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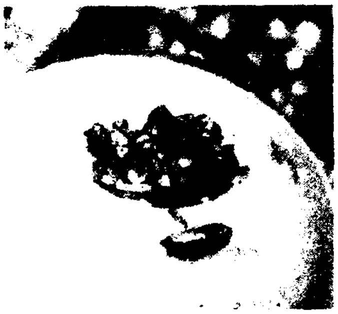

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CONTROL STRATEGIES FOR ZEBRA MUSSEL INFESTATIONS AT PUBLIC FACILITIES

by

Andrew C. Miller, Barry S. Payne

Environmental Laboratory

Frank Neilson

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

and

Robert F. McMahon

Center for Biological Macrofouling Research
University of Texas at Arlington
Arlington, Texas 76019-0498

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U.S. Army Engineer Waterways Experiment Station, Environmental and Hydraulics Laboratories, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199, Center for Biological Macrofouling Research, Box 19498, University of Texas at Arlington, Arlington, TX 76019-0498

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13. ABSTRACT *(Maximum 200 words)*

On September 16-18, 1991, the U.S. Army Corps of Engineers held a meeting in Ft. Mitchell, KY (near Cincinnati, OH), to develop strategies for the detection and control of zebra mussels. More than 50 scientists and engineers prepared a preliminary list of strategies to deal with zebra mussel infestations at public facilities. It was decided that sites where zebra mussel infestations would be most apparent were components of (1) navigation locks (walls, miter gates, filling and emptying control valves, air vents, filling and emptying culverts, trash racks, submerged emergency closure gates, bulkhead slots, raw water fire prevention systems, ice and debris deflector systems, cathodic protection systems, and raw water intakes and plumbing); (2) gated navigation dams (control, tainter and roller gates, lifting cables or chains, seals, and bulkhead slots); and (3) stream gaging stations or other pressure-sensing devices. Problems will probably occur at storage reservoirs if water levels do not fluctuate frequently. Zebra mussel infestations could be associated with discharge control valves or

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gates, air vents, conduit surfaces, trash racks, bulkhead slots, and raw water intakes and plumbing. Storm water pumping stations will probably not be affected unless they are an integral part of the floodwal Closure structures for storm water drainage facilities could be aff they are in a river or navigation pool. Problems could be expected ish racks, control gates or valves, bulkhead slots, pumps, and cooling ems. Preferred strategies were those that relied on physical or chemical means of killing zebra mussels such as steam, hot water, or chlorine. Mechanical means of removal will be required although disposal of a large number of zebra mussels could be an issue if there are concerns over contaminants. Coating surfaces with thermal metallic sprays or other antifouling compounds, use of copper inserts, and oxygen depletion were also discussed.

PREFACE

On September 16-18, 1991, the U.S. Army Corps of Engineers held a meeting in Ft. Mitchell, KY (near Cincinnati, OH), to develop strategies for the detection and control of zebra mussels (*Dreissena polymorpha*). This report contains a summary of the strategies recommended and discussed at that meeting. Items discussed formed the basis of a research program at the U.S. Army Engineer Waterways Experiment Station (WES) to develop environmentally sound methods and strategies to control zebra mussels at public facilities.

This report was written by Dr. Andrew C. Miller, Dr. Barry S. Payne, Environmental Laboratory (EL), WES, Dr. Frank Neilson, Hydraulics Laboratory, WES, and Dr. Robert McMahon, Center for Biological Macrofouling Research at the University of Texas at Arlington. Comments on a draft version of this report were provided by Mr. Glenn Drummond and Mr. Earl Eiker, Headquarters, U.S. Army Corps of Engineers (HQUSACE). The text was based on notes made at the meeting and augmented by information from the literature and knowledge of the authors. Presentors and facilitators at the meeting were: Dr. John Ingram, Dr. Payne, Dr. Neilson, Dr. Miller, and Dr. Edwin Theriot, WES; Mr. Tony Bivins, U.S. Army Engineer District, Nashville; Dr. Robert McMahon, University of Texas at Arlington; and Mr. Glenn Drummond, HQUSACE. Mr. Tim Race, Construction Engineering Research Laboratories, provided information on antifoulant coatings. Mr. Ron Yates, U.S. Army Engineer Division, Ohio River, conceived the idea of having this meeting, prepared the list of attendees, and was instrumental in obtaining funds to hold the meeting. Mr. Bill Rushing, HQUSACE, assisted in obtaining funds and planning the meeting.

