawinnamakee Lake and Pelican Brook veliger and adult monitoring to determine location and densities of zebra mussels. Continue education and outreach programs to inform lake and brook users about the risk of downstream zebra mussel transport.
>
> **Objective 2** – Implement dispersal control strategies that limit zebra mussel dispersal from Muskie Bay into Pelican Brook.
>
> **Objective 3** – Implement population control strategies that target reduction or limit the growth of the zebra mussel population in Ossawinnamakee Lake.

Objective 1

Prior to administering copper sulfate treatments in Muskie Bay in the summer and fall of 2004, MN DNR personnel completed field sampling of the lake and brook in 2003 and early 2004. The field sampling results over the two-year period reported that successful reproducing zebra mussel populations had become established within the lake, but only a few sporadic adults were found near the outlet structure in the brook. Continued monitoring of both lake and brook populations and veliger densities is recommended and is critical to establish the locations of the zebra mussels. In addition, continued monitoring will aid determination of treatment alternative efficacy. If similar sampling points are monitored pre-treatment and post-treatment, the implemented strategies can be monitored and evaluated. Implementation of control strategies without continued monitoring is not recommended. A sound-monitoring plan that builds upon existing monitoring reports is strongly encouraged.

In order for the in-water treatment alternatives to be effective, strong public outreach, education and support are also required. Proliferation of existing invasive species programs developed and administered by MN DNR and Minnesota Sea-Grant are a critical step in the control of zebra mussels. When possible and technically feasible, the general public should be encouraged to contribute to the control of zebra mussels, especially due to the threat of zebra mussels spreading through overland transport to other areas such as the Whitefish chain of lakes to the North of Ossawinnamakee Lake. This contribution can occur through such activities as distribution of materials, voluntary involvement in application and maintenance of treatment alternatives, and through active participation in monitoring activities. In addition, it may be possible to involve the general public in surrounding communities in a zebra mussel tracking system. Under this scenario, the public is encouraged to report suspected locations of zebra mussels in areas around the Ossawinnamakee Lake. This scenario allows the public to be an active participant in the control process.

Objective 2

Ossawinnamakee Lake has one outlet structure that represents the only in-water dispersal point for zebra mussels from the lake to Pelican Brook. Protection of this outlet from the population in the lake represents the most critical control point for downstream transport. Several treatment alternatives could be applied to control the movement out of the lake at the outlet structure; however, the size and anticipated flow rates through the structure present a challenge for implementation of a control strategy that is feasible to construct and economically responsible to operate. As an alternative to an aggressive solution at the outlet structure, a more passive system could be implemented at the exit of Muskie Bay. Under this scenario, a permeable barrier could be employed that would allow for the movement of water but would restrict the movement of in-water organisms, including veligers. A barrier similar to the Marine Life Exclusion System manufactured by Gunderboom, Inc. (discussed in **Section V**) may be a viable option. A physical barrier of this type would encompass the entire water column at the exit area of Muskie Bay (**Figure VI-1**). The barrier would protrude slightly out of the water and stretch to the bottom of the lake. The barrier would be moored into place presumably at each shore and also be anchored along the bottom of the lake to exclude mussels from the outlet area of lake (see **Figure V-2** in **Section V**).

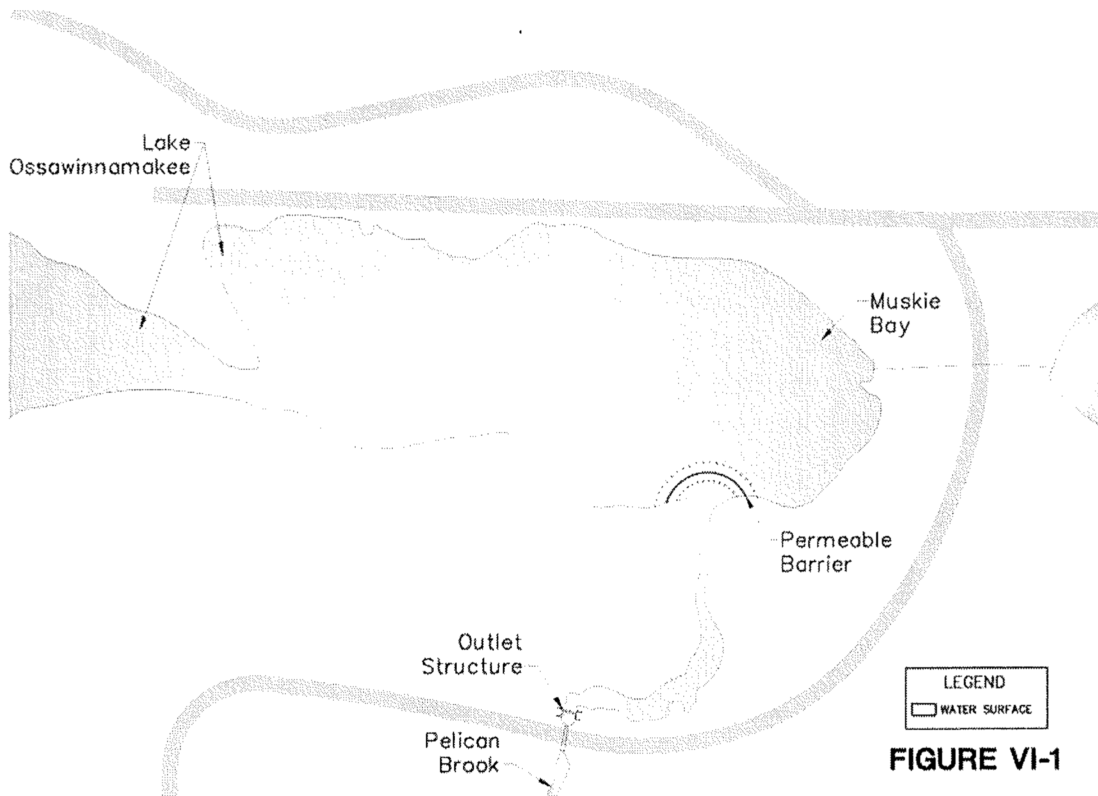


Figure VI-1. Permeable Barrier Location

Figure VI-1 displays a conceptual plan view that illustrates the potential location of the permeable barrier system. This type of physical dispersal control strategy has several advantages that would aid the zebra mussel control efforts. These advantages include relatively low maintenance, reduced on-site staff time, limited moving parts, minimal utility costs, and the capability to pass large volumes of water. Disadvantages of this system include the likelihood that floating debris will require routine but random removal, exclusion of boat traffic to the outlet area of the lake, potential blockage of desirable species movement into the area of Ossawinnamakee Lake downstream of Muskie Bay and upstream of the outlet structure, and possible limitations of certain chemical treatments due to clogging.

Objective 3

While evaluating the downstream movement of zebra mussels, it was determined that control of the population within Ossawinnamakee Lake in addition to control of zebra mussels that are dispersing or moving downstream is critical. While the size of the lake can present a logistical challenge for many of the evaluated treatment alternatives, it is believed that measures targeting the adult populations established in the lake may reduce the veliger densities that represent the probability of downstream dispersal.

Based on the results of the prioritization matrix analyses (see **Table VI-1**), there are several treatment alternatives that could be implemented as spot treatments. It is believed, however, that chemical treatment alternatives utilized proactively are most likely the best alternative for limiting the growth of juvenile or adult populations (see **Table B-1** in **Appendix B** for a list of chemicals). For example, the proprietary activated starch reagent developed by Barkley Distribution, LLC. could be advantageous, if the high efficiencies and low environmental impacts documented by the manufacturer can be achieved in the lake and/or brook. Ozone could also be a viable option if high capital and/or operational costs can be managed. The spot treatment locations could include Muskie Bay but also other areas of the lake where populations have become established. **Figure VI-2** displays the potential treatment area for population control at this time, but this area could be expanded to incorporate other established populations if needed.

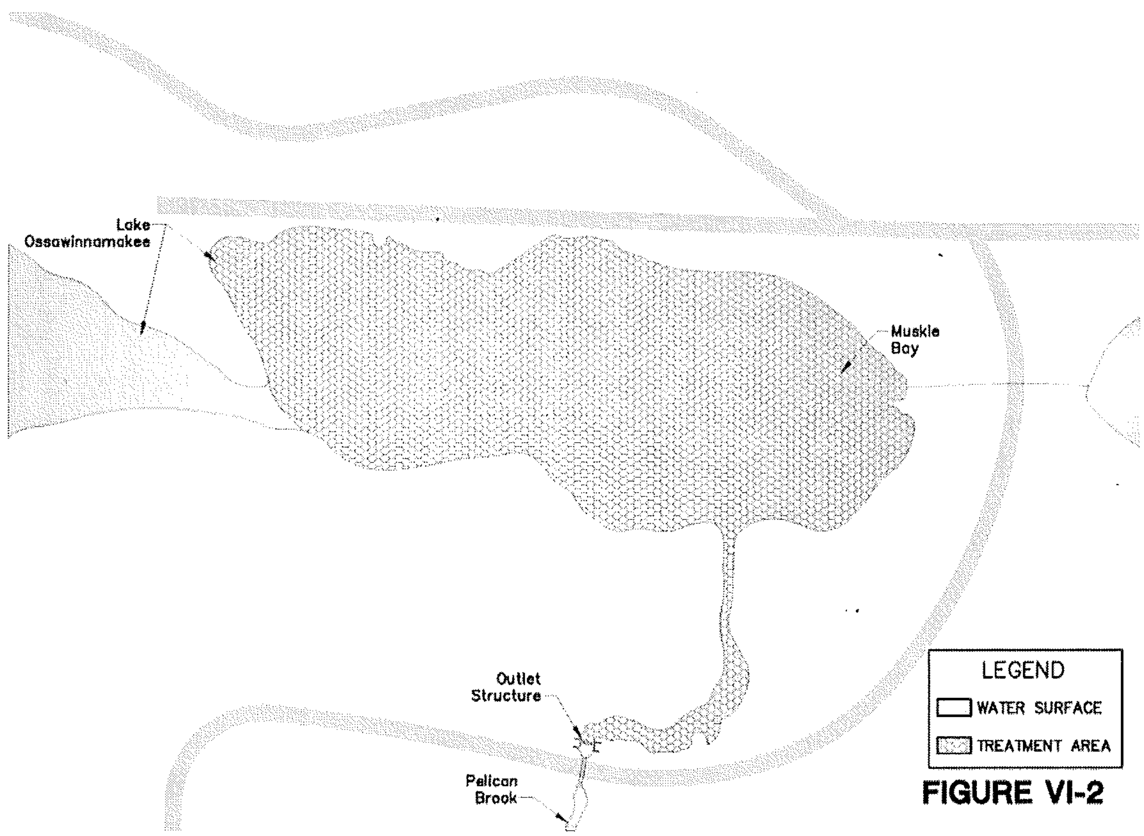


Figure VI-2. Population Control Area

Summary

Objective 1 incorporates established zebra mussel monitoring and education strategies that should be continued to the greatest extent possible by MN DNR, Minnesota Sea-Grant, and the local public. This objective is key to the successful reduction of zebra mussels downstream of

Ossawinnamakee Lake. The combination of Objectives 2 and 3 provide a potential solution for limiting downstream dispersal (**Objective 2**), while targeting population control in the lake (**Objective 3**). Together these treatment alternatives have the capability to reduce the probability that zebra mussel veligers will be transported out of Muskie Bay downstream to Pelican Brook. In addition, the two alternatives represent a passive solution to dispersal and a proactive solution to population control that will not require significant staff and operation hours to implement. While chemical agents and a permeable barrier are relatively easy to implement, compared to most of the other treatment alternatives evaluated, there are some drawbacks, primarily potential toxicity and recreation/migration impacts to non-target species. However, these disadvantages are minor, manageable disadvantages when compared to other treatment alternatives outlined in **Table VI-1**.

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII. Appendices

A. Regulatory Overview
B. Treatment Alternatives Expanded Data
C. Surveys and Data for Ossawinnamakee Lake and Pelican Brook
D. Literature Review
E. Prior Zebra Mussel Studies
F. Meeting Summaries
G. List of Abbreviations Used
H. Glossary of Terms

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Section VII

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII–A. Regulatory Overview

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METHOD OF INVESTIGATION

On line permitting and regulatory information was reviewed for the U.S. Army Corps of Engineers, St. Paul District (Corps), the Minnesota Department of Natural Resources (MNDNR), and the Minnesota Pollution Control Agency (MPCA). Information on regulations pertaining to new construction and modifications to existing structures was reviewed and summarized as it relates to the control of the spreading zebra mussel population.

SUMMARY OF REGULATIONS

Federal

U.S. ARMY CORP OF ENGINEERS

If a project to install and/or modify structures at the existing locks and dams or at new river locations is proposed to be undertaken by the Corps of Engineers, no state or local permits are required. In addition, the Corps does not issue permits to itself to implement projects. The implementation of a project by the Corps may require environmental review under NEPA regulations as well as a Chapter 106 historic and cultural resources review.

If a zebra mussel project is going to be implemented at the State level, an Army Corps permit will be required of that State Agency. The following summarizes Corps permit authority and requirements:

Under Section 10, a Corps' permit is required to do any work in, over or under a Navigable Water of the U.S. (these are generally called the "Section 10 waters") or to do any work that affects the course, location or condition of the waterbody in such a manner as to impact on its navigable capacity. Waterbodies have been designated as Section 10 waters based on their past, present, or potential use for transportation for interstate commerce. These waters include many of the larger rivers and lakes, such as the Minnesota and Mississippi rivers along with Lake Superior, Lake Michigan and the Mississippi headwaters and many other rivers and lakes.

The U.S. Army Corps of Engineers routinely applies for state waters permits out of comity. The Corps is required to obtain State Water Quality Certification for projects involving fill in waters of the United States as part of Section 404(b) of the Clean Water Act. In addition to the Section 10 Rivers and Harbors Act requirements described in the report, any work in proximity to the navigation dams would require planning in consultation with the appropriate Corps of Engineers

District, and approval by the Corps. This would be needed to ensure compatibility with the operations and maintenance of the navigation project.

Activities such as dredging and construction of docks, bulkheads and utility lines require review under Section 10 of the Rivers and Harbors Act of 1899 to ensure that they will not cause an obstruction to navigation and are not contrary to the public interest.

Under Section 404, a Corps' permit is required for the discharge of dredged or fill material into waters of the U.S., which include wetlands. Regulated discharges include filling wetlands for development, grading or pushing material around within a wetland, disturbing wetland soil during land clearing, etc. The general rule is that for an activity to receive a 404 permit it must comply with the EPA's Section 404(b)(1) guidelines.

In general, the guidelines require that the activity be the least environmentally damaging alternative that is feasible, and that adverse impacts are avoided, then minimized, and then compensated for (such as creating or restoring wetlands to replace those that would be filled). Activities also must not be contrary to the public interest, as determined by the Corps.

Certain discharges for some farm, forestry, maintenance and other purposes are exempt from Section 404 regulation. Exempt discharges must be for defined purposes and must satisfy certain conditions. The Corps should be consulted prior to the discharge of any material considered to be except to potentially avoid violating Federal law.

Some general permits can be confirmed or issued in a day, while other general permits and Letters of Permission may require a 30-day agency and public review process depending on the nature and location of the project and will take 45 days or more. Standard individual permits typically require a 30-day agency and public review and take 60 to 120 days or more.

State

MINNESOTA

Minnesota DNR: Projects Requiring Public Waters Work Permits

Under Minnesota Statutes 103G.245, Subdivision 1 (except as provided in Subdivisions 2, 11, and 12), the state, a political subdivision of the state, a public or private corporation, or a person, must have a MNDNR Public Waters Work Permit to: construct, reconstruct, remove, abandon, transfer ownership of, or make any change in a reservoir, dam, or waterway obstruction on public waters; or change or diminish the course, current, or cross section of public waters, entirely or partially within the state, by any means, including filling, excavating, or placing of materials in or on the beds of public waters. The installation of new structures or modification of existing, state or locally owned structures would require a MNDNR Protected Waters Permit.

Minnesota Pollution Control Agency Water Quality Permit Application

Under Minnesota Statutes Chapter 7000, and in particular, Chapter 7050, the MPCA water quality permits establish specific limits and requirements to protect Minnesota's surface and ground water quality for a variety of uses, including drinking water, fishing and recreation. Permits are regularly reviewed and updated as they expire, allowing the MPCA to incorporate new information about the impacts of pollutants to the environment in subsequent permits. Permits are enforced through a combination of self-reporting (reports to the MPCA, U.S. EPA or both) and compliance monitoring.

SUMMARY

Based on review of available on-line permit guidance, modification of these structures by a federal agency in an attempt to stop or contain the spread of exotic species, such as zebra mussels, would not require federal permits. However, depending upon the proposed activity, environmental review (EA and/or EIS) may be required along with a historic resources review under the Chapter 106 National Historic Resources Preservation Act. The federal government does not seek state permits when implementing federal projects. During the implementation of a federal water resources project, State agencies are afforded the opportunity to provide review and comment to the Federal agency that is proposing to build a project.

The implementation of a "structural" project by a state or local agency will require federal, as well as state permits by the various natural resources agencies, dependent upon where in the Mississippi Basin the project is proposed to be located. Minnesota has a combined State/Federal permit application for working in protected water bodies. It is highly recommended that this joint state/federal permit application and review process be utilized for any proposed zebra mussel/barrier solutions.

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-B. Treatment Alternatives Expanded Data

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Table B-1. Efficiency and Impacts of Chemicals Tested for Zebra Mussel Control

Category	Specific Chemical	Target Age	Efficiency	Lethal Conc.	Exposure Time	Toxicity	Major Disadvantage
Oxidants	Chlorine	Veligers	75-100%	0.5 ppm	2 hours	High	Toxicity
	Chlorine dioxide	Veligers	100%	0.5 ppm	24 hours	High	High Maintenance
	Chloramines	Veligers	100%	1.2 ppm	24 hours	High	Toxicity
	Bromine	Adults	90-100%	0.5 ppm	1 to 3 weeks	High	High Maintenance
	Ozone	Veligers	100%	0.5 ppm	5 hours	Low	Expensive
	Potassium Permanganate	Adults	90-100%	2.5 ppm	Weeks	Medium	Continuous dosing
	Hydrogen Peroxide	Veliger/Juvenile	26-100%	100 ppm	6 hours	Medium	Toxicity
Nonoxidants	Activated Starch	Veliger	100%	3.0 to 6.9 ppm	21 to 72 hours	Very low	Unknown
	Aluminum Sulfate	Veligers	50%	126 ppm	24 hours	Low	High solids load
	Sodium Chloride	Veliger/Juvenile	100%	20,000 ppm	6 hours	Low	High dose required
	Calcium Chloride	Veliger/Juvenile	100%	10,000 ppm	6 hours	Low	High dose required
	Potassium Chloride	All	100%	100 ppm	48 hours	Medium	Continuous dosing
	Potassium Phosphate	All	95-100%	30 to 100 ppm	2 wks /48 hrs	Medium	Continuous dosing
	Potash	All	95-100%	30 to 100 ppm	2 wks /48 hrs	Medium	Continuous dosing
	Copper Ions	Veligers	100%	5 ppm	24 hours	High	Toxicity
	Cutrine-Ultra	Veligers	99%	0.03 to 0.08 ppm	24 hours	Unknown	Toxicity
	Cutrine-Ultra	Adults	99%	1.7 ppm	96 hours	High	Toxicity
	MacroTech (Cu and Al)	All	95-100%	5 ppm or less	24 hours	Low	Continuous dosing
Quaternary Ammonium Compounds	Bulab 6002	All	100%	1.0 ppm	10 days	High	Nonbiodegradable
	Calgon H-130M	All	100%	1.1 ppm	48 hours	High	Must be deactivated
	Clam-Trol	All	100%	1 to 10 ppm	120 hours	Medium	VERY corrosive
	Macrotrol 9210	All	100%	10 to 100 ppm	24 hours	High	Must be deactivated
	Nalco 9380	All	100%	1 to 12 ppm	24 hours	High	Must be deactivated
	Veligon	All	50%	1.5 to 3.0 ppm	96 hours	High	Filter needed
Aromatic Hydrocarbons	Bulab 6009	All	100%	1.0 ppm	6 days	Very High	VERY corrosive
	Mexel 432	All	100%	1 to 4 ppm	3 days	High	Continuous dosing
	Endothall	All	100%	3.0 ppm	6 days	Very High	VERY corrosive
	Acridine	All	64%	2.5 ppm	48 hours	Medium/High	Continuous dosing

Primary Souce: Sprecher and Getsinger 2000
Secondary Sources: Beolman et al. 1997, Stantec 2003, Waller and Fisher 1998, Waller et al. 1993

Ryan Keith

From: Kevin Nordfors [KNordfors@gunderboom.com]
Sent: Wednesday, March 16, 2005 12:56 PM
To: Ryan Keith
Cc: Matt Cochran; Meghan Oh; Bob Dove; Hal Dreyer; Andy McCusker; Melissa Hamlin; Jenny Ryals
Subject: RE: Gunderboom Marine Exclusion System to Control Zebra Mussels...

Ryan,

After reviewing the information we feel that we can provide an effective system to reduce the migration of zebra mussel veligers out of Muskie Bay. Based on the anticipated flow rate and known depth we recommend a Marine Life Exclusion System (MLES™) that is approximately 300 – 400 feet in length and with an average depth of 25 feet. It appears that the turbidity and TSS levels are very low, which may allow for a manual AirBurst™ system to be installed for operations and maintenance purposes, compared to an automated system, but this would have to be verified through further investigation. Gunderboom undertakes these projects, which are essentially design/build or engineered systems, in a phased approach. This approach allows both our client and ourselves an opportunity to carefully work into the project and limit the cost until such time that enough data and evaluation has been performed to allow for a reasonable decision of feasibility. This step-by-step approach provides "hold" points so determinations to move forward are based on credible information. Based on this phased approach, Gunderboom can develop an accurate cost estimate for each project through the determination of site variables such as flow velocity, TSS level, bottom type, fauna for exclusion, fabric filtration performance, interaction with a biocide, etc.; however an engineer's estimate for a Marine Life Exclusion System (MLES™) is approximately $730,000 – $1,070,000. The following shows a brief description of our phased approach.

Phase I - Preliminary Investigation

This is a "desk study" combined with a site visit to look at the facilities and intended location in more detail (if applicable), gain a better understanding of the operations and review the parameters under which the MLES™ would need to operate. The desk study portion of the work involves a review of all the relevant data and information that can be located from previous investigations and studies. The deliverable under this phase is a summary report of findings, a more definitive look at conceptual design and feasibility based upon findings, a preliminary cost estimate and, most importantly, a list of the field investigations and further studies that are recommended.

Phase II- Field Investigation & Preliminary Engineering

This program derives from the determinations made in the Phase I effort. There are a variety of field investigations and studies that may be appropriate, some of which are:

- On-Site Fabric Flow Test

  This is accomplished by either mobilizing the Fabric Flow Test Apparatus (FTA) to the project site and conducting flow tests of several different fabric treatments to both determine the most likely candidate and further confirm sustained flow rates or conducting a pilot demonstration, as discussed below.

- Confirmation of Bathymetry

- Current Velocity & Direction Studies

- Geotechnical Investigations
- Computer Modeling (CFD Flow Dynamics Study)
- Physical Modeling

  This would include a scaled version of the system deployed in a modeled hydraulics lab setting to confirm operation and physical characteristics of performance

- Pilot Demonstration

  The concept of providing a Pilot Demonstration project is something that is being implemented at several locations at the present time. The approach is to devise a small scale system that can be deployed and be subjected to the physical impacts that a full deployment would operate with.

The deliverable from this phase is a definitive report of findings that highlights the biological findings and the significant design considerations for the engineering department to consider when moving forward. The conceptual designs are updated to reflect new findings and the cost is adjusted to accommodate those items that may impact the project budget.

