

**ZEBRA MUSSEL BIOFOULING CONTROL IN COTTAGE
AND OTHER SMALL VOLUME WATER SYSTEMS**

PART A: Gerald L. Mackie, University of Guelph

SOME FACTS ABOUT ZEBRA AND QUAGGA MUSSELS

PART B: Barb Crosbie, Aquatic Sciences Inc.

**AN INVESTIGATION INTO THE ABILITY OF
SIX DIFFERENT PRODUCTS TO
PREVENT ZEBRA MUSSELS FROM
INFESTING A SMALL VOLUME WATER SYSTEM**

PART C: Report by Steering Committee

A CONSUMERS GUIDE TO EVALUATING THE DEVICES TESTED

**THE GEORGIAN BAY ASSOCIATION
19 Edgecombe Avenue
Toronto, Ontario M5N 2X1
www.georgianbay.ca**

**Partially funded by:
The Greater Bay Area (G.B.A.) Foundation
48 Lesmill Road
Don Mills, Ontario M3B 2T5**

TABLE OF CONTENTS PARTS A, B, C

EXECUTIVE SUMMARY	<i>i</i>
--------------------------------	-----------------

PART A:

A COTTAGER'S GUIDE TO UNDERSTANDING THEIR LAKE

INTRODUCTION	A-1
SOME FACTS ABOUT ZEBRA AND QUAGGA MUSSELS.....	A-2

PART B

BACKGROUND.....	B-1
INTRODUCTION	B-3
STUDY SITE	B-4
METHODS.....	B-4
RESULTS	B-11
DISCUSSION.....	B-19

PART C

ZEBRA MUSSEL REMOVAL/ELIMINATION.....	C-1
TURBIDITY AND SUSPENDED MATERIAL REMOVAL	C-2
MAINTENANCE.....	C-3
INSTALLATION, AVAILABILITY AND COST.....	C-4

EXECUTIVE SUMMARY

Zebra mussels (*Dreissena polymorpha*) were first discovered in Lake St. Clair in 1988. Since that time the mussel has spread throughout North America and has now invaded all the Great Lakes and over 50 Ontario lakes and rivers within the Great Lakes drainage basin. In addition, the quagga mussel (*Dreissena bugensis*), first discovered in 1990 in Lake Ontario, has spread throughout Lake Erie and Lake Ontario, with a few sightings on the Mississippi River. The impact on industries drawing water from the Great Lakes was rapid, and caused shutdowns due to severe flow reductions as mussels attached to intake structures and the insides of pipelines. The potential spread of mussels to more inland lakes and their impact on cottage intakes, and other small volume intake structures, were predictable.

This report provides cottagers with information to help prevent zebra and quagga mussels from plugging their intake structures. The report is divided into two parts. Part A describes three differences between zebra and quagga mussels that are needed to recognize them, such as:

- (i) unlike zebra mussels, quagga mussels have an ability to live and reproduce in deep parts of lakes, so that cottage intakes at all depths will be affected
- (ii) the zebra mussel is much more colourful than the quagga mussel and has alternating yellow, brown, black and/or white stripes
- (iii) the zebra mussel has a much flatter bottom surface than does the quagga mussel whose bottom is more typically clam-shaped.

Part A also provides information that explains why zebra mussels are a problem (e.g., they have unique life cycle and they adhere to surfaces using byssal threads) and their potential impact on recreational activities and the ecology of the lake. Most importantly, cottagers are shown how to determine if zebra and quagga mussels will be a problem. For example, the cottager need not worry about infestations if:

- (i) the pH is <7.0
- (ii) the calcium level is <10 mg/L
- (iii) water temperature is >15°C for fewer than 7 to 10 days.

Cottagers would be wise to take action if:

- (i) the pH is > 8.0
- (ii) the calcium level is >20 to 25 mg/L
- (iii) if water temperature is >15 to 18°C for more than 20 to 30 days.

In Part A, the cottagers are also given some simple control methods to try before selecting a control device. If a control device is needed, the cottagers are told how to select an appropriate device, when to begin the control program and how to know if the control program is working.

The second part of this report, Part B, describes the performance of six different zebra mussel control methods under rigorous test conditions. The ability of these products to remove zebra mussels from the water column, preventing settlement in the test system, was the key parameter used to measure performance. The products were tested over a four month period, with each system receiving approximately 400 000 L of water. The configuration of the experimental test systems was intended to mimic that found in a cottage intake system.

The products tested in this trial included five filters and one small-scale chlorination treatment. The cost of the product, the ease with which it was installed, the level of maintenance required and its availability to the consumer were considered here in the performance evaluation. Part C compares the performance of the six devices tested here. The zebra mussel removal efficiency ranged from 73% to 100%, except for one product that experienced mechanical difficulties for the entire duration of the test. The filter products effectively removed zebra mussels from the water column and prevented settlement (>95%) in the test systems. However, several of these products required a high level of maintenance throughout the experiment. Also, the high cost associated with a number of these products would deter many consumers. A few of these products were difficult to install and would require either a professional assistance or a local handyman. The chlorination treatment, although effective in removing zebra mussels, would also be associated with high residual chlorine that may negatively impact non-target biota.

Part A

Some Facts About Zebra and Quagga Mussels

Gerald L. Mackie
Department of Zoology, University of Guelph
Guelph, Ontario N1G 2W1

GBA Webmaster's note:

This document varies slightly from the original printed document. It has been recreated as well as possible, given the various file formats the graphics were created in. It is clearly marked in the text where tables or figures are missing.

A COTTAGER'S GUIDE TO UNDERSTANDING THEIR LAKE

(To be published in fall 1999)

by Gerald L. Mackie

Much of the text of Part A in this report is from the above guide, to be submitted for publication in the fall of 1999. The information for the guide is taken from the textbook, "Applied Aquatic Ecosystem Concepts", written by the same author. The text is published by the University of Guelph and is required for the three courses that he teaches, "Introduction to Aquatic Environments", "Biology of Running Waters" and "Biology of Polluted Waters".

Dr. Mackie's research at the university of Guelph over the past 25 years has examined the impacts of lake enrichment, lake acidification, artificial impoundments and exotic species on the ecology of organisms that live on the bottom of lakes and streams. His research in the last ten years has focussed on the biology, impact and control of zebra mussels. He was the first to discover and report on zebra mussels in the Great Lakes. In addition to the above textbook, he has published more than 130 scientific papers in refereed journals, 7 chapters in books and co-authored (with Renata Claudi, another member of the Zebra Mussel Control Products Testing Group who conducted this Georgian Bay Association study) one book on zebra mussel monitoring and control.

Dr. Mackie has applied most of the concepts that he teaches at the university to learn about the lake that his cottage is on, including "sounding" the lake to develop a bathymetric map, assessing the lake's water quality and determining if zebra mussels will ever be a problem in the lake. He has dealt with many issues for his lake, including nutrient enrichment, lake acidification, nuisance growths of algal, declining fish populations, nuisance bloodsuckers, extensive weed growths and zebra mussels. Many of the issues, or "problems", are the result of natural phenomena, others are the result of human negligence. Recognizing the causes and the symptoms are key to restoring any lake's health and are discussed in the guide.

Having experienced the cottage scene nearly all his life, Dr. Mackie has asked most of the same kinds of questions as other campers and cottagers. Most have heard the same answers, but the logic behind each is often missing. For example, "What is the maximum wave height for a lake?". Most have an answer that is peculiar to their lake, but few know how to estimate the maximum wave height. "Should one boil lake water before drinking it?". Some say yes, some say no. But when one discovers what microorganisms live in even the cleanest of waters, many of the noes soon turn to yeses. The guide answers more than 200 questions, and gives the logic behind each answer. Most of the illustrations in Part A of this report are from his guide. Here is a sample of some of the questions answered in the guide:

1. Can zebra mussels REALLY be a problem in my lake?
2. How can I protect my intakes from zebra mussels? Do I really need a filter device?
3. What are the big "blobs of jelly" (algae) on my shore? How do I get rid of them?
4. Is my lake polluted?
5. Where have all the fish gone? Why?
6. What is purple loosestrife? How do I control it? Do I need to control it?
7. What are the "foamy streaks" on my lake?
8. Are motor boats really a pollution problem?
9. Bloodsuckers, yuck. How do I get rid of them?
10. What does lake colour mean?
11. What is the most dangerous (lethal) animal in lakes?
12. Should other cottages be built on my lake?

Advance orders for the Cottager's Guide are being accepted at:

Phone and Fax: 519-767-6684

email: gmackie@uoguelph.ca

TABLE OF CONTENTS

INTRODUCTION	A-1
I. SOME FACTS ABOUT ZEBRA AND QUAGGA MUSSELS	A-3
What You Should Know About Zebra Mussels, and Why	A-3
Characteristics of Zebra and Quagga Mussels	A-3
Differences Between Zebra and Quagga Mussels	A-3
Generalized Life Cycle	A-5
Potential Impacts of Zebra and Quagga Mussels	A-7
Navigational and Vessel Impacts	A-7
Encrusting the hulls of boating and sailing vessels	A-7
Encrusting of navigation buoys	A-7
Private Property Impacts	A-7
Fouling of cottage plumbing and intake structures	A-7
Formation of shoals of shell debris on beaches	A-8
Ecological Impacts	A-8
Potential loss of fisheries	A-8
Elevated levels of contaminants	A-8
Reduced turbidity/increased water transparency	A-8
Loss of endemic species of clams	A-8
Alteration of benthic community structure and abundance	A-8
Increased potential as vectors of parasites	A-9
Dispersal Mechanisms, or How Zebra Mussels Get to Different Lakes	A-9
Now that Zebra Mussels are in a Lake, Will they be a Problem?	A-11
Some Basic Requirements of Zebra Mussels	A-11
How To Determine pH and Calcium Content	A-13
Some Tolerances of Zebra and Quagga Mussels	A-13
What to do if Zebra Mussels are a Problem	A-15
Some Basic Principles	A-15
The KISS Principle	A-16
High Flow Rates	A-16
Thermal shock	A-16
Oxygen Deprivation	A-17
How to Decide What Type of Control Method to Use	A-18
Mitigation by Chlorination Devices	A-20
Mitigation Using Physical Methods	A-20
Filters	A-20
Low Levels of A-C Current	A-20
Ultraviolet Light	A-21
APPENDIX A-I	A-22

INTRODUCTION

The purpose of this report is to inform cottagers and other small volume water users of the potential for zebra and quagga mussels to *biofoul* (making something unfit for its intended use by fouling it with organismic growth(s)) water intake systems and how to prevent or limit biofouling. Indeed, some water users may not have to worry at all about biofouling mussels because the water chemistry will not support their growth or reproduction. Even if mussels are present and have the potential to biofoul intakes, there are some simple tactics that can be used without installing filters or other devices designed for preventing biofouling. However, as described below, the intensity of biofouling depends on numerous factors, such as the water's pH and calcium content, its turbidity, the lake's size and depth and its trophic (nutrient) status, the depth of the intake, the type of intake, frequency of pump use, duration of pump use, and even type of waste disposal or treatment. This matrix of factors makes each cottage unique, and each water user must consider all factors before deciding if a filter or another device is required to prevent mussels from plugging their water intake.

Part I of the report provides cottagers, and others, with enough information about zebra mussels so that they can decide, by themselves, whether they need to worry about zebra mussel infestations, and if so, how to deal with them. Most of the information is taken from Mackie (1999)¹. Some concepts are more important than others but, fortunately, there are some simple "rules of thumb" to help apply the most useful ones. These are indicated in the left margin by:

Rule of Thumb Here

Part II of the report describes different control device options for cottagers and others with low volume intakes and their efficacy (efficiency) at preventing biofouling. Tests were performed on six devices, in the Welland Canal, following a typical cottage use scenario, from June until November, 1998.

The manufacturers of zebra mussel control products are knowledgeable people who have been attending conferences and seminars for at least the past five years to learn all about the mussel's biology and ecological tolerances and requirements. However, often manufacturers forget that they too were novices at zebra mussel control and begin to use scientific jargon that the lay person may not understand. For the most part, this report uses lay terms. If there is not a lay term that is a suitable substitute for a scientific term, the latter is used, but it will be well defined.

¹Mackie, G. L. 1999. A cottager's guide to understanding their lake. In preparation for publication in 1999. *See the following page for details.*

I. SOME FACTS ABOUT ZEBRA AND QUAGGA MUSSELS

What You Should Know About Zebra Mussels, and Why .

There are two kinds of biofouling mussels, the zebra mussel and the quagga mussel . Scientists call them *Dreissena polymorpha* and *Dreissena bugensis* , respectively (they always italicize scientific names of animals). The two species are very different in appearance and have very different ecological tolerances and requirements, as outlined below, but since they can be controlled with the same methods, the term “biofouling mussel” is used when a concept applies to both species. The following describes some biological characteristics of zebra and quagga mussels and the reasons why each characteristic is important to know.

Characteristics Of Zebra And Quagga Mussels

Scientists have several reasons for knowing the differences between the two species, but cottagers really only need to concern themselves about one - *unlike zebra mussels, quagga mussels have an ability to live and reproduce in deep parts of lakes, and if a cottage water intake is in more than 30 m (100 ft) of water, biofouling will be more probable by quagga mussels than by zebra mussels.* However, ***water chemistry will determine the potential size of the infestation for each species.***

There are several differences (e.g shape, physiology, genetics, ecology), but cottagers should concern themselves only with differences in shape (needed to readily identify them) and ecological tolerances and requirements (needed to determine the potential for invasion in a lake).

Fig. 1 shows a side view of each species, *the zebra mussel usually being much more colourful, with alternating yellow, brown, black and/or white stripes, than the quagga mussel.* Also, *the zebra mussel has a much flatter bottom surface than the quagga mussel whose bottom is more typically clam-shaped (Fig. 2).* A simple way to tell the two species apart is to place the shells on a table, with the bottom side down; *if the mussel remains upright, it is a zebra mussel; if it rolls over on its side, it is a quagga mussel.*

Fig 1 (zebra mussel) here

Fig. 1 (Quagga) here

Figure 1. Zebra (left) and quagga mussels. The zebra mussel is attached to a native clam and is the first specimen to be reported from Lake St. Clair in 1988.

Incidentally, the zebra mussel’s shell shape is a perfect adaptation to exploit life on hard surfaces. The ventral surface is flat and, with help from the ***byssal apparatus*** (discussed below), allows the mussel to be pulled tightly against the surface of the substrate. With a triangular shape (in end view), it is very difficult for predators to grasp and pull the mussel from

the surface. The zebra mussel is the only freshwater bivalve that has this adaptation.

All mussels have two *valves* (hence the scientific class name, *Bivalvia*). The valves are hinged by a non-living *ligament* on the top side (Fig. 2), so the opening, or *valve gape*, is widest on the bottom edge. The hinge ligament is “spring-loaded” and forces the

Fig 2 here

valves to gape. Two muscles (called *adductor muscles*), one at the front and one at the back, attach the two valves together, and when contracted, close the two valves. Since the two muscles can be contracted only when the mussel is living, closed valves indicate living mussels. The adductor muscles must be relaxed when the mussel wants to extend its foot through the gaping valves. When the mussel dies, the adductor muscles are non-functional, so the valves gape due to the spring-loaded action of the hinge ligament. *Hence, if one wishes to know if a control program is killing adult mussels, a simple rule-of-thumb for death is gaping valves that do not close after touching or gentle prodding.*

Another unique feature of exotic bivalves (others being shell shape and colour) is their ability to attach to solid surfaces by means of a *byssus*. The byssus consists of numerous threads that are secreted by a *byssal gland* in the base of the foot. Some native clams can produce byssal threads, but only during their larval or juvenile stages. *Hence, another diagnostic feature that helps to differentiate native clams from exotic mussels is the presence of a byssus on the latter.* When an adult mussel attaches itself to a surface, first the adductor muscles are relaxed, then the foot is extended through the gaping valves, and then a thread is secreted. The byssal thread is liquid at first, but hardens into a thread when water contacts the

liquid. The mussels can produce about 12 threads per day. If an adult mussel has not detached itself, it can secrete as many as 600 byssal threads in its life time. A small, circular space on the bottom, inner edge of the valves allows the mussels to close the valves without pinching the threads (Fig. 2).

Generalized

Zebra and quagga mussels are the most prolific mollusc species in freshwater, producing over one million eggs per female each year in their two- to three-year life span. As in European populations, there are one or two spawning seasons per year. The first lasts about three months (early to mid-May to early to mid-August) and is comprised of several spawning events; the second occurs in August or September. If only one spawning season occurs, spawning peaks about the end of August, but several small spawning events may occur even into October in the Great Lakes.

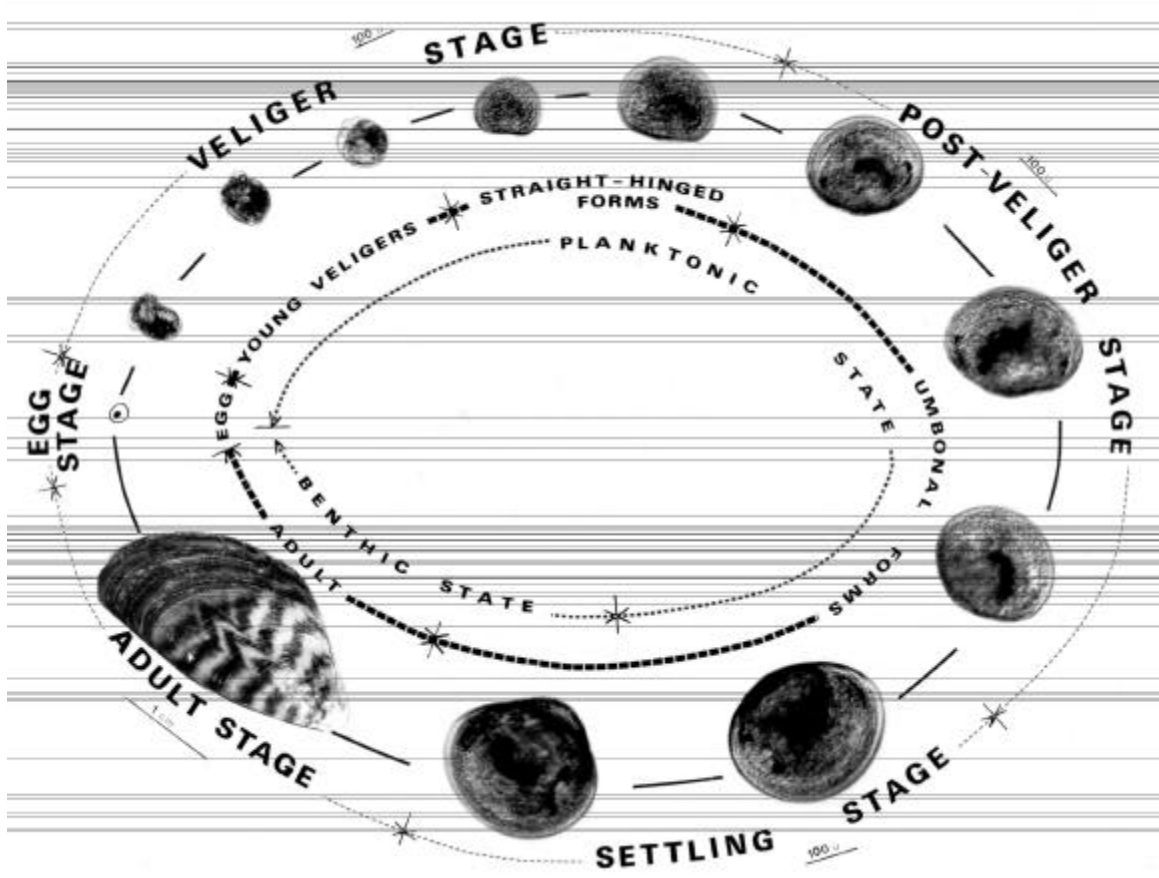
The sexes are separate, with both males and females occurring (~ 1:1 ratio). Development of ovaries and testes in adults occurs through the fall and winter months. Shell growth resumes in the spring when the water temperature reaches 8-10 °C. Eggs and sperm are released when the water temperature reaches 12-15 °C. The rate of larval development is highly variable and depends on temperature; the warmer the water, the faster the development. On average, development from the egg to the settled stage requires 21-30 days, as the water temperature rises from 12-20 °C. However, when the water temperature peaks and is maintained at an average of at least 15-18 °C over a two- to three-week period, only 10-15 days may be required for development from egg to settlement. Hence, a good rule-of-thumb to use in deciding when to begin a zebra mussel biofouling control program is to *monitor the temperature and begin biofouling control before the water temperature reaches 15-18 °C*.

The larvae pass through several developmental stages in the water column before settling to the bottom (Fig. 3). The larval stages are extremely small (40-500 µm). The human eye can detect specks as small as 2-3 µm¹, under perfectly ideal conditions (e.g. light object on dark background, perfect vision), but shapes and forms are not discernable even at 40 µm diameter. The egg, which is ~ 40 µm diam, (or ~ diam of an eyelash - see caption of Fig. 3 for size relationships), hatches into a *trochophore* larva **which persists for about 2 days and grows to ~83-95 µm**. The trochophore has no shell and swims by means of cilia on a structure called a *velum*. The formation of a thin, transparent shell marks the beginning of the **D-shape veliger** stage, which grows to 125 µm (range 95 - 160 µm) over the next 2-7 days. The trochophore and D-shaped larvae are part of the **veliger stage** of development. An *umbone*, or beak, forms and replaces the flat part of the “D” and denotes the beginning of a *veliconcha* larva. **The veliconcha develops over**

Fig 3 here

¹Pers. Comm. Dr. Robert Miller, Optometrist, Guelph, Ontario

Figure 3



the next 2-3 days, growing to a mean shell length of 200 μm (range 120-280 μm). Both the D-shaped veliger and the veliconcha larva are planktonic, swimming in the water column by means of cilia on the velum. But the velum is gradually replaced by a foot and the larva loses its ability to swim and remain in the water column. The developing foot marks the beginning of the *pediveliger* stage, which ranges in shell length from 167-300 μm (average \sim 230 μm). The veliconcha and pediveliger are part of the *post-veliger stage* of development. When the velum is completely absorbed and replaced entirely by a foot, the larva settles to the bottom and becomes a *plantigrade* larva, **ranging in shell length from 158-500 μm** (average 325 μm). The plantigrade larva then develops into a juvenile and by \sim 5-8 mm forms gonads and becomes an adult. The umbone that started forming in the veliconcha stage, represents the oldest part of the shell in the adult. Shell material is added concentrically about the umbone, so the newest part of the shell is at the growing edge (Fig. 3).