During the conduct of this study Dr. John Harrison was Chief, EL, Dr. C. J. Kirby was Chief, Environmental Resources Division, and Dr. Edwin Theriot was Chief, Aquatic Habitat Group, at WES.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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CONTENTS

CONTROL STRATEGIES FOR ZEBRA MUSSEL INFESTATIONS AT PUBLIC FACILITIES

PART I: INTRODUCTION

Background

1. The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Congressional Record--House, 27 October 1990) specified that the Assistant Secretary of the Army, Civil Works, will develop a program of research and technology development for the control of zebra mussels (*Dreissena polymorpha*). As a result of this legislation, the U.S. Army Engineer Waterways Experiment Station (WES), initiated a 4-year program to develop environmentally sound control methods and strategies for this species. Research is directed toward all public facilities along waterways and includes water-ntake plants, navigation locks, gated dams, outlet works, pumping plants, hydroelectric power plants, and drainage structures. The intent of this program is to develop control methods that use mainly physical rather than chemical means to ensure that native biota and potable water supplies will not be negatively affected.

2. Control strategies developed for use by the U.S. Army Corps of Engineers (USACE) will be based on modifying existing operations, maintenance, or design features of the facilities. Nondisruptive procedures that reduce the severity of zebra mussel infestations and decrease costs associated with total shutdown of equipment will be instituted. As part of this program, laboratory studies are being conducted by WES in conjunction with other research organizations to evaluate the tolerance of zebra mussels to desiccation, elevated temperatures, and hypoxia. The biology, physiology, physical condition, and size demography of naturally occurring populations of zebra mussels are being monitored at key sites in major waterways. Field laboratories have been established in the Hudson and Illinois Rivers; and, in 1992, field studies will be initiated in the upper Mississippi River.

Basis for the Research Program

3. In the summer of 1991, just 3 years after they were first collected in Lake St. Clair (Roberts 1990), zebra mussels were found in the Hudson,

Illinois, upper Mississippi, Susquehanna, lower Ohio, Cumberland, and Tennessee Rivers. Because of the number and size of these recently collected organisms, veligers were likely present in these watersheds during the summer of 1990. Mussels are just now becoming large and dense enough to be collected and identified. Within a relatively short time, this species has spread throughout the United States. It is apparent that it will become a serious macrofouler along major waterways in North America.

4. European workers have reported extremely high densities of zebra mussels immediately after introduction to a new habitat (Stanczykowska 1977). Biologists at Detroit Edison reported that zebra mussel densities on an intake screen climbed from 200/sq m in 1988 to 700,000/sq m in 1989 (Roberts 1990). The rapid exploitation of new habitats by *Corbicula fluminea* and *D. polymorpha* has been discussed by Morton (1979) and Mackie et al. (1989), respectively. Therefore, within 10 or 20 years of colonization, densities of zebra mussels in the north-central United States will likely decline as natural predators and diseases begin to act as control agents. Densities of zebra mussels in much of Europe are now much less than densities currently being reported in the Great Lakes region. It is difficult to predict equilibrium densities since European populations are limited by pollution and other water quality factors. The design of the WES research program considered the likelihood of rapid colonization by zebra mussels, extremely high densities within several years, and then a gradual decline to equilibrium conditions. Therefore, quickly testing and applying suitable control strategies to minimize the economic impact of zebra mussel infestations is important. Devoting resources to questionable methods with little chance of success is considered unwise. Commercial and domestic water users, as well as those who depend on the movement of bulk commodities along waterways, will require that some control strategies are in place by 1992 or 1993.

A Meeting to Develop Strategies for Zebra Mussel Control at Public Facilities

5. On September 16-18, 1991, the USACE held a planning meeting on zebra mussels in Ft. Mitchell, KY (near Cincinnati, OH) (see Appendix A). Over 50 scientists and engineers (see Appendix B) with experience in the design, operation, and maintenance of locks, dams, reservoirs, and other public facilities attended. The purpose was to identify facilities and their structural

components likely to be negatively affected by zebra mussels. In addition, attendees prepared a preliminary list of strategies to deal with zebra mussel infestations. A major purpose of the WES research on zebra mussels will be to evaluate the suitability of these strategies at demonstration sites and field laboratories. Meeting attendees were shown an example of a matrix (see Appendix C) to serve as a basis for categorizing public facilities, their structural components, and suitable control strategies. The matrix was developed prior to the meeting by WES personnel and was based on an approach used successfully by Ontario Hydro. In addition, meeting attendees were given a list of public facilities of concern (Appendix D). These materials were given to attendees to assist with development and organization of ideas. This report contains the strategies formulated at the meeting.