Phase III- Final Engineering & Design

The suite of information developed through the work undertaken in Phases I and II is incorporated into a final engineering and design process. This results in a set of manufacturing plans and specifications, work packages for field activities, installation plans and recommendations, commissioning guidelines, operation & maintenance manuals and special considerations, if any.

Phase IV - Manufacture & Delivery of System

The Phase IV program includes the manufacturing of the system and appurtenances in our facility, assembly of the AirBurst™ system, acquisition of support materials and equipment, factory testing and delivery of the product to the project site.

This is an exciting project with a subject (zebra mussel) that provides some unique challenges. As we discussed on the phone, we feel we can provide a significant reduction in the amount of zebra mussel veligers that migrate out of Muskie Bay, but that a biocide working in concert with our system would probably be the most effective solution. I look forward to hearing from you to move forward to the next step.

Best regards,

Kevin Nordfors
Regional Sales Engineer
GUNDERBOOM, Inc.

-----Original Message-----
From: Ryan Keith [mailto:Ryan@fishpro.us]
Sent: Wednesday, March 09, 2005 9:27 AM
To: Kevin Nordfors
Cc: Matt Cochran; Meghan Oh; Bob Dove; Hal Dreyer; Andy McCusker; Melissa Hamlin
Subject: RE: Gunderboom Marine Exclusion System to Control Zebra Mussels...

Kevin,

Thanks for following up. Agreed - the previous site information that was sent was minimal at best. Attached is a scaled drawing of the Muskie Bay and outlet to Pelican Brook. As for specific site dimensions, at this conceptual and study level, we don't have them. Hopefully, your crew can scale off the drawing to get any ball-park estimates that they might need. As for the lake bottom substrates, from what I recall, they are mixed silt, sand, and marl. The maximum depth of the lake is about 65 feet with a mean depth of about 22 feet deep. I would imagine that navigation of small recreational boats i.e., canoes and small fishing boats might be an issue. Please let us know if there's any other site information needed.

Thanks

Ryan Keith

-----Original Message-----
From: Kevin Nordfors [mailto:KNordfors@gunderboom.com]
Sent: Wednesday, March 09, 2005 7:30 AM
To: Ryan Keith
Cc: Matt Cochran; Meghan Oh; Bob Dove; Hal Dreyer; Andy McCusker; Melissa Hamlin
Subject: RE: Gunderboom Marine Exclusion System to Control Zebra Mussels...

Ryan,

Thank you for the information. We will review and try and to get a cost estimate to you by early next week. In the meantime, could you provide a little more site data? What is the bottom like (i.e. Mud, sand, etc...)? Do you have an aerial or site plan that shows the layout and dimensions of the water body? Are there any debris issues to worry about? Is this water body used for recreational boating, that we might have to worry about navigation? As we discussed on the phone, I believe a combination of our Marine Life Exclusion System and a biocide would solve the zebra mussel problem, if that is the direction the client wants to go. If so, we would recommend performing some site investigation and testing to further refine our design and provide a more accurate estimate of our filtration capabilities when it comes to 25 um sized veligers. I look forward to hearing from you.

Best regards,

Kevin Nordfors
Regional Sales Engineer
GUNDERBOOM, Inc.

-----Original Message-----
From: Ryan Keith [mailto:Ryan@fishpro.us]
Sent: Tuesday, March 08, 2005 2:42 PM
To: Kevin Nordfors
Cc: Matt Cochran; Meghan Oh
Subject: Gunderboom Marine Exclusion System to Control Zebra Mussels...

Kevin,

Per our telephone, please provide a cost estimate to install Gunderboom's Marine Exclusion System to control the dispersal of zebra mussel veligers from a lake in northern Minnesota to a small brook located near the head waters of the Mississippi River. At this preliminary/conceptual level, a range of costs is appropriate. The following information includes some general site information and water quality data.

Flow rates - The outlet from that lake has a continuous flow that averages 40 to 50 cfs (18,000 to 22,500 gpm) and has been known to vary from 30 to 85 cfs (13,500 to 38,250 gpm).

Water surface elevation - Mean 367.4 m (1,205.5 feet); Min. 367.3 meters (1,205.0 feet); Max. 367.8 meters (1,206.8 feet)

Total Phosphorus - Mean 11 ug/l (ppb); Min. 10 ppb; Max. 13 ppb

Chlorophyll a - Mean 3 ppb; Min. 2 ppb; Max. 5 ppb

Secchi Disc Transparency - 5 meters (16.4 feet)

pH - Mean 8.4 SU

Alkalinity - Mean 125 mg/l (ppm)

Turbidity - Mean 0.730 NTU

Total Suspended Solids - Mean 1.35 ppm

Conductivity - Mean 210 umho/cm

Thanks in advance for your assistance.

Ryan Keith
Biologist
FishPro/Cochran & Wilken, Inc.
phone: 217-585-8333
fax: 217-585-1890

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stantec.com

Stantec

January 30, 2003

Barkley Resources Group
c/o Greg Harney
Attention Mr. B. R. Cameron
401-915 Fort Street
Victoria, B.C. V8V 3K3

Dear Mr. Cameron:

Following is my report summarizing the studies conducted by Stantec Consulting Services Inc. related to the efficacy of the starch-based reagent you have developed for control of the zebra mussel.

Efficacy of Barkley Resources Group Starch-Based Reagent as a Proactive Control for the Zebra Mussel: In-Field Flow-Through Tests: October-November 2002

1.0 Background

Buildings
Environment
Industrial
Transportation
Urban Land

The Barkley Resources Group (BRG), headed by Mr. B. R. Cameron, has developed a starch-based product to control the zebra mussel (Dreissena spp.). To produce the reagent food-grade starch is mixed with water, and for a period of time the starch-water mixture is exposed to, and activated by, a proprietary technology developed by Mr. Cameron. The exposure to the equipment is reported to affect the valence electrons of the starch and results in the aqueous mixture retaining a low-grade charge for a relatively long-term (i.e., shelf-life). The longer the starch-water mixture is exposed to this proprietary technology the more molecules of starch receive a charge (limited by the concentration of starch). BRG defines the charged water-starch mixture as the product or "reagent". In developing the product for control of the zebra mussel Mr. Cameron directed several basic tests including efforts, in which the starch-water mixture was tested on organisms before and after activation. The results indicated the mixture, when not activated, had no effect on zebra mussels,

Industry and agencies have expressed interest in the reagent since there are several potential advantages for industry in using this starch-reagent as a control for the macrofouling zebra mussel. For example, data indicates the reagent is generally non- toxic, and when released to the environment it will degrade naturally (e.g., by bacterial action), and the degradation will be relatively rapid.

2.0 Preliminary Studies

2.1 Static-Test Field Study

As a step in product development a series of preliminary in-field static-tests were conducted, June 6-8, 2000, by Beak Consultants Inc. (Beak*), to further demonstrate the product's effect on zebra mussels. The static-tests were completed at a site in Louisiana, an Entergy electric generation facility, where there was access to Mississippi River (River) water and the River's resident planktonic mussels. The planktonic mussels are the targeted life-stage. In these tests a diluted form of the BRG product demonstrated efficacy (100% mortality) in the control of planktonic zebra mussel veligers.

To conduct these static tests, paired treatment and control samples were collected using 64 micron mesh plankton nets to concentrate the veligers or other plankton resident in the River water. Reagent-treated and untreated (control) test samples were held in separate plastic test chambers. All samples were gently and continuously aerated in the tests. The chambers were suspended in a tank with a flow of raw River water (i.e., a water bath) to maintain the temperature of the test chambers to that of the River. The bath held the samples at ambient River water temperature, though the chambers were sealed against any contact with the bath water.

The concentration of the stock reagent was 133,333 mg/l (whole product), this reported to be the maximum concentration of starch that would be used to produce the reagent. Prior to being brought to the site the stock reagent was charged, for a matter of minutes, using Mr. Cameron's technology. At the site raw River water was used to serially dilute the stock reagent to three concentrations, these being:

- **6.9 mg/l;**
- **5.6 mg/l;** and
- **3.0 mg/l.**

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Mussels in the treatment samples were exposed to the reagent at these concentrations. Within 44 hours there was 100 percent mortality of all planktonic zebra mussels in all three test solutions, while there was only minimal, natural mortality in the controls. Minimal mortality of mussel plankton in raw water is expected, is typically due to natural causes, and this natural-mortality generally accounts for mortality of organisms observed in experimental control samples.

The next step to commercializing the reagent was to conduct a flow-through field study. However, these tests required permission from State and/or Federal agencies as well as from the facility hosting the flow-through test, and a series of specific reagent toxicity tests.

2.2 Laboratory Toxicity Tests

2.2.1 Seven Day Replacement Toxicity Tests

The potential to have a relatively inexpensive molluscicide (a control for organisms such as mussels) that would quickly degrade through bacterial action when released into the environment was, as mentioned, of interest to industries using raw water. For similar reasons personnel at the United States Environmental Protection Agency (USEPA) in Dallas, Texas were also interested. They indicated the starch reagent would certainly be an alternative to existing control measures if the appropriate tests demonstrated the reagent had minimal effect on other organisms. To address this, and as a preliminary step to conducting flow-through field trials, they suggested completing laboratory evaluations (seven day replacement toxicity tests) using fathead minnows and ceriodaphnia. The USEPA personnel concurred that the protocol outlined by Lewis et al (1994[1,2]), and which is generally adopted by the USEPA as a method to determine toxicity, would be appropriate for the tests. These toxicity tests were conducted in the Stantec Consulting Services Inc. (Stantec*) Ecotoxicity Laboratory in August 2002. The stock solution used was at the same concentration as that used in the field tests (133,333 mg/l, whole product), though the stock solution was reportedly charged for the maximum period of 3.8 hours. This BRG stock solution was used to produce multiple serial dilutions for the seven-day replacement toxicity tests on fathead minnows and ceriodaphnia following the protocols of Lewis et al (1994[1,2]).

The results of the laboratory tests on the reagent were:

- The lethal concentration for fifty percent of the fathead minnows (**LC_{50}**) was **99,000 mg/l;**
- The **LC_{50}** for ceriodaphnia was **59,000 mg/l;**
- The no-effect-concentration (**NOEC**), for both the fathead and ceriodaphnia was **2083 mg/l; and**
- The low-effect-concentration (**LOEC**) for both the fathead and ceriodaphnia was and **4167 mg/l.**

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2.2.2 Whole Effluent Toxicity Tests

The Louisiana Department of Environmental Quality (LDEQ), in consultation with the USEPA, determined that the LC_{50}, LOEC and NOEC concentration data for the seven day replacement toxicity tests, in comparison with the anticipated concentrations of reagent needed to control zebra mussel justified a flow through field trial. The LDEQ amended the National Pollution Discharge Elimination System (NPDES) permit for Entergy's Little Gypsy Plant (a three-unit electric generation facility) to accommodate a flow-through test of the reagent at the La Place, LA site. However, the LDEQ placed a stipulation in the permit that a 48-hour whole-effluent-test (WHT) bioassay of the plant discharge water was required at the initiation of the flow-through test. They directed the bioassay to be conducted using fathead minnows and Daphnia magna as the test organisms. The objective was to determine the toxicity, if any, of the plant cooling water effluent when it included the reagent at the highest concentration to be discharged during the flow-through test. Samples for these toxicity tests (WHT) were collected at the power plant's circulating water discharges after the reagent had been flowing into the test stand, and then into the plant forebay at the Mississippi River levy for about two hours. During this period the reagent was injected at the highest concentration used during the study. (Note: Unit 3 was off-line for maintenance during the entire study).

Stantec contracted with CK Associates Inc. (CK) in Baton Rouge, LA to complete the 48-hour toxicity tests. CK reported that the 48-hour, WHT evaluations indicated the effluent was none toxic, and the flow-through tests commenced.

2.0 Flow Through Tests

The objectives of the flow-through tests were to demonstrate the effectiveness of the starch-based reagent as a proactive control in a field setting. The primary targets for these tests were again the planktonic life-stages and, if the tests could be initiated prior to the major fall mussel settlement event (i.e., the initiation of conduit fouling), the settlement-life-stage/ settlement-event would also be examined. The flow-through tests were originally scheduled to begin in early to mid-September, 2002. This schedule was designed to take advantage of the high densities of planktonic mussels that are typical in the lower Mississippi River water in the September-October time period. However, because of unavoidable delays, including pre-field and in-field mobilization efforts, the toxicity tests, test-stand construction, system calibration and finalization of procedures, the field crew could not be on site until October 17th, and the first valid flow-through sample was not collected until October 30th. The field effort ended on November 12th 2002.

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After test-stand setup, and during the field study, it was found that the densities of D-form and umbonal form mussels in the River water were low though still high enough to evaluate reagent-effects on these life-stages. River water temperatures varied from the mid-seventies down to the mid-sixty degree Fahrenheit range during the study. Precipitation was encountered during the study, and the rainfall was intense on several occasions and appeared to alter River water turbidity for short periods. Turbidity reportedly might affect the reagent available to control mussels, though this was not evaluated.

A test stand was constructed on the Mississippi River levy adjacent to the Entergy Little Gypsy Plant (LaPlace, LA) circulating water pumps, forebay, and traveling screens. A single, four inch PVC pipe was tapped into a service water pump for the plant's Generation Unit 1. The pump provided a constant flow of raw River water from the forebay to the test-stand at rate of approximately 20 gpm. The four inch line was reduced and "T'ed" into two, two-inch PVC lines (legs) that were designated as the treatment or control legs. Flow control valves in each leg were used to maintain an equal flow of River water through in-flow ports located inside respective treatment and control tanks, the tanks located at the end of each leg. Although there was little potential for siphoning or back-flow from the treatment leg into the control leg, a two-inch check valve was installed in the treatment leg to eliminate the possibility. Two oval, 150 gallon plastic tanks were placed, in tandem, at the end of the treatment and control legs (four tanks in total). The first tank of each pair at the end of a line/leg was elevated by about 33 cm relative to the second. The configuration resulted in a free flowing cascade of water through discharge ports and lines from the first to the second tank in each leg.

As mentioned, water entered the upper tank in each leg through a pair of in-flow ports. The ports were located centrally and near the inner edge of a tank, and just above the water surface. These ports directed flow in two directions around the edges. Water exited each of the four tanks through a pair of two-inch discharge lines located opposite the in-flow ports. In the upper tanks the closely-spaced, parallel lines ran from the central area of each tank to discharge through bulkhead-fittings in the wall of the tank. Each discharge line in these tanks was fitted with a submerged port located just above mid-depth. The lines were slightly different in length such that water entered, via gravity, into the port of the shorter line about half way between the edge and the center of the tank, while water similarly entered the other port from the central area of the tank. The placement of the in-flow and discharge ports was intended to distribute and mix the water in each tank. The flows from the lower treatment and control tanks (and so all tanks) were discharged into the forebay of Unit 2. Units 1 and 2 forebays are physically separated at the levy. This separation prevented recycling and mixing of treatment-reagent and control water, discharged from the test tanks, with raw River water pumped to the test-stand inflow line from Unit 1 (i.e., via the four inch PVC supply pipe). However, beyond the levy mixing of water from Units 1 and 2 occurs prior to discharge back to the River.

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The reagent to be injected into the treatment leg of the test-stand (stock solution concentration 44,443 mg/l fully charged, whole product) was maintained in a 38 gallon plastic drum. A 3/8-inch Tygon feed line was routed from the drum to the inlet of a

Pulsatron metering pump (model LPD4SA-PC1-500) that then directed a metered flow of the reagent from the pump discharge through another 3/8-inch Tygon tube to a 3/8 inch foot valve. The foot valve was tapped into the two inch raw water feed line in the treatment leg. Using a graduated cylinder, the reagent's flow rate was calibrated and intermittently checked by measuring the output of the metering pump before entering the foot valve. In all measurements the flow rate was ~43 ml/min +/- 1. At the designed reagent and raw water flow rates and associated in-line dilution the resulting concentration in the 150 gallon treatment tanks was ~17 mg/l. This was a higher concentration than used in static-tests because it was anticipated it might require a higher concentration in a flow-through versus a static situation to achieve the same effect.

However, after a few days into the project it was determined that the injection-rate of the reagent into the raw water was less than indicated by the metering pump calibrations (based on reagent used). The problem was found to be the foot valve not the metering pump. Intermittently, the foot-valve was partially clogging and reducing the reagent flow, at times to about 25 percent of the designed and calibrated reagent delivery rate. Correspondingly, the reagent concentration to which mussels were exposed was effectively reduced to about 4.5 mg/l, possibly less. This flow variation persisted during the entire study except for the first 20 to possible 30 hours of the study, and for an additional period of several hours after the clogging problem was discovered (this assessment again based on reagent used). Although the exact reagent concentration in the treatment tank was unknown for much of the test period, it ranged between ~4 to a maximum or 17 mg/l throughout the study (these being whole product concentrations as opposed to active product).

As in the static-tests, plankton nets were used to collect samples, which is a standard procedure for Stantec's scientists in conducting field studies. However, there were no published protocols relative to holding and maintaining planktonic-stage mussels for in-field, flow-through tests. Stantec scientists developed a preliminary protocol prior to entering the field and modified them in Louisiana, as necessary.

The test chambers used for the flow through studies were, polyvinylchloride (PVC) plankton-net buckets. The chambers were typically 8 cm in diameter by 20 cm deep, with a side opening (window) area of approximately 150 cm^2. The window was covered with 64 micron mesh stainless steel screen. Air, via air-stone, was gently pumped into each control and treatment chamber to insure water circulation within each chamber and gas transfer through the screen. The chambers were either floated on, or suspended in the water in the upper treatment or control tanks, as appropriate. Dissolved oxygen and pH in the treatment and control tanks, and the sample chambers were intermittently measured. After a period of hours (~21 to ~96 hours), a treatment and sample chamber pair were washed into sample bottles and examined in the on-site laboratory. The samples were examined using microscopes fitted with cross-polarized light apparatus. The number of live and dead zebra

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mussel D-form and umbonal form plankton in each sample were determined following standard procedures used by Stantec scientists for zebra mussel projects.

During the study six valid sample pairs (six treatment, six control samples) were evaluated. The first valid sample pair was examined after being exposed for about 21 hours, even though the static-tests suggested it could require up to 44 hours to attain 100 percent mortality.

In the "21 hour" sample a differential mortality was observed but not at the 100 percent level. This suggested the reagent required more time to produce the full effect, and a less than 100 percent mortality would be expected given the short exposure time-period and static-test data. Also, at the time it was not known that the reagent concentration could have been less than anticipated because of the foot-valve problem. The mean mortality (D-form and umbonal form mussels) rate in this treatment sample was still appreciable at 69 percent, while it was 15 percent in the control.

The other five samples were held in their respective tanks for 72 to approximately 96 hours. In all these samples the mortality rate for D-form and umbonal form mussels was 100 percent. The data indicates that 100 percent mortality might be achieved between 21 and 72 hours after first exposed to the reagent. The mean mortality in the controls for these samples ranged from 0 to 14 percent. As discussed in section 2.1, this control sample mortality is natural, and the range of natural-mortality-rates observed in the study is often typical of mortality in raw river water.

Although not studied in detail, there was no noticeable effect on Ostracods or Copepods, in the treatment samples. Other organisms such as rotifers and nematodes, were also observed to be live and apparently healthy in the treatment samples, while there was 100 percent mortality in the zebra mussel plankton. The detritus in the river water was often found loosely clumped in the treatment samples and bottom-oriented organisms were often found associated with these detrital-clumps.

After mixing the reagent with raw water and holding the mixture for several hours there was olfactory indication that bacteria had begun to breakdown the reagent. The reagent appeared to have little if any effect on pH, and when water movement and/or aeration was maintained dissolved oxygen was similar in treatment and control chambers. Oxygen depression is anticipated to be partially an artifact of containment in test chambers in association with natural degradation. The data indicates variation in oxygen will be insignificant in full scale injections. The potential for oxygen to be a factor in the 2002 study was eliminated by using in-chamber aeration as described.

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4.0 Conclusions

As in the 2000 static-tests, the 2002 flow-through study data indicated the starch-based reagent can be used to proactively control D-form and umbonal-form zebra mussels at a mortality rate of 100 percent. One-hundred percent mortality was achieved with relatively low concentrations, ranging between about 4 and 17 mg/l of whole starch-based product, in 72 hours or less. Reports of independent laboratory tests (seven day replacement toxicity and whole effluent tests as prescribed by State and Federal agencies), indicated acceptable minimal to no effect on none target, test organisms. Data indicated that the reagent breaks down naturally and rapidly when exposed to raw river water. This natural breakdown is an environmentally-friendly factor.

The potential for the starch-based reagent to control zebra mussels has prompted Entergy, a large energy corporation and water user with zebra mussel fouling and related operational problems, to investigate a long-term application of the reagent at an Entergy facility. This project would be conducted in early 2003.

* During the period of the studies outlined in this report, Beak, its offices, equipment, and contracts were purchased by Stantec. All Beak employees also transferred to Stantec.

5.0 References

Lewis, P.A., D.J. Klenm, J.M. Lazorchak. 1994[1], "Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms. Fathead minnow, *Pimephales promelas*, Larval Survival and Growth Test" Method 1000.0. EPA/600/4-91/002. Environmental Monitoring Systems Laboratory - Cincinnati Office of Research and Development. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Lewis, P.A., D.J. Klenm, J.M. Lazorchak. 1994[2]. "Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms". EPA/600/4-91/002. Environmental Monitoring Systems Laboratory - Cincinnati Office of Research and Development. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

Sincerely,
STANTEC CONSULTING SERVICES INC.

A. Garry Smythe
Senior Scientist/Project Manager

Stantec

FishPro Consulting Engineers and Scientists
5201 South Sixth Street Road, Springfield, IL 62703-5143

TELECON SUMMARY

Person Richard Cameron **Date** 3-18-05

Phone No. 866-227-5539 **Time** ____ ___ AM X PM

Company: Barkley Distribution, LLD **FishPro No.** ____

Project: Zebra Mussel Study **Project No.** 05003

Regarding Activated Starch Reagent

Phase ___ Proposal ___ Design ___ Bidding ___ Construction X Other

Discussion & Comments: ___ Call Incoming ___ Outgoing X Returning

Richard Cameron is the scientist that developed the Barkley Zebra Mussel Reagent. He informed FishPro that the food-grade starch molecule acts as a carrier after being subjected to a proprietary treatment that activates the molecule. He conveyed that the reagent has been used in closed systems and open discharges to proactively treat zebra mussel infestations and that Barkley Distribution would be interested in researching use of their proprietary reagent in an open water system. The reagent is typically administered via remote surface application utilizing point stations that are connected through satellite. After the reagent is administered, it is believed that the zebra mussels ingest the starch and consequently tear apart. Mr. Cameron believes the reagent is capable of producing 100% mortality of all life stages without any harm to other aquatic species or the environment and confirmed that this reagent is EPA approved for zebra mussel control. Although, he also commented that if the zebra mussel is not killed that development is prevented, suggesting that mortality rates may not be 100%. After an inquiry about price, we were informed that the prices are very competitive, but estimates can only be determined after a proper system to deliver the reagent is developed at the site. Mr. Cameron feels that the product has been fully tested and proven in zebra mussel control and encouraged us to contact the person that conducted the toxicity testing, Gary Smythe.

Follow-up Required and By Who

Contact Gary Smythe as a group.