The foregoing provides more detail than most cottagers need, but if any of the above terms appear in magazine articles, at least the cottagers will know what they mean. The two most important messages from the above are: (1) *filters with pore sizes larger than 40 μm will not keep zebra/quagga mussels out of cottage pipelines*; (2) *the biofouling stage begins with the settled plantigrade form, the planktonic larval stages do not cause biofouling problems*.

Considerable mortality of the larvae may occur, up to 99%. Most of this mortality probably occurs during the settling event, especially if the plantigrade form does not find a suitable substrate on which to attach. In spite of this high mortality, zebra mussels are the most prolific of all the exotic (22 species) and native molluscs in North America. Scientists have shown that females can produce over one million eggs, and even with 1% survival, \sim 10,000 grow to adult stage. In Lake Erie, the average density of adult mussels on the bottom is 25,000 - 50,000/ m^2 . Half of these are females; so the population is capable of producing 125,000,000 - 250,000,000 new recruits per square metre each year! Fortunately, there is considerable mortality at the adult stage as well.

The quagga mussel has a greater reproductive potential than the zebra mussel because it can reproduce at lower temperatures, as low as 9 $^{\circ}\text{C}$, and grow at lower temperatures (at least 7 $^{\circ}\text{C}$). It is also capable of living in mud. Since the deep parts of most lakes are dominated by soft bottoms, the quagga mussel will occupy a greater percentage of lake bottoms than will the zebra mussel.

One last word of caution. Adult mussels are known to *translocate*, that is, detach from a substrate and be carried by water currents, waves, etc. to another location and re-attach. Generally, translocation is not sufficient in itself to plug intakes. Also, much of the translocation seems to occur during winter months, when most pumps and intake systems are shut down. However, *if the dwelling is a permanent residence and intakes are not shut down (e.g. winterized), it would be prudent to examine exposed intakes for translocated adults in the spring, or at least before the next settlement event*.

Potential Impacts of Zebra and Quagga Mussels

So far we have alluded to the plugging or blockage of cottage intakes (e.g. foot valves) and pipelines, but there are other impacts that cottagers need to know. A thorough treatment of zebra mussel impacts is beyond the scope of this report, and only impacts that are relevant to cottagers are summarized below, including plugged intakes. The overview should impress upon cottagers the importance of keeping mussels out of lakes.

Navigational and Vessel Impacts

1. ***Encrusting the hulls of boating and sailing vessels*** : This is a common sight in the Great Lakes. Fouling not only detracts from the aesthetic value of the vessels but also from the sailing efficiency.
2. ***Encrusting of navigation buoys to the point that the buoys sink deeper in the water than normal***: This has also been demonstrated in the Great Lakes, especially for fishing markers/buoys.
3. ***Fouling of cottage plumbing and intake structures*** There are increasing numbers of reports that foot valves and/or screens protecting the plumbing lines are being fouled by zebra mussels.
4. ***Formation of shoals of shell debris on beaches that will detract from the beach's recreational and aesthetic value***: This was a common sight on some large beaches on Lake Erie in 1990-1992.
5. ***Potential injury and health problems*** . For example, one hospital in cottage country reported that, in the summer of 1998, the greatest number of visits to emergency was due to cuts caused by zebra/quagga mussel shells.
6. ***Potential loss of fisheries*** : Fish species that feed on plankton will be affected through the filtering feeding activities of the zebra mussels. This has not yet been proved for Great Lakes fisheries, but conversations with commercial fishermen on Lake Erie and Lake St. Clair suggest that impacts are only now being manifested as smaller catches of perch, smelt, and walleye. This may be related, in part, to declines in some deepwater benthos (bottom-dwelling organisms). Apparently the recent declines in deep water smelt populations are being enhanced by diversion of energy to large quagga mussel populations in eastern Lake Erie, both through induced changes to the biomass and composition of the plankton as well as to reduced sizes of ***deep water amphipod*** populations. With the introduction of the zebra mussel, there has been a shift from a ***pelagic*** -dominated food web to a ***benthic*** -dominated food web. In some lakes (e.g. Lake St. Clair, Lake Ontario) there has been an increase in benthic biomass, especially in worms, snails, midge fly larvae, amphipods, and crayfish.
7. ***Elevated levels of contaminants*** : *Dreissena* may accumulate organic and inorganic contaminants which are passed up the food chain. This ***biomagnification*** can result in reproductive problems such as reduced clutch sizes and high embryo mortality in ducks.
8. ***Reduced /increased water transparency*** : The dense population of zebra mussels in North American waters has resulted in the removal of suspended materials from the water, which has resulted in reduced plankton biomass and increased water clarity. The reduced levels of plankton are predicted to have a negative impact on fish that feed on the plankton. However, there have been some beneficial impacts. ***Macrophyte*** (large aquatic plants) and benthic algae biomass and diversity have increased and SCUBA divers have benefited from the increased water clarity.
9. ***Loss of clams*** : All native ***freshwater pearly mussels*** (also called ***mother-of-pearl clams***) on the Ontario shores of Lake St. Clair, where the mussel was first introduced, were eliminated by the zebra mussel by 1992. Similar results have been documented for other North American lakes (mostly Great Lakes) and rivers. Significant declines in clam densities seem to occur when infestation levels exceed 10 zebra mussels/clam. The decline in clam diversity may also be due, in part, to species-specific rates of starvation.

10. ***Alteration of benthic community structure and abundance*** : Changes in biomass of benthic algae and macrophytes (see 7 above) were followed by changes in the benthic invertebrate community, with ***grazers*** (algae eaters) and ***herbivores*** (plant eaters) showing a greater contribution to the total diversity. Numerous studies document changes in community structure and abundance in benthic invertebrates, in part due to increased loadings of faeces, ***pseudofaeces*** (material ingested but not digested and eventually released by zebra mussels) and particulates placed on the bottom by zebra mussel filtering activities, which are hypothesized to affect fish community structure and abundance.
11. ***Increased potential as vectors of parasites whose definitive hosts are important species of fish and/or waterfowl*** : This has not yet been demonstrated in North American waters but has occurred in Europe.

Dispersal Mechanisms, or How Zebra Mussels Get to Different Lakes

More than twenty-three different dispersal mechanisms have been attributed to the larval and adult stages of the zebra mussel (Table 1). These can be divided into five natural (e.g. water currents, birds and other animals) and fifteen human-mediated mechanisms (e.g. ballast water, hulls of sailing vessels, etc.). The enormous number of pathways has impressed upon us the near impossibility of preventing the spread of zebra mussels once they have been introduced. "It is not a question of IF it will get here, it is more a question of WHEN it will get here" is now a cliché for describing the dispersal powers of the biofouling mussels. However, it is extremely important that we delay their dispersal into lakes as long as possible and that we maintain a constant vigilance on human-mediated introductions, such as by boats, bait buckets, fish wells, etc.

Mackie (1998)² rated the various dispersal mechanisms according to the potential distance that the mussels could be moved. For example, some mechanisms (e.g. river flow, mammals) are useful for dispersing mussels only within a watershed or small region, others (e.g. waterfowl, boats, trailers, fishing gear), between provinces or states within North America, that is, intra-continently; and still others (e.g. ship ballast, aeroplanes), between continents outside of North America, or inter-continently. Cottagers should concern themselves with mechanisms that disperse mussels regionally and within North America.

While currents are an effective mechanism for dispersing planktonic larval stages, they are not effective for sustaining populations in streams. The byssal apparatus will help to maintain the position of the adults in streams, but the flow of water will carry the larvae well downstream of the parent population, which will ultimately disappear, unless an upstream population can rejuvenate/replenish the colony. The distance that the larvae are carried depends upon the water velocity and the duration of the planktonic stage. Zebra mussels introduced to a stream will survive one life span at best, unless they are dispersed again to the same site, which is not likely if there are no adults upstream, or unless there is an impoundment to retain the planktonic larvae. Indeed, reservoirs will

²Mackie, G. L. Applied aquatic ecosystem concepts. Available in manuscript form from University of Guelph Bookstore, ISBN 0901024311

Table 1 here

serve to provide breeding habitats for establishing and maintaining populations downstream. Once rivers become slow enough and currents are such that the position of the developing larvae can be maintained up to and including settlement, the populations can be self-sustained by the adults attached to the bottom. Therefore, without mainstream reservoirs, zebra mussels will not succeed (or at least will not be as great a pest) in most rivers in North America. Streams with an average velocity of 0.1 m/sec (= 8.64 km/day) would carry larvae with development times of 20 to 30 days, about 173 to 260 km downstream before settlement would occur. For a population to maintain its position within 100 m of itself, the average water velocity must be less than 0.00006 m/sec, a velocity exceeded in most streams, and possibly many reservoirs (based on Drift Distance = Average Development Time x Water Velocity; therefore, velocity = 100 m/21 days = 100 m/(21 days x 24 hrs/day x 60 min/hr x 60 sec/min) = 0.00006 m/sec). Only back eddies in pools of rivers, mainstream impoundments or reservoirs would provide such low velocity currents for the complete development of the larvae. *Hence, neither zebra nor quagga mussels can survive indefinitely in streams lacking impoundments.*

Support for the above is given in Fig. 4, which shows the current distribution of zebra mussels in Ontario. Mussels have been reported from two large riverine systems, the Trent River/Canal and the Rideau River/Canal. Both systems have numerous lakes that “seed” populations downstream. With few other riverine exceptions (e.g. Green River), most sightings are from lakes. The distribution map is based on data obtained from the Ontario Ministry of Natural Resources and Ontario Federation of Anglers and Hunters. *Updated information can be obtained by calling the **Invading Species Hotline: 1-800-563-7711***

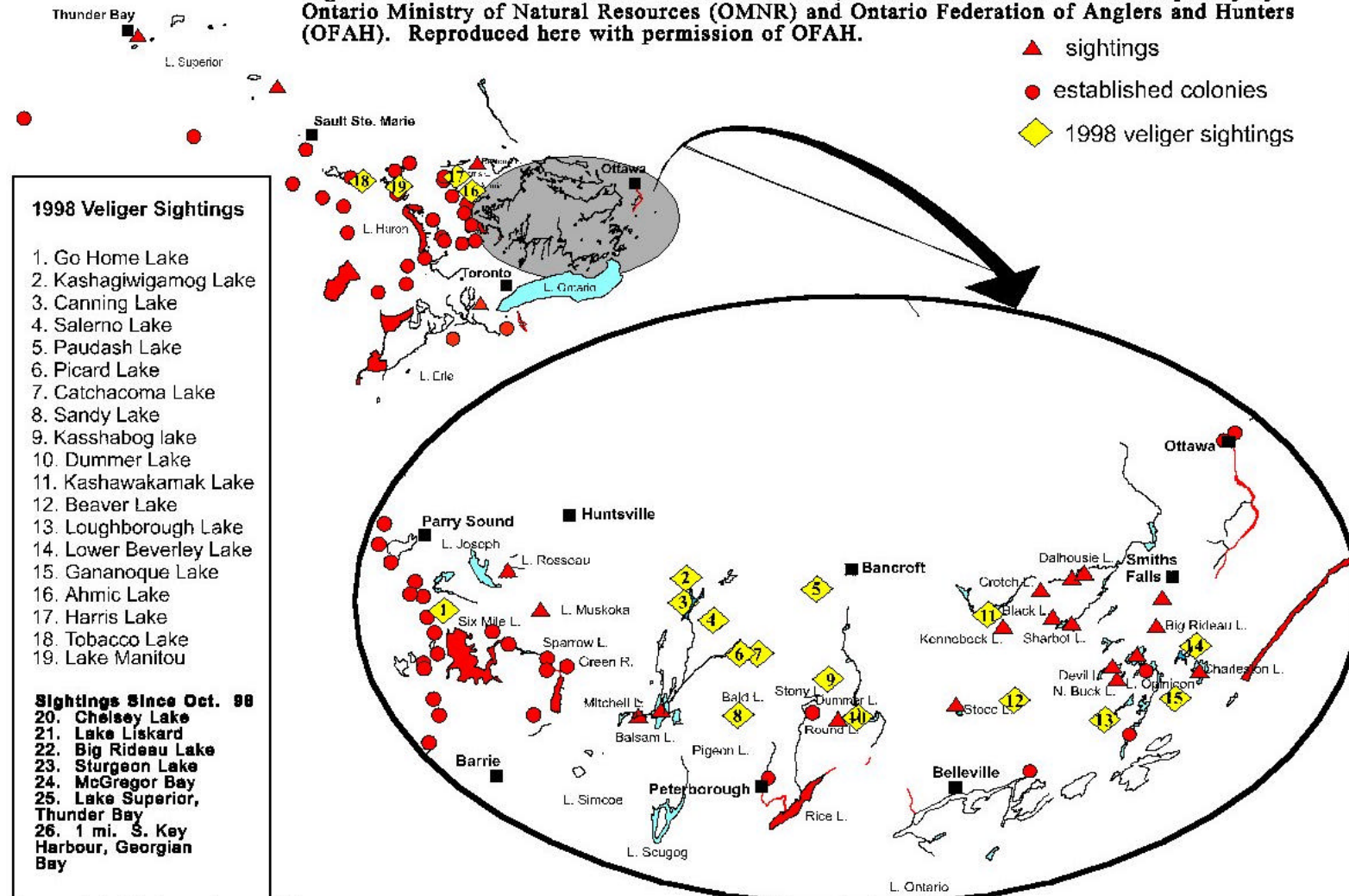
Now that Zebra Mussels are in a Lake, Will they be a Problem?

All aquatic organisms have certain requirements in order to grow and reproduce, once introduced into an environment. Optimum growth and reproduction occur when the limiting factors are present in optimal amounts. If sub-optimal amounts are present, sub-optimal growth and reproduction occur. Organisms must also be able to tolerate, for short periods of time, conditions that are beyond sub-optimal amounts. The following describes some tolerances and requirements of zebra and quagga mussels.

Some Basic Requirements of Zebra Mussels

Three variables are critical for optimal growth and reproduction in zebra and quagga mussels: temperature, calcium content, and pH of the water. Zebra mussels require at least 8-10 °C to begin growth and at least 12-15 °C to begin reproduction. Quagga mussels have lower thermal requirements, both growth and reproduction beginning to occur at about 7 °C. The duration of these temperatures is more important than the absolute temperature itself. Temperatures of at least 15-18 °C are needed for the life cycle to be completed in 21 to 30 days for both species. *Hence, temperatures above 15-18 °C must be maintained for at least 21 to 30 days in order for settlement to occur for both zebra and quagga mussels.*

Figure 4. Distribution of zebra mussels in Ontario, as of October 1998. Produced jointly by Ontario Ministry of Natural Resources (OMNR) and Ontario Federation of Anglers and Hunters (OFAH). Reproduced here with permission of OFAH.



1998 Veliger Sightings

1. Go Home Lake
2. Kashagiwigamog Lake
3. Canning Lake
4. Salerno Lake
5. Paudash Lake
6. Picard Lake
7. Catchacoma Lake
8. Sandy Lake
9. Kasshabog lake
10. Dummer Lake
11. Kashawakamak Lake
12. Beaver Lake
13. Loughborough Lake
14. Lower Beverley Lake
15. Gananoque Lake
16. Ahmic Lake
17. Harris Lake
18. Tobacco Lake
19. Lake Manitou

Sightings Since Oct. 98

20. Chelsey Lake
21. Lake Liskard
22. Big Rideau Lake
23. Sturgeon Lake
24. McGregor Bay
25. Lake Superior, Thunder Bay
26. 1 mi. S. Key Harbour, Georgian Bay

For updated information call the
 Invading Species Hotline 1-800-563-7711

All bivalves need calcium for their shells. Studies have shown that a minimum of 7 mg/L is required for growth and 15 mg/L for reproduction to occur. **Infestation** intensities (a measure of biofouling potential) increase with increasing calcium levels between 10 and 25 mg/L.

Infestation intensity is high and not affected by calcium levels above 25 mg/L. Hence, *none to little biofouling can be expected to occur between 7 and 15 mg Ca/L,*

moderate to intense biofouling between 15 and 25 mg Ca/L, and extensive biofouling, with possible taste and odour problems associated with high mussel mortality, above 25 mg Ca/L.

In general, the hydrogen ion content, usually expressed as **pH** (power of hydrogen) is a measure of acidity and is closely correlated with calcium levels, since the pH is controlled by the amounts of calcium bicarbonate and carbonate in the water. The amount of calcium (usually expressed as mg/L or ppm - parts per million, where 1 mg/L = 1 ppm) in the water is a measure of the calcium hardness. The amount of bicarbonates and carbonates is a measure of the water's **total alkalinity**, or the ability of the water to consume hydrogen ions or to neutralize the acidity. Optimal growth and reproduction for both zebra and quagga mussels occurs at pH levels greater than 8.0. *None to little*

biofouling can be expected to occur below pH 7.5, moderate to intense biofouling between pH 7.5 and 8.0, and extensive biofouling above pH 8.0.

How To Determine pH and Calcium Content

The procedures for measuring pH and calcium levels is relatively simple, using relatively inexpensive water testing kits (Appendix A-I). The pH can be measured with either a colour comparator or an electronic device. Appendix A-I provides the names and addresses of companies that sell water testing equipment and supplies. The pH tester should be able to measure pH in the range of at least 5.5 to 8.5. The colour comparators used for determining pH of swimming pools will do, but those with a "colour disc" provide greater accuracy. Basically, the pH is determined by adding an indicator solution to a water sample and then matching the colour of the sample to a pH colour on the disc. Details instructions for using the pH colour comparator and pocket meter are provided by Hach.

The easiest and simplest method to estimate the calcium level from the calcium hardness. Calcium hardness kits are available only at stores that specialize in water testing, such as those listed in Appendix A-I. Unfortunately, the calcium hardness kit is available only in combination with the total hardness kit, which is not needed here (but is useful for other water quality tests, as described in the cottagers guide (see Introduction). The calcium hardness kit comes with "powder pillows" (called CalVer) which contain a dry "indicator" chemical, a buffer solution and a titrating solution (called EDTA). A 2-ml water sample measuring tube and a 5-ml vial are also provided for mixing the water sample. Instructions for measuring calcium hardness in mg CaCO₃/L are given in the Hach kit. The calcium level in mg Ca/L is estimated by dividing the calcium hardness (in mg CaCO₃/L) by 2.5.

Some Tolerances of Zebra and Quagga Mussels

Zebra and quagga mussels are tolerant of a wide variety of conditions, including polluted, low oxygen, warm waters. They are also able to tolerate some desiccation and high silt loads (measured as turbidity).

The thermal tolerances of biofouling mussels are well described. For zebra mussels the chronic lethal temperature is 34-37 °C, while the **acute** (i.e. sudden) lethal temperature ranges from about 33 °C to 42.3 °C. However, the amount of previous exposure to warm water greatly

affects both the acute and *chronic* (long-term) lethal temperatures. ***The tolerance times at different temperatures increase with increasing exposure times and decreasing shell size. The time to death of zebra mussels is rapid at freezing temperatures, death occurring in less than 24 h at -3 °C (= 27 °F).*** However, the temperature rarely falls below 4 °C in deep water and is between 1 and 3 °C in shallow, unfrozen water.

Several thermal tolerance studies were conducted to determine the feasibility of using high temperatures to control biofoulers. In general, molluscs, like all other aquatic organisms, adjust their upper thermal tolerance limits by acclimating to increasing summer temperatures as the summer progresses. Most molluscs have the ability to seek a preferred temperature and can usually find it in thermally stratified waters. This may include even the zebra mussels because they can translocate, by releasing themselves from their byssal attachment, and resettle in a more suitable thermal regime, as long as the dissolved oxygen levels are appropriate.

Zebra mussels cannot tolerate even short periods of no oxygen but can survive short periods of low oxygen levels (~ 2 mg/L) for about 2 weeks. Quagga and zebra mussels can survive 5 to 13 days in low humidity. Without renewed oxygen supplies, the mussels eventually succumb to accumulations of toxic end-products during dry periods, but are known to survive out of water for up to at least 7 days under damp conditions (e.g. rain).

Of all the physiological parameters of importance to exotic molluscs, tolerances to turbidity is the least understood. Associated with increasing loads of suspended particles are increasing rates of silt deposition on the bottom, especially in lakes, and in streams with slow current velocities. High deposition rates create silty bottoms, in which zebra mussels cannot survive, but quagga mussels do well. One effect of turbidity on native bivalves is a depression of the respiratory rate, with normal levels of turbidity having little or no effect on the rate of oxygen uptake. However, with zebra mussels the rate of oxygen uptake is only relatively depressed at low turbidities, near 5 NTU³ (Nephelometric Turbidity Units), and both zebra and quagga mussels can partially recover over a 4-week period to turbid water conditions (80 NTU) by adjusting their metabolic rate.

Both zebra and quagga mussels appear to have the same requirements for calcium. Neither can survive in waters with calcium levels below 7 mg/L. Infestation levels of growth and reproduction occur in waters with calcium levels above 25 mg/L. The quagga mussel can grow (7 °C) and reproduce (9 °C) at lower temperatures than the zebra mussel (8-10 °C for growth, 12-15 °C for reproduction) and therefore has a greater potential to infest more northern lakes than the zebra mussel. However, some scientists claim that quagga mussels can be more abundant at thermally enriched sites than at sites unaffected by thermal discharges and dispute claims that zebra mussels can tolerate higher temperatures than quagga mussels. It appears that quagga mussels prefer the relatively constant temperatures characteristic of deep water (e.g. ~ 4-7 °C) over the highly variable temperatures found in shallow waters.