PART II: NAVIGATION LOCKS AND ASSOCIATED STRUCTURES

Miter Gates on Navigation Locks

6. Miter gates, which seal the chamber for lockages, will probably be susceptible to zebra mussel infestation. Alternate types of gates (such as one-, two-, and three-leaf submersible lift gates) are used at many projects. Miter gates are on the upriver and downriver portions of a lock chamber. When the gates are fully opened (so vessels can enter or leave the chamber), they are recessed into the wall. The upstream miter gates open outward, but the downstream gates open into the chamber. The gates can be operated directly by a speed-reduced electrical motor or by a system that uses an electrical motor to drive a hydraulic pump, piston, and gear assembly. Water level differentials on both sides of the gate must be measured within a few centimeters; otherwise, the overfill cannot be controlled, and the gate could be subject to excessively high reverse loading.

Detecting infestations

7. An early warning of the presence of zebra mussels can be obtained by placing appropriate test substrates immediately outside a lock chamber. Although concrete blocks attached to a rope or cable can be used, polyvinyl chloride (PVC) plates are recommended since recently settled zebra mussels can be more quickly spotted or felt on a smooth surface (Marsden 1991). A section of PVC pipe, weighted on one end if necessary, can be secured to a wall. The pipe has an advantage of sampling a continuous water depth. Test surfaces should be placed in areas with moderate currents (0.5 to 0.7 m/sec) and well-oxygenated water (70 to 100 percent air oxygen saturation).

8. Test surfaces should be examined at least once a week when temperatures are greater than 12 °C. Recently settled larvae are so small (<1 mm) that they cannot be seen, although they can often be identified by touch. Attached zebra mussels can be scraped off the test surface and preserved in 5 percent formalin (or 70 percent ethyl alcohol) for later examination. If zebra mussels are observed through regular inspection, more detailed examination of hard-to-reach surfaces or specific components (such as fire protection systems or intake pipes for sensor devices) should be initiated immediately.

Areas of concern

9. Meeting attendees determined that the following could be caused by zebra mussel infestations on miter gates:

a. Increased metallic corrosion. Increased metallic corrosion under encrusting layers of mussels could lead to increased maintenance or structural damage of the gate.

b. Inability of gates to fully close. Infestations of zebra mussels on the miter seal would result in increased filling time and consequential delays to traffic. Vibration caused by leakage could cause structural damage to gates at high-lift projects.

c. Added weight on the miter gates. A heavy infestation of zebra mussels could strain the hinges of the gates, warp the gate leafs, and interfere with opening and closing.

d. Reduced clearance for fully opened gates. Heavy infestations of zebra mussels could make it impossible for gates to be completely opened and recessed into the chamber wall. In this position it is likely that the exposed gate could be scraped and damaged by moving vessels.

e. Interference with bubbler systems. Many locks have a bubbler system on the gates to disperse ice and other floating debris. Release of air under pressure oxygenates and maintains an ambient velocity even with no hydraulic devices in operation. These conditions are favorable for the development of zebra mussel infestations. The bubbler system for ice control will be used in winter when water temperature is near freezing and dissolved oxygen concentration is at or near saturation. It is unlikely that operation of the bubbler system at that time will be conducive to zebra mussel attachment. If conditions are appropriate, infestations could cause the bubbler system to be inoperable.

f. Increased routine maintenance. Zebra mussel infestations on miter gates will increase the need for inspection, the difficulty of inspection, and the time required for cleaning and other maintenance. For example, corrosion at the submerged pintles is difficult to observe and is likely to be increased by the presence of even a few zebra mussels.

Preventing problem infestations

10. The following techniques were suggested at the meeting to remove or reduce problem levels of zebra mussels on miter gates:

a. Coatings. Metallic surfaces could be thoroughly cleaned and coated with materials that are toxic to zebra mussels such as thermal sprays or copper-based antifoulant paints. The term "thermal spray" refers to a process for applying a metallic coating by either a wire flame spray or two-wire arc process. Any material that can be made into a wire, for example, aluminum, copper, or zinc, can be applied as a thermal spray. Slick-surface coatings that zebra mussels either cannot adhere to, or attach to weakly, could also be used.

b. Physical removal. Zebra mussels could be removed by scraping, brushing, or spraying water at high pressure.

c. Chemical treatment. Meeting attendees felt that chemical treatment is not a suitable control technique at locks in navigable waterways. It is theoretically possible that the chamber could be flooded, sealed, and a toxic material such as chlorine, bromine, or a commercially available biocide could be injected. However, these materials would be difficult and labor-intensive to apply and could negatively affect native biota.

Lock Culverts

11. Large culverts are used to convey water in and out of a lock chamber. Water must move quickly so lockages are not delayed.