Shaw Environmental Group

716-871-2021

garry.smythe@shawgrp.com

Copies to: Matt Cochran Telecon Prepared by: Meghan Oh

Ryan Keith

End of Telecon

FishPro Consulting Engineers and Scientists
5201 South Sixth Street Road, Springfield, IL 62703-5143

TELECON SUMMARY

Person A. Garry Smythe **Date** 3-21-05

Phone No. 716-871-2021 **Time** ____ X AM ___ PM

Company: Shaw Environmental **FishPro No.** ____

Project: Zebra Mussel Study **Project No.** 05003

Regarding Activated Starch Reagent

Phase ___ Proposal ___ Design ___ Bidding ___ Construction X Other

Discussion & Comments: ___ Call Incoming ___ Outgoing X Returning

FishPro contacted senior researcher A. Garry Smythe formerly of Stantec, now with Shaw Environmental on March 21, 2005 to inquire about the proprietary activated starch reagent developed by Barkley Resources Group (BRG), which has been used to control zebra mussels. Mr. Smythe has conducted case studies on the effectiveness of the BRG starch-based product. Research has shown that the starch reagent should be applied proactively and is biodegradable and has no known environmental impacts. While the mode of action remains unknown, Smythe reported that most zebra mussels treated with the starch reagent exhibited a response (i.e., mortality) usually within 24 to 48 hours. Smythe estimated costs of the starch product would likely be higher than chlorine but lower than molluscicides. Mr. Smythe stated that the product had promise to control zebra mussels in smaller, controlled type settings but remained largely unproven for applications in a large open water environment.

Follow-up Required and By Who

Copies to: Matt Cochran
Meghan Oh

Telecon Prepared by: Ryan Keith

End of Telecon

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-C. Surveys and Data for Ossawinnamakee Lake and Pelican Brook

FISHPRO
Consulting Engineers & Scientists
A Division of Cochran & Wilken, Inc

Site Code:320

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

River or Stream Survey
Date(s) of Field Work June 21 to August 24, 2000

Initial Survey X
Resurvey X

Leader Lloyd Anderson
Assistant(s) See notes

NAME, LOCATION, AND FLOW CHARACTERISTIS

1. Stream Name Pelican Brook
2. Alternate Name(s) None
3. Tributary Number M-106-2
4. Counties Crow Wing
5. Watershed Name and Number Mississippi Headwaters 15
6. Sequence of Waterways to Basin To Pine River to Mississippi River
7. Map(s) Used Crow Wing Co. Platt book, U.S.G.S. Quadrangles- Lower Whitefish 1994, Tromald 1959, Pelican lake 1994, Arial Photos CCW 20-64, CCW 21-67
8. Length of Stream 8.4 miles (2000)
9. Average Width-Upper Station 29.8' Lower Station 54.0'
10. Mouth Location T. 136N R. 27W S. 8
11. Flow at Mouth 50.6 cfs. Date 7-25-00
12. Flow at Gaging Station-Minimum NA cfs Average cfs
13. Location of Gaging Station NA
14. Initial Source of Sustained Flow Ossawinnamakee Lake 18-352
15. Gradient 1.0 ft/mile
16. Sinuosity 1.3

WATERSHED DESCRIPTION AND USE

17. Description of Watershed (soil types, cover types, topography, land use age and ownership.

a. Entire Watershed The watershed that drains into Pelican Brook is comprised of 9 fishing lakes plus numerous smaller bodies of water. Many of these lakes are heavily developed. Along the stream, the watershed is characterized by well drained sand to sandy loam soils on moderately sloping hills. Aside from lake homes, most of the land is in a wild state.

b. Land adjacent to stream Private ownership accounts for 50% of the land, with Northwest Paper Company owning 35% and the rest divided between the state and county. The upper ½ is lined with sedge, alder, and other lowland species. The lower ½ is mainly oak, birch, aspen, jackpine and other upland species.

Orig.
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GENERAL INFORMATION ON THE STREAM

18. Reason for Survey obtain basline data. Crow Wing County is experiencing rapid population growth and development.
19. Previous Investigations and Surveys None known
20. Special Problems or Conditions None known

21. Sources of Polution None known

Source	Loc(mi. from mouth)	Substance discharged

22. Erosion

Type	Degree	Affected Reach
Bank	Moderate	8.3

23. Stream Alterations (dredging, channeling) - location and date None known
24. Dams and other obstructions (including beaver dams)

Type	Mi. from Mouth	Head	Length of Dam	Type of Control Structure	Use	Fish Barrier	Owner	Status
Loose Rock	1.0	0.3	50'			No		

25. Use of Water: Fishing X Recreation X Com.Nav. ___ Power ___ Irrigation ___ Livestock Watering ___ Other (specify) ___

26. Access (location and ownership) There are no designated accesses. Access to the stream must be obtained through private property, public land, and road crossings.
27. Shoreline Developments Homes located at miles 0.9, 4.3, 4.4, 7.0, 8.3, paddy rice operation located at mile 1.0

28. Recreational Boating - a) Navigable reach 0.0-8.4
    b) Type of Boating canoe travel, (recreation, hunting, fishing)

29. Tributaries/Springs

Names and/or Tributary Numbers	IN Number	Bank (R or L)	Length Miles	Width at Mouth (feet)	Miles from Mouth	Flow (c.f.s.)	Stage (high, normal low)	Temp. °F Mouth Air	Temp. °F Mouth Water	Temp. °F Source Air	Temp. °F Source Water	Time	Date
IN4	18-345 Lake	L	0.6	No definiate channel	7.7	-	N	60	61			1030	6-21-00
IN3	Tamarac Bog	R	0.02	0.5	6.6	0.5	N	72	50			1130	6-21-00
IN2	Spring	R	0.001	1.0	5.55	Slight	N	72	54			1155	6-21-00
IN1	Alder Bog	L	0.01	2.0	5.50	Slight	N	72	50			1210	6-21-00

Remarks

(30) Stream Physical Characteristics

a) station no.	1	2	3	4
b) Date	7-25-00	7-26-00	7-27-00	7-28-00
c) Loc. (mi. from mouth	0.10	3.75	6.85	8.15
d) Length of station	500'	500'	500'	500'
e) % of station in:				
Pools	5	10	12	26
Riffles and rapids			22	
Runs	95	90	66	74
Other (list)				
f) Average width (ft.)	54.0	46.4	41.4	29.8
g) Average depth (ft.)	1.0	1.4	1.4	1.7
h) Flow (cfs)	50.6	60.8	76.8	85.5
I) High water mark	1.2	0.8	1.2	0.8
j) Present stream stage (high, normal, low)	L-N	N	N	N
k) Banks:				
Average height	1.2	1.1	1.3	0.9
Height range	0.3-2.2	0.2-3.3	0.2-12.0	0.6-2.2
Erosion(lt.,mod.,severe)	light	light	light	moderate
% grazed	0	0	0	0
% ditched or channeled	0	0	0	0
l) Shade[1]	light	light	moderate	light
m) Pools[2]				
Average width	16	50	24	18
Width range				16-20
Average depth	1.8	2.2	1.9	3.0
Maximum depth	2.6	3.0	3.3	4.1
Type - No. of each				
A		1	1	1
B	1			
C				1

Pools (Continued)

Station	1	2	3	4
Bottom type - %				
Boulder				
Rubble				
Gravel		10		4
Sand	50	10		68
Silt	50	80	100	28
n) Riffles and rapids				
Average width			55	
Width range			50-60	
Average depth			1.2	
Maximum depth			1.5	
Max. velocity range (fps)			1.3	
Bottom type - %				
Boulder				
Rubble			3	
Gravel			97	
Sand				
Silt				
o) Runs:				
Average width	56	46	40	34
Width range		45-47	39-41	32-37
Average depth	1.0	1.3	1.4	1.3
Maximum depth	1.4	2.6	1.9	2.2
Max. velocity range (fps)	1.7	1.1	1.1	1.7
Bottom type - %				
Boulder				
Rubble	1			
Gravel	8	35	63	1
Sand	85	60	30	93
Silt	6	5	7	5
Marl				1
Average width				
Average range				
Average depth				
Station	1	2	3	4
Maximum depth				
Velocity range (fps)				

Bottom type - %				
DATA PERTAINING TO SIMILAR REACH				
q) Location (mi. to mi.)	0.0-8.4			
r) Gradient (ft./mi.)	1.0	(1206-1198)		
s) Sinuosity	1.3			
t) Channel changes (slight, mod. exten.)	slight			

[1] Shade:
- light
- moderate
- heavy

[2] Pool types:
- A -
- B -
- C -
- D -

[3] Bottom types:
- Ledge rock -
- Boulder -
- Rubble -
- Gravel -
- Sand -
- Silt -
- Clay -
- Muck -
- Detritus -
- Marl -

31) Characteristics of Water

a) Station no.	1	2	3	4
b) Date	7-25-00	7-26-00		
c) Loc. (mi. from mouth)	0.10	3.75		
d) Length of station	500'	500'		
e) Time	1400	1420		
f) Air temp. ºF.	80	78		
g) Water temp. ºF.	77	78		
h) Color	Clear	Clear		
I) Cause of color				
j) Secchi disc. (ft.)				
FIELD DETERMINATIONS: Diss. oxygen (ppm)				
Free carbon dioxide (ppm)				
FIELD DETERMINATION OR LABORATORY ANALYSIS 7-6-00 (Indicate by F or L) Total alkalinity (ppm) L	119	117		
Conductivity (micromhos/cm) L	248	241		
pH L	8.08	8.13		
LABORATORY ANALYSIS Total nitrogen (ppm)				
NH_3 (ppm)				
NO_2 (ppm)				
NO_3 (ppm)				
Total phosphorus (ppm) L	0.024	0.014		
Orthophosphates (ppm)				
Sulfate ion (ppm)				
Chloride ion (ppm) L	1.8	2.0		
B.O.D. (ppm)				
or C.O.D. (ppm)				
Turbidity (JTU)				
Tot. diss. solids (ppm) L	158	168		

Remarks

(32) Temperature Profile

Date	Location (miles from mouth)	Water Temp.	Air Temp.	Water Stage	Time	Cloud Cover
8-24-00	0.1	77	84	N	1708	Clear
8-24-00	4.4	78	84	N	1700	Clear
8-24-00	8.4	75	84	N	1652	Clear

Remarks:

(33) Biological Characteristics

a) Station no.	1	2	3	4
b) Date	7-25-00	7-26-00	7-27-00	7-28-00
c) Loc.(miles from mouth)	0.10	3.75	6.85	8.15
d) Length of station	500'	500'	500'	500'
e) Aquatic plants or filamentous algae:[1] Species	Abundance	Abundance	Abundance	Abundance
Arrowhead	R		O	O
Bluntleaf Pondweed	C	O		
Canada Waterweed	O	O	O	
Chara		C	A	A
Claspingleaf Pondweed	R	R		R
Common Cattail		R	R	O
Coontail	R	C	O	
Filamentous Algae	O	C	C	
Great Water Dock		R		
Great Duckweed		R	R	
Hardstem Bulrush			R	
Lesser Duckweed	R	O	R	
Mud Plantain	O	O	A	O
Narrowleaf Cattail				C
River Pondweed	O			
Sago Pondweed	C	A	A	A
Sedge		R	O	O
Spikerush			R	
Water Moss		R		
Water Starwort		R		
White Waterlily	R	O	O	C
Wild Celery		A	A	

[1] Plant or algae abundance
A = Abundant C = Common O = Occasional R = Rare P = Present

f) Distribution of Aquatic Plants: ______

(33) Biological Characteristics

a) Station no.	1	2	3	4
b) Date				
c) Loc. (miles from mouth)				
d) Length of station				
g) Common invertebrates: order or family (check blank if present)	Samples taken , but not identified			
Aeshnidae				
Baetidae				
Belostomatidae				
Cambaridae				
Ceratopoganidae				
Chironomidae				
Coenagrionidae				
Coenidae				
Calopterygidae				
Corduleogastridae				
Corixidae				
Culicidae				
Dytiscidae				
Elmidae				
Ephemeridae				
Erpobdellidae				
Gamphidae				
Gerridae				
Glossiphoniidae				
Gyrinidae				
Halipidae				
Helicopsychidae				
Heptageniidae				
Herbridae				
Hydrobiidae				
Hydropsychidae				
Leptoceridae				
Limnaeidae				
Limenphilidae				
Macromiidae				
Perlidae				

34) Fishery Characteristics

a) Station no.	1		2		3		4	
b) Date	8-17-00		8-17-00		8-17-00		8-17-00	
c) Loc. (miles from mouth)	0.10		3.75		6.85		8.15	
d) Length of station	500'		500'		500'		500'	
e) Gear Station Smith-Root 2.5 GPP pull behind shocker	Volts 120 Percent 30 AMPs 3.0 High Range		Volts 120 Percent 40 AMPs 3.8		Volts 120 Percent 40 AMPs 3.2		Volts 120 Percent 40 AMPs 3.3	
f) Amt. of sampling effort	20.5 minutes		14.5 minutes		21.7 minutes		19.8 minutes	
g) Species Present	No.	Wt.	No.	Wt.	No.	Wt.	No.	Wt.
Central Mudminnow	3							
Northern Pike	2		1				1	
Brassy Minnow	10		9		7			
Horneyhead Chub	106		29		110		17	
Common Shiner	38		54				5	
Spotfin Shiner	29		5		2			
Mimic Shiner	12							
Bluntnose Minnow	10				1			
Fathead Minnow			2					
Blacknose Dace	3		24		87			
Longnose Dace	1		3		5			
Creek Chub			1					
White Sucker	20		22		19		20	
Yellow Bullhead			1				1	
Tadpole Madtom	5		8		5		4	
Burbot	6							
Brook Stickle Back	7							
Rock Bass	56		19		24		27	
Hybrid Sunfish	1		3		13		30	
Pumpkinseed	1				2		3	
Bluegill	30		18		63		74	
Largemouth Bass	4		3		4		4	
Johnny Darter	48		10		12			
Yellow Perch	2		19					
Log Perch	2		3		2		8	
Walleye					2			

Remarks: A reasonable effort was made to capture all stunned fish.

Total length in inches/Species	Northern pike	Horny-Head Chub	White Sucker	Yellow Bullhead	Tadpole Madtom	Burbot	Rock Bass	Hybrid Sunfish	Pumpkin-seed	Bluegill	Large-mouth bass	Yellow Perch	Walleye
1.5-1.9							6						
2.0-2.4		1			4		2				3		
2.5-2.9		12	2				16	1	1	2	2		
3.0-3.4		7	2				18			15		1	
3.5-3.9		6			1		5	1	3	22		9	
4.0-4.4		6					14	6	1	22	1	9	
4.5-4.9		5	1				10	2	1	13		3	
5.0-5.4		3	1	1			7	6		6		4	
5.5-5.9			2				10			3	1	1	
6.0-6.4	1		1				10	2		4		2	
6.5-6.9			2			2	5			1			
7.0-7.4			1				7			1			
7.5-7.9			5				3				1		
8.0-8.4			8										
8.5-8.9			10			1	1				1		
9.0-9.4			5	1		1					3		1
9.5-9.9			15										1
10.0-10.4			6										
10.5-10.9			7			1							
11.0-11.4			6										
11.5-11.9			6			1					1		
12.0-12.4			1								2		
12.5-12.9													
13.0-13.4													
13.5-13.9	2												
18.0-18.9	1												
Totals	4	40	81	2	5	6	114	18	5	89	15	29	2

(36) Age and Growth of Gamefish NO SCALES TAKEN

a) Age class distributions

Species	Sample Size	Subsample size	Number of fish in age group I	II	III	IV	V	VI	VII	VIII
Bluegill	27	27		13	8	5	1			
Largemouth bass	13	13		1	4	3	2			
Northern Pike	3	3	2	1						
Walleye	2	2	2							

b) Growth of gamefish NO SCALES TAKEN

Species	Calculated mean total length at time of last annulus formulation I (N)	II (N)	III (N)	IV (N)	V (N)	VI (N)	VII (N)	VIII (N)
Bluegill		2.86 (13)	4.35 (8)	5.46 (5)	6.68 (1)			
Largemouth Bass	2.25 (1)	6.41 (4)	7.95 (3)	10.81 (2)				
Northern Pike	9.70 (2)	13.43 (1)						
Walleye	5.17 (2)							

(37) Escape Cover for Gamefish

Similar reach	Type[1] and Amount[2] of Cover
1) 0.0-8.4	LJ-O, OV-F, UB-O, IV-F
2)	

[1]Cover types:
- LJ - log jam
- B - boulders
- OV - overhanging vegetation
- UB - undercut bank
- IV - instream vegetation

[2]Amount of cover:
- S - Scarce
- O - occasional
- F - frequent

(38) Portion of Stream Suitable for Gamefish

Species	Suitable Reach (mi. to mi.)
Northern pike (small)	0.0-8.4
Bluegill (small)	0.0-8.4

(39) History of Stream and Fishing Conditions

a) Comparisions with past investigations and surveys. None known

b) History of fishing conditions Angling is rarely pursued on Pelican Brook. One canoe party was encountered during the survey. Their intent was to begin fishing seriously once they reached Pine River. There does not appear to be significant numbers of white sucker running in the spring time to attract spearers.

(39) History of Stream and Fishing Conditions (continued)

c) Records of past management None Known

Fish Stocking

Special regulations NONE KNOWN			
Year Installed	Type and Amount	Location Cost (mile to mile)	Present Condition

(40) Discussion of Fishery

a) General charateristics: Little effort is put forth to catch fish in Pelican Brook. The most available fish species would be the numerous small bluegills and occasional norhtern pike.

(40) Discussion of Fishery (continued)

b) Fish management problems Lack of cover in the form of deep water pools severely restricts the size of the fish.

(41) Ecological Classification of Waterway Class 12- warmwater gamefish
Bluegill, Largemouth bass, Northern pike

(42) Summary Pelican Brook is a shallow, warmwater stream, 8.4 miles in length. It connects the Ossawinnamakee chain of lakes to the sizeable Pine River. While not known for sport fishing, it does offer a safe and scenic canoe route for day trippers. Development is sparse along the stream and most of the immediate watershed is in a wild state. Six bridges cross Pelican Brook. These consist of 2 hiway, snowmobile, and 3 private wooden structures. Several old beaver dams are present but do not impede the stream. The substrate is mostly sand, and instream vegetation is common. Snails cover the bottom the entire length of the stream. A rice paddy and cranberry operation is located on the north side at mile 1. An assortment of of minnow species are present, including the horney head chub. Bluegill sunfish are the most abundant gamefish, but average only 3 to 5 inches in length. Also present are small pumpkinseed, northern pike and largemouth bass. Two 9 inch walleyes were captured at station 3. Scale aging indicated good growth for all species. According to a man who has resided at mile 4.3 for the last 20 years, there has never been a spawning run of walleyes and only a small amount of white sucker adults. Rapid growth in the Brainerd area will likely face Pelican Brook with the prospect of increased development.

(43) Credits and Signatures

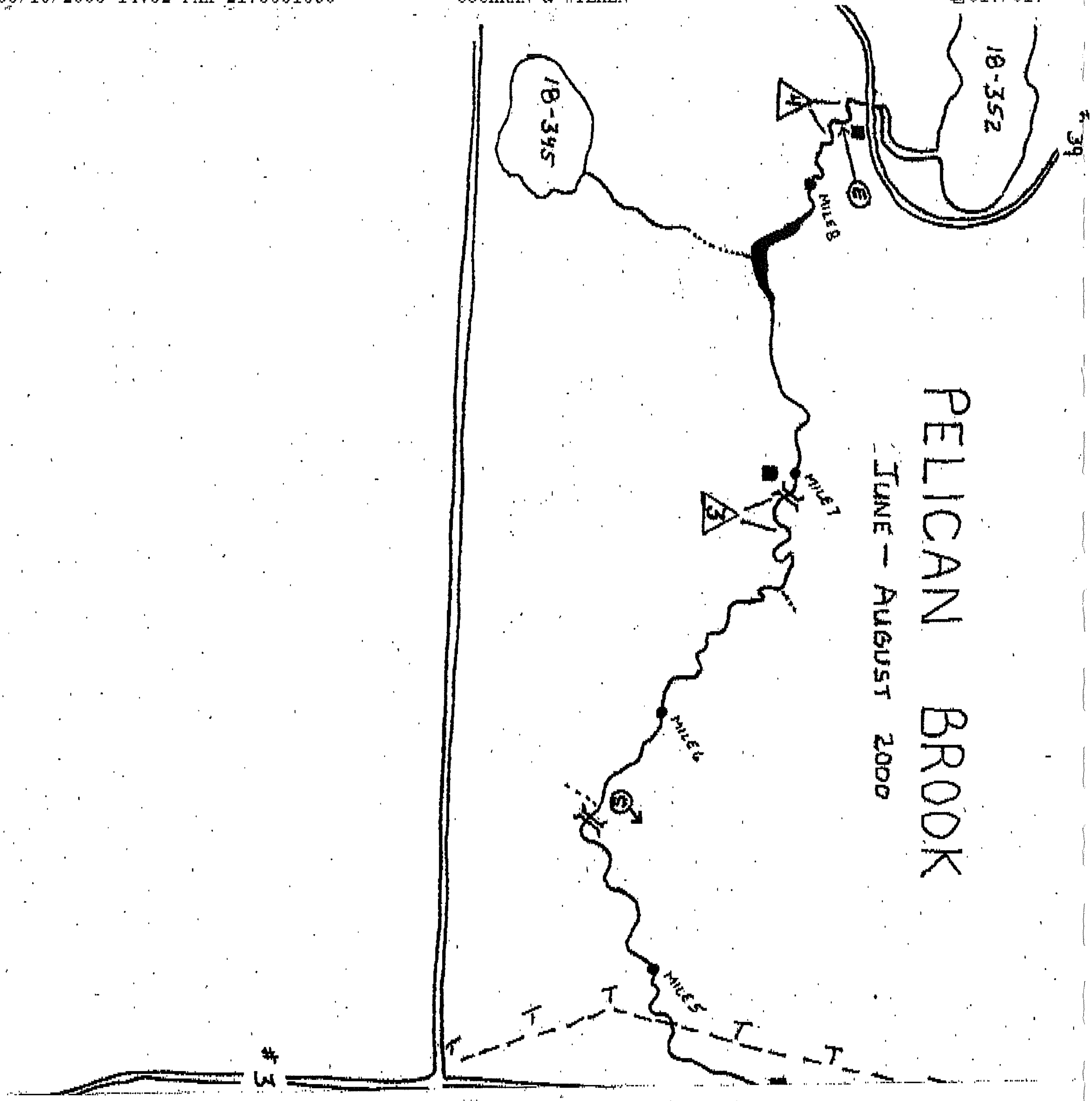
a) Funding

b) Field work by
Name of crew leader Lloyd Anderson
Name of aide(s) Tim Brastrup, Jerry Grant, Paul Radomski, Kevin Woizeschke, Ruth Ziegler

c) Completed report by
Name Lloyd Anderson
Title Fisheries Technician

TJB
Approved by Timothy J. Brown Date 04-27-2001
Regional Fisheries Manager

Typist's Initials: rz


PELICAN BROOK
JUNE - AUGUST 2000
18-345
18-352
MILE 8
MILE 7
MILE 6
MILE 5
#3

11/10/94

Minnesota Department of Natural Resources
Section of Fisheries

Lake Survey Report

Division of Waters inventory number:	18-0352-00	Starting date of survey:	06/21/93
Lake name:	OSSAWINNAMAKEE	Alternate name:	N/A
Lake class number:	25	Alternate classes:	NA
Area-code:	320	Map ID:	B0012
Survey-type:	Resurvey		

Lake Location Information

Counties: Crow Wing
Nearest town: Ideal Corners
Legal description: Township - 136N; Range - 28W; Sections - 2, 3, 4, 5

Public Access

ID#	Ownership	Type	Location Description / Comments
AC- 1	Minnesota DNR	Concrete	T.136; R.28; S.2; LOT 2 D.N.R. OWNERSHIP Located on East end of lake.

Previous Surveys and Investigations

Initial Survey:
Resurveys: 1983;
Population assessments: 1988;1979;
Creel surveys:
Other kinds of survey:

Lake and Watershed Characteristics

Lake area (acres):	644	Shoreline length (mi):	13.13
Area in MN (acres):	644	Maximum fetch (mi):	N/A
DOW area (acres):	739	Fetch orientation:	E
Littoral acres:	225.4	Watershed size (acres):	N/A
Maximum depth (feet):	63	Major watershed number:	11
Mean depth (feet):	N/A	Minor watershed number:	N/A
Primary USGS Quad map code:	L13B		

Surrounding Watershed Characteristics (continued)

Use / Coverage	% Use	Relief	Location / Comments
Other	20	Rolling	Residential devel around lk & scattered.