Apparently quagga mussels have a lower upper thermal limit and a greater instantaneous mortality rate across acclimation temperatures than do zebra mussels. However, there appears to be no difference in instantaneous temperatures required to cause 100% mortality in either species. Quagga mussels also have the same functional response as zebra mussels to turbidity, acclimation turbidity and ambient turbidity, and both breathe normally in turbidities as high as 80 NTU when previously acclimated to high suspended loads.

³In water with a turbidity of 5 NTU, one can see their hand at least 1 metre (3 ft) below the surface; at 80 NTU, the hand disappears about 0.15 m (6 in) below the surface.

What to do if Zebra Mussels are a Problem

Claudi and Mackie (1994)⁴ review numerous physical, chemical, mechanical and biological methods for controlling zebra mussel biofouling. Most methods apply to industrial and domestic intakes, and only those that can be used in small-volume intakes are discussed here.

There are two basic strategies used to control biofouling. A **proactive strategy** employs methods that prevent the initiation of biofouling. A **reactive strategy** allows some biofouling to occur, but control methods are applied just before nuisance growths and problems occur. The proactive strategy generally employs control options all year, or most of the year, while the reactive strategy employs control options on a specific life stage (usually adults) for only part of the year. For example, as a proactive strategy, chlorine may be applied at levels (e.g. 0.5 mg/L) that do not kill veliger larvae but disturb them enough to prevent the plantigrade larvae from settling and attaching to the inside walls of pipes and wet wells. The chlorine would have to be applied from about June to November, while the larvae are in the water. As a reactive strategy, an industry may want to wait until November, after all larvae have settled, and then apply lethal doses (~2 mg/L at end of system) of chlorine until all attached adults are dead. While the costs may be lower for the reactive strategy, there are some disadvantages that are not usually encountered with a proactive strategy. Firstly, large numbers of dead (and often putrefying) shells must be discarded. Secondly, the effluent water usually has to be detoxified because high levels of chemicals are needed to kill the adults. If chlorine is used, sodium metabisulphite must be added at the end of the pipe to dechlorinate the water before it enters the receiving waters.

Some Basic Principles

Knowing the life cycle and tolerances and requirements of zebra and quagga mussels is important in preventing biofouling of cottage intakes. Lakes that have low pH (~ 7.0) and calcium levels (< 10 mg/L) will have few to no mussels and control devices will not be required. *Lakes with pH levels near 7.5 and calcium concentrations near 15 mg/L will have some mussels which over time may accumulate to nuisance levels, but annual cleaning, or removal of intakes during the winter, would prevent large infestations from forming.* The following summarizes some thought processes in selecting a control option.

Keep It Simple Stupid is a good principle to apply. There is no point in spending money on a zebra mussel control device if none is needed. *And if a control device is required, use one that is easy to use and maintain.*

Here are some simple options to consider before spending money on a control device.

:

Numerous studies have shown that the amount of attachment varies with water velocity.

⁴Claudi, R. and G. L. Mackie. 1994. Practical manual for zebra mussel monitoring and control. Lewis Publishers, Boca Raton, FL.

Mussel attachment rates tend to increase from 0 to 0.5 - 1.0 m/sec but above 1.0 m/sec, mussel settlement intensity decreases with increasing water velocity, until 1.5 m/sec when little or no settlement will occur. In some cases (e.g. there are exceptions), velocities exceeding 2.0 m/sec may flush some mussels off the walls of pipes. *Hence, flushing of pipes with flows exceeding 2.0 m/sec will help to keep pipelines clear of mussels.* However, it is difficult, or expensive, to increase flows in pipelines; one must either purchase a new pump that provides higher flow rates, or install a pipeline with a smaller inside diameter. But, the rule-of-thumb can still be used to determine if the existing system is sufficient to reduce mussel settlement inside the pipeline.

To determine the water velocity in a cottage pipeline, divide the flow rate of water (which varies with the horsepower of the pump and the height of lift, but specs on the pump will provide an estimate) by the cross-sectional area of the pipeline. For example, if a cottage has a pipeline with a 1-in (2.54 cm) inside diameter (cross-sectional area = $\pi r^2 = 3.1416 \times (2.54/2)^2 = 5.08 \text{ cm}^2$) and a 1/2 horse-power jet pump with a 3-m water lift that supplies a flow of 12 Imperial gal/min (= 0.2 gal/sec, or 0.909 L/sec = 909 cm³/sec), a velocity of 909/5.08 = 178.9 cm/sec, or 1.8 m/sec, can be achieved and will prevent mussels from settling but will not flush any mussels off. If the flow rate is unknown, merely record the time (in minutes) it takes to fill a pail to a 20-L mark; divide by 60 to obtain L/sec. Table 2 provides estimates of water velocities for pipelines of three different inside diameters and flow rates from pumps (incorporates effects pump horse power and lift). Many submersible pumps have much higher flow rates (~ 65 Imp. gal/min = 295 L/min = 4.92 L/sec = 4920 cm³/sec) and will easily flush any settled mussels off the inside of 1 in diameter pipes (@ ~9.72 m/sec). Otherwise, table 2 shows that only pipelines of 0.75 in diam and flows above 8 gal/min or pipelines of 1 in diam and flows > 14 gal/min will flush mussels off the insides of the pipes. Note: Some pump flow rates are given in U.S. gal/min. Hence, if flow rate is 65 U.S. gal/m, metric equivalent is = 65 U.S. gal/min x 3.78 L/U.S. gal = 246 l/min.

:

A rapid increase in water temperature is very effective at removing attached mussels. However, the rate of temperature increase, the difference in temperature between ambient and the upper lethal temperature, and the acclimation temperature affect the rate of mortality. Claudi and Mackie (1994) provide data that show the times needed by industries to kill zebra mussels at temperatures between 34 and 37 °C, but the industry must be able to increase water temperatures by thermal back-flushing. This may be possible with some cottage systems, if the foot valve can be placed in a vat of hot (near boiling) water for 10-15 min and the water pumped to waste. For any removable intake, a good rule-of-thumb is to: *immerse any encrusted and removable components in boiling water for 5-10 minutes.* The shells will gape quickly and will not close with gentle prodding, indicating that the mussels are dead.

kill zebra mussels in the pressure tank of pump, allow water to backflow from the hot water tank into pressure tank and draining the water in the fall, the water sits 0-15 min, drain the pressure tank.

Table 2. Velocity of water through pipes with different diameters and pumps with different flow rates.

Inner Pipe Diameter		Flow Rate (Imperial gallons/min above, <i>L/sec below in italics</i> @ 1 gal = 4.546 L)									
		2	4	6	8	10	12	14	16	18	20
<i>Inch</i>	<i>Cm</i>	<i>0.15</i>	<i>0.30</i>	<i>0.45</i>	<i>0.61</i>	<i>0.76</i>	<i>0.91</i>	<i>1.06</i>	<i>1.21</i>	<i>1.36</i>	<i>1.52</i>
0.75	1.91	0.5	1.1	1.6	2.1	2.7	3.2	3.7	4.2	4.8	5.3
1.00	2.54	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
1.25	3.18	0.2	0.4	0.6	0.8	1.0	1.2	1.3	1.5	1.7	1.9
1.50	3.81	0.1	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.3
1.75	4.45	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
2.00	5.08	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8

:
 Oxygen deprivation is a useful method and can be used under natural conditions, if the conditions are appropriate. Zebra mussels are relatively intolerant of hypoxia (low oxygen) or anoxia (no oxygen), exhibiting 100% mortality within 6 days at 17-18 °C, 4 days at 20-21 °C and 3 days at 23-24 °C. However, anoxia tolerance increases with increasing acclimation temperature.

All water has a **chemical oxygen demand (C.O.D.)** and a **biochemical oxygen demand (B.O.D.)**; that is, all water has some inorganic material that is oxidized and uses oxygen (C.O.D.) and organic material that bacteria decompose, and in the process use oxygen dissolved in the water (B.O.D). The more inorganic and organic material, the greater the C.O.D. and B.O.D. The B.O.D. is always measured on a 300 ml water sample in the laboratory at 20 °C over a 5-day period. Enriched lakes have B.O.D. values in excess of 3 mg/L. That is, over 5 days, 3 mg/L of dissolved oxygen is used to decompose the organic material present. Hence, if water is left to stagnate in a pipeline for an extended period of time, all the dissolved oxygen would be consumed by bacteria. To determine if anoxia develops in pipelines, follow instructions in Appendix I.

The solubility of oxygen increases with decreasing temperature. Table 3 shows the 100% saturation value for several different temperatures. *The table also gives the time (in days) required to kill all mussels in pipes with waters of different B.O.D. values, the estimates being based on the 100% kill rates at 17-18 °C (6 days), 20-21 °C (4 days) and 23-24 °C (3 days). Less time is needed in warm waters because there is less oxygen*

Table 3. Time in days to kill all mussels in water with temperatures of 17-18 °C, 20-21 °C and 23-24 °C and B.O.D. values of 1, 3, 5 and 7 mg O₂/L. First two columns give the 100% oxygen saturation value at temperatures between 10 and 25 °C. The times assume that the water was 100% saturated with oxygen just prior to shutting the pump off.

Water temp. °C	100% O ₂ saturation value mg/L	B.O.D. mg O ₂ /L											
		1			3			5			7		
		17-18	20-21	23-24	17-18	20-21	23-24	17-18	20-21	23-24	17-18	20-21	23-24
10	11.33	62.7	60.7	59.7	24.9	22.9	21.9	17.3	15.3	14.3	14.1	12.1	11.1
11	11.08	61.4	59.4	58.4	24.5	22.5	21.5	17.1	15.1	14.1	13.9	11.9	10.9
12	10.83	60.2	58.2	57.2	24.1	22.1	21.1	16.8	14.8	13.8	13.7	11.7	10.7
13	10.6	59	57	56	23.7	21.7	20.7	16.6	14.6	13.6	13.6	11.6	10.6
14	10.37	57.9	55.9	54.9	23.3	21.3	20.3	16.4	14.4	13.4	13.4	11.4	10.4
15	10.15	56.8	54.8	53.8	22.9	20.9	19.9	16.2	14.2	13.2	13.3	11.3	10.3
16	9.95	55.8	53.8	52.8	22.6	20.6	19.6	16	14	13	13.1	11.1	10.1
17	9.74	54.7	52.7	51.7	22.2	20.2	19.2	15.7	13.7	12.7	13	11	9.96
18	9.54	53.7	51.7	50.7	21.9	19.9	18.9	15.5	13.5	12.5	12.8	10.8	9.81
19	9.35	52.8	50.8	49.8	21.6	19.6	18.6	15.4	13.4	12.4	12.7	10.7	9.68
20	9.17	51.9	49.9	48.9	21.3	19.3	18.3	15.2	13.2	12.2	12.6	10.6	9.55
21	8.99	51	49	48	21	19	18	15	13	12	12.4	10.4	9.42
22	8.83	50.2	48.2	47.2	20.7	18.7	17.7	14.8	12.8	11.8	12.3	10.3	9.31
23	8.68	49.4	47.4	46.4	20.5	18.5	17.5	14.7	12.7	11.7	12.2	10.2	9.2
24	8.53	48.7	46.7	45.7	20.2	18.2	17.2	14.5	12.5	11.5	12.1	10.1	9.09
25	8.38	47.9	45.9	44.9	20	18	17	14.4	12.4	11.4	12	9.99	8.99

dissolved (first two columns) than in cold water.

How to Decide What Type of Control Method to Use

For cottages, a proactive strategy is recommended because it eliminates any potential problems created by using a reactive strategy in which large doses (typically of chlorine) are used. Also, taste and odour problems may develop from putrefaction of large masses of mussels after they are killed. Further, since reactive strategies are usually used at the end of the year, someone must be present for one to two weeks while the control device is being used. This is not an issue for permanent dwellings but could be an issue for seasonal dwellings. While a proactive strategy eliminates most of these problems, it is usually more expensive to use because the devices are designed to operate continuously, or at least every time the pump is used.

The following is a step-wise procedure for selecting a control device, once convinced that a device is required. It is assumed that the dwelling is seasonal, but intakes may be either permanent, usually in deep water, or temporary, usually in shallow water and removed every fall.

Most dwellings of permanent residence have their own well water and the intakes are not subject to zebra mussel infestations.

1. Call the district Ministry of Natural Resources or of Environment and Energy for data on pH and calcium content of the water; if they do not have data, measure with standard pH and calcium hardness kits, using the methods described in Appendix I.
2. Decide if the lake has potential for large zebra mussel infestations using the information above. Select one of the following options, either 1a or 1b:
 - 1a. Infestations not possible **Do nothing**
 - 1b. Infestations possible **Go to 2a or 2b**
- 2a. Temporary foot valve **Go to 3a or 3b**
- 2b. Permanent foot valve **Go to 5a or 5b**
- 3a. Infestations light **Go to 4a or 4b**
- 3b. Infestations heavy **Go to 5a or 5b**
- 4a. Flow rate exceeds 2 m/sec (see Table 2), OR B.O.D. sufficient to prevent biofouling (see Table 3) **Clean or boil removable components and drain pipeline in the fall (drying or freezing will kill all mussels during the fall and winter period).** Field experiments have shown that mussel attachment intensity on materials tends to be least on copper (90% Cu) and greatest on plastics (e.g. ABS), with other materials exhibiting the following order of mussel attachment efficacy: copper has < brass has < galvanized iron has < aluminum has < acrylic has < black steel has < polyethylene has < PVC has < ABS. However, the experiments were done in standing waters, and flow rate affects the amount of settlement in pipelines. **Consider modifying the intake structure, such as using a brass cover plate, instead of a stainless steel plate around the foot valve.**
- 4b. Flow rate < 2 m/sec (see Table 2), OR B.O.D. insufficient to kill mussels (Table 3) **Clean or boil removable components during year as required, leave pipeline until fall (drying or freezing will kill all mussels during the fall and winter period), or go to 5a or 5b**
- 5a. Flow rate exceeds 2 m/sec (see Table 2), OR B.O.D. sufficient to prevent biofouling (see Table 3) **Clean or boil intake structure and/or components as required, or go to 5b**
- 5b. Flow rate < 2 m/sec (see Table 2), OR B.O.D. insufficient to kill mussels (Table 3) **Select a biofouling control option, read the following, and then go to Part II for advice**

Mitigation by

Chlorine is the only chemical being used in low-volume intake devices. In industries and utilities, chlorine is used either proactively or reactively, the only differences being the concentrations used (e.g. low for proactive, high for reactive treatment) and the frequency of application (e.g. continuous for proactive, intermittent for reactive treatment). In the chlorine cottage device tested here, only a reactive strategy is recommended by the manufacturer. **However, before selecting this option, contact the district Ministry of Natural Resources or Environment and Energy for permission to use the device.**

Chlorination is effective for controlling bacterial, algal and viral biofouling, but four huge disadvantages with chlorine are: (i) **its tendency to form trihalomethanes (THMs) that are well-known carcinogens;** (ii) **if large dosages of chlorine are used, it has a great potential**

to kill micro-organisms needed to digest wastes in septic systems; (iii) large numbers of dead and often putrefying shells may accumulate and must be disposed of annually; and (iv) any chlorine that leaks or leaches into the lake, either from the device or from submerged pipes/components carrying chlorine, will seriously impact fish and other aquatic life.

Any filter being considered must have a maximum pore size of 35 μm to remove the eggs (~ 40 μm) of zebra or quagga mussels. The down side to a very small pore size is that frequent back-flushing will be required in turbid waters, or the filter screens/sleeves will have to be replaced or washed frequently. Although none were tested here, some filters are designed to be placed between the pump and the cottage. However, the pump and its intake (e.g. foot valve) will need to be protected using another method (e.g. use of copper screens around and tight to the foot valve). Otherwise, the pump and foot valve must be cleaned each fall. **Note: Before selecting a filter, refer to Appendix B-I where Hueton and Claudi describe advantages and disadvantages of filter materials, “nominal” vs “absolute” pore size and effect of suspended solids on the operation of filters.**

Cottagers are now being offered an electrical method for keeping intakes and pipelines clear of mussels. The A-C voltage is very low, about 8 to 10 volts per inch. Similar devices are being used in industrial settings, with excellent results. However, remember that water and electricity are a dangerous mix and can be fatal if not correctly wired. A qualified electrician is highly recommended for installing the equipment. The main advantage of electrical devices over filtering devices is that their efficiency is not affected as much by turbidity.

Ultraviolet (UV) Light

UV light has very short wave lengths and very high frequencies. Wavelengths of about 254 nm (called UVC) are readily absorbed by materials (e.g. organic compounds, silt, organisms) suspended in the water. However, in clear water, UVC is sufficient to destroy genetic material of microorganisms. UV light of higher wavelengths, especially 365 nm (called UVB), is not as readily absorbed by suspended materials in the water and is capable of destroying biological tissues. Recent studies by Lewis and Whitby (1995)⁵ demonstrated that UVB can be used for the prevention of zebra mussel infestation for low volume users. However, technology using UV light for controlling zebra mussel biofouling of cottage intakes has not been developed yet. It would be useful only in cottages that have a constant source of electricity, and would not be suitable for cottages that rely on generators for power, or in highly turbid waters.

⁵Lewis, D. and G. E. Whitby. 1995. Potential use of ultraviolet radiation for the control of zebra mussels. Phase I - Lab studies. Phase II - Field trials. Final report to the Ontario Ministry of Environment on Energy. RAC Project No. 598C. ISBN 0-7778-3199-6.

APPENDIX A-1

Below are the names and addresses of companies that sell water quality test kits for pH, calcium hardness and dissolved oxygen. Only the less expensive methods, but accurate enough for the purpose intended here, are described below. The cost per kit, not including taxes, is about 90 - \$110.00, depending on the test and the company. Electronic devices that measure dissolved oxygen and pH, and digital titrators for the calcium hardness test, are also available, but the costs range from \$350 to \$700 dollars. The pH pocket tester is an inexpensive electronic device (~\$80). Halltech Environmental Inc. also sells water sampling equipment, like “Kemmerer” and “Van Dorn” water samplers (see cottagers guide to understanding your lake, described in Introduction). These devices take water samples and allow one to measure temperature and dissolved oxygen levels from the deepest site in the lake. Both companies take credit card numbers (Master Card or Visa) for payment.

COMPANY	TEST	NO. TESTS
<i>Halltech Environmental Inc.</i> 503 Imperial Road N., Unit #2 Guelph, Ontario Phone: 519-766-4568 Fax: 519-766-0729	Dissolved Oxygen, Modified Winkler, 1-20 mg/L	100
	pH, mid-range (5.5-8.5), with colour disc	200
	Total and Calcium Hardness	100
<i>Anachemia</i> 6535 Millcreek Drive, Unit #69 Mississauga, Ontario L5N 2M2 Phone: 1-800-361-0209 Phone: 905-567-8292 FAX: 905-567-5939	Dissolved Oxygen, Modified Winkler, 1-20 mg/L	100
	pH, mid-range (5.5-8.5), with colour disc	200
	pH pocket tester (needs 2 batteries)	Several
	Total and Calcium Hardness	100

PART B

**AN INVESTIGATION INTO THE
ABILITY OF SIX DIFFERENT PRODUCTS TO
PREVENT ZEBRA MUSSELS FROM
INFESTING A SMALL VOLUME WATER SYSTEM**

**ASI Project M9527
FINAL REPORT**

Submitted

February 26, 1999

**Aquatic Sciences Inc.
St. Catharines, Ontario**

PART B - TABLE OF CONTENTS

1.0 BACKGROUND	B-1
2.0 INTRODUCTION	B-3
3.0 STUDY SITE	B-4
4.0 METHODS	B-4
4.1 Experimental Design.....	B-4
4.2 Daily Monitoring.....	B-6
4.3 Weekly Monitoring	B-6
4.3.1 Turbidity and Total Suspended Solids (TSS).....	B-7
4.3.2 Flow Rates and Temperature.....	B-7
4.3.3 Zebra Mussel Densities	B-7
4.3.3.1 Suspended Zebra Mussels	B-7
4.3.3.2 Settled Zebra Mussels.....	B-8
4.3.3.3 Quality Assurance/Quality Control.....	B-9
4.4 End of Test	B-9
4.5 Statistical Analyses.....	B-10
5.0 RESULTS	B-11
5.1 Zebra Mussel Removal	B-11
5.1.1 Suspended Zebra Mussels.....	B-11
5.1.1.1 Device #1	B-11
5.1.1.2 Device #2.....	B-11
5.1.1.3 Device #3.....	B-11
5.1.1.4 Device #4.....	B-13
5.1.1.5 Device #5.....	B-13
5.1.1.6 Device #6.....	B-13
5.1.2 Settled Zebra Mussels.....	B-13
5.2 Device #3	B-15
5.3 Physical Parameters.....	B-17
5.3.1 Turbidity and TSS.....	B-17
5.3.2 Water Flow	B-17
5.3.3 Water Temperature	B-17
5.3.4 Maintenance.....	B-19
6.0 DISCUSSION	B-19
6.1 Device #1	B-20
6.2 Device #2	B-20
6.3 Device #3	B-20
6.4 Device #4	B-21
6.5 Device #5	B-22
6.6 Device #6	B-23

LIST OF FIGURES

- Figure 1: Location of Study Site
- Figure 2: Test System Schematic
- Figure 3: Flow Through System Schematic
- Figure 4: The performance of device #1 compared to the control
- Figure 5: The performance of device #2 compared to the control
- Figure 6: The performance of device #3 compared to the control
- Figure 7: The performance of device #4 compared to the control
- Figure 8: The performance of device #5 compared to the control
- Figure 9: The performance of device #6 compared to the control
- Figure 10: Total settlement including weekly PVC plate scrapes, biobox scrape and intake line scrape
- Figure 11: Mean turbidity entering the bioboxes from each treatment
- Figure 12: Mean water flow entering the bioboxes
- Figure 13: Water temperature throughout the study period (July 17 to October 30, 1998)

LIST OF APPENDICES

APPENDIX I

Filter Materials and Selection

APPENDIX II

- Device #1 (Zebra Mussel Filter Systems, Inc.)
- Device #2 (AquaStand)
- Device #3 (Z-Eliminator)
- Device #4 (Zebra 5000)
- Device #5 (Z-Ban©)
- Device #6 (Zebra 12000)

APPENDIX III

Table A:	Control Zebra Mussel Densities
Table B:	Device #1 Zebra Mussel Densities
Table C:	Device #2 Zebra Mussel Densities
Table D:	Device #3 Zebra Mussel Densities
Table E:	Device #4 Zebra Mussel Densities
Table F:	Device #5 Zebra Mussel Densities
Table G:	Device #6 Zebra Mussel Densities
Table H:	QA/QC Sample Analysis Results
Table I:	Intake Pipe Sections (#.m ⁻²) – Test Termination
Table J:	Siphon Samples (#.m ⁻²) – Test Termination
Table K:	Biobox Scrape Samples (#.m ⁻²) – Test Termination
Table L:	Control Operational Parameters
Table M:	Device #1 Operational Parameters
Table N:	Device #2 Operational Parameters
Table O:	Device #3 Operational Parameters
Table P:	Device #4 Operational Parameters
Table Q:	Device #5 Operational Parameters
Table R:	Device #6 Operational Parameters

Suspended Solids Data

APPENDIX IV

Turbidity – Total Suspended Solids Rating Curve

**THE GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE
ABILITY OF SIX DIFFERENT PRODUCTS TO
PREVENT ZEBRA MUSSELS FROM
INFESTING A SMALL VOLUME WATER SYSTEM
ASI Project M9527
February 26, 1999**

1.0 BACKGROUND

Since the zebra mussels (*Dreissena polymorpha*) introduction into the Great Lakes ecosystem in the mid 1980s, they have spread rapidly into a number of the inland lakes of North America. A considerable amount of attention has been given to the industrial impact of zebra mussel infestations, however, it has also created havoc with the intake lines of small volume water users, such as cottages, golf courses, greenhouses, and resorts. These intake lines are especially vulnerable to infestation as they are typically 4 cm in diameter, or smaller, suspended in three to six metres of water, and generally demand-operated. Such conditions coincide precisely with the environmental requirements of the zebra mussel.