Dominant soil types: Sand; Glacial Till
Comments about soils: Mostly loamy sand.

Shoreline Characteristics

Use / Coverage	% Use	Relief	Location / Comments
Undeveloped forest or woodland	75	N/A	Mixed hardwood w/scattered conifers.
Marshland	5	Flat	Larger areas on S side.
Residential	20	Gradual	Very well devel around entire lk

Number of homes/cabins: 277
Comments about shoreline development: Horseshoe channel SW shore, 12-unit condo on N sho

Resorts / Campgrounds

ID#	Name	Cabins	Campsites	Comments
RE-1	Twin Points	10	0	0
RE-2	Popular Point	6	0	Campsites available
RE-3	Woodlawn	6	4	N/A
RE-4	Highview Campground	0	132	100 elect sites, 32 tent sites.

Aquatic Vegetation and Shoalwater Substrates

Number of transects: 30
Maximum depth of aquatic vegetation sample (ft): 20.0
Dates of field work: 08/03/94 through 08/04/94

Abundance of Aquatic Plants

Common Name	Type	Frequency of Occurence (%)	Abundance Rating	Mean Abundance
Muskgrass	Submergent	90	Abundant	71.7
Sedge	Emergent	50	Rare	31.7
Sedge	Emergent	13	Rare	4.4

Abundance of Aquatic Plants (continued)

Common Name	Type	Frequency of Occurence (%)	Abundance Rating	Mean Abundance
Coontail	Submergent	83	Common	42.8
Carex (Sedge)	Emergent	13	Rare	2.2
Needlerush	Emergent	10	Rare	6.1
Canada Waterweed	Submergent	93	Common	56.7
Spikerush	Emergent	3	Rare	1.7
Filamentous Algae	Submergent	30	Rare	13.9
Mud Plantain	Emergent	10	Rare	2.8
Blue Flag	Emergent	3	Rare	0.6
Rushes	Emergent	10	Rare	1.7
Rush	Emergent	3	Rare	0.6
Lesser Duckweed	Submergent	10	Rare	3.9
Northern Water Milfoil	Submergent	90	Common	58.3
Bushy Pondweed	Submergent	20	Rare	6.7
White Waterlily	Submergent	47	Rare	14.4
Yellow Waterlily	Submergent	30	Rare	19.4
Little White Waterlily	Submergent	30	Rare	5.0
Largeleaf Pondweed	Submergent	27	Rare	10.0
Variable Pondweed	Submergent	47	Rare	15.6
Cane	Emergent	7	Rare	2.2
Illinois Pondweed	Submergent	43	Rare	19.4
Floatingleaf Pondweed	Submergent	30	Rare	8.3
Water Smartweed	Submergent	3	Rare	0.6
Pondweed	Submergent	3	Rare	0.6
Claspingleaf Pondweed	Submergent	97	Common	36.1
Broadleaf Pondweed Group	Submergent	10	Rare	2.8
Narrowleaf Pondweed Group	Submergent	3	Rare	0.6
Sago Pondweed	Submergent	83	Common	35.0
Robbins' Pondweed	Submergent	3	Rare	0.6
Narrowleaf Pondweed	Submergent	67	Rare	26.7
Largesheath Pondweed	Submergent	20	Rare	8.9
Flatstem Pondweed	Submergent	97	Common	58.3
White Water Buttercup	Submergent	3	Rare	1.7
Great Water Dock	Emergent	7	Rare	1.1
Hardstem Bulrush	Emergent	20	Rare	11.1
Arrowhead/Duck Potato Group	Emergent	17	Rare	3.9
Wool Grass	Emergent	3	Rare	0.6
Threesquare	Emergent	10	Rare	1.7
Floatingleaf Burreed	Submergent	3	Rare	2.8
Stiff Wapato	Emergent	20	Rare	3.3
Common Cattail	Emergent	13	Rare	3.3
26 Wild Celery	Submergent	20	Rare	7.8
Wild Rice	Emergent	3	Rare	1.7

Notes: 1. Floating-leaf species are tallied with emergent species
2. See User's Manual for calculation details.

Fish Diseases and Parasites (continued)

Species	Disease/ Parasites	# of Fish	Number Examined
Black Bullhead	None observed	4	
			4
Bluegill	Neascus	34	
Bluegill	Open Sores/Hemorrhages	1	
Bluegill	None observed	13	
			48
Bowfin (Dogfish)	None observed	2	
			2
Brown Bullhead	None observed	5	
			5
Green Sunfish	Neascus	1	
Green Sunfish	None observed	2	
			3
Hybrid Sunfish	Fungus	1	
Hybrid Sunfish	Neascus	17	
Hybrid Sunfish	None observed	19	
Hybrid Sunfish	Yellow Grub	1	
			38
Largemouth Bass	None observed	2	
			2
Northern Pike	Neascus	8	
Northern Pike	Open Sores/Hemorrhages	3	
Northern Pike	None observed	23	
			34
Pumpkinseed Sunfish	Neascus	7	
Pumpkinseed Sunfish	None observed	18	
			25
Rock Bass	Neascus	4	
Rock Bass	None observed	21	
Rock Bass	Yellow Grub	2	
			27
Shorthead Redhorse	Open Sores/Hemorrhages	1	
Shorthead Redhorse	None observed	3	
			4
Silver Redhorse	Open Sores/Hemorrhages	3	
Silver Redhorse	None observed	4	
			7
Smallmouth Bass	None observed	1	
			1
Tullibee (Cisco)	Tumors	1	
Tullibee (Cisco)	None observed	24	
			25
Walleye	None observed	11	
			11

Fish Diseases and Parasites (continued)

Species	Disease/ Parasites	# of Fish	Number Examined
White Sucker	None observed	11	
			11
Yellow Bullhead	None observed	29	
Yellow Bullhead	Yellow Grub	2	
			31
Yellow Perch	Neascus	1	
Yellow Perch	None observed	1	
Yellow Perch	Yellow Grub	4	
			6

Sampling of Natural Reproduction - Boat Electrofishing

No data reported in ELECTROF.DBF

Sampling of Natural Reproduction - 1/4 Inch Trapnets

No data reported in TESTNET.DBF

Sampling of Natural Reproduction - Seining

Number of sein hauls: 3
First haul on: 08/25/93
Last haul on: 08/25/93
Sampling method: Standard sampling.

Seining Catch

Species	Total YOY	Number Age >1	Number YOY Measured	YOY Mean Length (in)	YOY Length Range (in) Minimum	Maximum
Banded Killifish	0	31	0			
Bluegill	0	64	0			
Bluntnose Minnow	0	17	0			
Fathead Minnow	0	1	0			
Green Sunfish	0	7	0			
Hybrid Sunfish	0	5	0			
Iowa Darter	0	18	0			
Logperch	0	11	0			

03/08/2004

Minnesota Department of Natural Resources
Section of Fisheries

Lake Survey Report

Division of Waters inventory number: 18-0352-00
Lake name: OSSAWINAMAKEE
Lake class: 25
Area code: 320
Survey type: Population assessment

Starting date of survey: 06/23/2003
Alternate name: N/A
Alternate classes: N/A
Map ID: B0012

Lake Location Information

Counties: Crow Wing
Nearest town: Ideal Corners
Legal description: Township - 136N; Range - 28W; Sections - 2, 3, 4, 5
Township - 137N; Range - 28W; Sections - 2, 33, 34

Public Access

ID #:	Ownership:	Type:	Location Description and Comments:
AC- 1	Minnesota DNR	Concrete	Located on the east end, off Co.Rd. 39.

Previous Surveys and Investigations

Initial Survey:
Resurveys: 1993;1983;
Population assessments: 1998;1988;1979;
Special assessments: 1994;
Creel surveys:
Other kinds of survey:

Lake and Watershed Characteristics

Lake area (acres): 644
Area in MN (acres): 644
DOW area (acres): 739
Littoral acres: 225
Maximum depth (feet): 63
Mean depth (feet): N/A
Primary USGS Quad map code: L13b

Shoreline length (mi): 13.1
Maximum fetch (mi): 2.2
Fetch orientation: E
Watershed size (acres): N/A
Major watershed number: 11
Minor watershed number: 061

Physical and Chemical Characteristics of Lake Water

Station ID	Sampling Date	Bottom Depth (ft)	Depth (ft)	Water Temperature (F)	Dissolved Oxygen (ppm)
WQ-1	6/23/2003	50.0	0.0	72.3	9.0
			5.0	72.1	9.3
			10.0	72.1	9.3
			12.0	71.4	9.4
			13.0	70.7	10.0
			14.0	69.6	10.1
			15.0	68.0	10.2
			16.0	66.4	10.6
			17.0	65.5	10.7
			18.0	64.0	11.2
			19.0	61.9	11.2
			20.0	60.3	10.6
			21.0	57.9	10.8
			22.0	56.5	9.7
			23.0	55.0	9.1
			24.0	53.1	7.4
			25.0	52.5	6.6
			26.0	51.8	5.1
			27.0	51.1	3.7
			28.0	50.5	2.8
			29.0	49.8	2.2
			30.0	49.3	1.6
			31.0	48.9	1.4
			32.0	48.7	1.3
			33.0	48.4	1.2
			34.0	48.0	1.0
			35.0	47.8	0.8
			36.0	47.5	0.8
			37.0	47.1	0.8
			38.0	46.9	0.8
			39.0	46.8	0.8
			40.0	46.6	0.8
			45.0	46.2	0.7
			50.0	45.7	0.7
WQ-2	6/23/2003	65.0	0.0	72.1	10.4
			5.0	72.1	10.5
			10.0	72.1	10.3
			14.0	71.6	10.5
			15.0	68.9	11.5
			16.0	62.8	13.3
			17.0	60.6	13.9
			18.0	57.4	13.8

Physical and Chemical Characteristics of Lake Water (continued)

Station ID	Sampling Date	Bottom Depth (ft)	Depth (ft)	Water Temperature (F)	Dissolved Oxygen (ppm)
			19.0	55.2	14.4
			20.0	53.8	14.4
			21.0	50.7	14.8
			22.0	49.3	14.1
			23.0	47.8	13.0
			24.0	47.1	12.3
			25.0	46.2	11.7
			26.0	45.3	10.2
			27.0	44.8	9.0
			28.0	44.1	6.9
			29.0	43.2	5.1
			30.0	42.6	4.0
			31.0	42.1	1.8
			32.0	41.7	1.2
			33.0	41.5	1.0
			38.0	41.4	0.9
			45.0	40.8	0.9
			50.0	40.5	0.9
			55.0	40.3	0.8
			60.0	39.9	0.8

Water Quality

Station ID	Sample Date	Sample Depth	Secchi (ft)	pH	Alkalinity	Water Color	Color Cause
WQ-1	6/23/2003	N/A	23.0	N/A	N/A	Green	Algae
						Color description: very light, mostly clear	
WQ-2	6/23/2003	N/A	19.0	N/A	N/A	Green	Algae
						Color description: very light, mostly clear	

LAKE ASSESSMENT PROGRAM

1993

Lake Ossawinnamakee
(ID # 18-0352)
Crow Wing County, Minnesota

Minnesota Pollution Control Agency
North Central Regional Office
and
Water Quality Division

in cooperation with

Minnesota Department of Natural Resources

Lake Ossawinamakee Association

May 1995

TABLE 1
LAKE MORPHOMETRIC, WATERSHED, AND FISHERY CHARACTERISTICS
LAKE OSSAWINNAMAKEE

STORET ID:	18-0352
MORPHOMETRIC DATA	
Area in Acres (ha):[1]	649.3 (259.7)
Mean Depth in ft. (m):	21.6 (6.6)
Max. Depth in ft. (m):[2]	63 (19.2)
Volume in acre feet (hm):[3]	14,008 (17.3)
WATERSHED CHARACTERISTICS	
Watershed Area in Acres (ha):[4]	9,296 (3,718)
Watershed Area to Lake Surface Area Ratio:	14:1
Estimated Mean Hydraulic Residence Time:	6 to 7 years
FISHERIES DATA	
Lake Class[5]:	27
NUMBER OF PUBLIC ACCESSES	1
LAND USE DATA	
Shoreland Zoning:	General Development
Development Trends[6] (Homes)	
1967 Survey	
Seasonal	78
Permanent	16
Total	94
1982 Survey	
Seasonal	184
Permanent	60
Total	244

Land Use Percentages:

	Forest	Open Water	Marsh	Pasture	Cultivated	Residential
Ossawinnamkee	65.0	18.5	2.4	6.0	1.0	7.0
Crow Wing County	60.2	11.6	2.6	10.8	8.5	5.7
Northern Lakes Forests	50-80	15-30		0-6	<1	0-7

1 Taken from MDNR data

2 MDNR Fisheries data

3 Calculated by the MPCA

4 Calculated by the MPCA-Brainerd.

5 Lake Class has replaced the Ecological Classification - Centrarchid - for Lake Ossawinamakee (See Schupp, D. DNR Fisheries Investigational Report 417.)

6 MDNR data

Since the land use affects water quality, it is useful to divide the state into regions where the land use and water resources are similar. For Minnesota, this results in seven regions, referred to as "ecoregions." Ecoregions are defined by the soils, land surface form, natural vegetation, and current land uses within the area. Representative minimally-impacted lakes have been sampled in each region. Data from these lakes serves as a reference for evaluating the condition of other lakes in the ecoregion. Lake Ossawinnamakee is located in the Northern Lakes and Forest Ecoregion (Map 3).

The average annual precipitation in the Lake Ossawinnamakee Area Watershed ranges between 26 and 27 inches. The evaporation rate ranges between 34 to 36 inches (Gunard, 1985). The summer (May to September) precipitation averages about 17 inches.

Lake Ossawinnamakee Water Levels

The Minnesota Department of Natural Resources, Division of Waters has monitored Lake Ossawinnamakee levels in cooperation with volunteer readers since 1992. Other historical elevations were collected from various sources. The water level has fluctuated 1.8 feet since 1938, from a high of 1,206.85 on June 17, 1944 to a low of 1,205.04 on November 11, 1939. In comparison to other lakes, the water level fluctuation is fairly low. In the 1940's a diversion ditch with a dam was constructed between Lake Ossawinnamakee and Pelican Lake. It was built to receive water from Pelican during high water periods. Pelican has not outflowed through this diversion in many years. The lake outlets via a stop log dam at elevation 1,204.8 into Pelican Brook which leads into the Pine River (Figure 1).

LAKE OSSAWINNAMAKEE FISHERY CHARACTERISTICS

Lake Ossawinnamakee belongs to Lake Class 25 which is characterized by moderately large, deep lakes with low littoral area. Secchi disk transparencies are in the moderate range and alkalinity's are high.

The most recent fisheries survey on Lake Ossawinnamakee was conducted in 1993. The data, however, was not available as of the writing of this report. Therefore, the summary of the lake survey conducted in 1988 was used in this report. Fish species discussed include: walleye, northern pike, bowfin, northern cisco, white sucker, black bullhead, yellow bullhead, brown bullhead, rock bass, bluegill, largemouth bass and black crappie.

FIGURE 1

Ossawinnamakee Lake Crow Wing County

RECORDED WATER LEVELS

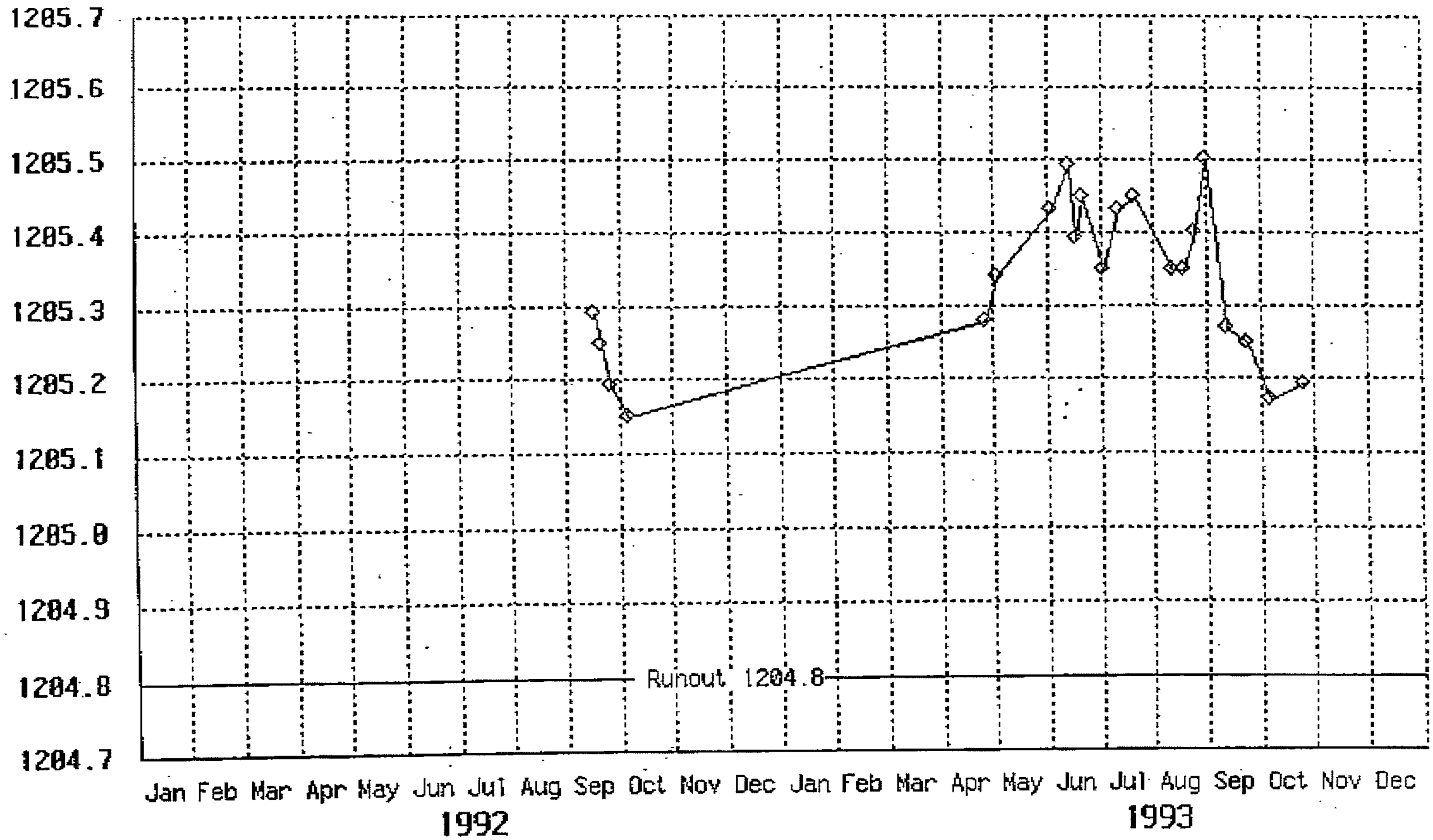


TABLE 3
AVERAGE SUMMER WATER QUALITY INDICATORS
Based on epilimnetic data from 1993
Lake Ossawinnamakee

Parameter	Lake Ossawinnamakee	Typical Range for Ecoregion[7]
Total Phosphorus (ug/l)	11.4	14-27
Chlorophyll a (ug/l) mean	3.12	<10
Chlorophyll a (ug/l) maximum	5.8	<15
Secchi disk (feet)[8]	16.8	8-15
Total Kjeldahl Nitrogen (mg/l)	.315	<0.75
Nitrite + Nitrate-N (mg/l)	.020	<0.01
Alkalinity (mg/l)	126.0	40-140
Color (Pt-Co Units)	10.0	10-35
pH (SU)	8.4	7.2-8.3
Chloride (mg/l)	1.47	<2
Total Suspended Solids (mg/l)	1.35	<2
Total Suspended Inorganic Solids (mg/l)	0.95	<2
Turbidity	0.730	<2
Conductivity (umho/cm)	210.0	50-250
TN:TP Ratio	31.8:1	25:1-35:1

stratification breaks down (due to cooling of the water and wind mixing) the phosphorus will be mixed into the water column and available for plant use. The highest hypolimnetic phosphorus concentration measured in Lake Ossawinamakee was 157 ug/L on September 20, 1993 at Site 103. The total summer mean hypolimnetic phosphorus was 45.5 ug/L for Site 101 and 106.5 ug/L

7 25 - 75th percentile of representative-minimally impacted (reference) lakes in the Northern Lakes and Forests Ecoregion (Heiskary and Wilson, 1988).

8 Includes CLMP data.

FIGURE 3

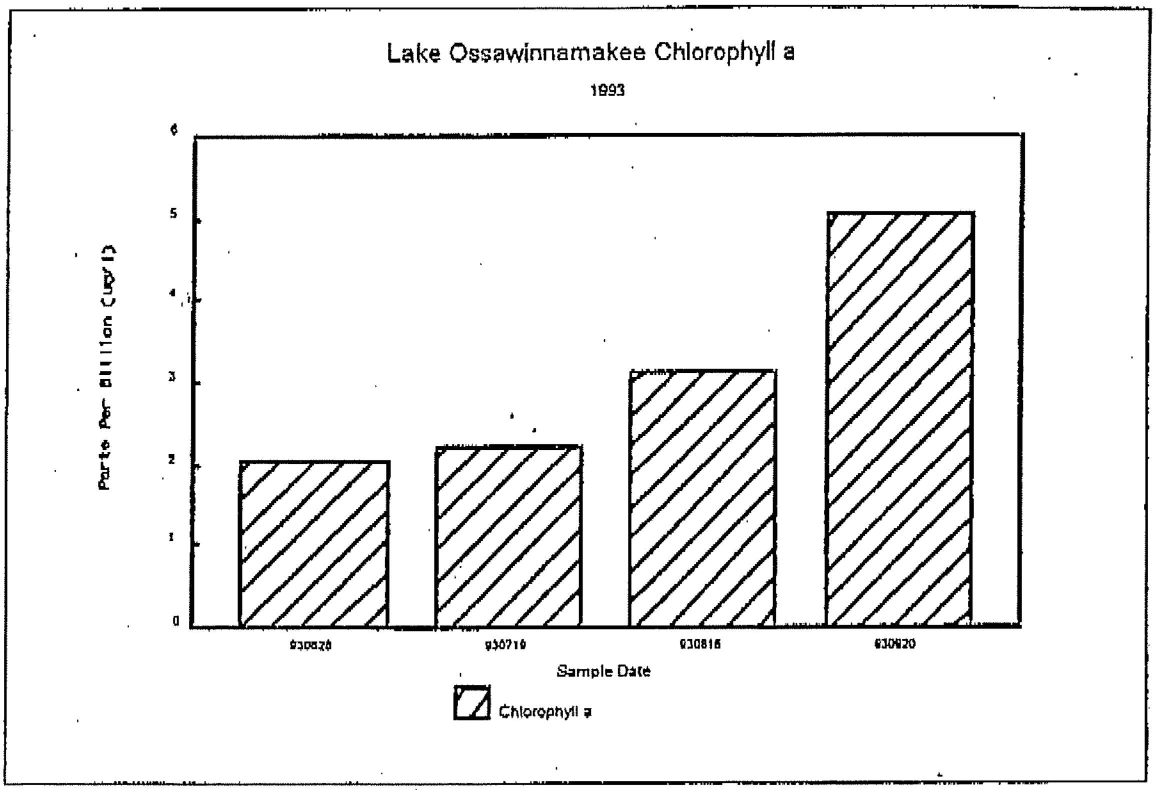
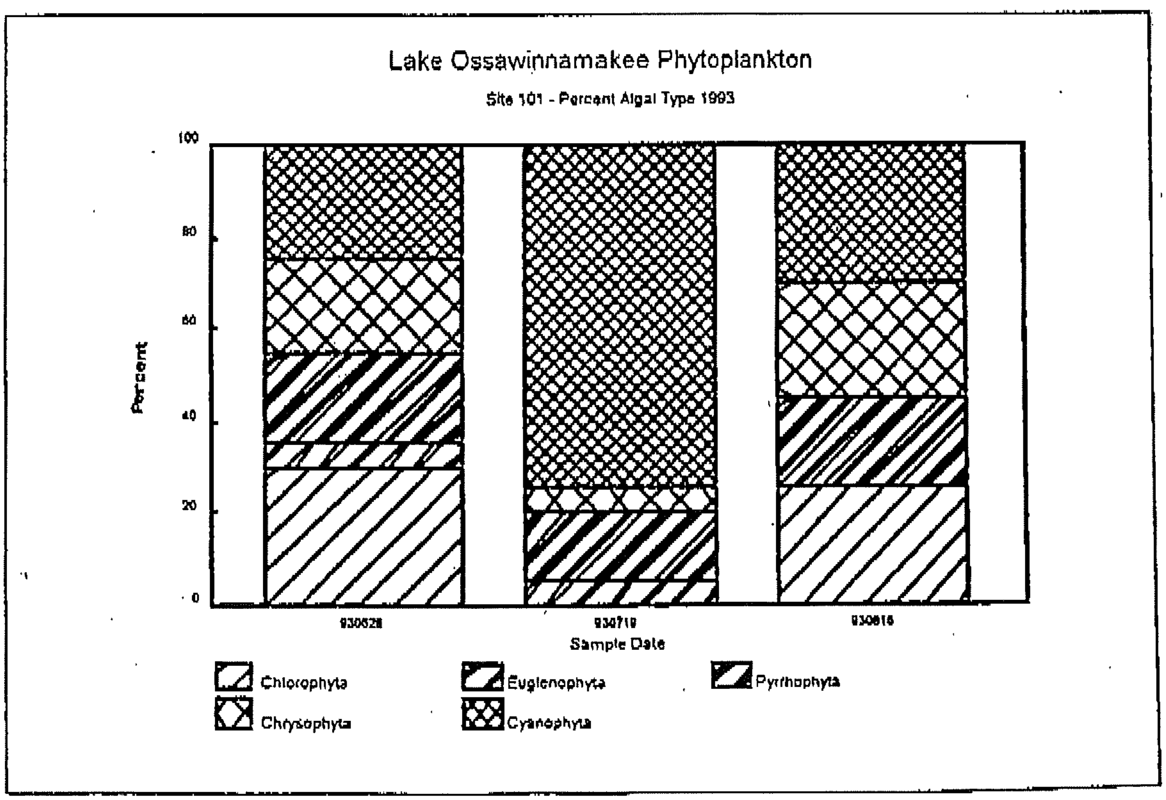


FIGURE 4



Secchi Disk data is available for this lake.

An Assessment Report was done on this lake in 1993.

Visit MPCA's Environmental Data Access system to download data for this lake.

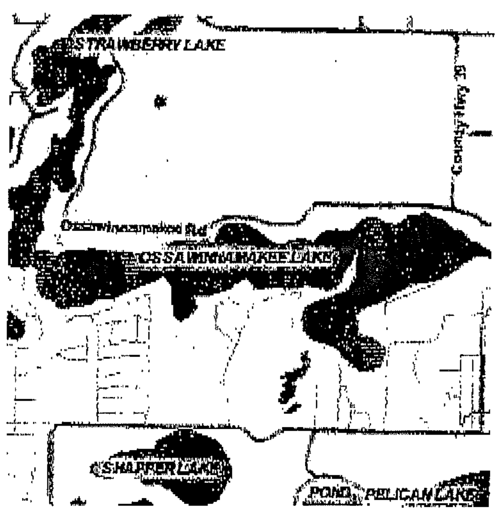
DNR Exit the MPCA web site and search the DNR Lake finder for information on this lake.

Need Help?
Full Supporting Documentation is available for this data or click on the specific links. You can also contact steven.heiskary for further information.

Lake Water Quality Summary Information

Physical Information

Name: OSSAWINNAMAKEE
DNR Lake ID number: 18-0352
County: CROW WING
Location from nearest town: AT BREEZY POINT
Latitude/Longitude: 46.62916667/-94.19916667
Ecoregion: NLF
Basin: UMB
Hydrologic Unit Code: 7010105
Surface Area: 644 (acres)
Maximum depth: 63 (feet)
Water Body Type: LP



	degrees minutes seconds	decimal degrees
	X	Y
UTM	408205	5164651

● Purple dot represents lake location.

Lake Water Quality Assessment

Monitored or Evaluated: Monitored
Data Quality: Fair
Aquatic Recreation Use Support: FS

Lake Water Quality Data Summary

Total Phosphorus Mean: 11 ppb (parts per billion)
Total Phosphorus Standard Error: 1 ppb
Total Phosphorus # of Observations: 4
Total Phosphorus Minimum: 10 ppb and **Maximum:** 13 ppb

Chlorophyll-a Mean: 3 ppb
Chlorophyll-a Standard Error: 0 ppb
Chlorophyll-a # of Observations: 4
Chlorophyll-a Minimum: 2 ppb and **Maximum:** 5 ppb

Secchi Disk Mean: 5 meters
Secchi Disk Standard Error: 0 meters
Secchi Disk # of Observations: 147
Secchi Disk Minimum: 4 meters and **Maximum:** 6 meters

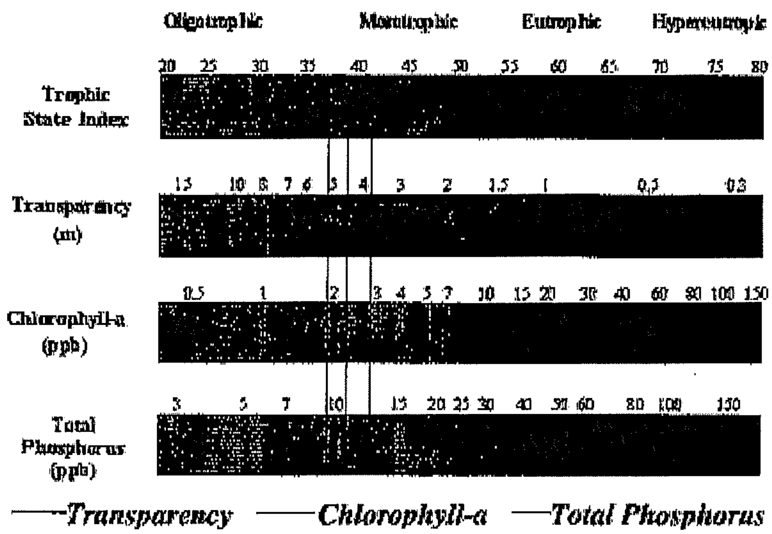
Alkalinity Mean: 125 ppm (parts per million)
Alkalinity # of Observations: 4

Color Mean: 11 Platinum-cobalt Units
Color # of Observations: 4

Carlson Trophic Status for Total Phosphorus: 39
Carlson Trophic Status for Chlorophyll-a: 42
Carlson Trophic Status for Secchi Disk: 37
Overall Trophic Status: O
(O=oligotrophic, M=mesotrophic, E=eutrophic, H=hypereutrophic)

See the Difference! **Oligotrophic** vs. **Hypereutrophic**

Compare this lake to reference lakes or all assessed lakes.



This page was last updated September 22, 2004

If you have suggestions on how we can improve this site, or if you have questions or problems, please contact us.
If you have questions or problems, contact webmaster@pca.state.mn.us
Minnesota Pollution Control Agency, 520 Lafayette Road, St. Paul, MN 55155-4194
Phone: 651-296-6300, 800-657-3864; 24-hour emergency number: 651-649-5451 or 800-422-0798; TTY: 651-282-5332, TTY 24-hour emergency number: 651-297-5353 or 800-627-3529

Lake information report

PRINTABLE VERSION

Name: OSSAWINAMAKEE

Nearest Town: Ideal Corners
Primary County: Crow Wing

Survey Date: 06/23/2003
Inventory Number: 18-0352-00

Public Access Information

Ownership	Type	Description
Minnesota DNR	Concrete	Located on the east end, off Co.Rd. 39.

Lake Characteristics

Lake Area (acres): 644.00
Littoral Area (acres): 225.00
Maximum Depth (ft): 63.00
Water Clarity (ft): 21.00

Dominant Bottom Substrate: N/A
Abundance of Aquatic Plants: N/A
Maximum Depth of Plant Growth (ft): N/A

Did you know? The state operates 17 hatcheries: 5 for trout and salmon and 12 for coolwater species.

Fish Sampled up to the 2003 Survey Year

		Number of fish per net			
Species	**Gear Used**	**Caught**	**Normal Range**	**Average Fish Weight (lbs)**	**Normal Range (lbs)**
Black Crappie	Gill net	0.5	0.5 - 2.7	0.52	0.2 - 0.4
	Trap net	trace	0.7 - 3.2	0.18	0.2 - 0.5
Bluegill	Gill net	1.4	N/A - N/A	0.14	N/A - N/A
	Trap net	28.1	5.6 - 42.3	0.13	0.1 - 0.3
Bowfin (Dogfish)	Trap net	0.8	0.4 - 1.0	4.89	3.1 - 4.8
Brown Bullhead	Gill net	0.2	0.3 - 2.2	1.16	0.6 - 1.0
	Trap net	0.6	0.3 - 1.5	0.99	0.6 - 1.0

Greater Redhorse	Gill net	0.3	N/A - N/A	3.31	N/A - N/A
	Trap net	0.3	N/A - N/A	3.75	N/A - N/A
Green Sunfish	Trap net	trace	0.2 - 0.9	0.07	0.1 - 0.2
Hybrid Sunfish	Gill net	trace	N/A - N/A	0.22	N/A - N/A
	Trap net	7.8	N/A - N/A	0.25	N/A - N/A
Largemouth Bass	Gill net	1.5	0.3 - 1.2	1.38	0.5 - 1.1
	Trap net	0.9	0.3 - 1.1	0.59	0.2 - 0.9
Northern Pike	Gill net	9.6	3.1 - 8.5	1.67	1.5 - 2.7
	Trap net	0.3	N/A - N/A	1.21	N/A - N/A
Pumpkinseed Sunfish	Gill net	1.0	N/A - N/A	0.18	N/A - N/A
	Trap net	2.8	1.7 - 8.2	0.15	0.1 - 0.2
Rock Bass	Gill net	4.1	0.3 - 2.0	0.71	0.3 - 0.5
	Trap net	2.1	0.6 - 2.5	0.29	0.2 - 0.5
Smallmouth Bass	Gill net	0.2	0.2 - 1.0	2.65	0.7 - 1.9
Snapping Turtle	Trap net	0.2	N/A - N/A	ND	N/A - N/A
Tullibee (Cisco)	Gill net	7.2	0.7 - 6.5	0.82	0.6 - 1.6
Walleye	Gill net	2.4	1.3 - 5.5	2.46	1.2 - 2.4
White Sucker	Gill net	1.5	0.5 - 3.5	2.41	1.6 - 2.4
	Trap net	trace	0.2 - 1.0	2.43	1.7 - 2.9
Yellow Bullhead	Gill net	1.5	0.9 - 10.0	0.76	0.5 - 0.7
	Trap net	3.9	1.5 - 7.7	0.63	0.5 - 0.8
Yellow Perch	Gill net	0.3	2.5 - 24.2	0.36	0.1 - 0.2
	Trap net	trace	0.5 - 2.7	0.07	0.1 - 0.2

Normal Ranges represent typical catches for lakes with similar physical and chemical characteristics.

Length of Selected Species Sampled for All Gear for the 2003 Survey Year

	Number of fish caught in each category (inches)								
Species	***0-5***	***6-8***	***9-11***	***12-14***	***15-19***	***20-24***	***25-29***	***>29***	***Total***
Black Crappie	0	5	2	0	0	0	0	0	7
Bluegill	135	83	0	0	0	0	0	0	218
Brown Bullhead	0	0	2	5	0	0	0	0	7
Green Sunfish	1	0	0	0	0	0	0	0	1
Hybrid Sunfish	18	69	0	0	0	0	0	0	87
Largemouth Bass	1	4	7	14	2	0	0	0	28
Northern Pike	0	1	4	5	70	30	3	4	117
Pumpkinseed Sunfish	26	15	0	0	0	0	0	0	41
Rock Bass	6	40	24	0	0	0	0	0	70
Smallmouth Bass	0	0	0	0	2	0	0	0	2
Tullibee (Cisco)	2	29	2	38	15	0	0	0	86
Walleye	0	0	0	3	15	10	1	0	29

Yellow Bullhead	0	4	44	6	0	0	0	0	54
Yellow Perch	1	1	2	0	0	0	0	0	4

*For the record, the largest **Shortnose Gar** taken in Minnesota weighed 4 lbs., 9.6 oz. and was caught by:*

Who: Matthew "Dewy" Ocel, Minneapolis, MN
Where: Mississippi River, Hennepin County
When: 7/22/84.
Statistics: 34.6" length, 10" girth

Fish Stocked by Species for the Last Five Years

Year	Species	Age	Number
1998	Walleye	Fingerling	2,800
	Walleye	Yearling	845
2000	Walleye	Fingerling	9,000
2002	Walleye	Yearling	7,450
	Walleye	Adult	99
	Walleye	Yearling	217

Fish Consumption Advisory

Meal Advice for Pregnant Women, Women who may become pregnant and Children under age 15

Species	less than 15"	15" to 20"	20" to 25"	25" to 30"	greater than 30"
Northern Pike			◑		

Meal Advice for the General Population

Species	less than 15"	15" to 20"	20" to 25"	25" to 30"	greater than 30"
Northern Pike			◔		

Symbol Key	unlimited	1 meal per week	1 meal per month	1 meal every 2 months	do not eat
Mercury	○	◔	◑		●
PCBs	□	◧	◩	◪	■

Status of the Fishery (as of 06/23/2003)

Ossawinamakee is a 644 acre lake located about three miles north of Breezy Point in Crow Wing County. A public access is located on the east end of the lake. The lake is heavily developed with 275 homes/cabins and several resorts and campgrounds along 13.1 miles of shoreline based on 1993 data. The maximum depth is 63' and about 35% of the lake is 15' deep or less. Shallow water substrates consist primarily of sand, marl, gravel, and rubble. The aquatic plant community is quite diverse with 47 species present and is critical to maintaining healthy fish populations. Emergent plants such as bulrush are somewhat common along the shoreline, and are important for shoreline protection, maintaining water quality, and provide essential spawning habitat for bass and panfish species. Submerged plants provide food and cover needed by fish and other aquatic species. Eurasian watermilfoil and zebra mussels are present is this lake and it is imperative that lake users take measures to prevent them from being introduced into other lakes and wetlands.

The 2003 walleye catch of 2.4/gill net is similar to past catches on this lake and typical of the catch on similar lakes. Average length and weight were similar to the previous netting in 1998 at 18.9" and 2.5 lbs. Northern pike were caught in high numbers in 2003 at 9.6/gill net, which is the highest catch to date. Average length and weight were also similar to 1998 at 19.1" and 1.7 lbs. Growth was average with 8% of these fish measuring at least 24".

Largemouth bass were caught in relatively high numbers when compared to similar lakes. Spring electrofishing resulted in a largemouth bass catch rate of 157/hr with an average length of 11.0" and 42% measuring at least 12". Bluegill were sampled in average numbers at 28.1/trap net. Growth was slow. Black crappies were present in relatively low numbers (0.5/gill net and 0.1/trap net) when compared to similar lakes.

Tullibee and yellow perch are important forage species for the lake's game fish. Tullibee abundance has been high in the past and continued to be in 2003 at 7.2/gill net while yellow perch abundance has been low in all nettings, including this one.

For Additional Information

Area Fisheries Supervisor:

1601 MINNESOTA DRIVE
BRAINERD, MN 56401
(218) 828-2550

Lake maps can be obtained from:

Minnesota Bookstore
660 Olive Street
St. Paul, MN 55155
(651) 297-3000 or (800) 657-3757
To order, use B0012 for the map-id.

General DNR Information:

DNR Information Center
500 Lafayette Road
St. Paul, MN 55155-4040
(651) 296-6157 or (888) MINNDNR
TDD: (651) 296-5484 or (800) 657-3929

Turn in Poachers (TIP):

Toll-free: (800) 652-9093

E-Mail: info@dnr.state.mn.us

Main Categories: Outdoor Activities | Regulations, Licenses, Permits | Natural Resources | Education & Safety | About the DNR | Maps | Publications | Employment | Volunteering | Technical & Financial Assistance | Public Input

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Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-D. Literature Review

FISHPRO
Consulting Engineers & Scientists
A Division of Cochran & Wilken, Inc

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Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-E. Prior Zebra Mussel Studies

FISHPRO
Consulting Engineers & Scientists
A Division of Cochran & Wilken, Inc.

FINAL REPORT OF THE EFFECTS OF CUTRINE® -ULTRA AND CUPRIC SULFATE ON THE ZEBRA MUSSEL, *DREISSENA POLYMORPHA*

Prepared for:
Minnesota Department of Natural Resources
St Paul, Minnesota

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Problem Statement

In 2003 adult zebra mussels (*Dreissena polymorpha*) were identified attached to a boatlift in the oligotrophic Lake Ossawinnamakee, central Minnesota (MN DNR, 2004). Further study confirmed that *D. polymorpha* were in several parts of the lake, and also a short distance downstream in the outlet brook. Although the presence of *D. polymorpha* was recorded in western Lake Superior, and in the Mississippi River both below and above St. Paul, to our knowledge, Lake Ossawinnamakee was only the second lake body in Minnesota known to support populations of *D. polymorpha*. Currently, Minnesota State Department of Natural Resources (MN DNR) is considering implementing a long-term strategy to prevent or reduce *D. polymorpha* spread from Lake Ossawinnamakee through Pelican Brook (flow = 47.2 cfs), into other local systems and ultimately into the upper reaches of the Mississippi River. MN DNR requested toxicological support from the Ecotoxicology and Environmental Risk Team (EERT) at the Engineering Research and Development Center, U.S. Army Corps of Engineers, Vicksburg, MS (ERDC USACE). Since literature review was unable to ascertain definitive copper (Cu) toxicity reference values (TRV) for *Dreissena* larvae, this support shall provide information on the efficacy of Cu, and in particular the proprietary algaecide Cutrine®-Ultra, for controlling planktonic larval stages of the zebra mussel *D. polymorpha* (Millward *et al.* 2004). In particular, MN DNR is permitted to use Cu-based products at 1 mg Cu/L for algal control, and has requested EERT to generate data to address whether such treatments might control the larval spread of zebra mussels. A recent application at this concentration in the western bay of Lake Ossawinnamakee was shown to result in aqueous concentrations around 0.2 mg Cu/L after one week and prior to reapplication (Montz, MN DNR pers. comm.). We used this application experience to present MN DNR with the expected efficacy of Cu application at this dose to control the spread of *D. polymorpha* veligers.

The Present Study

The study entailed site-water specific assessment of Cu toxicity to planktonic larvae of the zebra mussel *D. polymorpha* sufficient to support technical advice on the efficacy of Cu-based products to prevent or reduce spread of zebra mussels in this system. A numbers of tasks were performed to achieve this objective, including:

- Development of a *D. polymorpha* culturing and larval toxicity testing protocol. Fisher *et al.* (1994) published a method for *D. polymorpha* pre-veliger toxicity testing, using 96-h-old larvae. This protocol was further developed to enable toxicity testing of *D. polymorpha* from pre-fertilization to 96-h-old life stages (See Appendix 1).
- Development of LC_{50} and LC_{99} (concentration required for 50 % and 99 % mortality) for Cutrine®-Ultra and Cu on pre-fertilized, post-fertilized, 24-h-old, 48-h-old, 72-h-old larvae (see Appendix 2).
- Development of LC_{50} and LC_{99} (concentration required for 50 % and 99 % mortality) for Cutrine®-Ultra and Cu on adult mussels (see Appendix 3).

- Development of LT_{50} and LT_{99} (exposure time required for 50 % and 99 % mortality) at the maximum permitted exposure to Cutrine®-Ultra on 24-h old larval mussels (see Appendix 4).
- Recommendations regarding use of Cutrine®-Ultra to control *D. polymorpha* in Lake Ossawinnamakee, MN. Data presented in Appendices 1 – 4 shall be used to address the problem statement. In addition, we present an explicit statement of areas of uncertainty, and recommendations regarding further options to limit spread of *D. polymorpha*.

Recommendations Regarding Use of Cutrine®-Ultra to Control *D. polymorpha* in Lake Ossawinnamakee, MN

Toxicity of Cutrine®-Ultra to larval and adult D. polymorpha

Laboratory trials indicate that Cutrine®-Ultra can be used to control larval *D. polymorpha* at permitted concentrations. We estimate 99 % control of larval *D. polymorpha* by 24-h exposure to 0.027 - 0.081 mg Cu/L Cutrine®-Ultra (from the LC_{99} range of Cutrine®-Ultra, Experiment 1, Appendix 2) in Lake Ossawinnamakee water at 18°C. MN DNR have communicated that control measures have used a weekly treatment with 1 mg Cu/L as Cutrine®-Ultra, which attenuated to as low as 0.2 mg Cu/L prior to reapplication (Montz, pers. comm.). We therefore conclude that the current weekly treatment employed by MN DNR is at least approximately 10× that required for 99 % efficacy, a factor that is likely to provide adequate control provided that water residence time in the treated area is not significantly less than 24 h. We also estimate 99 % control of *D. polymorpha* larvae following 52-minute exposure to Cutrine®-Ultra concentrations as low as 0.331 mg Cu/L (Appendix 4).

In addition, Appendix 2 indicates that this Cutrine®-Ultra concentration is likely to prevent fertilization of released gametes, due to a toxic action other than that of the chelated Cu, and possibly due to the surfactant/penetrant combination in Cutrine®-Ultra.

Adult *D. polymorpha* were significantly more resistant to Cutrine®-Ultra than were larval stages. Estimates for 99 % adult control were dependent upon exposure time, and ranged from 1.7 mg Cu/L (96-h exposure) to 8.8 mg Cu/L (48-h exposure) in Lake Ossawinnamakee water at 18 °C. We conclude that exposure to the current Cutrine®-Ultra treatment regime for up to 96 h is insufficient to control adults. However, since our 96-h data do suggest 99 % adult control in 1.7 mg Cu/L, it is likely that longer exposures to Cu at 1 mg Cu/L might provide adequate adult control in Lake Ossawinnamakee water. Although the data are not sufficient to support this theory, MN DNR might consider whether to treat Lake Ossawinnamakee at 1 mg Cu/L for a single prolonged period as a control measure for the entire adult *D. polymorpha* population.

Areas of uncertainty

Limitations in this data set have direct consequences on the ability to make recommendations for field application of Cutrine®-Ultra and $CuSO_4$ to control *D. polymorpha* larvae. As a result of these limitations, implicit and explicit uncertainty should be considered in determining the use of Cu and Cu-based products to control zebra mussels. Limitations and uncertainty include:

- This report does not sanction the use of Cu or Cu-based products in the control of zebra mussels. This decision is the responsibility of MN DNR, or any other party, with due regard to relevant permits and regulations. EERT and ERDC do not take responsibility for actions taken by any party based upon information in this report.
- Cu toxicity data are highly dependent upon the temperature, hardness, and alkalinity of water. These data only apply for the water quality parameters stated in Table 1, Appendix 1. If necessary, the data can be used to model toxicity estimates under other water quality conditions.
- Larval data only pertain to 0 – 96-h old larvae. While these are key planktonic phases, we were not able to test Cutrine®-Ultra efficacy on later life stages.
- LC_{99} data are modeled estimates, not observations.
- Similarly, the 95 % confidence intervals are modeled estimates, not observations.
- These tests were performed under controlled laboratory conditions. There remains uncertainty as to the application of mussel sensitivity data to field situations.