Manufacturers, of the various products currently being used, claim that their product(s) prevent or inhibit zebra mussel colonization of small volume water intake systems. Many of these products have not been rigorously tested by the manufacturer, thus providing the consumer with a product that may or may not meet their expectations. To meet consumer demands, a regimented trial of these products is necessary to determine their capabilities and limitations, therefore allowing the consumer to make an informed choice. The results are also essential to the manufacturer for marketing purposes or, in some cases, to improve the design of prototypes.

Aquatic Sciences Inc. (ASI), under funding and direction of the Ministry of Environment (MOE) and the Ontario Ministry of Natural Resources (OMNR), undertook one such study in 1992 to examine the effectiveness of ten products. The results of that study are available through the MOE. However, the spread of zebra mussels has increased the demand for products to prevent infestations. To meet these demands, new products have been developed since 1992 that require a rigorous and unbiased field test to determine their effectiveness.

In early 1997 the Georgian Bay Association (GBA) facilitated the assembly of scientists and other experts in the zebra mussel field. The purpose of this group was to offer independent advice on the best zebra mussel control products for the 5,000 families in the GBA, on the eastern and northern shores of Georgian Bay and adjacent lakes and water bodies. It was hoped that the generation of such information would prove to be very helpful to all cottagers in zebra mussel infested areas across Ontario and eastern North America.

All known North American control product manufacturers were contacted to submit products. The cost of the testing was funded by the participating manufacturers while the scientific technical review and publishing of the report was funded by the Greater Bay Area (G.B.A.) Foundation – a registered Canadian Charity (#895811066 RR0001) that funds research and educational projects in the Georgian Bay area.

The members of the Zebra Mussel Control Product Testing Group (ZMCPTG) were:

Members	Affiliation
Paul Wianko/Renata Claudi	Ontario Hydro
John Birnbaum	Georgian Bay Association
John Hueton	Canadian Product Specialist
Gerald Mackie	University of Guelph
Carmen Sferrazza/Barb Crosbie	Aquatic Sciences Inc.
Roy Schatz	Greater Bay Area Foundation
Charles O'Neil*	U.S. Product Specialist

*Used as a resource by this group

The group developed a schedule for their work as follows:

Tasks	Time Line
1 Solicitation of products from all known North American Manufacturers	November 1997 to June 1998
2 Agreements in place from manufacturers	June 1998
3 Field testing	July 1998 – October 1998
4 Final report and scientific panel review	February 1999
5 Final results released to cottage associations and manufacturers	March 1999
6 Information seminars, conference presentations, etc.	Spring, Summer, Fall 1999

2.0 INTRODUCTION

Since its introduction over ten years ago, the zebra mussel has had a devastating impact on water intake structures. The ability of this organism to settle and colonize in low flow environments has allowed zebra mussels to proliferate and clog pipes, blocking the flow of water through the system. These infestations resulted in industries spending large sums of money on implementing control methods, in addition to the cost of research required for the development of new methods. Many mechanical and chemical control techniques have been employed to alleviate the problem of zebra mussels, with the best control solution varying from one industry to the next.

In an environment where small volumes of water are required, for a variety of uses, the most appropriate control method for zebra mussel veligers is, generally, fine mesh filters. A chemical alternative is often unsuitable in this type of situation since many of the water uses involve direct human contact, such as bathing and consumption. Also, the chlorinated wastewater may affect bacterial decomposition processes if water is sent to the septic tanks. However, proper filtration of the water, prior to introducing the water into the system, can prevent zebra mussel colonization, provided the pore size is appropriate.

Many types of filters exist for zebra mussel control, however, the ability of different filters to successfully remove these organisms from the water column, while operating efficiently, needs to be considered. The filters used must have a pore size less than 35 μm due to the zebra mussel egg size (for more information on filter materials see Appendix I and Part A). In addition to this, the materials that these filters are made of must be durable enough to withstand the conditions present in an aquatic environment. This poses a problem in turbid waters where suspended sediment can clog filters, decreasing their life-span. The overall applicability of the filter, with respect to cost, durability, ease of installation, clogging frequency and zebra mussel removal rates needs to be evaluated.

This study examined the effectiveness of six different products in preventing zebra mussels from infesting small volume water systems. The test was performed over a 17-week period when zebra mussel densities were at their highest levels. Each product was evaluated for zebra mussel removal efficiency, cost, ease of installation, frequency of

maintenance and availability. These factors were evaluated collectively to determine the best overall product. In addition to these factors, the ability of the products to remove suspended material from the water column was also evaluated. The information presented here allows consumers to make an informed choice when purchasing a product for the control of zebra mussels.

3.0 STUDY SITE

ASI has a permanent zebra mussel research facility at the Decew Falls Generating Station that is only minutes from the St. Catharines office (*Figure 1*). The high densities of zebra mussels and close proximity made this location ideal for the experiment. In addition, this location is supplied with a reliable source of power that ensured the project operated continuously. A previous product testing study, undertaken by ASI and the Ministry of the Environment, was conducted at the same site in 1992. Due to the success of this prior experiment, in obtaining adequate zebra mussel densities, the same study site was used for the 1998 study.

4.0 METHODS

4.1 Experimental Design

Six devices were tested in this study. Submissions included products from the following list of vendors:

- 1) Zebra Mussel Filter Systems, Inc.
- 2) Precise Solutions Inc. (Aquastand)
- 3) Z-Eliminator
- 4) Alex Milne and Associates Ltd. (Zebra 5000)
- 5) Delta Applied Technology, Inc. (Z-Ban©)
- 6) Alex Milne and Associates Ltd. (Zebra 12000)

The experimental systems were installed and were operational by the first week of July. Seven test systems were constructed. The test products were placed in approximately 3 m of water, 15 m from the shoreline (*Figure 2*). Each system was connected to a brass foot valve (with the exception of devices #5 and #6), that was connected to 6 to 9 m of 2.54 cm diameter black polyethylene tubing. The test products were attached to an anchoring device to keep the apparatus in place and upright, to ensure proper functioning. The whole assembly was connected to a 1/3 H.P. jet pump (with the exception of device #6) that was located inside the research trailer. Three, 36 L bioboxes

were connected by 2.5 cm diameter braided PVC tubing to the discharge of each pump (*Figure 3*). This allowed replicate samples to be collected for each device. Ball valves on the inlet of each holding tank allowed ASI technicians to ensure the same amount of water entered each biobox. Six, 15 cm by 15 cm, PVC settling plates were placed in each biobox, which were outfitted with a standpipe to keep the plates submerged between flow cycles. Vacuum gauges were connected to each pump to indicate possible restrictions in water flow.

The set up for device #6 was slightly different, as a submersible pump is a component of the test product. For device #6, the apparatus was connected directly to 9 m of 2.5 cm black polyethylene tubing, which ran directly into the lab, connecting to the set of three 36 L bioboxes. The vacuum gauge was connected to the intake line on-shore, with a line running from the submersible pump. Another deviation from the original design was that a foot valve was omitted from device #5 and replaced by a check valve on the intake of the pump. A brief description of each device is presented in Appendix II.

The 1992 results were used to help design this study. The telephone survey data collected in 1992 were used to construct the pumping system configuration. In an attempt to simulate the maximum zebra mussel densities that would enter a small volume water system, the total volume of water used in one cottage season was estimated. The value was obtained based on two individuals occupying a cottage from the Victoria Day weekend to Thanksgiving, or from approximately May 20 to October 12. This encompasses 147 days, with major water consumption resulting from toilet use, showers and regular kitchen activities. Suggestions from Mr. John Hueton resulted in a total volume of 48 000 L. This value was adjusted following comments from Mr. Chuck O'Neil, to incorporate year-round cottage users such as those in the Finger Lakes region. Therefore, the target water flow for each product was 83 000 L. Combining the desired total volume and the duration of the study, translated into approximately 37.5 L flowing through the device every hour.

To obtain the required water flow rate through each device system, automatic one-hour timers were connected to the power source of the pumps to control the duration of flow. The exception to this setup was device #5 which was directly connected to the power source and was cycled on and off with the pressure switch on its water pump. The holding tank was connected to the hourly timer to obtain the desired volume in the biobox. Each device was set to pump at an overall rate of 30 to 50 L/min (10 to 17 L/min per biobox), for an initial operation time of 2.5 minutes per hour. The ball valves on the intake of each biobox were left open to obtain the desired flow rate. Weekly flow measurements were obtained from each system to ensure that the proper flow rates were being maintained. If the flow was incorrect, the pumping duration was altered to ensure that each system received the same volume of water. However, the pumping duration could not exceed 20 minutes owing to a limited power supply. If the desired volume could not be achieved in this time period the device system was shut down and the necessary maintenance was completed. All devices were operated during the same 17-week period (July 5 to October 30), however, operational problems resulted in temporary delays. Also, the pumping duration was increased to 5 minutes each hour on September 11, to encourage more zebra mussel settlement.

4.2 Daily Monitoring

Technicians monitored the experiment daily, from Monday to Friday, throughout the entire duration of the study (July 7 to October 30, 1998). This ensured that the systems remained operational and allowed for early detection of potential incidents. The vacuum gauge readings were recorded during these inspections. A major shift in these readings was used as an indicator of potential clogging. General observations on flow rates in the bioboxes, operational problems and the amount of solids in the holding tanks were recorded.

4.3 Weekly Monitoring

Samples were collected each week to determine water temperature, turbidity, suspended solids content, zebra mussel densities and water flow rates in each of the devices. The data collected during the test period are provided in Appendix III.

4.3.1 Turbidity And Total Suspended Solids (TSS)

Weekly turbidity measurements were recorded, in triplicate, from each device. Samples were taken from the same biobox replicate for all devices while the pump was running, and analyzed using a HACH 2100P Turbidimeter. The turbidity results were used to determine which device to sample for TSS. A weekly TSS sample was collected from one of the various devices to cover the range of turbidity encountered throughout the experiment. Ten samples were collected for TSS over the study period to generate a turbidity-TSS rating curve (*Appendix IV*). At the end of the study, the ten representative TSS samples were sent to an accredited laboratory for analysis.

4.3.2 Flow Rates and Temperature

Weekly flow rates and water temperatures were collected from the same biobox replicate, for each device. The length of time required to fill a 10 L bucket from the biobox outlet, with the pump running, was recorded. The time was entered into the formula below to determine the pumping duration. The timer was adjusted accordingly to compensate for major changes in flow rate.

$$\frac{37.5\text{L} \times \text{time to } 10\text{L}}{10\text{L}} = \text{timer setting}$$

This process equalized the amount of water flowing through each device.

4.3.3 Zebra Mussel Densities

4.3.3.1 Suspended Zebra Mussels

Weekly water samples were obtained from each device to determine the presence/absence of zebra mussel larvae in the water, according to ASI Standard Operating Procedures (SOPs). While the pump was running, 20 L of water was collected from the same biobox replicate every week. The water was siphoned from the biobox and filtered through a 63 μm nitex nylon mesh plankton cup, according to standard plankton sampling methods. The filtrate was concentrated to approximately 100 mL and placed in a clean, labelled 250 mL sample jar. The plankton cup was rinsed thoroughly into the same sample jar with filtered water to ensure the contents of the plankton cup were in the sample. The samples were kept in a chilled cooler until analysis.

ASI personnel transported samples to the laboratory for microscopic examination. Filtered water samples were analyzed for free-swimming veligers and post veligers and included determination of the presence, density, and mortality of zebra mussel larvae, according to ASI SOPs.

For filtered water samples, the sieve contents were rinsed back into the sample jar and the volume was recorded. Five, 1 mL replicates were extracted from the condensed sample, using a clean 1 mL pipette, and placed in a clean, 2 mm gridded Sedgewick-Rafter counting chamber. A coverslip was placed over the replicate and the sub-sample was examined at a magnification ranging from 50x to 80x. Each square on the grid was examined and larvae were enumerated by life stage and mortality. The number of larvae observed were grouped according to life stage. Each of the five replicates was recorded separately. The density of the zebra mussels in the water column was calculated for each sample, according to the following formula:

$$\frac{\text{Total Number Counted}}{5 \text{ mL}} \times \text{Condensed Volume} \times \frac{1}{20 \text{ L}} \times 1000 \frac{\text{L}}{\text{m}^3} = \text{Density of Larvae.m}^{-3}$$

4.3.3.2 Settled Zebra Mussels

To avoid contamination, 15 cm² plate scrape samples were collected after the 20 L water samples were obtained. One plate from each holding tank was sampled to determine the density of settled larvae. The plate to be sampled was extracted from the rack, and one corner was placed in the mouth of the 250 mL sample jar. A paint scraper was used to scrape one side, beginning at the top corner and avoiding the edge. Filtered water was used to rinse the contents of the first side into the jar. The second side was then scraped and rinsed into the same jar, with the edges of the scraper also rinsed into the jar. The samples were kept in a chilled cooler until analysis.

Plate scrape samples were filtered through a 63µm sieve that was rinsed directly into a 10 mm gridded petri dish. The entire sample was analyzed under 14x magnification. Each square was examined and the larvae present were enumerated by life stage. Percent mortality in the sample was also recorded. The total number of larvae observed per life stage was recorded.

The density of the settled zebra mussels was calculated for

each sample, according to the following formula:

$$\frac{\text{Total Number Counted}}{\text{Plate Area (cm}^2\text{)}} \times 10\,000 \frac{\text{cm}^2}{\text{m}^2} = \text{Density of Larvae.m}^{-2}$$

4.3.3.3 Quality Assurance/Quality Control

To meet with ASI quality assurance/quality control (QA/QC) guidelines, one replicate was collected for every ten scheduled samples, which translated into weekly replicate sampling (14 samples collected weekly, suspended and settled combined). Replicate sampling of plate scrapes and replicate analysis of filtered water samples was initiated on alternate weeks. To determine the inherent variability in settlement densities, a second plate (replicate) from a holding tank was sampled. For the filtered water samples, a sample was selected for QA/QC analysis, and a 1 mL replicate was analyzed by two different technicians.

4.4 End Of Test

The final sampling occurred on October 30, 1998. In addition to the normal weekly sampling requirements, samples were obtained from the sides of the biobox, the bottom of each biobox and the intake lines. The tested products were removed from the water and from each intake line. Three, 10 to 15 cm sections were removed and preserved in ethanol. Prior to collecting the biobox scrapes, the water level in each biobox was reduced to a depth of approximately 5 to 8 cm, to facilitate scraping the sides of the biobox. Starting at the water line, a paint scraper was drawn up the tank wall, scraping off any accumulated mussels and sediment. The debris was allowed to gather on the scraper, and was rinsed off into a clean, labelled jar. When completely scraped, the sample was preserved with ethanol and transported back to the ASI laboratory for analysis. Two walls of each holding tank were scraped, with the surface area sampled approximated at 0.112/m² per biobox. The inlet and outlet ends were not included in this sample. Sediment was sampled off the bottom of each biobox by siphoning an area of approximately 0.033m² through a 100 µm nitex nylon mesh bag. The bottom of the biobox, in front of the inlet, was selected in each biobox to reduce possible spatial variability. The contents of the mesh bag were emptied into a clean, labelled jar, and the mesh bag itself was rinsed thoroughly into the same jar. The sample was preserved with ethanol and transported back to the ASI laboratory for analysis.

All siphon and scrape samples were analyzed, according to ASI SOPs, for settled zebra mussels (pediveligers, juveniles, adults). Samples were further concentrated in the laboratory by filtering the samples through a 63 μm sieve, according to standard plankton sampling protocol, and washing the contents directly into a petri dish for analysis. Sample analysis and density were determined by the methods described in Section 4.3.3.2. The intake pipe subsections were analyzed by cutting each section in half, and examining the pipe sections under 14x magnification for pediveligers, juveniles and adults.

4.5 Statistical Analyses

The performance of each product, with respect to the removal of zebra mussel veligers, were compared using a one-way ANOVA with a post-hoc Tukey's Honestly Significant Difference (HSD) test. The zebra mussel densities suspended in the water column and the settlement densities were evaluated independently for each device. The Tukey's HSD allows all devices to be compared simultaneously, indicating whether a difference exists between the devices and where the differences lie. This statistical technique is more powerful as it substantially reduces the probability of finding significant relationships when none actually exist.

The total zebra mussel settlement was calculated for each device by summing the settlement on the plates (based on weekly totals). In addition to this, the settlement on the sides of the biobox, and mussels settled on the intake pipe were calculated. These measures were examined separately and summed together as an estimate of overall settlement in each device. The values were compared to the control settlement to determine how effectively the device prevented zebra mussels from entering the system. These values were also compared with the devices to determine whether device performance differed significantly among the products tested.

The density of zebra mussels suspended in the water column was compared among the devices to determine if significant differences in performance existed. The values were compared to the control densities to determine how effectively the device prevented zebra mussels from entering the system. These values were also compared with the devices to determine whether device performance differed significantly among the products tested.

The turbidities in each device were compared to the control to evaluate whether the device removed suspended material from the water column. A total suspended solid (TSS)-turbidity rating curve was generated (*Appendix IV*) to determine how much material each device was capable of removing from the water column. This information was essential in assessing the applicability of each device in aquatic systems of varying water clarity. It also provided us with an indication of the inorganic fraction in the water column. In addition, this value provides the consumer with some insight on how it may benefit other filtration systems that are used to purify the water further.

5.0 RESULTS

5.1 Zebra Mussel Removal

5.1.1 Suspended Zebra Mussels

5.1.1.1 Device # 1 (Zebra Mussel Filter Systems, Inc.)

The density of zebra mussels in the water column from device #1 was generally lower than the control during the experiment (*Figure 4*). The mean zebra mussel density in the water after passing through device #1 was $204 \pm 352/\text{m}^3$ (*Table 1*). This value was significantly lower than the mean density for the control, $1162/\text{m}^3$ (one-way ANOVA, Tukey's HSD, $p < 0.001$).

5.1.1.2 Device #2 (Aquastand)

Similar results were found for device #2, where the zebra mussel density in the water was generally lower than the control (*Figure 5*). The mean suspended zebra mussel density at $266 \pm 383/\text{m}^3$ in device #2 was also significantly lower than the control (*Table 1*, one-way ANOVA, Tukey's HSD, $p < 0.001$).

5.1.1.3 Device #3 (Z-Eliminator)

Device #3 was not designed as a filtering unit and did not remove zebra mussels from the water column (*Figure 6*). Therefore, the number of mussels present in the water column was not different from the control. (*Table 1*, one-way ANOVA, Tukey's HSD, $p > 0.05$).

Table 1 - Not Available

5.1.1.4 Device # 4 (Zebra 5000)

The zebra mussel density in the control water was higher than device #4 on all occasions except one (*Figure 7*). On October 23, the density in device #4 slightly exceeded the control. The mean density of suspended zebra mussels through device #4 was $156 \pm 187/\text{m}^3$ was significantly lower than the control (*Table 1*, one-way ANOVA, Tukey's HSD, $p < 0.001$).

5.1.1.5 Device # 5 (Z-Ban©)

The density of zebra mussels in the water after passing through device #5 was below the value found in the control (*Figure 8*). The mean density of organisms present in the water column was $98 \pm 231/\text{m}^3$ during the test period, however, this test system was only sampled 9 out of the 17 weeks due to set-up delays. Regardless, the density of suspended zebra mussels in device #5 was significantly lower than the control (*Table 1*, one-way ANOVA, Tukey's HSD, $p < 0.0001$).