Recommendations for monitoring of Cutrine®-Ultra

We recommend daily measurements of aqueous Cu to ensure adequate control. Accurate, field-based analytical techniques are widely available. Concentrations of Cutrine®-Ultra should be maintained at approximately 0.3 mg Cu/L, should a 10× protection factor be required. In addition, water residence time in the treated area should be assessed and used to gauge the suitability of these data for the measured water residence time in the treated area.

We also recommend that any Cu treatment regime be amended to reflect any residual Cu in the water column at time of treatment, to ensure that Cu concentrations in the water body do not exceed 1 mg Cu/L at any time.

Recommendations for monitoring D. polymorpha

We recommend regular plankton screening in the spring and summer, to monitor for occurrence of *D. polymorpha* larvae in the water column. Observations of *D. polymorpha* larvae during these screens may be used to initiate Cutrine®-Ultra treatment prior to onset of 12 °C water temperatures. In the absence of *D. polymorpha* Cutrine®-Ultra treatment can be suspended.

In addition, regular monitoring of suitable settlement sites downstream for emergent adult *D. polymorpha* populations is recommended.

Recommendations for physical treatment

Both physical methods of control and physical aspects of stream habitat deserve brief consideration. With respect to physical habitat limitations, it is noteworthy that Strayer (1991), based on a thorough analysis of European zebra mussel distribution, concluded that this species does not reside in streams less than 20 m wide. In slight contrast, Horvath *et al.* (1996) found that zebra mussel colonization of small streams is possible, but only if there is a nearby, upstream lake source. Even then, populations declined exponentially with downstream distance from the source such that only isolated mussels were found much more than one km downstream. The outlet brook from Lake Ossawinnamakee is probably too small to sustain a zebra mussel population, although the larger streams farther downstream may provide suitable habitat. There is no doubt that this species is best adapted to the sublittoral zones of very large lakes (such as Lake Erie in North America) and impounded reaches of large rivers (such as the series of pools in the Upper Mississippi River).

Physical methods of control (e.g., filtration, heat, aerial exposure) can be reliably used in some settings, but appear to be of limited value in the present situation. The most viable physical control method may be the use of disposable substrates in the upstream end of the outlet brook. Large numbers of disposable substrates (e.g., nylon or fabric "mops") placed in several rows along the channel (parallel to flow) or in the lake at the channel inlet (perpendicular flow) could reduce the number of veligers entrained into the flowing brook. These substrates create ideal settling conditions for the planktonic veligers by providing a firm surface and reduced flow velocity. Periodically (at least annually) the substrates would have to be removed and replaced. Disposable substrates have not been used much, as they are only partially effective. Percent control of 50 % is probably a reasonable expectation (O'Neill 1996).

Appendix 1. Development of *D. polymorpha* Culturing and Larval Toxicity Testing Protocol

Overview

The purpose of the study was to evaluate the toxicity of Cutrine®-Ultra and Cu (as $CuSO_4$) on *D. polymorpha.* Because of the potential differences in sensitivity at various life stages and levels of development, exposure methods were developed for fertilized eggs, trochophore, and veliger stage organisms.

Materials and Methods

Test organisms

The zebra mussel, *Dreissena polymorpha*, is an exotic freshwater bivalve that was likely introduced to North America in the mid-1980s in Lake Saint Claire near Detroit, MI (Ram *et al.* 1993; Hincks and Mackie 1997). The life history of *D. polymorpha* consists of a ciliated trochophore/pre-veliger stage (57-121 μm), a D-shaped veliger stage (70-160 μm), an umboned veliger stage (120-280 μm), a settling pediveliger (167-300 μm), plantigrade (158 - 500 μm), juvenile (500 - 5000 μm) and adult (Ackerman 1995). Although adults are considered sedentary, smaller individuals were observed to use byssal threads to climb substrate, such as the sides of the aquaria in this study. Juvenile/adult mussels range from 1-50 mm, although most are <20 mm; sexual maturity can occur in mussels as small as 5 mm (Ackerman 1995). Adults can be resistant to application of some chemicals by avoidance via valve closure. The trochophore stage is rarely observed outside of laboratory culture (Ackerman 1995), is assumed to be more sensitive than juveniles/adults to many chemicals (Fisher *et al.* 1994), has an extremely high rate of natural mortality sometimes exceeding 99 % (Stoeckel and Garton 1993; Vanderploeg *et al.* 1996) and is the subject of the toxicity tests to follow.

USACE-ERDC obtained individuals from two populations of *D. polymorpha.* Mussels were collected by Nick Rowse (U.S. Fish and Wildlife Service, Twin Cities Field Office) on April 19, 2004 close to the mouth of the St. Croix River (near St. Paul, MN), and by Orlando Sarnelle (Dept Fisheries and Wildlife) and Stephen Hamilton (Kellogg Biological Station), Michigan State University on May 10, 2004 from Gull Lake at Michigan State University's Kellogg Biological Station (near Battle Creek, MI). Mussels were wrapped in damp paper towels and shipped overnight in coolers containing cold packs. A very low mortality rate (<2 %) was observed following shipment.

Maintenance of D. polymorpha

Mussels were held in 5-gallon aquaria (100 mussels/aquarium) containing hard reconstituted water (HRW) formulated according to the U.S. Environmental Protection Agency (US EPA, 2002). The HRW had a pH of 8.2, a hardness of 171 mg/L as $CaCO_3$, and an alkalinity of 110 mg/L as $CaCO_3$. The HRW was chosen since it has similar composition to water at Lake Ossawinnamakee (see Table 1). Aquaria were aerated vigorously using air stones and filtered using a charcoal filter/jet. To keep mussels from adhering to one another, inert rocks were scattered along the bottom of aquaria as in Stoeckel and Garton (1993). Aquarium water temperature was held at 12 ± 1 °C in a water bath to inhibit spawning (Ram *et al.* 1993, Fisher *et al.* 1994). Mussels in each aquarium were fed daily with 30 mL of concentrated *Raphidocelis subcapitata* (formerly *Selenastrum capricornutum*) from a laboratory-maintained culture (US EPA 2002). Conductivity, temperature and ammonia levels were monitored daily. A 50 – 100 % water exchange was conducted if total ammonia levels exceeded 2 mg/L. Dead mussels were removed from holding tanks daily, although only 2 mussels died during the holding period (20 April – 12 July 04).

Table 1. Properties of Lake Ossawinnamakee and reconstituted water.

Properties	HRW [1]	Lake Ossawinnamakee
pH	8.2	8.4
Hardness	171 mg L^{-1} (as $CaCO_3$)	163 mg L^{-1} (as $CaCO_3$)
Alkalinity	110 mg L^{-1} (as $CaCO_3$)	126 mg L^{-1} (as $CaCO_3$)
June Temperature	18 ± 1 °C [2]	18 – 21 °C [3]

1 Hard reconstituted water (US EPA 2002)
2 Temperature used in exposure experiments
3 Approximate temperature range of Lake Ossawinnamakee, June (Montz, pers. comm.).

Spawning induction

Spawning was induced by 30-minute exposure of 10 – 20 mm* mussels (acclimated for 18-h at 18 ± 1°C) to a 5×10^{-4} M solution of serotonin creatinine sulfate monohydrate (CAS# 61-47-2), as conducted in previous study (Ram *et al.* 1993, Fisher *et al.* 1994, John Lynn, LSU, per. comm.). Males were observed to spawn within 15 – 30 minutes, at which point they were transferred to clean HRW. Mussels that did not spawn in 30 minutes were assumed to be female and were transferred to clean HRW. Viable females spawned in clean HRW after 60 – 90 minutes as observed in previous study (Ram *et al.* 1993, Fisher *et al.* 1994). Gametes were used in subsequent trials within 1.5 h of sperm production. After 15 minutes, to allow fertilization to occur, HRW containing fertilized eggs was gently aerated (2-3 bubbles/sec) to provide flow to embryos, and maintained at 17 ± 1°C.

Larval exposure protocols

Studies have demonstrated that the pelagic larval stages of *D. polymorpha* may be the most sensitive stage for control measures (Vanderploeg *et al.* 1996). In addition, Fisher *et al.* (1994) showed that the sensitivity of zebra mussel life stages to different molluscicides varied, although in most cases the veliger stages were more sensitive than later stages. Therefore TRV data were derived for *D. polymorpha* larvae across a range of developmental stages. Previous studies have shown that laboratory-reared *D.*

* Smaller mussels did not produce a suitable stock of gametes, while larger mussels produced gametes of inconsistent quality.

polymorpha larvae are viable for up to approximately 10 d without feeding (Stoeckel and Garton, 1993). Further work has demonstrated that rearing *D. polymorpha* larvae past the settling and metamorphosis stages is highly problematic (Vanderploeg *et al.* 1996). Fisher *et al.* (1994) found that larvae were susceptible to handling mortality at < 72-h old, and were most resistant to handling stress after 72 – 96 h. Consequently, they were able to perform toxicity tests on 72 – 96-h-old pre-veligers. Our preliminary trials confirmed this observation, leading to adaptations of the methods of Fisher *et al.* (1994). While these authors pipetted larvae from a culture into exposure vessels, we transferred unfertilized eggs into the exposure vessels, where they could be fertilized *in vitro*. This method removed the necessity for handling stress of larvae, and hence enabled us to derive TRV from pre-fertilization to 96-h old larvae.

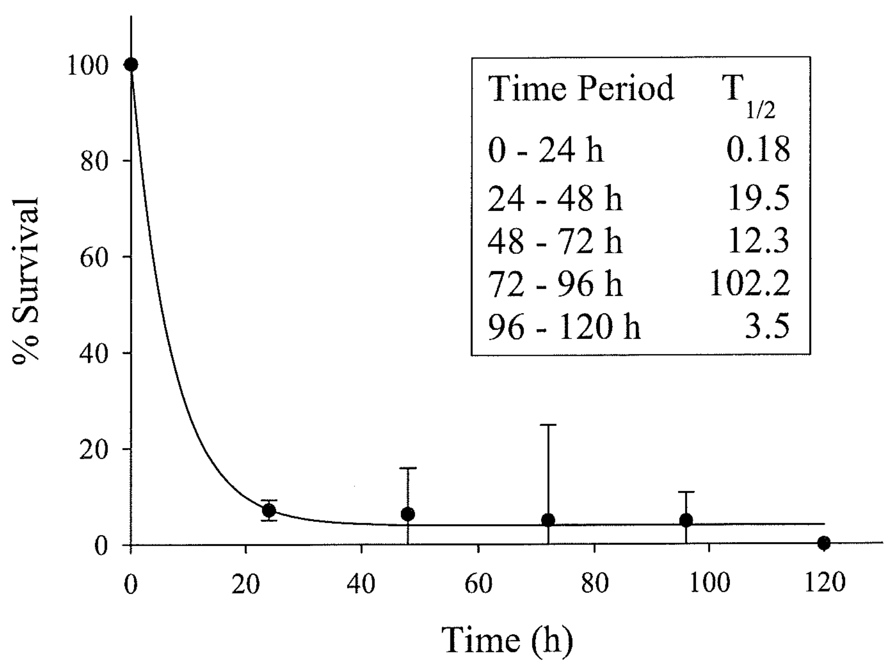
Results and Discussion

Survival from fertilization to hatching was highly variable in all experiments, ranging from 4 – 21 % larval survival (i.e., hatching success). Large females (> 20 mm) often produced opaque eggs which were either nonviable or of very low viability. We therefore selected smaller females for the toxicity trials, and avoided eggs that appeared opaque. Survival from unfertilized egg to 96-h-old larval stage is shown in Figure 2, using egg hatching and survival data from the control treatment in the first experiment (see Appendix 2). Biological half-lives were calculated for each 24-h period, for pre-fertilization to 120-h old, using the equation:

$$T_{1/2} = \frac{0.693}{k_1}$$

where k_1 is the slope of the veliger survival curve, and T is in minutes. Half-lives are also presented in Figure 2.

Figure 2. Survival curve and half-lives for *D. polymorpha* larvae



Time Period	$T_{1/2}$
0 - 24 h	0.18
24 - 48 h	19.5
48 - 72 h	12.3
72 - 96 h	102.2
96 - 120 h	3.5

Figure 2 demonstrates that hatching and survival rates from 0 – 24 h were low (7 %). Survival from 24 – 96 h was much higher, particularly between 72 – 96 h, when survival was 97 %. The biological half-life for 72- to 96-h-old larvae was 102.2 h, which was close to the range of 36.0 – 67.2 presented by Fisher *et al.* (1994) for laboratory-spawned *D. polymorpha* of the same age. Mortality beyond 100 h is observed due to larvae no longer feeding on yolk sacs and subsequently requiring micro-algae food. Background control mortality was accounted for in the subsequent toxicity tests by using Abbott's correction within the ToxCalc© software package (Tidepool Scientific, McKinleyville, CA).

Appendix 2. LC_{50} and LC_{99} Values for Cutrine®-Ultra and Cu for Larval D. polymorpha

Overview

The effects of Cutrine®-Ultra and Cu (as $CuSO_4$) on larval *D. polymorpha* were studied using 24-h LC_{50} aqueous exposures. Separate 24-h exposures were employed to compare the relative toxicities of Cu (as $CuSO_4$) and Cutrine®-Ultra, and also to establish relative sensitivities of life stages from pre-fertilization to 96 h after fertilization to these two toxicants.

Materials and Methods

Chemicals

Cutrine®-Ultra is a commercially available chelated copper (9.0 % Cu) solution in an emulsified surfactant. In addition to Cutrine®-Ultra, reagent grade cupric (II) sulfate, $CuSO_4$ (CAS 7758-98-7), with a 98.2 % purity was used to assess zebra mussel life stage relative sensitivities to copper alone. All solutions were formulated in HRW water. The Cu content of both Cutrine®-Ultra and $CuSO_4$ exposure solutions was evaluated using the highest exposure solution (0.050 mg/L nominal Cu) collected from the test chambers at the termination of each 24-h test. Since the lowest exposure concentrations were below method detection limits, all lower concentrations were made up by serial dilutions of this test solution. Copper concentrations in solutions were calculated from this value, using the appropriate dilution factor. Copper concentrations in control solutions were less than the method detection limit. Aqueous solutions were acid digested using EPA method 3010A (US EPA 1996a), and analyzed using inductively coupled plasma – mass spectrometry (ICP-MS, US EPA 1996b), with method detection limit $\leq 1\ \mu g\ L^{-1}$.

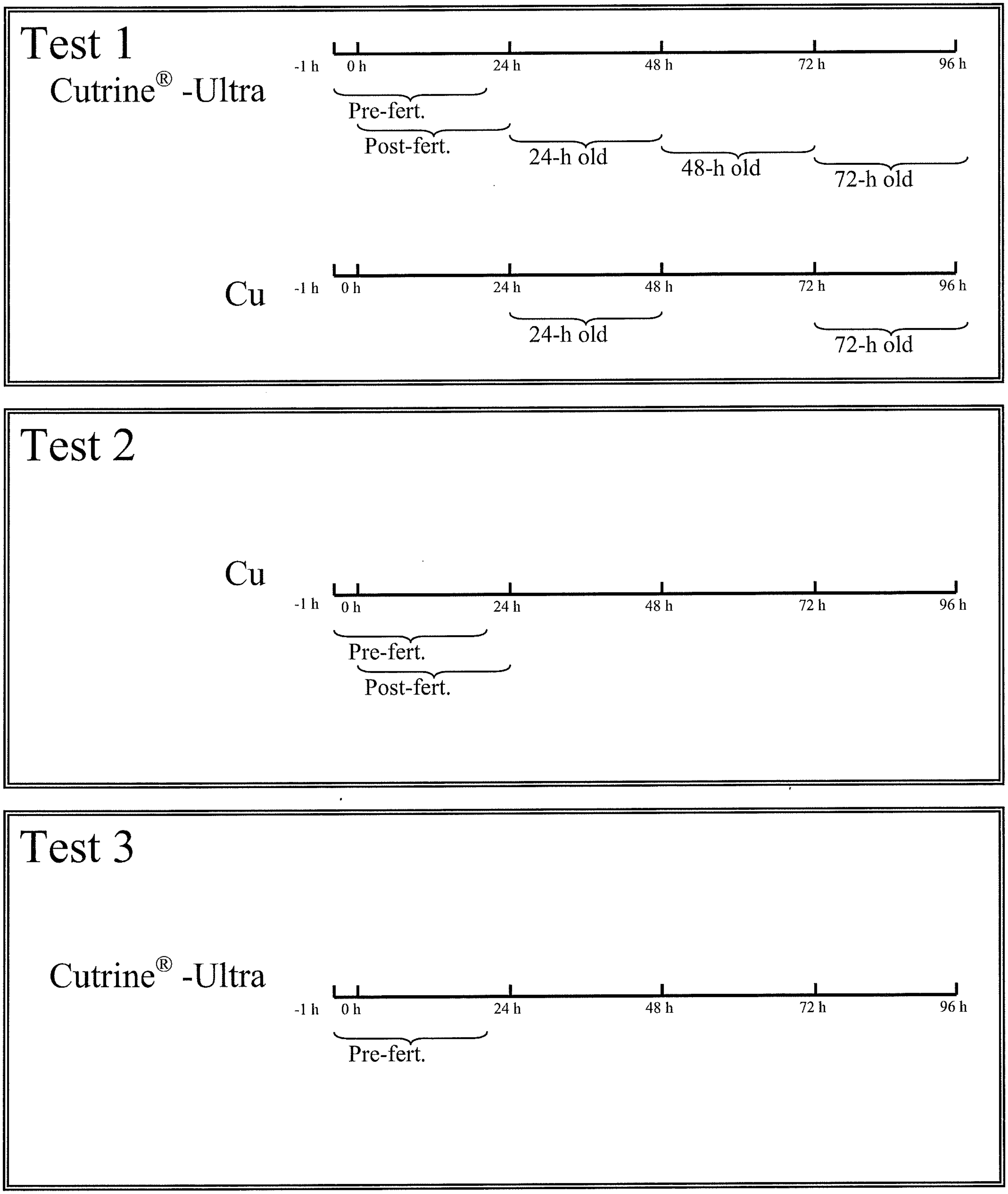
Exposure methodology

Tests were initiated pre-fertilization, post-fertilization, and at 24 h, 48 h and 72 h after fertilization. Tests are referred to using the time at which the 24-h exposure was started (e.g., pre-fertilization test refers to the exposure started prior to fertilization and continuing for 24 h, the post-fertilization test refers to the exposure started after egg fertilization and continuing for 24 h, etc). A schematic representation of all the tests conducted in this unit is presented in Figure 3. Three experiments were conducted to establish the toxicity of Cutrine®-Ultra and Cu to larval stages. The first experiment addressed Cutrine®-Ultra toxicity at all life stages, with additional Cu toxicity tests at 24 and 72 h as references. The second experiment addressed Cu toxicity on pre- and post-fertilization stages. The third experiment was designed to support the discovery in the first experiment that Cutrine®-Ultra led to significantly higher toxicity in pre-fertilization stage eggs compared to post-fertilization stage eggs, with an LC_{50} close to the lowest exposure concentration. This third experiment repeated the pre-fertilization test of the first experiment, with lower exposure concentrations to allow a more definitive estimation of LC_{50}.

Experimental designs were modified from the veliger toxicity tests conducted by Fisher *et al.* (1994) (See Appendix 1). All testing used Costar Inc. (#3516) 6-well plastic multi-well plates (Corning Inc., Corning, NY), with 10 mL of exposure solution per well. Tests used six Cu exposure concentrations and a control, with each treatment consisting of 12 replicates using two well plates. Exposure concentrations* selected for the first and second experiments were 0.001, 0.002, 0.005, 0.010, 0.020, and 0.050 mg Cu/L, and for the third experiment were 0.0001, 0.0005, 0.0010, 0.0050, 0.0100, and 0.0500 mg Cu/L. All tests were conducted for 24-h at 18 ± 1 °C, the approximate temperature of Lake Ossawinnamakee in June. Following successful spawning of 2-5 females, the density of eggs in the combined solution was determined to establish the volume of solution that contained 150-200 eggs, and this volume was added to each well (i.e., 150-200 eggs/replicate). Eggs were fertilized by the addition of 10 μL of a concentrated sperm solution.

* All concentrations listed as nominal.

Figure 3. Schematic of 24-h exposure tests, larval *D. polymorpha* TRV



Pre-fertilization and post-fertilization tests

These tests were designed to address effects of Cu treatments on fertilization rate. In the pre-fertilization tests, addition of Cu solutions to eggs prior to fertilization addressed treatment effects on gamete viability, fertilization processes and 0 to 24-h development of larvae. In contrast, the post-fertilization tests enabled measurement of treatment effects during 0 to 24-h development. Significant differences in sensitivity between the pre-fertilization and post-fertilization tests were interpreted as treatment effects upon gamete viability and fertilization processes. For post-fertilization tests, Cu solutions were added ≥ 15 min after sperm addition, to allow fertilization in the absence of Cu treatments. Effects of Cu solutions on fertilization rate were assessed by recording the number of living larvae as a fraction of eggs added per well. Moving larvae were considered to be alive.

Pre-veliger tests

These tests addressed the effects of Cu treatments on 24-h-, 48-h- and 72-h-old larvae. At the start of each test, the number of living pre-veligers was recorded and the appropriate Cu spiking solution was added. At test termination, surviving larvae were counted.

Data analyses

Data were analyzed using trimmed Spearman-Karber probit analysis to estimate LC_{50} and LC_{99} values and, when the model allowed, 95 % confidence limits. Control mortality was corrected using Abbott's correction. TRVs were considered significantly different when 95 % confidence limits did not overlap. ToxCalc© software was used for all analyses (Tidepool Scientific, McKinleyville, CA).

Results and Discussion

Results for LC_{50} data are summarized in Table 2. LC_{50} values are shown in bold type, and 95 % confidence limits in parentheses where the model allowed this estimation. All data are mg Cu/L.

Results from experiment 1 reveal that LC_{50} data for Cutrine®-Ultra were similar in all stages of larval development from post-fertilization to 72 h old, ranging from 0.008 to 0.013 mg Cu/L. These values were also similar to those for Cu as $CuSO_4$, which ranged from 0.007 – 0.008 mg Cu/L. These findings suggest that, for these life stages, Cu is the active toxic compound in Cutrine®-Ultra, and that Cutrine®-Ultra toxicity might be predicted by Cu concentration alone. In contrast, Cutrine®-Ultra exhibited a significantly higher toxicity in the pre-fertilized egg exposures than did Cu alone. This was confirmed by the third experiment, which utilized lower exposure concentrations to enable a more definitive estimate of LC_{50}. Comparison of these data with those for Cu also indicates that the toxicity of Cutrine®-Ultra to pre-fertilization stage eggs was higher than that associated with Cu alone.

Table 2. Summary of LC_{50} values.

Expt	Chemical	Pre-fert LC_{50}	Post-fert LC_{50}	24-h LC_{50}	48-h LC_{50}	72-h LC_{50}
1	Cutrine	**0.001**	**0.013** (0.006 – 0.019)	**0.008** (0.002 – 0.014)	**0.009**	**0.012**
	$CuSO_4$	-	-	**0.008**	-	**0.007**
2	Cutrine	-	-	-	-	-
	$CuSO_4$	**0.004** (0.002 – 0.005)	**0.005**	-	-	-
3	Cutrine	**0.002**	-	-	-	-
	$CuSO_4$	-	-	-	-	-

Since there was no difference in the toxicity of Cutrine®-Ultra and Cu to post-fertilization stage eggs, we conclude that Cutrine®-Ultra has a mode of toxicity upon gamete viability or the fertilization physiology other than that associated with Cu exposure.

Literature TRVs for *D. polymorpha* are scarce, although Fisher *et al.* (1994) determined LC_{50} values for six molluscides and concluded that larvae were more sensitive than adults to five of the compounds. The only Cu-related *D. polymorpha* information that these authors are aware of is unpublished by McMahon and Tsou (1990) from a conference proceeding, indicating that 5 mg Cu/L 100 % mortality of *D. polymorpha* veliger in 24 h in unknown water quality conditions. Based on results from the current study, such levels of mortality can be achieved at much lower concentrations of Cu in Lake Ossawinnamakee water.

Results for LC_{99} data are summarized in Table 3. LC_{99} values are shown in bold type, and 95 % confidence limits in parentheses where the model allowed this estimation. All data are mg Cu/L.

Table 3. Summary of LC_{99} values.

Expt	Chemical	Pre-fert LC_{99}	Post-fert LC_{99}	24-h LC_{99}	48-h LC_{99}	72-h LC_{99}
1	Cutrine	**0.081**	**0.027** (0.018 – 0.189)	**0.039** (0.019 – 17.414)	**0.038**	**0.047**
	$CuSO_4$	-	-	**0.0207**	-	**0.020**
2	Cutrine	-	-	-	-	-
	$CuSO_4$	**0.016** (0.010 – 0.054)	**0.014**	-	-	-
3	Cutrine	**0.147**	-	-	-	-
	$CuSO_4$	-	-	-	-	-

Estimates of LC_{99} from all experiments demonstrate that 24-h exposure with Cutrine®-Ultra can be expected to control the majority of *D. polymorpha* larvae at all life stages in the range 0.027 – 0.147 mg Cu/L, using the water quality parameters for Lake Ossawinnamakee in June.

Appendix 3. LC_{50} and LC_{99} for Cutrine®-Ultra and Cu for Adult D. polymorpha

Overview

The effects of Cutrine®-Ultra on adult *D. polymorpha* were studied using 96-h LC_{50} aqueous exposures. In addition, at the termination of the 96-h exposures, surviving organisms were transferred to clean HRW to investigate delayed mortality after removal of Cu stressors.

Materials and Methods

Chemicals

Cutrine®-Ultra is a commercially available chelated copper (9.0 % Cu) solution containing an emulsified surfactant. All solutions were made up in HRW water. The Cu content of Cutrine®-Ultra exposure solutions was evaluated using the highest exposure solution (5 mg/L nominal Cu) collected from the test chambers at the termination of each 24-h test. Copper concentrations in solutions were calculated from this value, using the appropriate dilution factor. Copper concentrations in control solutions were less than the method detection limit. Aqueous solutions were acid digested using EPA method 3010A (US EPA 1996a), and analyzed using inductively coupled plasma – mass spectrometry (ICP-MS, US EPA 1996b), with method detection limit $\leq 1\ \mu gL^{-1}$.

Exposures

Adult mussel toxicity tests were adapted from Waller *et al.* (1993). A range-finding test was conducted to determine adult mussel sensitivity to acute Cutrine®-Ultra exposure (24 - 96 h). A definitive toxicity test was then conducted with Cutrine®-Ultra using five nominal concentrations (0.01, 0.10, 0.50, 1.00, 5.00 mg Cu/L) and a control (HRW). Each treatment consisted of three replicate 600 mL glass chambers containing 500 mL HRW and five mussels (15 - 25 mm). Mussels were allowed to acclimate and adhere to chambers containing clean HRW 48 h prior to exposure. The 96-h acute toxicity tests were static-renewal (24 h) and conducted at 18 ± 1 °C. Survival and presence of filtering activity were assessed daily, and animals were not fed. Mortality was assumed if gaping mussels did not respond to gentle prodding and avoidance was assumed if mussels were not actively siphoning during regular inspections. Dead mussels were removed daily.

Data analyses

Data were analyzed using trimmed Spearman-Karber probit analysis to estimate LC_{50} and LC_{99} values and 95 % confidence limits. TRV were considered significantly different when 95 % confidence limits did not overlap. ToxCalc© software was used for all analyses (Tidepool Scientific, McKinleyville, CA).

Results and Discussion

Results for LC_{50} and LC_{99} data are summarized in Table 4. LC values are shown in bold type, and 95 % confidence limits in parentheses. All data are mg Cu/L.

Table 4. Summary of adult LC_{50} and LC_{99} values

Cutrine®-Ultra	Adult LC_{50}	Adult LC_{99}
48 h	**1.2** (0.9 – 2.1)	**8.8** (4.1 – 53.5)
72 h	**0.6** (0.4 – 0.9)	**2.6** (1.3 – 38.2)
96 h	**0.3** (0.2 – 0.5)	**1.8** (1.0 – 7.7)

The results from this study suggest that 99 % mortality of adult *D. polymorpha* in the size range 15 – 25 mm would be expected following 96-h exposure to 1 mg Cu/L. However, our 24-h data (not shown) suggest that 24-h exposures to significantly higher concentrations might not elicit a significant effect, due to reduced exposure following valve closure (Mersch *et al.* 1996). Following an additional 24-h exposure, however, mussels were observed to die at high rates at the aforementioned concentrations. Several previous studies have derived Cu-relevant TRVs in various water characteristics for adult *D. polymorpha.* Rao and Khan (2000) exposed mussels (15 – 20 mm) to solutions at 20 °C using reagent grade $CuCl_2$ and determined 48-h and 96-h LC_{50} values of 0.755 and 0.487 mg Cu/L, respectively. They observed increased sensitivity at 25°C. Kraak *et al.* (1992) observed approximately 28 % mortality for mussels (16 – 20 mm) at 15°C after 9-week exposures to 0.104 mg Cu/L ($CuCl_2$) but observed no adverse effect at 0.013 mg Cu/L. These data compare well with results from the current study. Waller *et al.* (1993), however, observed much higher tolerance to Cu for mussels (20 – 25 mm), resulting in a 48-h LC_{50} of 5.38 (3.65 – 7.93) mg Cu/L.

Adult mussels exposed to ≥ 1.0 mg Cu/L remained closed for the duration of the 96-h toxicity test. Substantial avoidance/valve closure was also observed in approximately 90 % of the individuals in the 0.1 and 0.5 mg Cu/L treatments; adults allowing valves to open did not extend their siphons (as in the control and 0.01 treatments) and were lethargic when gently probed. We did not observe a significant difference in filtering activity in the 0.01 mg Cu/L treatment. Kraak *et al.* (1992) derived a 48-h NOEC (0.016 mg Cu/L), and EC_{50} (0.041) for filtering activity, which is supported by our observations. Monitoring the frequency of valve closure in *D. polymorpha* is a good indicator of overall water quality (Stuijfzand *et al.* 1998). According to previous studies (e.g., Morton 1958, Kraak 1992), the filtering apparatus of adult *D. polymorpha* may possess chemoreceptors that can detect Cu at elevated concentrations, resulting in significantly reduced filtration rates. This valve closure/avoidance ability may have contributed to the relatively low mortality observed after 24 h in the 5.0 mg Cu/L (27 %) and 1.0 mg Cu/L (1 %) treatments.

Appendix 4: Effect of Exposure Time on Cutrine®-Ultra Toxicity.

Overview

To determine the exposure time necessary for pre-veliger mortality at the permitted 1 mg Cu/L, short-term toxicity tests were conducted at 18 ± 1°C to determine the LT_{50} and LT_{99} for both Cutrine®-Ultra, $CuSO_4$ at a nominal 1 mg Cu/L.

Materials and Methods

Chemicals

Cutrine®-Ultra is a commercially available chelated copper (9.0 % Cu) solution containing an emulsified surfactant. In addition to Cutrine®-Ultra, reagent grade cupric (II) sulfate, $CuSO_4$ (CAS 7758-98-7), with a 98.2 % purity was used to assess zebra mussel life stage relative sensitivities to copper alone. All solutions were formulated in HRW water. Aqueous solutions were acid digested using EPA method 3010A (US EPA 1996a), and analyzed using inductively coupled plasma – mass spectrometry (ICP-MS, US EPA 1996b), with method detection limit ≤ 1 µg/L. Analysis showed that actual Cu concentrations in the Cutrine®-Ultra treatment were 0.331 mg Cu/L, and in the $CuSO_4$ treatment were 0.440 mg Cu/L.

Exposures

Larvae were obtained as described for the toxicity tests using 24-h old pre-veligers (see Appendices 1 and 2). The number of 24-h old pre-veligers was recorded and exposure wells were spiked with Cutrine®- Ultra or copper (controls were spiked with clean HRW). Two well plates (six wells/replicates) were used for each chemical. The time points selected were 15, 30, and 45 minutes.

Data analysis

Data were analyzed using trimmed Spearman-Karber probit analysis to estimate LT_{50} and LT_{99} values and 95 % confidence limits. TRV were considered significantly different when 95 % confidence limits did not overlap. ToxCalc© software was used for all analyses (Tidepool Scientific, McKinleyville, CA).

Results and Discussion

Control mortality was negligible over the exposure time used in these experiments. The LT_{50} and LT_{99} for Cutrine®-Ultra and Cu are presented in Table 5. LT values are shown in bold type, and 95 % confidence limits in parentheses. All data are in minutes.

The analyses show that exposure to Cutrine®-Ultra and Cu resulted in similar temporal responses in 24-h-old *D. polymorpha* larvae. The fitted models predict 99 %

mortality following 52 min (range = 36–186 min) exposure to 0.331 mg Cu/L as Cutrine®-Ultra, and following 38 min (range = 36–43 min) exposure to 0.440 mg Cu/L as CuSO4.

Table 5. Summary of pre-veliger time to mortality data.

Treatment	**LT_{50}**	**LT_{99}**
Cutrine®-Ultra	**18** (11-23)	**52** (36-186)
$CuSO_4$	**11** (10-12)	**38** (36-43)

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Aquatic invertebrates in upper Pelican Brook – Impacts from copper sulfate treatment of Muskie Bay, Lake Ossawinnamakee

Gary Montz, Jodene Hirsch and Richard Rezanka
Division of Ecological Services, Minnesota DNR
November 2004

Introduction

Pelican Brook is a small stream that begins as an outlet from Muskie Bay in Lake Ossawinnamakee (Crow Wing County), and flows approximately 5.5 miles until it is tributary to the Pine River. In fall 2003, zebra mussels were confirmed in Lake Ossawinnamakee in a variety of sites, attached to docks, vegetation, rocks and wood. Additional sampling in Pelican Brook immediately below the lake outfall discovered scattered single zebra mussels attached to natural substrate in the stream. The discovery of zebra mussels in both the lake and the immediate vicinity of the brook raised alarm that the veliger (larval) stage of this exotic could be transported in water of the brook to the Pine River. This could create a reproducing population that could move veligers downstream in the Pine River, which is tributary to the Mississippi River.

To address the threat of veliger downstream transport, the Minnesota DNR contracted with a private aquatic pesticide applicator to apply copper sulfate to approximately 26 acres of Muskie Bay weekly from mid-June through September, 2004. Application dose rates were 0.6ppm of Cutrine Ultra, with 400 gallons applied per treatment via subsurface injection.

Methods

Monitoring of copper levels was conducted immediately at the outflow location (Highway 39) in the brook and approximately 2.5 miles downstream (Highway 3) at the next road crossing. Water samples were collected and monitored at the sites using a Hach pocket colorimeter II test kit for copper. Monitoring began prior to the start of the first treatment (to establish a baseline) and continued nearly daily through October.

Sampling for zebra mussel veligers was conducted during the summer by vertical tows with a Wisconsin plankton net at a site in the main lake basin and the treatment area (Muskie Bay) to determine efficacy and relative veliger densities. Samples were analyzed by examining collected material with cross-polarized light to separate veligers from other microinvertebrate fauna.

Samples of aquatic macroinvertebrates were collected in 2004 from three sites in Pelican Brook using D-frame kicknets. Sites sampled were at the highway 39 bridge crossing, the Highway 3 bridge crossing, and approximately 0.5 miles downstream of the highway 3 bridge. At the first two sites (highways 39 and 3), two kicknet samples were taken in rock/cobble substrate, and one qualitative composite was colleted from woody debris at each site. At the site downstream of Hwy 3 only a single sample was collected from rock/cobble substrate. Samples were collected in spring prior to any treatments (17 May) and in fall after treatments (9 September). Samples were preserved in the field, transported back to the office, and sorted and identified under a dissecting microscope. Aquatic insects were identified generally to genus if possible, with the exception of the

Chironomidae, which were left at the family level. Other invertebrate taxa (snails, amphipods, flatworms, etc) were identified to varying levels, depending on available taxonomic keys.

Results and Discussion

Copper levels: Monitoring showed consistent declines in copper levels from day of treatment to at or near baseline levels within 5 – 7 days (Fig. 1). Each treatment spiked copper levels back up, with peak concentrations between 0.6 - 0.8ppm. Highest levels of copper were recorded at the outlet site. The downstream site levels were often approximately half the peak levels recorded at the lake outlet site. However, three times during the summer the downstream site recorded peak levels near or at that recorded at the outlet site. Field notes indicate that two of these coincided with precipitation events during or prior to application. This suggests that perhaps increased discharge could have transported more dissolved copper further downstream at an increased rate, accelerating the dissipation normally seen during the summer. Copper levels never exceeded label restrictions for the product. However, monitoring suggests that low levels (0.6ppm or less) were present in the waters of Pelican Brook at least 2.5 miles downstream throughout the majority of the summer during the treatment period.

Veliger densities: Sampling in the lake and bay pre-treatment showed veliger production at a low level in the beginning of the season. However, while densities rose in lake samples, veliger densities collected one-day post-treatment in various weeks in the bay remained at low or undetectable levels (often less than 0.1 per liter). This suggested that successful reproduction was occurring in the main body of the lake, but densities were not rising in the bay. Additional contracted research with the Army Corps of Engineers suggested that LC100 levels for veligers were 10x less than the dosage rates used for treatments during the season. It appears that the copper treatments were successful in dramatically reducing or eliminating veligers in Muskie Bay, thus cutting off the downstream flow of the zebra mussel larval stages.

Aquatic macroinvertebrates: Aquatic invertebrate communities sampled in spring showed a diverse assemblage of taxa. Ephemeroptera and Trichoptera were predominant in numbers of taxa as well as numbers of organisms collected. Coleoptera were also commonly collected, all belonging to the family Elmidae. Plecoptera were uncommon, represented by only a few specimens in one family. Also uncommon were Odonata, although the habitat sampled may have missed species more associated with bank vegetation. The rock/cobble in the sites sampled was not a common substrate for the brook, which was dominated by sand, and sand/silt bottom. However, it presented a consistent habitat and showed good diversity in the aquatic invertebrate fauna.

Non-insect invertebrates were present in the samples, often in substantial numbers. Snails were more abundant at the outlet site than at other sites. This may be a consequence of export from the lake of these taxa, or a result of more algal production due to nutrients exported from the lake. Also present were single zebra mussels, attached to rock or more commonly to woody debris in the brook. At the Hwy 3 site, Amphipoda were very abundant, while no zebra mussels were collected.

In contrast, fall sampling revealed significant changes in the invertebrate fauna (Fig 2). Ephemeroptera were no longer collected in any samples from any sites, and the diversity of Trichoptera was substantially reduced. Elmidae (Coleoptera) were still collected at all the sites. However, at the outlet site numbers of organisms collected were extremely reduced compared to spring sampling. Downstream, diversity and abundance were higher at the Hwy 3 site compared to the outlet site in September; however, it was still very low compared to spring abundances. An exception to this was the Simuliidae, which were overwhelmingly dominant in abundance in the fall samples from Hwy 3. Non-insect invertebrates also were substantially reduced. Only one snail was collected in all fall samples, from the Hwy 3 site. Additionally, no amphipods were found in any fall samples. No zebra mussels were found at the outlet sites on any rocks or other substrate where they had been collected from in spring.

It would appear that the continual flush of copper at low levels from the lake into Pelican Brook had a significant negative impact on the aquatic invertebrate community at both the outlet and at least up to 2.5 miles downstream. This is not unexpected for the Mollusca (snails, bivalves) as copper sulfate is used to attempt to control swimmers itch outbreaks by killing snail populations (interrupting the cercaria life cycle by eliminating one host). However, literature suggested that adult zebra mussels were more resistant to copper, with LC50's reported in the 5 ppm range for several days. It would appear that constant presence of much lower levels of copper killed attached zebra mussels in the stream. However, it also appeared to have eliminated the native unionid fauna in the outlet area. During spring sampling, many native mussels were observed in the stream. Observations in the fall found no live mussels, and many empty shells from what appeared to be recent mortality. At the Hwy 3 site, many empty shells were also seen, although a very small number of live native mussels were also observed. It is possible that the distance had allowed some native unionids to survive the copper, although numbers may have been reduced below viable reproductive levels. While snails may repopulate the stream from export of lake populations, it is uncertain if native unionids will re-establish populations.

Another group seriously impacted were the Amphipoda. While very common in spring samples and abundant at Hwy 3, no amphipods were collected in any samples in fall. It is unknown if this impact would be seen in the larger Crustacea (crayfish) as these were not sampled in any numbers in either sample period.

The impacts seen in the invertebrate community are consistent with other studies that have examined impacts of copper on different aquatic invertebrates. Studies have suggested that Ephemeroptera are extremely sensitive to copper, as well as reports of sensitivities of Amphipoda to levels lower than or equal to copper levels recorded in the brook. Some work has also suggested that some caddiflies, in particular the Hydropsychidae, are very resistant to copper. Indeed, this group was still present in samples collected in the fall. Also seen in fall samples were pupae of Limnephilidae, suggesting that not only was this caddisfly not impacted in the larval stage, but grew to the pupal stage in their life cycle.

It might be argued that these impacts noticed cannot necessarily be attributed to the copper, as there was no real "control" stream in this survey. Only pre- and post-treatment samples in the brook receiving copper outflow were collected. However, the magnitude of the impacts and agreement with literature documenting similar impacts suggests that the copper flowing out of Muskie Bay from veliger control treatments was responsible for the serious negative impacts seen.

The significant negative impacts, however, need to be viewed in the context of the goal of the copper treatments. Managers and biologists realized at the beginning that copper might have major impacts. While it was hoped that the lower dosage rate (0.6ppm) would provide some safety, it was also recognized partway through the season that the copper would be present almost continually in the waters of the brook, although at very low levels. Data from veliger sampling in the bay and sampling in the brook for settled attached adult zebra mussels suggest that not only were veligers significantly eliminated from the bay, but that any which survived the initial copper treatment in the lake were unlikely to survive in the brook. Veligers that may have received less than a lethal dose of copper in the bay would be continually exposed as they drifted in the stream, suggesting that survival would be seriously compromised. Survival of zebra mussels is highest once they develop a shell and settle. The apparent mortality or disappearance of attached adults in the outflow area suggests a hostile and lethal environment to this more resistant stage. Thus, the objective of preventing export and establishment of zebra mussels via Pelican Brook appears to have been successful, at cost to a substantial part of the invertebrate community.

Copper treatments are viewed as a short-term, stopgap measure to buy time while alternatives for long-term physical interdiction of the veligers is investigated. It was assumed that this type of treatment might be needed for one or two years, depending on the results of a long-term control study. There is consensus that if no viable long-term alternatives are found, copper treatments are not likely to be recommended as an annual operational treatment.

Recommendations

1. Continue spring and fall invertebrate sampling at the established sites. Sampling should occur at minimum during any seasons with copper treatment, and should be extended for a number of seasons after treatment is stopped to document recovery of the invertebrate community.
2. Investigate availability of a second stream, comparable to Pelican Brook, to begin monitoring as a control stream.
3. Examine access further downstream on Pelican Brook or Pine River to assess distance of travel for copper and potential impacts.
4. After treatments are stopped, examine possibility of transplanting native unionids to upper reaches of Pelican Brook, to try and re-establish this fauna.

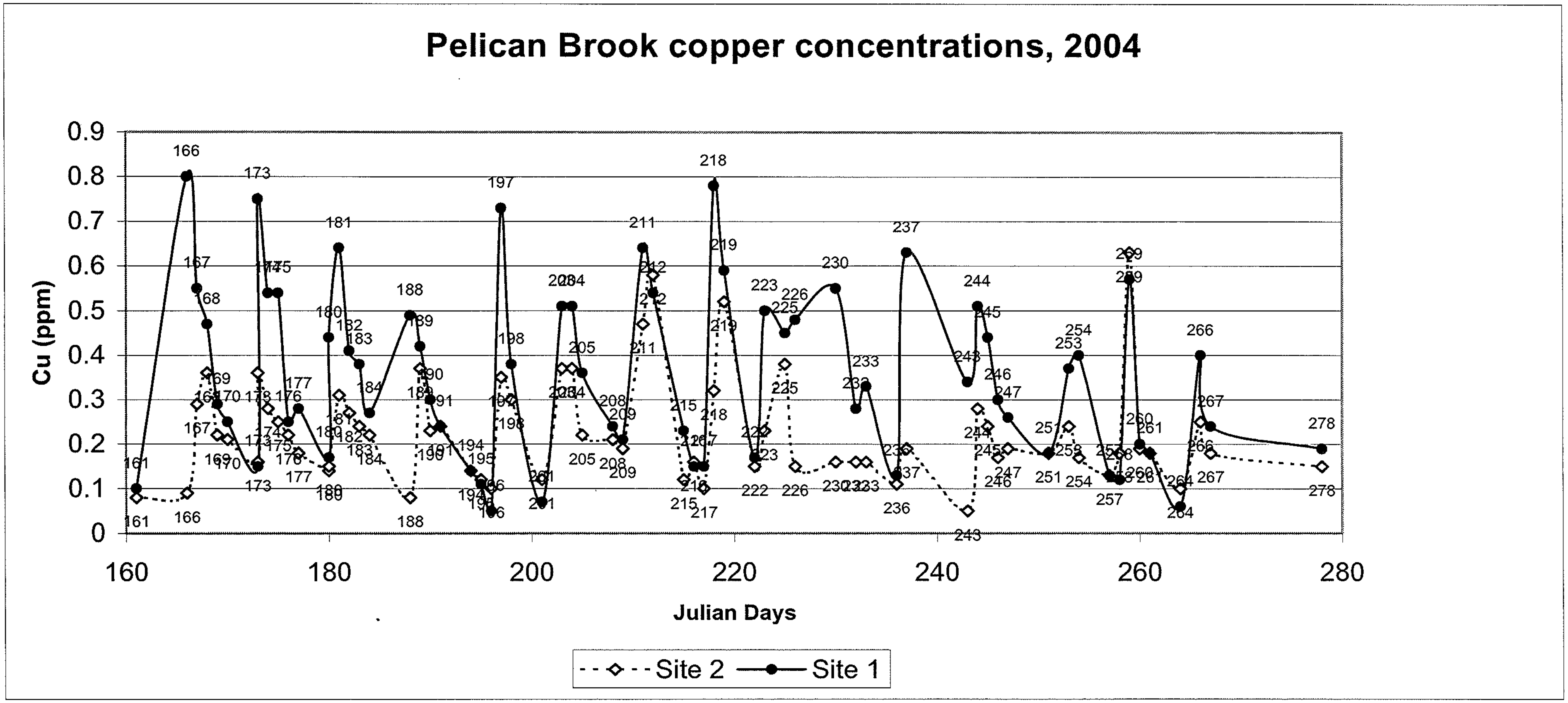

Figure 1. Copper concentrations in Pelican Brook, June – October 2004. Site 1 – Highway 39 bridge, outlet area. Site 2 – Highway 3 bridge, approximately 2.5 miles downstream from outlet. (graph from R. Rezanka)