5.1.1.6 Device # 6 (Zebra 12000)

The density of zebra mussels in the water exiting device #6 exceeded that in the control on a number of occasions (*Figure 9*). Also, the mean density in device #6, $1180 \pm 1028/\text{m}^3$, was similar to the control (*Table 1*), and significantly higher than the other products tested.

5.1.2 Settled Zebra Mussels

The density of zebra mussels that settled on the PVC plates was totalled for each device (*Table 1*). The highest settlement was found in the control at $250/\text{m}^2$. Device #6 and device #3 had a relatively high settlement of $62/\text{m}^2$ and $71/\text{m}^2$, respectively. The remaining devices had substantially less settlement, with only $7/\text{m}^2$ present in device #1 and device #2 and zero settlement occurring on the PVC plates in device #4 and device #5. The settlement density in the control system was significantly higher than in the devices, except for device #3 (one-way ANOVA, Tukey's HSD, $p = 0.002$).

Table 2 Not Available

At the end of the experiment the biobox and intake pipe were examined for settlement (*Table 2*). Settlement was only detected in the intake pipe in device #1 (50/m²) and device #6 (58/m²). The biobox scrape detected settlement in all devices except for #4 and #5. The highest settlement was found in the control (95/m²), followed by device #6 (66/m²). The settlement in device #3 was 20/m². Very low settlement densities were present in devices #1 and #2 (5 and 6/m², respectively).

The settlement on the PVC plates, the intake pipe and the biobox sides were summed for each device to provide a measure of total zebra mussel settlement from July to October (*Figure 10*). The largest settlement density was associated with the control, followed by device #6, device #3, and device #1 and device #2 with substantially lower settlement densities. Devices #4 and #5 had zero settlement overall.

The biobox siphon provides an indication of additional zebra mussels that entered the test systems, however, these mussels were presumed to be dead since they were associated with the sediment. The highest density was associated with device #3 and the control system, followed by device #6, device #2, device #1, device #4 and device #5. A much higher density of zebra mussels was associated with the bottom sediment than with the biobox sides or intake pipe. This is typical, since large quantities of dead zebra mussel larvae are associated with the sediment of water bodies infested with zebra mussels. The mortality rates in the early life stages are very high, reaching almost 99%. When the larvae die, the weight of the shells causes them to drop out of suspension and accumulate in the sediment.

5.2 Device #3 (Z-Eliminator)

The performance of this product was evaluated separately, prior to the injection of calcium hypochlorite and following its injection on October 2, 1998. The pre-chlorination data represent an average of the results collected during the first 12 weeks the system was operational, prior to adding the calcium hypochlorite. The post-chlorination data reflect the sampling period on October 9, one week following the addition of the chemical. The average density of zebra mussels in the water column and settled on the PVC plates was much higher during the pre-chlorination period (*Table 3*). However, the mortality of the settled zebra mussels increased to 100% following the injection of calcium hypochlorite.

Table 3 - Not Available

The total residual chlorine (TRC) present in the bioboxes connected to device #3 was 2.2 ppm, a level much higher than that recommended for drinking water.

5.3 Physical Parameters

5.3.1 Turbidity and TSS

The ambient turbidity levels ranged from 3 NTU to 12 NTU in the control and device #3 (*Table 4*). All devices had mean turbidity levels that were lower than the control, with values ranging from 0.7 NTU to 7 NTU (*Figure 11*). The turbidity levels in device #4 (1.63 NTU) were significantly lower than all other devices, except for device #5 (4.14 NTU; one-way ANOVA, Tukey's HSD, $p < 0.0001$). When converted to TSS, device #4 was capable of removing a maximum of 30.46 mg/L of suspended material (*Table 4*). Device #5 and #1 could remove up to 27.61 mg/L, device #6 up to 21.47 mg/L and device #2 up to 18.41 mg/L.

5.3.2 Water Flow

The flow rates for each device were highly variable throughout the study (*Table 4*). For the entire experiment, the water flow ranged from 2 L/min in device #4 to 78 L/min in device #5. The variability in flow rates was high in the control, device #4 and device #5, as reflected by the large standard deviation (*Figure 12*). However, low flow rates resulting from clogging occurred only in device #4, where high variability was coupled with a significantly lower mean water flow rate (one-way ANOVA, Tukey's HSD, $p < 0.0001$). The mean water flow rate for device #2 was also significantly lower, likely due to sediment settling on the mesh bag. All remaining devices (#1, #3, #5, #6) did not differ from the control, or each other, with respect to water flow.

5.3.3 Water Temperature

The water temperature ranged from 12°C to 23°C throughout the experiment (*Figure 13*). The water temperatures were high from the initiation of the test, July 7 until August 28, 1998. At this point the temperature steadily declined by approximately one degree each week. This steady drop in water temperature was inversely related to zebra mussel settlement, which first appeared on August 21.

Table 4 - Not Available

5.3.4 Maintenance

The number of incidents, which resulted in device shut down or deviate from the experimental design, are presented in Table 4. The control system required service on one occasion as the pump had lost its prime, this occurred near the beginning of the experiment. Device #1, #2 and #6 did not require any maintenance during the 17-week test period. Device #3 required the addition of calcium hypochlorite on October 2, to evaluate how effectively zebra mussels could be eradicated from the test system. Device #4 required the filter cartridges to be replaced on three occasions due to clogging. Device #5 had the most incidents, possibly due to its design mimicking the water supply system in a cottage. Also, the filter cartridge required replacement at the mid-point of the experiment, however, this unit filtered twice as much water as the other products tested here since the pump was almost always running due to the back-flush system. Device #5 also caused a number of power failures in the trailer when the demands on the circuit exceeded its output, due to its constant cycling. It should be noted that the setup of device #5 in a cottage situation would be quite different and it is reasonable to assume that the maintenance requirements would also change.

6.0 DISCUSSION

In general, the products tested in this experiment were capable of either preventing zebra mussels from entering the small volume water systems, or eradicating the population that had settled. The majority of the devices were capable of removing over 75% of the zebra mussels in the water column, thereby preventing their settlement in the bioboxes and intake lines. Also, the products removed suspended material from the water column and therefore improved water clarity, except for device #3. Most of the products operated for the 17-week period with little maintenance. The large volume of water that passed through each product, coupled with the high turbidity present in these waters, provided a very rigorous test for the devices. The results of this study reflect how well the products remove zebra mussels when a volume of water that is four times the amount that would normally be used in a seasonal cottage. The performance of each product is discussed separately, according to the parameters measured in this experiment. For a detailed comparison of the products tested, using the parameters selected by the steering committee, see Part C.

6.1 Device #1 (Zebra Mussel Filter Systems, Inc.)

This product performed well in the experiment by removing over 80% of the zebra mussels in the water column, thereby reducing settlement on the PVC plates by 97%. Also, this product removed up to 58% of the suspended material in the water column without becoming blocked. These factors indicate that it is an effective and versatile product for year-round cottagers, if a small amount of zebra mussel settlement can be tolerated. However, this device was designed for maintenance to be performed by a diver, where filters are changed with the unit in-place. The maintenance involves exchanging the spent filters with a re-built unit that is approximately one-half the cost of the original unit. In terms of price, the expense of contracting divers to change the filters in Canada may place the unit to be above the budget of many small volume water users. However, for cottage owners that have iron intake pipes, underwater maintenance would be essential and the configuration of this unit would be ideal.

6.2 Device #2 (Aquastand)

The Aquastand performed well in this experiment by removing over 73% of the zebra mussels in the water column. This prevented over 97% of the potential settlement. This product was initially designed to remove turbidity, however, in this experiment it removed a maximum of 38% of the suspended material. The device has been designed with a machine washable mesh bag, 35 μm nominal, that stood up to the extremely turbid conditions in the system. Due to the simple design of this product, the only foreseeable maintenance would be cleaning of the bag. This product would be a good choice for consumers who desire a device that is easy to install and maintain, is relatively maintenance free and available at a low price. However, the consumer must be able to accept a small number of zebra mussels entering and possibly settling in their water system.

6.3 Device #3 (Z-Eliminator)

The Z-Eliminator is a unique device tested in this experiment. The method by which this product eliminates zebra mussels is through the use of calcium hypochlorite pellets. A comparison of the time prior to adding the calcium hypochlorite (pre-chlorination) and following (post-chlorination) revealed that this method effectively killed 100% of the settled zebra mussels. Despite the ability of

this device to eliminate zebra mussels from the test system, it is unable to offer some of the advantages offered by the other filters tested (i.e., removing suspended material from the water column). However, since this product does not provide any filtering capability there were no problems with reduced water flow due to clogging. The initial cost of this product was high and the costs associated with its use would increase with the annual purchase of calcium hypochlorite (approximately \$10 US per year).

The optimal method for using Z-Eliminator would be to deploy it at the end of the summer, in a year round cottage, and leave in place for a weekend with the water running continuously. Alternately, this unit can be left in year round and the 25 cm nipple can be removed to inject the calcium hypochlorite. However, while this system is in-place, the water would be unfit for human use due to high residual chlorine levels. A carbon filter can be installed to lower the chlorine levels, however this option was not tested here. Regardless, zebra mussel shells may cause interfere or clog pipes if the seasonal growth rates are high. Also, this process may be a major inconvenience for some small volume water users who are unable to access water directly from the lake or have other treatment systems on their intake line.

The calcium hypochlorite chamber is made with a double fail-safe (foot valve and line check) of the highest grade stainless steel and has been approved for use in the United States. However, the Canadian consumer should check with their local conservation authority or Ministry of Natural Resources prior to purchasing this unit. Lastly, the impacts of chlorination on septic beds were not evaluated in this study, however, the literature suggests that this device could affect the active biotic population in a septic tank.

6.4 Device #4 (Zebra 5000)

Due to the small, 1 to 5 μm nominal filters, the Zebra 5000 removed over 87% of the zebra mussels in the water column. This prevented any settlement of zebra mussels from occurring in the test system. However, the device required the filters to be changed three times during this experiment as it removed as much as 65% of the suspended material in the water column. Therefore, the product would not be a good choice in turbid environments since the level of maintenance required would be high and the associated costs would rise as filter replacement frequency increased.

Additional problems occur with frequent filter replacement, especially if performed while the unit is submerged. A series of o-rings is used to seal the filters to ensure that all water entering the system is filtered first. When filters are changed underwater, the probability of losing the o-rings increases, as happened in this study. The incomplete seal may explain why zebra mussels were observed in the device system. Care must be taken to install this unit specifically to the manufacturer's guidelines to prevent damage from wave activity and ensure stability. In clear waters the Zebra 5000 would be an extremely cost-effective method for small volume water users to prevent zebra mussel infestations.

6.5 Device #5 (Z-Ban©)

The Z-Ban© is an advanced version of the systems installed in the Lake Champlain area that was tested for the first time in this experiment. The device was able to remove over 90% of the zebra mussels from the water column and prevent settlement in the test system during the 9 weeks it was operational. However, the system experienced a number of setbacks due to a delay at test initiation, filter clogging and a malfunction in the backwash system.

The test system consisted not only of the unit shown in photograph #5, but components of a cottage water supply system, which caused delays in the delivery, installation and operation. Regardless, the numbers presented here reflect performance after approximately 200 000 L had passed through the filter. The system design included a holding tank that released water hourly, according to the timer setting, and two backflush tanks that were triggered by a pressure switch at the pump. Since the pump constantly operated, this system filtered twice as much water as the other devices in half the time. The Z-Ban© also contained an electrically charged (9 volts AC) mesh to prevent zebra mussel settlement on the submerged unit. Since a direct power source was connected to this product, underwater, concerns regarding the proper wiring and installation arise. Therefore, the Z-Ban© electrical unit should be wired and installed by an electrician. This system has been designed such that the majority of the post-installation maintenance can be performed in the cottage, with the unit in the water requiring little to no attention.

The high cost, poor availability in Canada, filter clogging and backflush problems suggest that this product requires further work before being released on the market. Despite

the problems encountered here, its ability to prevent over 90% of the zebra mussels from entering and settling in the test system suggests that it could be a competitive zebra mussel control option in the future.

6.6 Device #6 (Zebra 12000)

The cage collapsed early in the testing and prevented the Zebra 12000 from removing zebra mussels as the mesh bag had been torn. The vacuum gauge readings did not indicate that this problem had occurred because it happened within the first week of operation. Instead, the problem was perceived to be an error in the installation of the gauge. Regardless, in a practical application, the consumer would have been unaware of the collapse until the product was removed from the water column. The test on this prototype indicates that it requires further work before being released to the market.

LIST OF FIGURES

- Figure 1: Location of Study Site**
- Figure 2: Test System Schematic**
- Figure 3: Flow Through System Schematic**
- Figure 4: The performance of device #1 compared to the control**
- Figure 5: The performance of device #2 compared to the control**
- Figure 6: The performance of device #3 compared to the control**
- Figure 7: The performance of device #4 compared to the control**
- Figure 8: The performance of device #5 compared to the control**
- Figure 9: The performance of device #5 compared to the control**
- Figure 10: Total settlement including weekly PVC plate scrapes, biobox scrape and intake line scrape**
- Figure 11: Mean turbidity entering the bioboxes from each treatment**
- Figure 12: Mean water flow entering the bioboxes**
- Figure 13: Water temperature throughout the study period (July 7 to October 30, 1998)**

Tables 1-3 not available

We apologize for any inconvenience

Please contact the GBA for more information

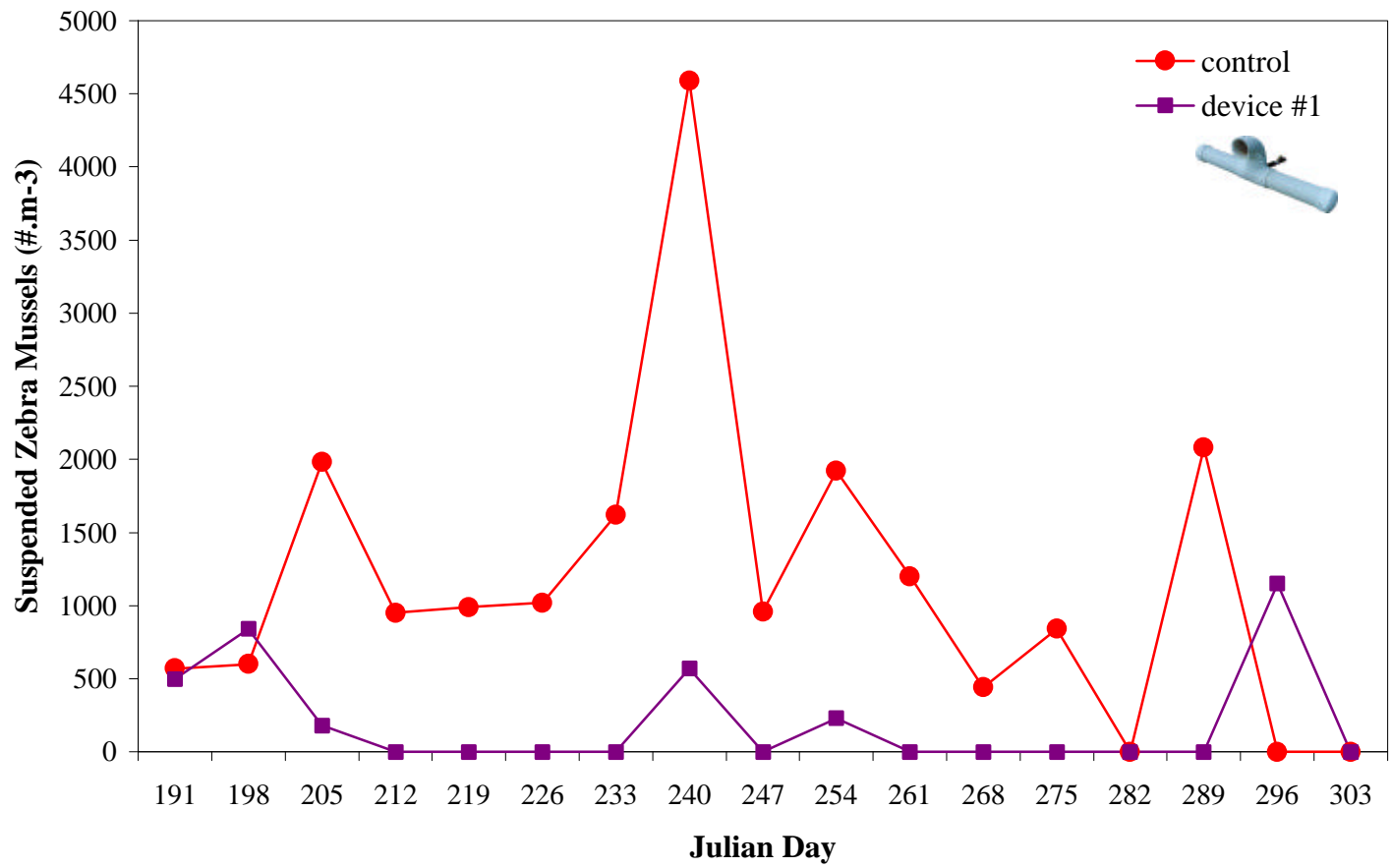


Figure 4. The performance of device #1 (Zebra Mussel Filters Systems, Inc.) compared to the control.

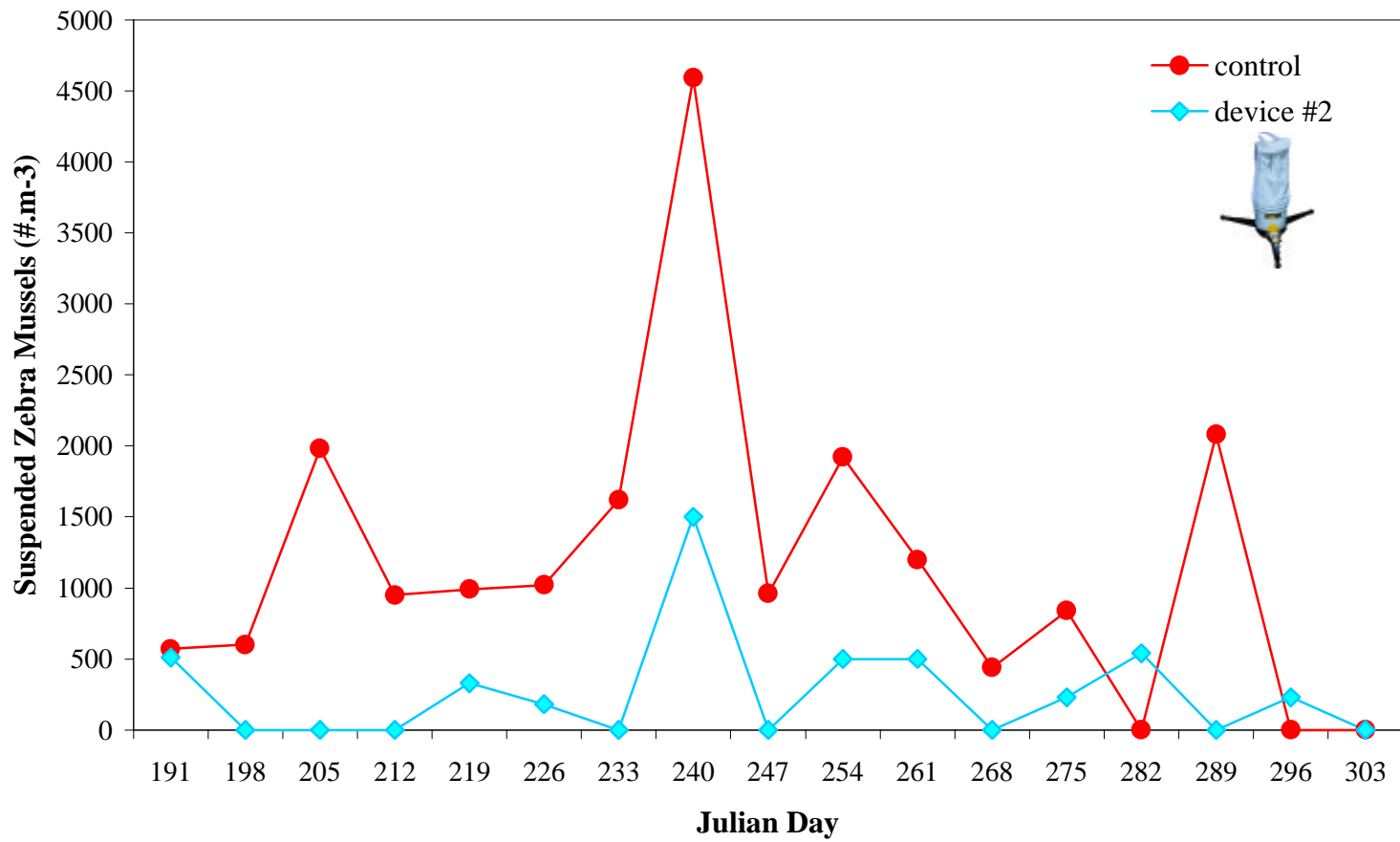


Figure 5. The performance of device # 2 (Aquastand) compared to the control.

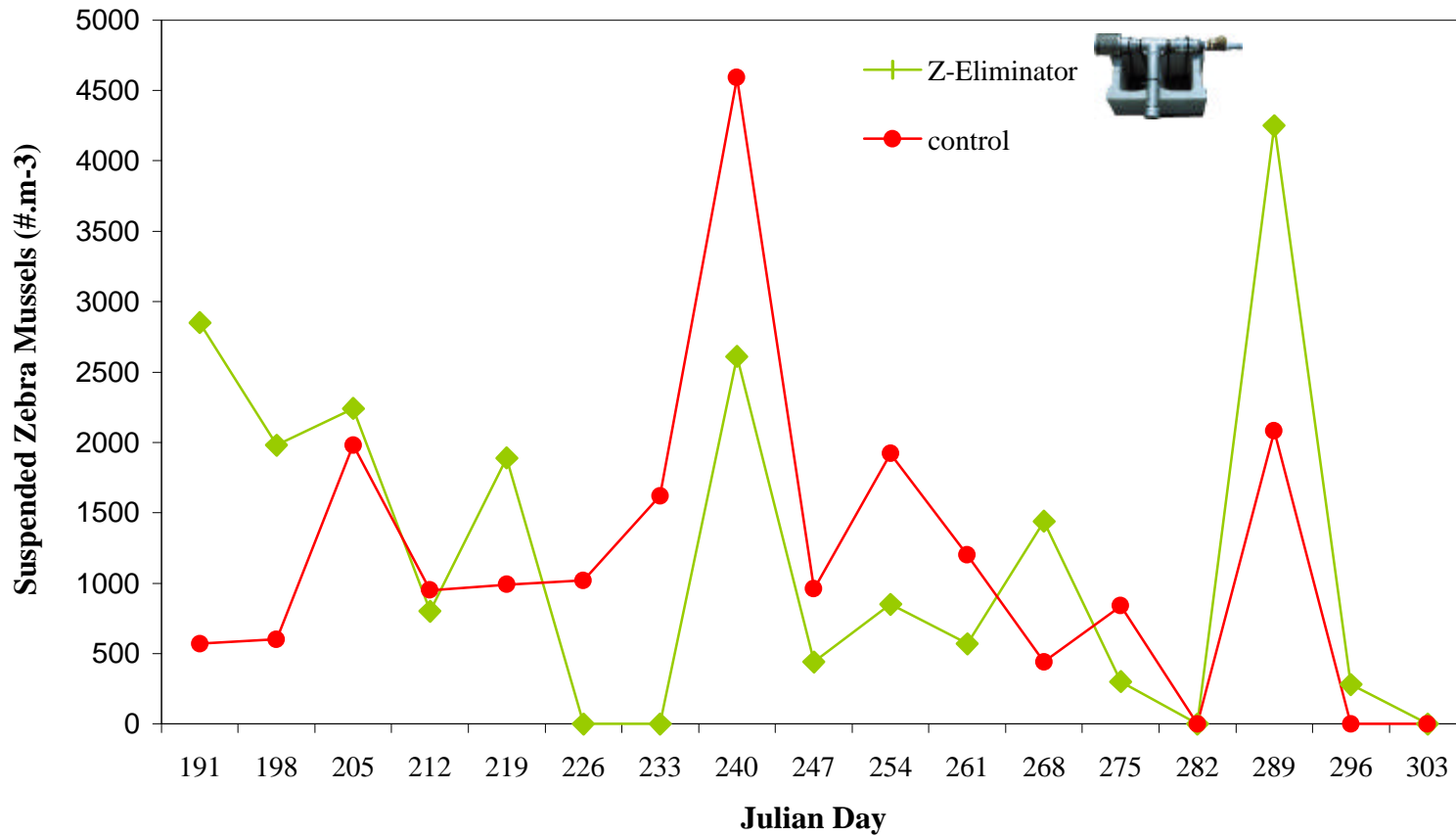


Figure 6. The performance of device #3 (Z-Eliminator) compared to the control.

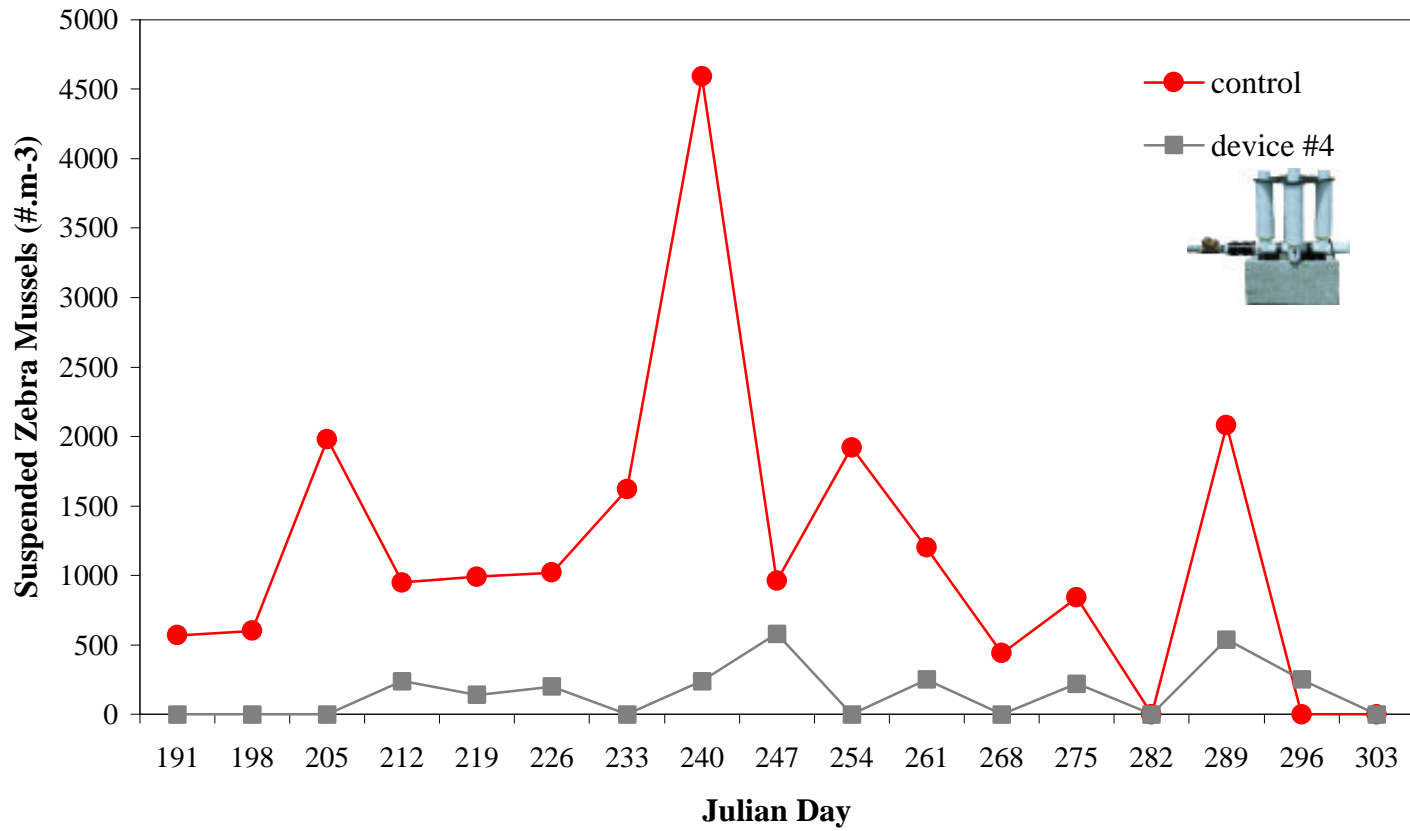


Figure 7. The performance of device #4 (Zebra 5000) compared to the control.

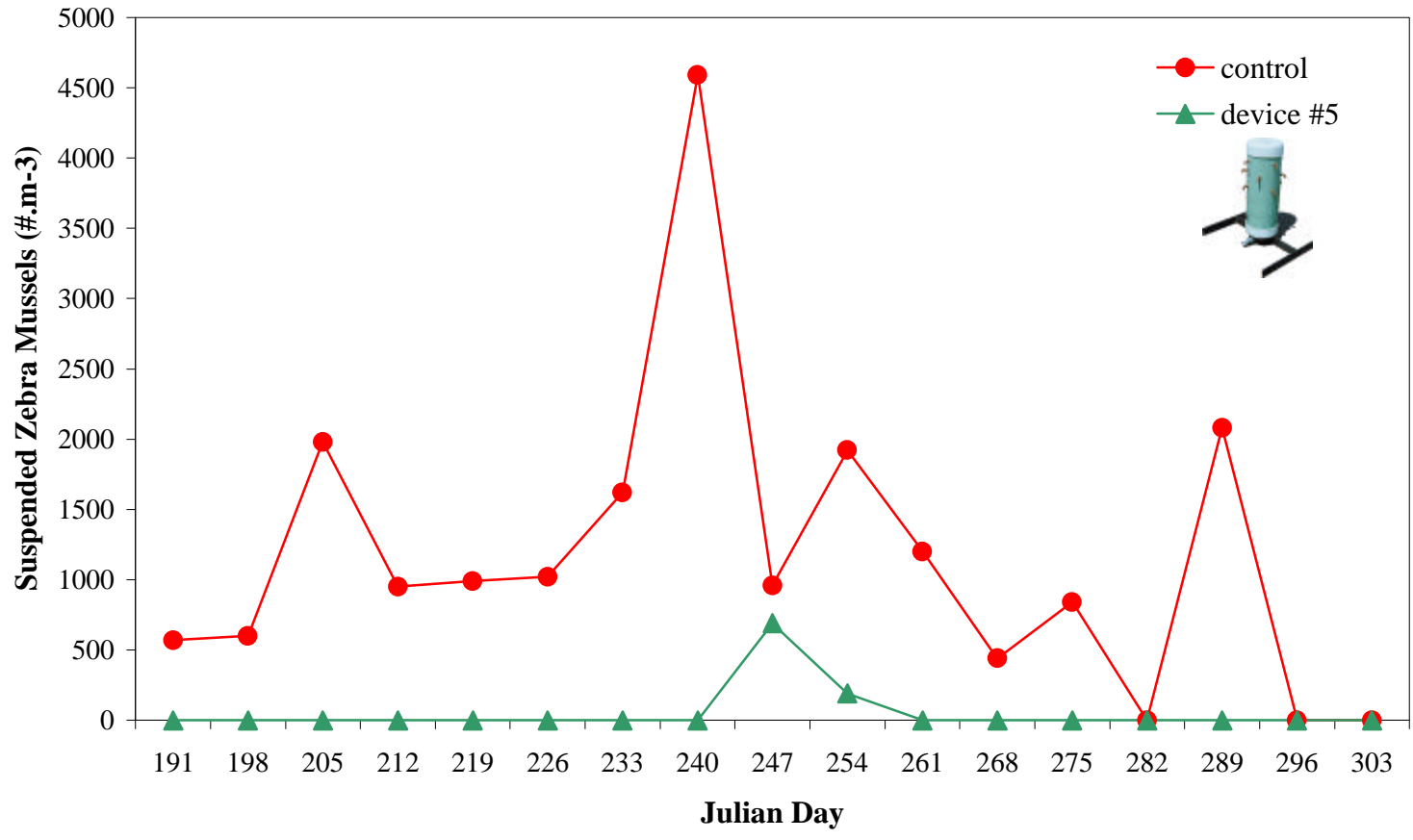


Figure 8. The performance of device #5 (Z-Ban) compared to the control.

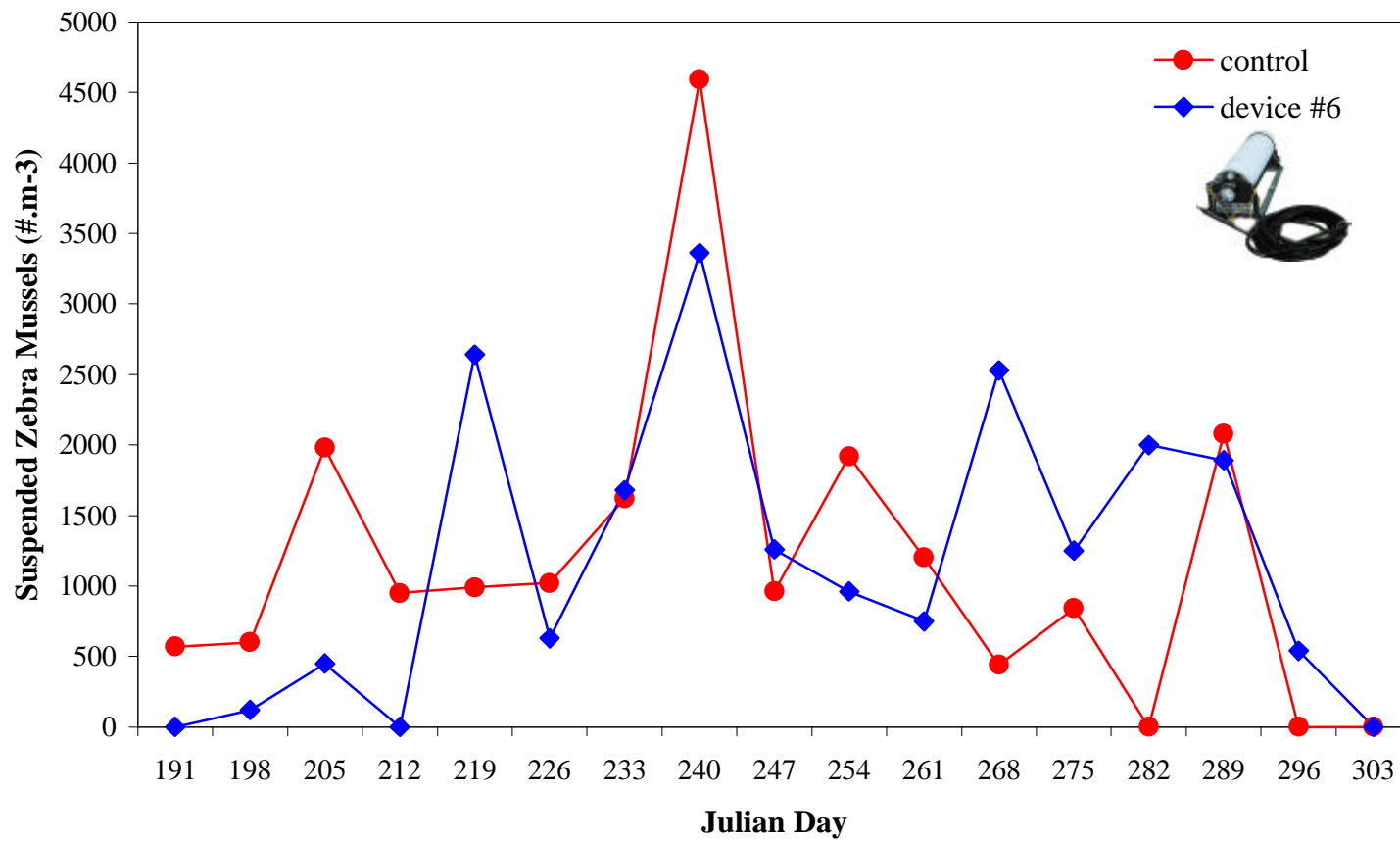


Figure 9. The performance of device #6 (Zebra 12000) compared to the control.

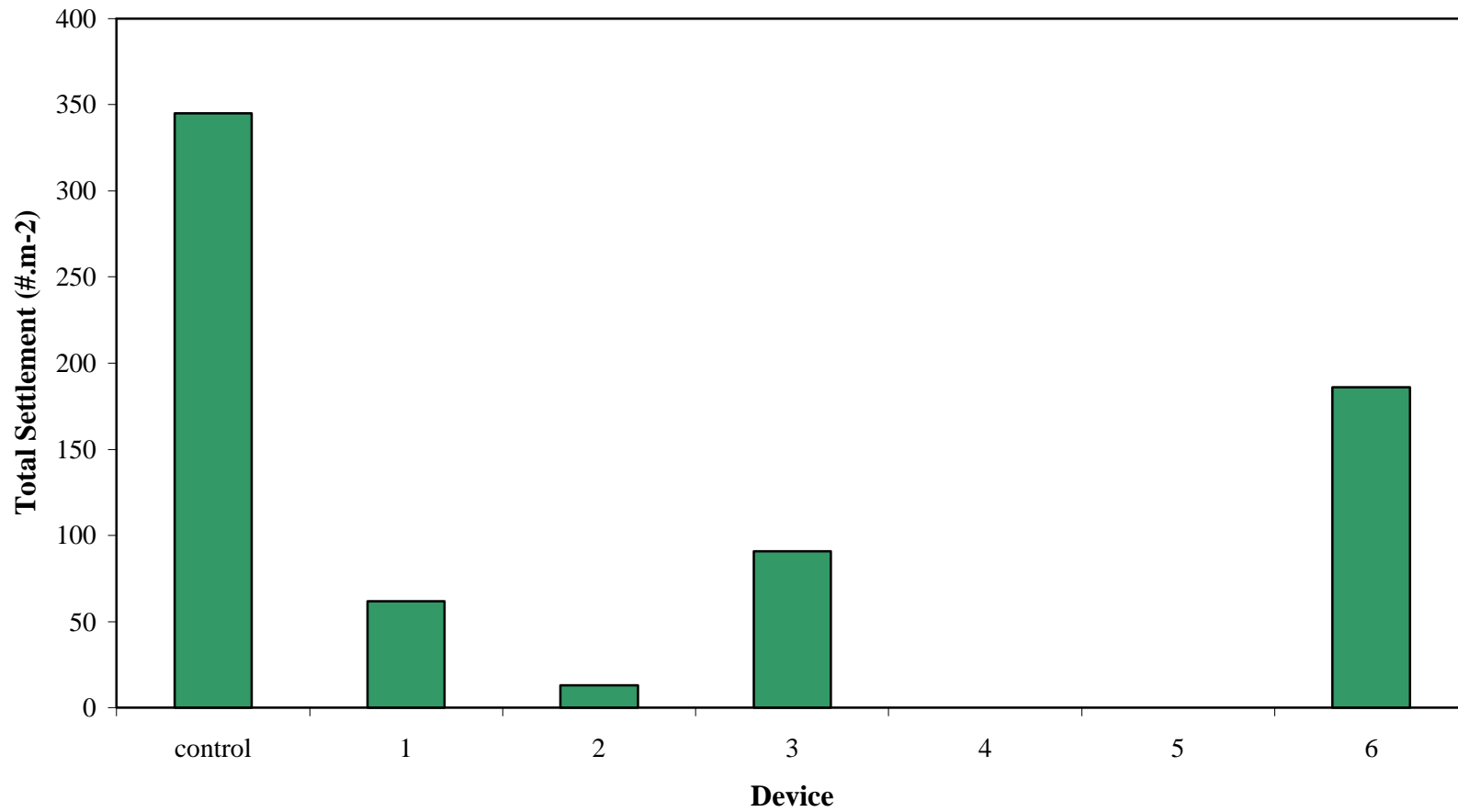


Figure 10. Total settlement including weekly PVC plate scrapes, biobox scrape and intake line scrape.

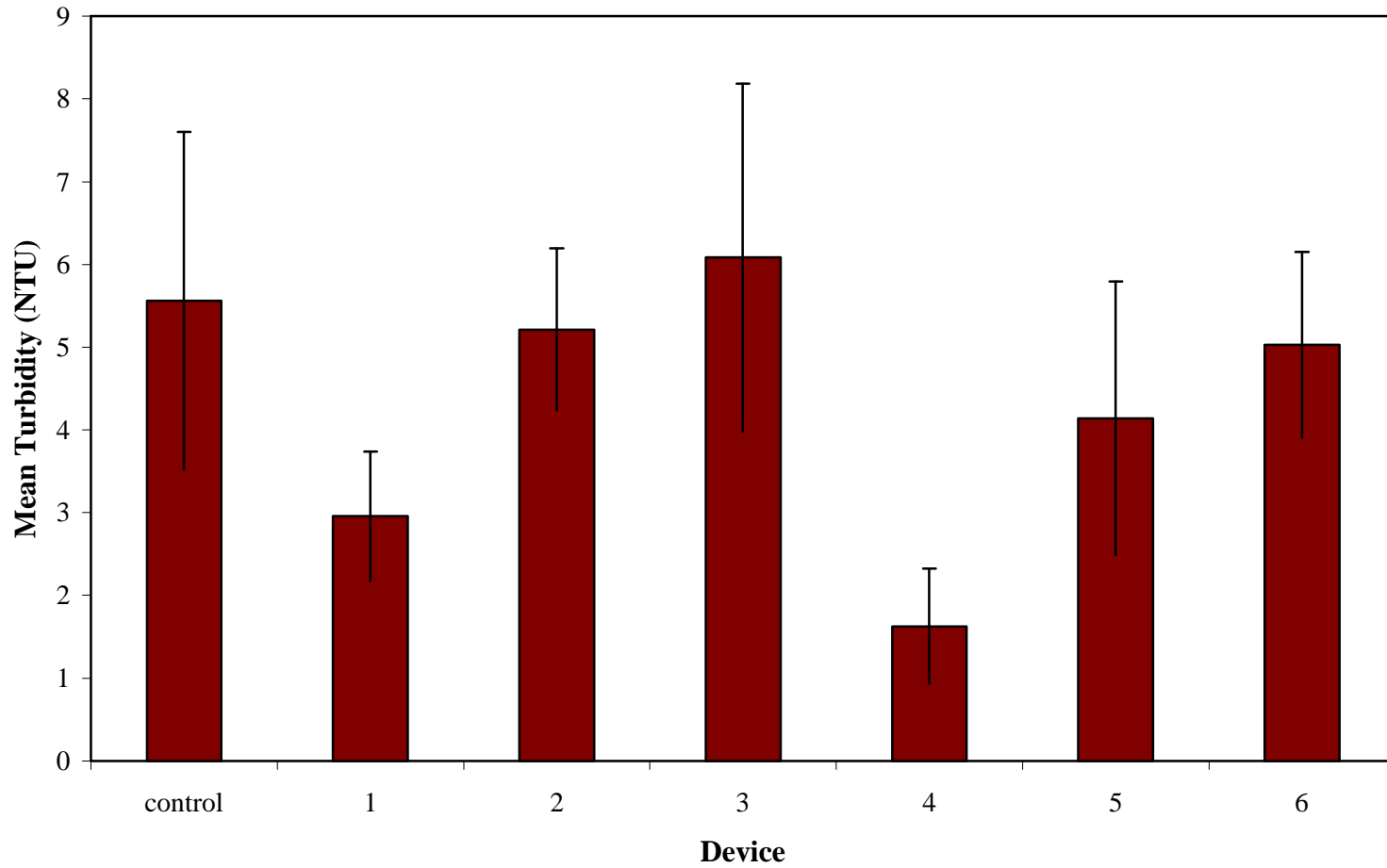


Figure 11. Mean turbidity entering the bioboxes from each treatment. Bars represent standard deviations for each treatment.