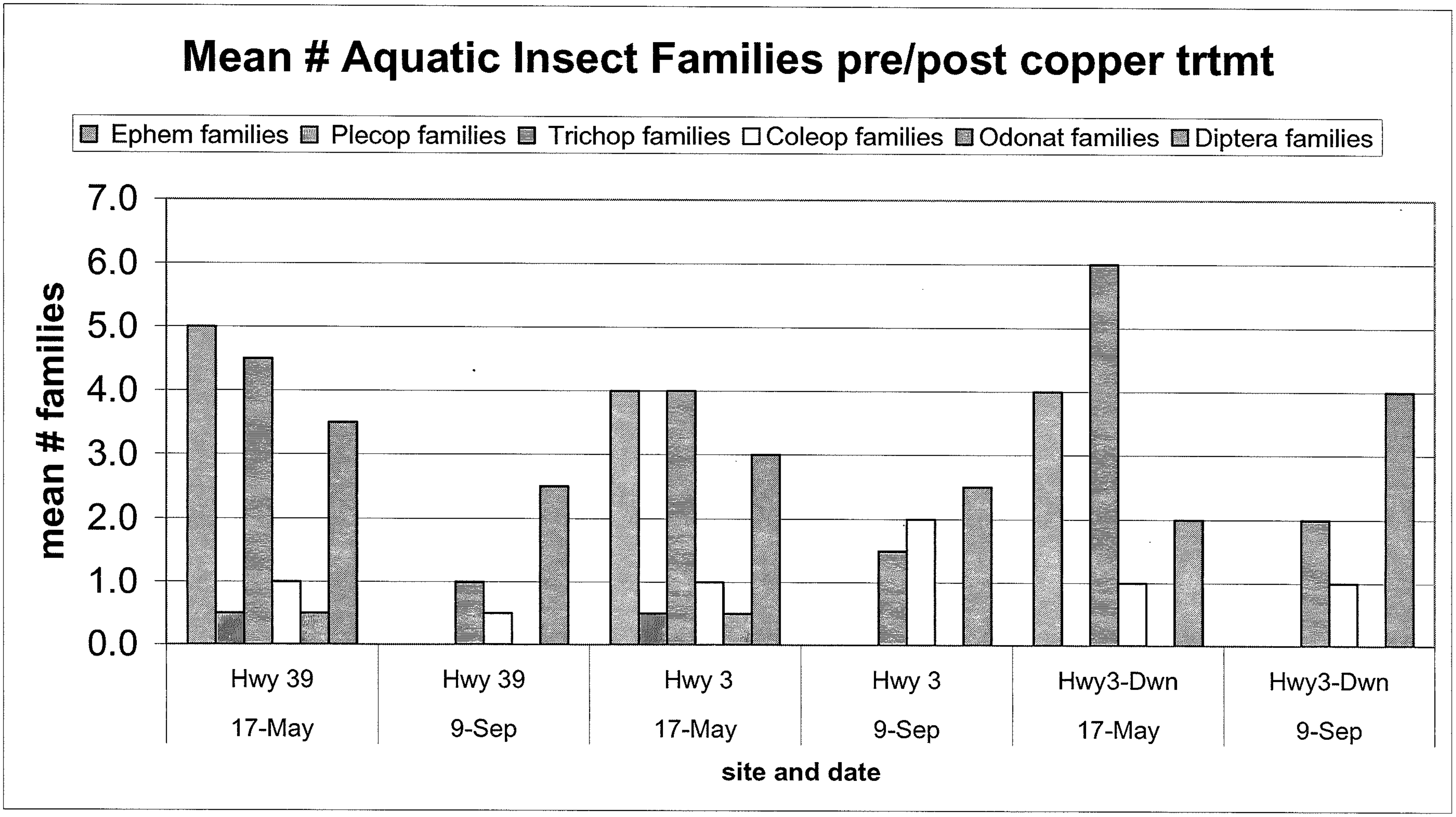

Figure 2. Mean number of families of aquatic insects collected pre- (17 May) and post- (9 September) 2004 treatments with copper sulfate in Muskie Bay, Lake Ossawinnamakee. Sites sampled were at highway 39 bridge (Hwy 39), highway 3 bridge (Hwy 3) and approximately 0.5 miles downstream of the highway 3 bridge (Hwy3-Dwn). Samples were collected with a D-frame kicknet in rock/cobble substrate.

Lake Ossawinnamakee and Pelican Brook – Zebra mussel occurrences
Summary of some DNR surveys
Response to FishPro information question 1 – Current Zebra Mussel Populations
Gary Montz, Division of Ecological Services, MN-DNR 31 Jan 2005

Lake Ossawinnamakee zebra mussel sampling
2003: Zebra mussels were reported to the Area Fisheries Manager in Brainerd in late fall on a dock removed from the lake by a commercial dock hauler. Specimens were confirmed in the Aquatic Invertebrate Biology office in St. Paul. A single day survey was done of various random shoreline sites. Survey methods involved wading in the shallow water, picking up rocks and woody debris at random, and examining for zebra mussels. Attached zebra mussels were found in several sites in the east-west main portion of the lake. Numbers were very low, less than 5 on any object, often only 1 – 3. Most were smaller size (approximately 1/4 – 3/8" long) suggesting settlement from 2003 reproductive effort. A few larger (3/4+" long) specimens were found, documenting the presence of reproductive size, +1 year old mussels. Submerged rooted aquatic vegetation was randomly sampling by casting a plant hook out and pulling it back along the bottom. Zebra mussels were more common on a few sites attached to aquatic vegetation, generally on the main stem area. Vegetation collected from as deep as 16+' had attached zebra mussels. Zebra mussels were not found at a shoreline survey site on the northern arm of the lake, approximately ¾ of the way up this portion of the lake.

2004: Early spring (May) shoreline sampling again documented zebra mussels on woody debris, rocks and on submerged aquatic vegetation. Very few were found in shallow water. However, in surveys on Lake Zumbro (a zebra mussel infested lake in southern MN on the Zumbro River) it has been found that mussels are not found in spring in shallow zones corresponding to ice-zones in the lake, suggesting that winter ice cover kills and scours mussels attached in these shallow zones. Veliger sampling (data in separate file) detected veligers in mid-June, documenting successful reproduction. Dive surveys were done in August in the lake. In the east-west basin, a site was chosen that was towards the western end of the lake. The lake bottom rises up to within about 10' of the surface and the substrate is sand, sand/silt, rocks and cobble and submerged aquatic vegetation. Zebra mussels were common in this area, from the top of the rise to a depth of approximately 20', where the rocks become less common and the thermocline was well established. Mussels were found in varying numbers, ranging from 5 – 20+ on an individual rock. Multiple size classes were present, varying from the current years settlement to larger multiple year age adults. Mussels could be easily found over a large area of lake bottom. A second site was chosen on the northern arm of the lake, about ¾ of the way north. At this site no zebra mussels were collected in survey. A third dive was done near the outlet of Kimball Creek (a small creek connecting Kimball Lake with Lake Ossawinnamakee, flowing into Ossawinnamakee). Substrate here was silt, with abundant submerged aquatic vegetation. No zebra mussels were documented in this area.

General conditions: Mussels observed and collected were attached to various substrate (natural as well as man-made) and appeared healthy. Presence of larger size mussels indicates survival of zebra mussels in the waters of the lake. Collection of veligers and occurrence of small zebra mussels (new settlement) indicates that reproduction has occurred successfully. Examination of unpreserved water sample collected in plankton net tow documented living veligers, evidenced by cilia movement and action.

Pelican Brook zebra mussel sampling
2003: Spot surveys of the brook immediately below the water control structure documented single or few attached zebra mussels sporadically attached to rocks and large woody debris. Further wading surveys by area fisheries and Exotic Species Program biologists during the fall found scattered sporadic attached zebra mussels up to 0.5+ miles downstream. Spot surveys at the next road crossing (approximately 2.5 miles downstream from the water control structure) found no attached zebra mussels.

2004: Spring spot surveys confirmed a similar finding as in fall 2003, with sporadic scattered attached zebra mussels found in the vicinity of the water control structure. As in 2003, no zebra mussels were documented at the next road crossing over Pelican Brook. Sampling in fall (after end of weekly copper sulfate treatments to Muskie Bay, immediately adjacent to Pelican Brook) found no attached zebra mussels in the outlet area, and none downstream. It is suspected that the maintenance of copper sulfate, through the bay treatment, led to the elimination of the attached zebra mussels.

Source of initial infestation of Lake Ossawinnamakee: The initial source for zebra mussels is unknown and likely will remain unknown. Zebra mussels are found in some Minnesota waters (Duluth/Superior Harbor, Mississippi River, Lake Zumbro) as well as in a number of lakes in states to the east (approximately 50 in Wisconsin, 200+ in Michigan). Zebra mussels can attach to boats or any other equipment left in infested waters, as well as aquatic vegetation and other natural substrates. Thus, it is impossible to document how the mussels entered the lake. However, veliger sampling and settled juveniles suggest that there are sufficient adults to sustain the population at this time.

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-F. Meeting Summaries

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February 25, 2005

MEETING SUMMARY

for

Review Meeting on Feasibility Study to Limit the Spread of Zebra Mussels from Ossawinnamakee Lake

FP/CWI No. 05008

A 50% review meeting was held on February 16, 2005 at 11:30 a.m. CST in Brainerd, Minnesota. The purpose of the meeting was to bring together the project team and MN DNR to discuss the progress and expectations of the study. A brief outline of the topics discussed at the meeting is provided below. The following were in attendance:

Gary Montz, MN DNR	Matt Cochran, FishPro/CWI
Tim Bratsrup, MN DNR	Richard Dirks, FishPro/CWI
Rich Rezanka, MN DNR	Ryan Keith, FishPro/CWI
	Meghan Oh, FishPro/CWI

The following outline reflects FishPro's understanding of the discussions that took place and any decisions that were made at the review meeting. If you have any questions, comments, or additions, please contact Matt Cochran. We will consider the minutes to be accurate unless we receive notice of any changes within ten working days of the issue date.

1. Matt Cochran initiated the meeting with a short overview of the FishPro study and the approach we plan to take to complete the study. Gary Montz replied with general comments: 1) The study is developing well and gives a good introduction to those not directly involved with zebra mussels 2) The background information on the lake and the species was good. Expansion of these areas of the report is not necessary beyond what is already included in the 50% draft. 3) It is good to include technologies that may not necessarily be feasible 4) It is important to list the reasons for discontinuing consideration of each method 5) Stay away from references to total eradication.

2. Section I. Gary commented that we should rephrase the last sentence in the second paragraph on page I-1. The intention of the study is not to wipe out the population in the lake, but rather stop the spread of downstream transport of zebra mussels. He also informed FishPro that the official contract date should be January 3, 2005.

3. Matt informed MN DNR that Section II would provide a very concise overview of the report; this will be presented at 95%.

4. Section III. Matt informed MN DNR that the figures in Section III would be further developed and that some of the information in this section may be expanded.

Rich Rezanka would like us to reference the Whitefish chain of lakes (North of Ossawinnamakee Lake) with respect to potential infestation through overland transport. Matt commented that this reference could be included in the global outreach section.

Tim Bratsrup clarified our explanation of the flow between Ossawinnamakee Lake and Pelican Lake. Water will not flow from Ossawinnamakee to Pelican, but can sometimes go from Pelican to Ossawinnamakee, although the water between Pelican and Ossawinnamakee is stagnant most of the time. Tim also confirmed that all other connections to the lake were not significant enough that they needed to be referenced or reviewed.

Ryan Keith and Meghan Oh inquired about supplemental water quality data that would describe the water quality during the non-summer months. Gary replied that there might be temperature data from a different lake that could be utilized for the purpose of this report.

There was a discussion about the specifications on the lake outlet structure. FishPro detected some discrepancies between reported numbers for the crest elevation and other structural design numbers for the outlet. Gary commented that he would talk to Glenn about the discrepancies on the elevations at the outlet and will utilize the sketch provided by FishPro to update the dimensions of the outlet structure.

Matt asked about the location of the fisheries sampling sites and Tim replied that all four sampling points are in Pelican Brook, starting at the confluence with the Pine River and working back. Gary clarified that the power point slides sent to FishPro by MN DNR reference the invertebrate sampling sites #1 and #2, not the four fisheries sampling sites. They both confirmed that Pelican Brook is 8 miles long, not 5.5 miles.

In relation to description of the water body beyond Pelican Brook, Tim and Gary commented that there was a river survey completed for the Pine River. The group decided to address inclusion of Pine River characteristics when Section VI is prepared.

5. Section IV. Ryan mentioned that we plan to add a glossary and Gary agreed that a glossary would be helpful. Gary was happy with the amount of information in Section IV and commented that we do not need to elaborate, other than providing a glossary. Gary also commented that the ANS discussion does not add anything to the report in his opinion, but Tim thought that it was a nice reference. Gary decided that the section should not be removed but should also not be added to.

6. Zebra mussel discussion. Ryan inquired about the zebra mussels obtained from the sampling events. Gary commented that the zebra mussels were collected in the late summer. He also informed us that zebra mussels are typically found at about 10 to 17 ft in Ossawinnamakee Lake, which corresponds to the location of the thermocline (between 15 and 20 ft according to Gary).

7. Section V. Matt explained that FishPro's goal was to list as much as we could and that we plan to expand the section in relation to implementation.

Gary commented that he was not sure what we meant by "habitual characteristics" and Meghan replied that water quality characteristics might be a better term.

Gary inquired about the supplemental treatments that will be included. Matt mentioned that Gunderboom manufactures large permeable curtains that could be utilized to prevent spread of zebra mussels from the lake into the outlet stream. He also asked if electrical barriers are encompassed in the treatment of zebra mussels (not fish) and Matt mentioned that we would document more specifics on electrical barrier treatments.

Gary commented that the management and monitoring should not be expanded. It is important to add it so that people see that it relates back to the treatment issues and MN DNR has been implementing these practices for a number of years. In relation to rapid response, the reader should get the impression that a rapid response does not necessarily lead to eradication or immediate treatment, but could include initiation of any procedure that would potentially aid in controlling nuisance populations. He also commented that page V-17 in this section is restating what was previously talked about.

There was a discussion about natural dispersal and the physical constraints of Pelican Brook. Matt commented that we could mention the turbulence factors in Section VI of the report and then proceed to discuss treatment options. We also briefly discussed the possibility of an altered habitat area in Pelican Brook. Gary informed us that MN DNR could look into developing such an area if they desired more information about this option.

8. Section VI. Gary commented that the population and dispersal control definitions are not obvious upon first glance. Matt verbally clarified the definitions, and Gary followed the explanation well. The group agreed that the definitions could be revised so that they are easier for the reader to follow.

Ryan inquired about a specific point that could be utilized to initiate an emergency response plan, as discussed in the study. Gary commented that MN DNR does not currently have a particular point, but he intended to think more about this response point.

In response to Ryan's question relating to treatment options that should not be considered, Gary mentioned that chlorine and bromine are not viable due to EPA regulatory concerns; chemical components with no regulatory approval are not worth spending time on. We also discussed electrical treatments; Gary would like us to include electrical barriers as a discussion point even if they are not probable.

9. The meeting was concluded just before 3:00 p.m. CST. The next meeting will be a conference call on a date to be determined, after the 95% submittal.

Non-verbatim minutes were prepared by: Meghan Oh, FishPro/Cochran & Wilken, Inc.

Cc: All in attendance

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-G. List of Abbreviations Used

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ABBREVIATIONS USED

ANS	Aquatic Nuisance Species
AZUS	Aquatic Zoogeographical Units
EDUS	Ecological Drainage Units
GIS	Geographic Information System
MN DNR	Minnesota Department of Natural Resources
MPCA	Minnesota Pollution Control Agency
NIS	Nonindigenous Species
T&E	Threatened and Endangered
UMR	Upper Mississippi River
UMRB	Upper Mississippi River Basin
UMRCC	Upper Mississippi River Conservation Committee
UMRS	Upper Mississippi River System
USCOE	United States Corp of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
cfs	Cubic Feet Per Second
cms	Cubic Meters Per Second
gpm	Gallon Per Minute
LC_{50}, LC_{100}	Lethal concentration for 50 and 100 percent of the test organism, respectively.
LT_{50}, LT_{100}	Time to 50 and 100 percent mortality, respectively.
ppt	Parts Per Thousand
ppm	Parts Per Million
ppb	Parts Per Billion

Feasibility Study

To Limit the Spread Of Zebra Mussels from Ossawinnamakee Lake

VII-H. Glossary of Terms

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GLOSSARY OF TERMS

The reader is encouraged to read and become familiar with the following terms that relate and pertain to zebra mussels. Most of the following terms were taken from the text entitled *Practical Manual for Zebra Mussel Monitoring and Control* authored by Claudi and Mackie, 1994.

Adult	Life stage that is capable of reproduction or is undergoing gametogenesis.
Algae	Either microscopic or macroscopic organisms capable of photosynthesis. Can be solitary, colonial, filamentous, or branched. Chlorophyll usually in chloroplasts, except in Cyanophytes (blue-green algae)
Attenuation	The process by which a compound or treatment is reduced in concentration over time, either through adsorption, degradation, dilution, and/or transformation.
Ballast	Material (usually water) used to provide stability for ocean-going vessels leaving freshwater ports with little or no cargo.
Benthic	Living on the bottom of lakes, ponds, rivers, streams, etc.
Biocide	Any chemical used to destroy life by poisoning (e.g., molluscicides).
Bivalve	An animal with a shell that is divided into two parts, the two hinged together by an elastic ligament.
Byssal threads	Tuft of hair-like threads produced by glands (byssal) in the base of the foot of dreissenids. Consists of root, shaft or stem, cuff, corrugated and smooth part of thread, and adhesive disc or plaque.
Capital Costs	Nonrecurring expenses of start-up or fixed assets, such as land, guideways, stations, buildings, and vehicles.
Chlorophyll a	Green pigment confined to structures called chloroplasts, except in blue-green algae in which chlorophyll lies free in the cell. Essential for the production of carbohydrates by photosynthesis. Since the biomass of algae grows in relation to the nutrient level, measurement of chlorophyll can be used as a reliable indication of the trophic status of the lake.
Clam	Any of various bivalve mollusks with equal shells closed by two adductor muscles of equal size, inhabiting fresh or marine waters.
Density	Abundance per unit area (usually number per $meter^2$) or per unit volume (usually number per $meter^3$).

Dioecious	Having the male and female organs in separate and distinct individuals.
Dreissenids	A group of mussels belonging to the family Dreissenidae.
Efficacy	A capacity for producing a desired results or effect.
Epifaunal	Living on top of or attached to animals.
Epilimnion	In thermally stratified lakes, the warmer, lighter (less dense) upper layer of water.
Euphotic Zone	The portion of a lake receiving sufficient light for photosynthesis to occur.
Eutrophic Lakes	Lakes with an abundant accumulation of nutrients that support a dense growth of algae and other organisms, the decay of which depletes the deeper water of oxygen in the summer.
Excurrent Siphon	The upper tube-like extension on the posterior end of bivalves through which water exits.
Exotic	Foreign. Not native. Introduced.
External fertilization	Fertilization of eggs outside the female, as in the water.
Fecundity	The number of eggs produced.
Gametes	Ripe eggs and sperm.
Gametogenesis	The maturation of gonads with development of mature gametes.
Hypolimnion	In thermally stratified lakes, the colder, denser water on the bottom of the lake.
Incurrent siphon	The lower tube-like extension at the posterior end of the bivalves through which water enters the mantle cavity.
Infaunal	Animals living in the sediments, such as burrowers.
Juvenile	The settles stage in which the gonads are not yet visible.
Lacustrine	Refers to standing waterbodies such as lakes and reservoirs.
Larvae	A term collectively referring to any prejuvenile stage.
LC_{50}, LC_{100}	Lethal concentration for 50 and 100 percent of the test organism, respectively.

Lentic	Refers to standing waters.
Life cycle	The history of developmental changes undergone by an organism fro inception to death.
Lotic	Refers to running of flowing waters.
LT_{50}, LT_{100}	Time to 50 and 100 percent mortality, respectively.
Macrophytes	Plants visible to the naked eye.
Metalimnion	In thermally stratified lakes, the zone of rapidly changing temperature between the epilimnion and the hypolimnion, the temperature gradient being the thermocline.
mg/l	Milligrams per liter. Unit of chemical concentration. Same as parts per million (ppm).
Molluscicide	A biocide developed specifically for destroying mollusks.
Mollusk	An animal with a calcareous shell. In freshwater includes bivalves and snails.
Monoecious	Having the male and female organs in the same individual.
Morphometry	Refers to the shape of the underwater basin.
Mussel	Any bivalve mollusk that produces a byssus, includes families Mytelidae (e.g., blue mussels and marine bivalves) and Dreissenidae (marine, brackish, and freshwater bivalves), and also includes Unionidae (freshwater bivalves), which do not produce byssus in adult life.
Oligotrophic lakes	Lakes with low levels of nutrients that support few algae and there is little organic matter to consume oxygen so levels of dissolved oxygen in deeper water are high.
O and M Costs	Operation and maintenance costs are the ongoing, repetitive costs of operating a treatment system; for example, man-hours (salaries, wages, and benefits) and costs for treatment chemicals and periodic equipment repairs.
Pediveliger	The stage of larval development of dreissenids immediately following the appearance of the foot.

pH	Negative log of the hydrogen ion concentration.. Measure of the degree of acidity, a logarithmic scale ranging from 0 to 14. This scale is known as the pH scale. A measurement along the lower portion of the scale, 0 to 6 indicates the degree of acidity while a measurement along the upper portion, 8 to 14 indicates the degree of alkalinity. A 7 on the pH scale is considered to be neutral.
Pheromone	A substance secreted by an organism that influences the behavior of other individual of the same species.
Phytoplankton	The aggregate of plants and plant-like organisms in the plankton.
Planktivores	Animals that feed on plankton.
Plantigrade	The settlement stage immediately following the pediveliger with the internal organs and shell undergoing metamorphosis into a young adult (juvenile).
Plankton	The aggregate of passively floating, drifting, or more-or-less motile organism in a body of water. Consists mainly of algae, protozoa, rotifera, micro-crustacea, and veligers.
Population	All the individuals of a single species in a particular habitat.
Post-veliger	A term collectively grouping the veliconcha and pediveliger larval stages of dreissenids.
ppb	Parts per billion. Unit for chemical concentration. Same as µg/l.
ppm	Parts per million. Unit for chemical concentration. Same as mg/l.
ppt	Part per thousand. Unit for salinity.
Primary settlement	The first major settlement event. Usually of about 2 to 3 weeks duration, but may be longer.
Pseudofeces	The undigestible material that has passed over the gills of bivalve and is wrapped in mucous for rejection out the incurrent siphon.
Recruitment	The appearance of a new group of young in a population.
Riverine	Refers to waterbodies that have higher flow velocities and exhibit more river-like characteristics.

Secchi disc	A 20-cm disc painted with alternating black and white quadrants. The disc is lowered into the water until it disappears from view. The depth at which it disappears is called the Secchi depth and is a relative measure of water clarity. It is usually measured in meters.
Secondary settlement	The resettlement of mussels that have been washed from the substrate or have otherwise detached themselves.
Thermocline	The gradient of rapid temperature change, usually $\leq 1^{\circ}C$ per meter, in a thermally stratified lake.
Threshold level	The level or amount required to just induce a response or produce an effect.
Translocator	Adults mussels that have been detached or have detached themselves to become part of the drift.
Trochophore	The larval stage immediately following the gastrula. Swims by cilia but the velum is not yet present. In native clams, this stage is passed within the developing embryo.
Trophic status	The nutrient status of water (oligotrophic, mesotrophic, and eutrophic).
Turbidity	The "cloudiness" of water. A measure of the quantity of material in the water.
Valve	One of the two shelled structures on either side of the body of a bivalve mollusk.
Veliconcha	Specific larval stage following the D-form (shape) after the second prodissoconch is formed.
Veliger	Specifically, the larval stage with a velum before the first prodissoconch is formed. Often used as a general term for any larval stage of bivalves found in plankton.
Velum	Ciliated structure on veliger larvae; used for swimming. Structure is resorbed and forms part of the siphons during metamorphosis to juvenile.
Zebra mussel	Dreissenid mussel, *Dreissena polymorpha*. Named because of the zebra striped pattern on its shell.
Zooplankton	The assemblage of animals in the plankton. Include primarily protozoans, rotifers, and crustaceans, as well as the larval stages of dreissenids.