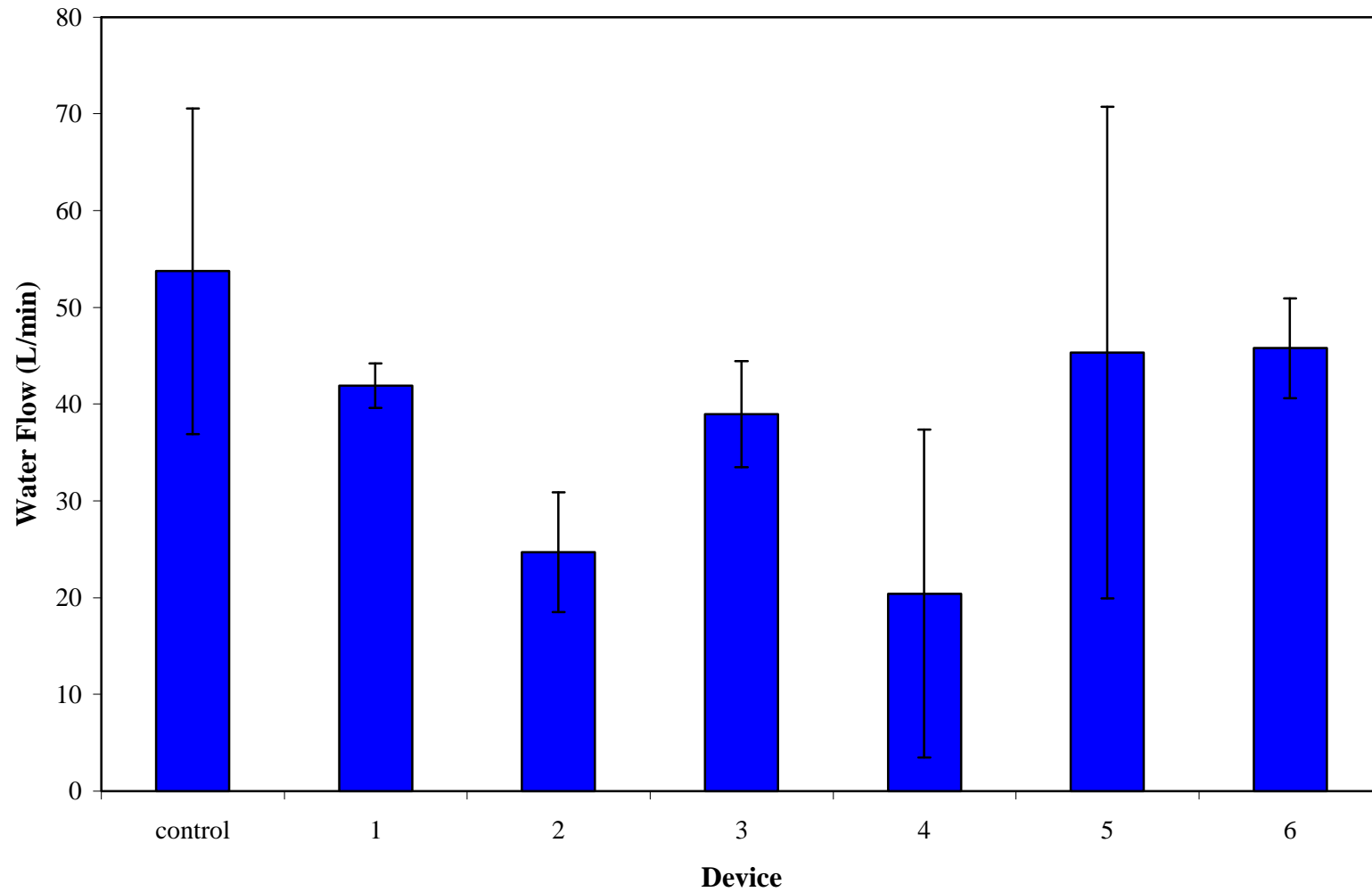


Figure 12. Mean water flow entering the bioboxes. Bars represent standard deviations for each treatment.

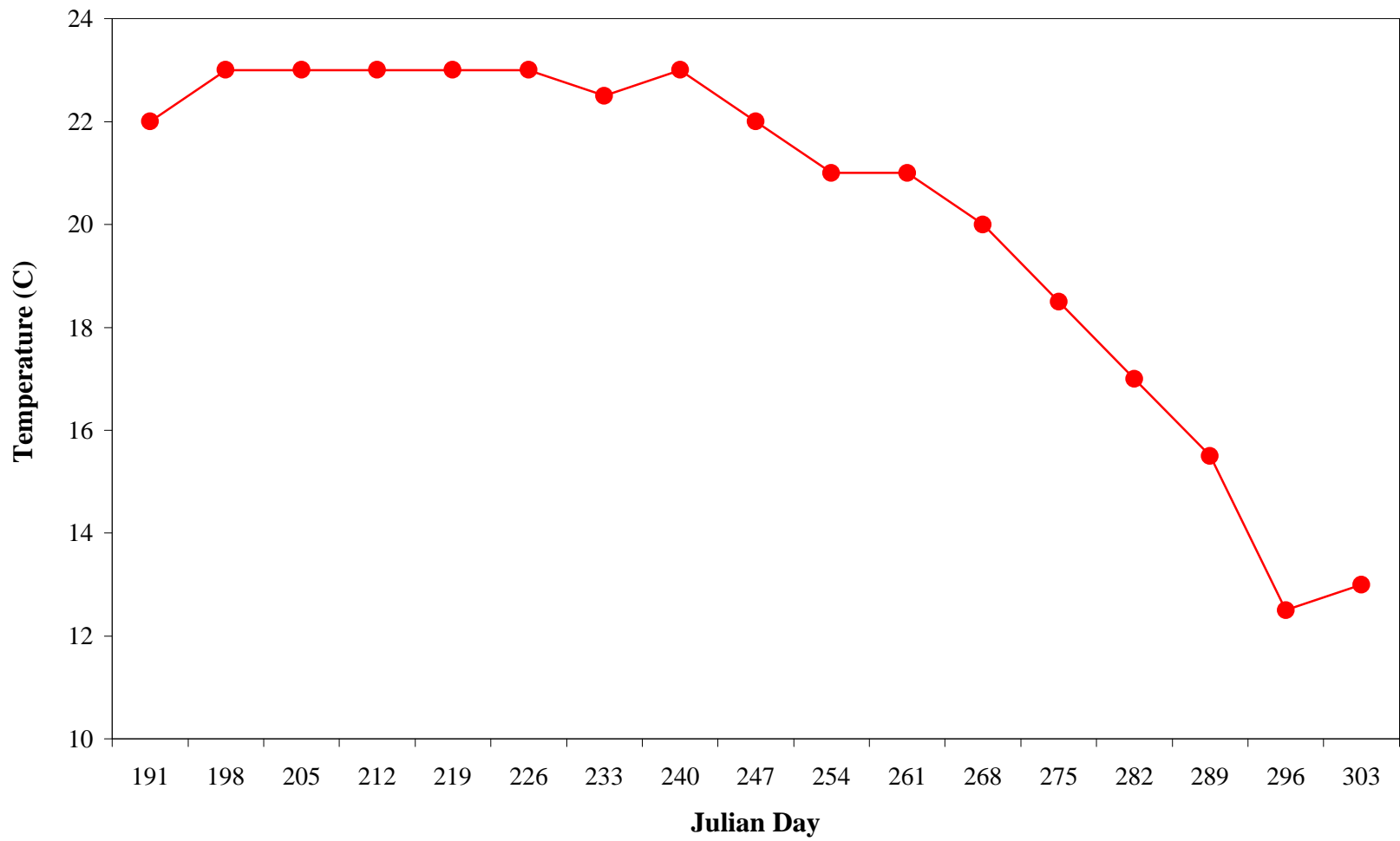


Figure 13. Water temperature throughout the study period (July 7 to October 30, 1998).

Appendix I - FILTER MATERIAL and SELECTION

by John Hueton & Renata Claudi

FILTER MATERIALS & PORE SIZES

Recently developed filters for removing zebra mussels are made of metal or plastic screens, of cloth bags or woven thread candles, or of hollow cylinders of sintered ceramic oxide particles.

All pores of equal size in metal screens (i.e., 35 μm), termed “absolute”, since spherical particles larger than 35 μm do not pass through the material. However, metal eventually corrodes in water and the pore sizes change, either becoming larger through metal loss or smaller through oxide buildup. Changes in pore size either reduce the efficiency of removing zebra mussels or reduce water flow.

Plastic screens can also have pores of equal size, but because the material is more flexible than metal, the pores can become larger, and the adjacent ones smaller. The pore boundary of the material moves under water pressure from debris build-up or may be punctured.

Cloth filters (i.e., devices #2 and #6) cannot guarantee consistent pore size during manufacturing. The threads surrounding each pore are flexible and move in a similar manner to plastic screens, enlarging or shrinking the pore size. Since the pore size cannot be guaranteed, the pore size rating is termed “nominal”. Cloth filters are constructed with layers of material to try to counteract distortion and the inability to guarantee that any particular pore is of the chosen size, and to prevent a channel of larger pores lining up right through the filter material. Surface area is increased to reduce the water pressure and reduce the likelihood of pore size distortion. Any desired micron size can be achieved; however, the smaller the pores size the more likely that suspended solids in the water will build up and clog the filter. Some cloth filters can be washed and reused to eliminate the cost of replacement.

Wound-thread candle filters (i.e., device #4) encounter similar problems to cloth filters. The thread diameter can be kept constant, when winding it on the candle; however, there is no guarantee that the laying down thread layer upon layer will leave no gaps. Different sized thread and thicknesses provide the desired pore size; however, these filters are nominal because holes can occur and are uncontrollable. Wound thread filters cannot be washed effectively, although they can be back-washed. However, once clogged they have to be discarded. If not discarded at season's end, they will have a distinct odour after winter storage out of the water.

The pore sizes in nominal filters may vary greatly. A 35 μm filter may have pores in the range 10 to 100 μm , while a 5 μm filter may have pores ranging from 1 to 70 μm . Only detailed microscopic examination can determine these pore sizes. Thus it is not practical for the manufacturers to carry out quality control during the production runs to generate an “absolute” pore size rating.

Sintered ceramic oxide filters (not tested here) can be made to provide “absolute” pore sizes by altering the size of particles sintered and compressed together and the

thickness of the filter body. The mechanical and physical properties of ceramic oxide particles limit the thickness of filter material that can be produced. These filters can be used almost indefinitely and are kept clear by back-flushing. They also may have to be washed in bleach at the end of each season to reduce the odour that arises during winter storage out of water.

All the zebra mussel filter manufacturers decided between larger pore size to permit water flow without clogging by suspended solids, or smaller pore sizes with increased likelihood of clogging, all at a cost suitable to purchasers. However, the ultimate goal is to eliminate zebra mussels from water systems.

PORE SIZE NEEDED FOR MUSSEL FILTRATION

Part A discusses the fact that the zebra mussel eggs are approximately 40 μm in size, suggesting that a 35 μm filter would keep them out of water systems. However, the eggs are malleable and easily deform to a sausage-shaped 10 μm thick shape. Thus they may slip through 35 μm absolute pores or the larger pores in 5 μm nominal filters. This does not pose a high risk as eggs do not equate with colonization as the eggs will pass out of the water system during use. If the system water is left stagnant, the eggs may hatch, however, provided that the dissolved oxygen is not depleted. Zebra mussel veligers, up to 120 μm in size, are capable of reducing their diameter to 40 μm and may slip through pores whether the filter is rated absolute or nominal, partially owing to the suction pressure at the surface of the filter.

Manufacturers of these filters are faced with the following dilemma: how to supply simple-to-install filters at reasonable cost, that keep out problematic mussel life, do not clog with suspended solids, do not require frequent maintenance, complicated piping and pump control systems for back-flushing and are sturdy and stable when in position on the lake or river bottom. Absolute filters rated at 35 μm or less may keep out all forms of mussels, depending on the suction pressure. Absolute 10 μm filters should exclude all forms, however, clogging from suspended solids is more probable with decreasing pore size. In such cases, back-flushing could be useful to mediate the clogging problem. Absolute or nominal filters rated above 35 μm may be necessary in turbid waters. Mussel ingress will be more likely, although the film of solid material forming on the filter will not be significant. Back-flushing will be necessary, or the installation of a washable or self-cleaning filter.

OBSERVATIONS

The work done for this report shows that in the past few years, the manufacturers in have made good progress in improving their systems. Work is still needed to produce suitable zebra mussel control systems that will keep all viable forms of mussel life capable of colonization out of small volume water systems. As of the date of this report, purchasers of zebra mussel removal products have to accept some risk that a small number of viable mussel forms may enter their water systems. The products tested here provided a good compromise between the zebra mussel removal versus clogging problems, and are cheap enough that they can be replaced if and when better

products reach the market. In addition, mussel filters fortuitously act as a preliminary coarse filter ahead of any fine filters installed within the residence to protect water sterilization equipment.

Other filtration systems (such as device #5) are being developed and may offer alternatives in the future.

APPENDIX II

Photograph 1: Device #1 - Zebra Mussel Filter Systems, Inc.

Photograph 2: Device #2 - Precise Solutions Inc., Aquastand

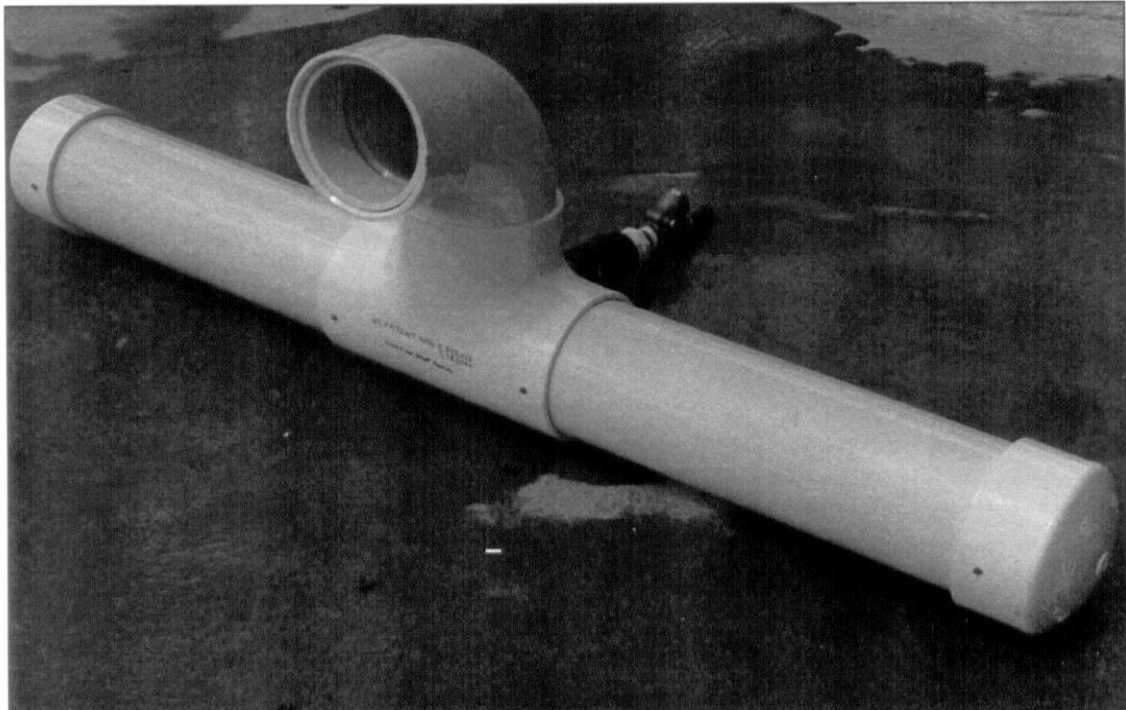
Photograph 3: Device #3 - Z-Eliminator

Photograph 4: Device #4 - Alex Milne and Associates, Zebra 5000

Photograph 5: Device #5 - Delta Applied Technology Inc., Z-Ban©

Photograph 6: Device #6 - Alex Milne and Associates, Zebra 12000

PHOTOGRAPH 1



Zebra Mussel Filter Systems, Inc.: Device #1

- 80% zebra mussel removal in the water column
- 97% reduction in zebra mussel settlement
- US \$600 to \$700, includes installation
- re-built unit US\$350
- 58% reduction in suspended material
- series of filters inside tube, 20 μm nominal
- no maintenance required in this experiment
- 1.5 metres long
- copper mesh on intake

**GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
ASI PROJECT M9527**

**Zebra Mussel Filter Systems, Inc.
PO Box 5681, Route 89
Romulus, NY 14541
Contact: Jeffery Band, 607-869-5859**

Aquatic Sciences Inc.

PHOTOGRAPH 2



Precise Solutions Inc., Aquastand: Devise #2

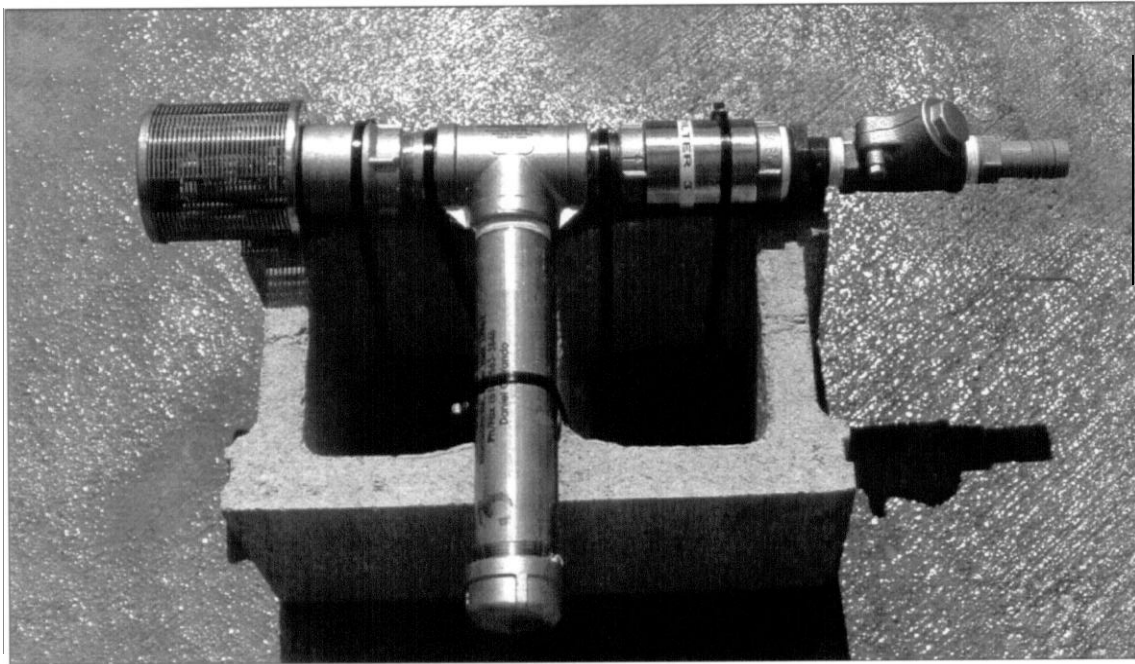
- 73% zebra mussel removal in the water column
- 97% reduction in zebra mussel settlement
- \$229
- 38% reduction in suspended material
- 35 μm cloth bag (nominal, hand stitched, machine washable)
- no maintenance required during this experiment
- bottom filled with rocks, gravel to stabilize unit in an upright position
- surface area maximized

GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
ASI PROJECT M9527

Precise Solutions Inc.
100 Lancing Drive, Unit 10
Hamilton, ON L6W 3L6 1-800-668-2183
Contact: Mark Gallant, 905-575-9458

Aquatic Sciences Inc.

PHOTOGRAPH 3



Z-Eliminator: Device #3

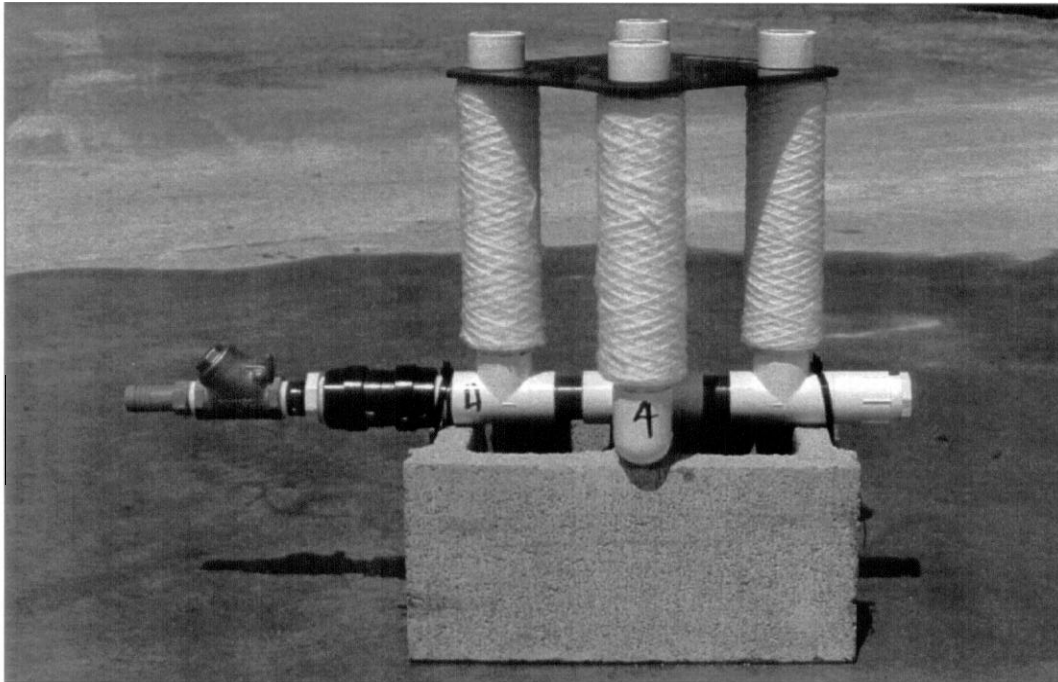
- killed 100% of settled zebra mussels
- us **\$700**
- calcium hypochlorite treatment, US \$10 per year
- pellets inserted at the end of each season
- residual chlorine levels need to be evaluated following treatment

GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
ASI PROJECT M9527

Z-Eliminator
1737 Route 22B
Morrisonville, NY 12962
Contact: Dan Yando, 518-563-3846

Aquatic Sciences Inc.

PHOTOGRAPH 4



Alex Milne and Associates Ltd., Zebra 5000: Device #4

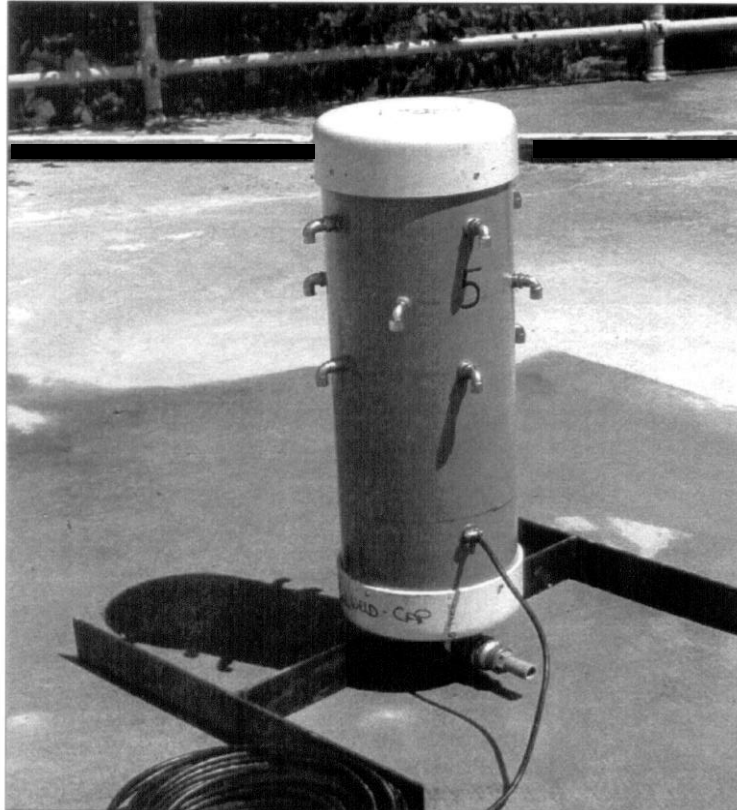
- 87% zebra mussel removal in the water column
- 100% reduction in zebra mussel settlement
- \$275
- replacement filters, \$35 per set of 5
- 65% reduction in suspended material
- 1 μm or 5 μm filters (nominal)
- filters replaced three times during this experiment
- required weight to anchor in an upright position

GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
ASI PROJECT M9527

Alex Milne and Associates Ltd.
6803 Steeles Avenue West
Etobicoke, ON M9V 4R9
Contact: Bill Milne, 416-742-4911

Aquatic Sciences Inc.

PHOTOGRAPH 5



Delta Applied Technology, Inc., Z-Banc: Device #5

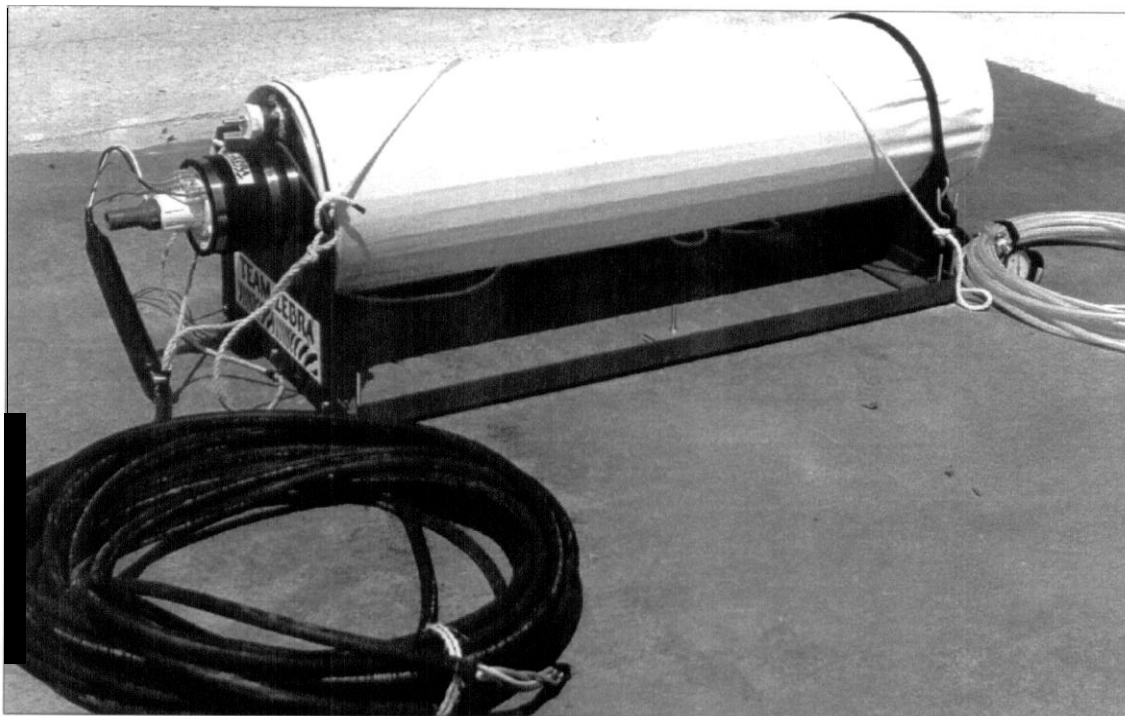
- 90% zebra mussel removal in the water column
- 100% reduction in zebra mussel settlement
- US \$1500** (complete system)
- US \$575** (unit displayed)
- US \$275** (low voltage system)
- 53% reduction in suspended material
- 35 μm nominal filter, **US \$6** per filter
- charged mesh inside unit **(9V) AC**
- holding tank and backflush system

GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
ASI PROJECT M9527

Delta Applied Technology, Inc.
100 Sandune Court, Suite \square
Pittsburgh, PA 15239
Contact: Clois Fears, 724-327-5150

Aquatic Sciences Inc.

PHOTOGRAPH 6



Alex Milne and Associates, Zebra 12000

- zebra mussel removal efficiency not applicable in this study
- \$725
- 25 μm cloth bag (nominal, machine-washable)
- submersible pump, $\frac{1}{2}$ HP
- over 1 m long and 45 cm high
- patio stones used to stabilize

GEORGIAN BAY ASSOCIATION
AN INVESTIGATION INTO THE ABILITY OF SIX
DIFFERENT PRODUCTS TO PREVENT ZEBRA
MUSSELS FROM INFESTING A SMALL VOLUME
WATER SYSTEM
PROJECT MS527

Alex Milne and Associates Ltd.
6603 Steeles Avenue West
Etobicoke, ON M9V 4R9
Contact: Bill Milne. 416-7424911

Aquatic Sciences Inc.

APPENDIX III

Table A: Control Zebra Mussel Densities

Table B: Device #1 Zebra Mussel Densities

Table C: Device #2 Zebra Mussel Densities

Table D: Device #3 Zebra Mussel Densities

Table E: Device #4 Zebra Mussel Densities

Table F: Device #5 Zebra Mussel Densities

Table G: Device #6 Zebra Mussel Densities

Table H: QA/QC Sample Analysis Results

Table I: Zebra Mussel Settlement Densities in Intake Pipe Sections (#.m⁻²) – Test Termination

Table J: Zebra Mussel Densities in Siphon Samples (#.m⁻²) – Test Termination

Table K: Mussel Settlement Densities in Scrape Samples (#.m⁻²) – Test Termination

Table L: Control Operational Parameters

Table M: Device #1 Operational Parameters

Table N: Device #2 Operational Parameters

Table O: Device #3 Operational Parameters

Table P: Device #4 Operational Parameters

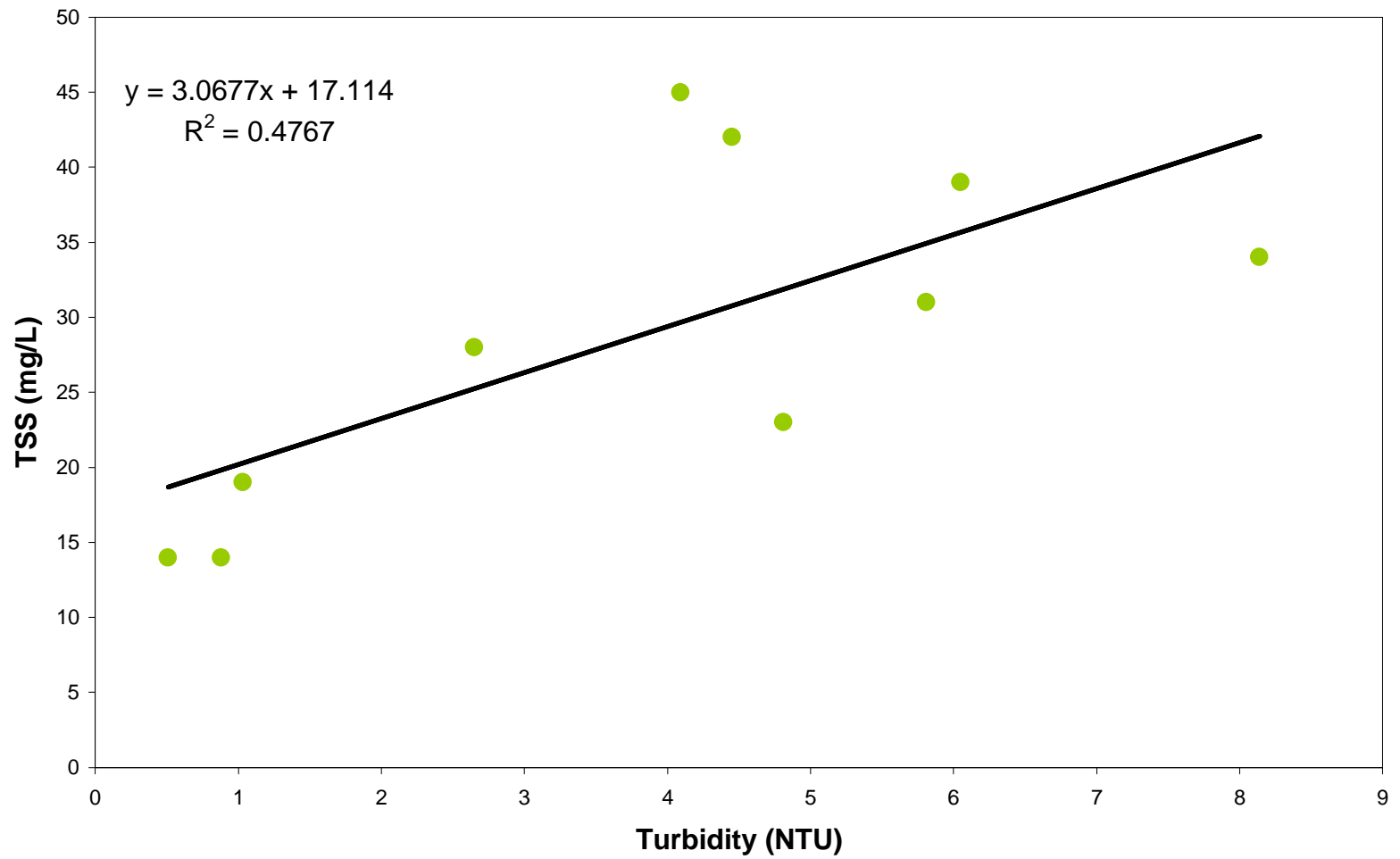
Table Q: Device #5 Operational Parameters

Table R: Device #6 Operational Parameters

Total Suspended Solids Data - *Not Available in this version of report*

APPENDIX IV

Turbidity - Total Suspended Solids Rating Curve



Turbidity - Total Suspended Solids (TSS) Rating Curve

PART C
A CONSUMER'S GUIDE TO
EVALUATING THE DEVICES TESTED

REPORT BY STEERING COMMITTEE

Submitted
February 26, 1999

PART C TABLE OF CONTENTS

1.0 ZEBRA MUSSEL REMOVAL/ELIMINATION.....C-1

2.0 TURBIDITY AND SUSPENDED MATERIAL REMOVAL.....C-2

3.0 MAINTENANCEC-3

4.0 INSTALLATION, AVAILABILITY AND COSTC-4

**A CONSUMER'S GUIDE TO
EVALUATING THE PRODUCTS TESTED
February 26, 1999**

The following discussion, generated from the data provided on Table 1, is intended for the reader to use when evaluating which product would be best for their situation. Device #6 (Zebra 12000) can only be evaluated for price and availability from the results of the experiment since the cage that supports the mesh bag collapsed early on in the experiment.

1.0 ZEBRA MUSSEL REMOVAL/ELIMINATION

The products tested here were capable of removing 73 to 90% of the zebra mussel veligers suspended in the water column, except for device #3 (Z-Eliminator) whose mode of action was chlorination, not filtration. The removal or elimination of settled zebra mussel larvae was much higher, ranging from 97 to 100%. The densities of mussels settling in the system was much lower than the densities suspended in the water column, indicating that the most of the mussels entering the system were not surviving and colonizing (devices #1, #2, #4, #5). Since the larger larval and juvenile zebra mussels (the settled fraction) pose a higher risk to the water system, the ability of these products to reduce settlement to 0-3% of the original population suggests that all are effective in preventing zebra mussel infestations in most small volume water systems. All products performed well in these waters; however, it is important to note that in waters with extremely high densities (i.e., greater than 50 000/m³) the products that allow zebra mussels to settle may not be sufficient. Even though removal efficiencies are quite high for these products, it is important to realize that only device #3 (Z-Eliminator) was capable of completely eliminating zebra mussels from the water system. Despite its efficiency in eliminating zebra mussels, the use of chlorine in a cottage situation should be approached with caution and the local Ministry of Natural Resources office should be contacted prior to purchasing this unit for use in Canadian waters.

2.0 TURBIDITY AND SUSPENDED MATERIAL REMOVAL

The location where the products were tested had turbidity levels ranging from 3 NTU to over 10 NTU, which translates into approximately 26 to 48 mg/L of total suspended solids. The total suspended solids level at the test station is quite high when compared to waters associated with most cottage areas (2 to 30 mg/L). Therefore, these performance trials acted as a worst-case scenario and tested the ability of these products to remove zebra mussels while dealing with high levels of suspended solids. In addition, this experiment also indicated how well each product could act as a pre-filter to water purification units found in many cottages.

The maximum amount of suspended material that these products were capable of removing was calculated by subtracting the minimum suspended solids concentration in each product from the maximum suspended solids concentration found in the control. These values ranged from a low of zero for device #3 (Z-Eliminator) to a high of 65% for device #4 (Zebra 5000). Device #2 (Aquastand) was capable of removing 38% of the suspended solids, where device #1 (Zebra Mussel Filter Systems, Inc.) removed 58% and device #5 (Z-Ban©) removed 53%. The amount of material removed was related to the pore size of the filters, or absence of filter in device #3 (Z-Eliminator), filters with smaller-sized removing more suspended material.

The importance of suspended solid removal to the cottager should be based on the suspended solids concentration present in the water body, the way they use the water (ingestion vs. cleaning) and the volume of water used per season. For water bodies with high concentrations of suspended material, a product that has a relatively large pore size (i.e., device #2, Aquastand) would be the best choice for zebra mussel removal. A smaller portion of the suspended solids will be removed; however, the majority of the zebra mussels will be prevented from entering the system and clogging would be infrequent. Alternatively, the chlorine injection system (device #3, Z-Eliminator) could be used to control zebra mussel populations without substantial changes in the suspended solids concentrations or flow rates. In typical cottage waters with low concentrations of suspended solids, any of the products

tested would work effectively, however, device #4 (Zebra 5000) would offer the most benefit, in terms of removing suspended material prior to a water purification system. Device #1 (Zebra Mussel Filter Systems, Inc.) and device #5 (Z-Ban©) would be effective at removing over half of the suspended solids in the water column while keeping zebra mussel densities extremely low, providing a balanced trade-off between zebra mussel control and suspended solids reduction.

3.0 MAINTENANCE

The amount of effort involved in keeping each test system operational during the performance trials was determined. The units requiring filter changes, chemical addition or alternate maintenance during the experiment were recorded to provide the consumer with an indication of possible problems that they may encounter.

Device #1 (Zebra Mussel Filter Systems, Inc.) did not require any maintenance throughout the experiment, nor is annual maintenance or removal required, according to the manufacturer. This unit is designed to be installed once with maintenance or filter changes performed by an underwater diver. A re-built unit is offered, at a reduced cost (US \$350), to the owner if and when the original filters become clogged.

Device #2 (Aquastand) did not require maintenance during this experiment; however, the bag on the unit was shaken by the divers at the mid-way point in the test as it became laden with sediment. The required maintenance for this product is to wash the mesh bag at the end of the year when the unit is removed from the water (or if water flow rates decrease dramatically at the tap).

Device #3 (Z-Eliminator) requires the 25 cm nipple to be removed at the end of the cottage season, or late fall, to inject the calcium hypochlorite and initiate the chlorination. Other than this annual activity, no other maintenance was required in this experiment.

Device #4 (Zebra 5000) had to be serviced on three occasions during the experiment. The filters had become

clogged with suspended material and water flow had decreased significantly. In these waters, the ability of this product to remove a large proportion of the suspended material resulted in maintenance problems. The manufacturer recommends that the filters be replaced at the end of each summer, when the unit is removed from the water. However, the results of this study indicate that if this unit is used in turbid waters, the filters will need to be changed more frequently.

Device #5 (Z-Ban©) required maintenance on a number of occasions throughout the experiment, however, many of these instances were due to the setup of the water supply system and not necessarily the performance of the filter. Due to the extensive setup that was required to operate this system (holding tank and back-flush tanks, operated by switches connected to the pump), and the limited power source at the test site, many delays and interruptions were encountered. It is reasonable to assume that in a cottage with an existing water system and reliable power supply, these problems may not occur. The only problem that related directly to the unit's ability to remove zebra mussels was when the filter clogged.

4.0 INSTALLATION, AVAILABILITY AND COST




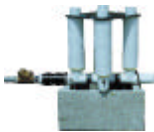


The degree of effort required to install each of these products has been rated, based on the experience of the ASI field crew (technicians and divers). Device #2 (AquaStand), Device #3 (Z-Eliminator) and Device #4 (Zebra 5000) were easy to install due to their small size and light weight. In a cottage situation, one person would easily deploy these products off a dock or from a boat. Device #1 (Zebra Mussel Filter Systems, Inc.) was more difficult to deploy due to its large size and cumbersome shape. More than one person would be needed to deploy this product from a boat or off a dock. Alternately, and ideally, a diver could be used to install this device. The last two products, device #5 (Z-Ban©) and device #6 (Zebra 12000), both required submersed electrical wiring to operate and would require an electrician. Also, the large size of device #6 and its associated weight made it difficult to put in place. A diver would be required to deploy both devices to preserve their

integrity. These last two systems would require professional assistance.

Except for device #6 (Zebra 12000) all products are readily available in Canada and/or the United States. The units stated as available in the United States could also be purchased in Canada; however, the installation of the units would not be included in these prices (as is presently the case when purchased in the United States). The distribution of these products ranges greatly, however, all are available directly from the manufacturer.

There was a wide range in price for the units tested in this experiment. The prices are provided in Table 1, in Canadian dollars, unless otherwise noted. The cost of the unit is provided, along with the price of the associated consumables. The cost associated with the latter represents an annual operating cost. When evaluating the cost of the unit to determine which product is best suited for their situation, the consumer should evaluate all other factors first. Also, the cost of the associated consumables should be incorporated into the final price, especially where annual costs are encountered.

Table 1. The performance of each device with respect to zebra mussel removal, cost, suspended material, installation, maintenance and availability.

Parameter	# 1	# 2	# 3	# 4	# 5	# 6
						
	Zebra Mussel Filter Systems, Inc.	Aquastan d	Z-Eliminator	Zebra 5000	Z-Ban©	Zebra 12000
Efficacy of zebra mussel removal/elimination						
A. Suspended veligers	80%	73%	0%	87%	90%	NA
B. Settled larvae	97%	97%	100%	100%	100%	NA
Reduction in suspended solids	58%	38%	0%	65%	53%	NA
Maintenance						
A. End of year	Not required	Wash bag	Add chlorine	Replace filters	Replace filters	Wash bag
B. Clogging (#)	0	0	0	3	1	1 (collapse)
Ease of Installation	Moderate	Easy	Easy	Easy	Difficult	Difficult
Availability	US	Canada/U S	US	Canada/U S	US	Prototype
Cost						
A. Unit tested	US \$600-700	\$229	US \$700	\$275	US \$1500	\$725
B. Annual Consumables	US \$0*	\$0	US \$10/chlorine treatment	\$35/set of filters	US \$6/filter	\$0

*US \$350 - for rebuilt unit to replace original