Areas of concern

12. Meeting attendees felt that the following problems could result from zebra mussel infestations in lock culverts:

a. Development of unbalanced forces. Many locks have a series of side ports along both sides that convey water into a central chamber. If uneven infestations (causing an uneven distribution of hydraulic roughness) of zebra mussels occur in these ports, it is likely that resulting unbalanced flow distribution could cause unacceptably large oscillations in the chamber. Commercial and recreational vessels in the chamber could be damaged by turbulence.

b. Clogged trash racks. Trash racks could become partially clogged with zebra mussels, shells, and other debris. Flow through the openings would be reduced, and higher velocities would be experienced if infestations occur on coarse-grid trash bars. Many of these screens are not removable and are difficult for divers to reach for cleaning.

c. Fouled bulkhead slots. The slots that allow bulkheads to slide up and down could become fouled with zebra mussels. It is likely that a buildup of zebra mussels along the sill (where the base of the bulkhead rests) could interfere with complete closure, causing leakage.

d. Damaged filling and emptying valves. Zebra mussels could interfere with complete closure of valves. This could cause leakage, and under some conditions, cavitation. If infestations are extremely severe, the weight of zebra mussels on the valves could be a concern.

e. Corrosion. Zebra mussels could encrust metal machinery parts associated with valves and gates. This could result in corrosion and reduced operating efficiency.

f. Blocked air vents. Air vents are provided to improve hydraulic performance and to prevent cavitation damage in high-head structures. Infestations within the vent could reduce the air supply sufficiently to cause surging in the culvert or more serious damage in high-head structures. Furthermore, infestations could cause structural damage to the vent pipe as a consequence of corrosion.

Preventing problem infestations

13. Meeting attendees recommended the following control techniques for lock culverts:

a. Cleaning/coating trash racks. Where trash racks are not easily removed, a diver could clean them manually with a scraper, stiff brush, hot water, or steam. For projects that are not yet operational, these screens should be coated with toxic compounds (zinc or copper thermal spray or paint) to reduce maintenance. There is the possibility that some of these compounds could be applied underwater.

b. Cleaning walls of the culvert. The volume of water in the culvert is usually too large to consider using chlorine or a biocide. A biocide could only be used if the culvert were sealed, the chemical introduced, and time allowed for it to mix and come in contact with zebra mussels. Large culverts could be cleaned by divers using manual scrapers, or scrapers with suction (similar to the vacuum cleaner concept) could be used to move shells to the top of the lock wall. These are now used by Ontario Hydro for removing zebra mussels. At most facilities, the culvert is totally dewatered only rarely, usually every 5 to 10 years. However, if the infestation is sufficiently great to require physical removal, it is likely that other components of the lock would also have to be cleaned. The lock could be dewatered for cleaning. Certain parts of the culvert could then be treated with foul-resistant or biocidal coatings, although these materials might not withstand high-velocity water.

c. Cleaning air vents. Zebra mussels could be removed from air vents by the use of hot water or steam.

Auxiliary Locks

14. On many large navigable waterways, a single 1,200-ft (365.7 m) main lock is used regularly for commercial traffic; an auxiliary lock, usually 600 ft (182.8 m) long, is used irregularly for pleasure craft, small tows, single tugs, and during maintenance for the main lock. Machinery and other equipment on the auxiliary lock could become fouled with zebra mussels during periods of inactivity. Methods for controlling zebra mussels at auxiliary locks would be similar to those recommended for the main lock.

Raw Water Systems

Description

15. Raw water systems associated with navigation locks could be particularly susceptible to infestations if they use untreated raw water. Fire prevention systems will be even more susceptible if some water is being regularly used for other purposes, such as washing equipment. Regularly using a pipe will keep the water aerated and increase the chances of zebra mussels entering and surviving. However, if these systems are truly stagnant, then zebra mussels will not survive because of anoxic conditions and lack of food. Other raw water systems used for cooling equipment or dewatering, besides those used for fire prevention, are also susceptible to zebra mussel infestations.

Preventing problem infestations

16. Meeting attendees suggested the following techniques for dealing with fire prevention and other small-diameter, raw water systems in locks:

a. Ensure that water in the system is truly stagnant. A leaky system may have a high enough flow and a continuous supply of oxygen and food to support a viable population of zebra mussels. Eliminating leakage is a preventative method since zebra mussels cannot survive in stagnant water.

b. Install screens. Screens can be installed at the entrance to intake pipes or other easy-to-reach areas within the system. Screens should be checked periodically and cleaned or replaced. Zebra mussel veligers are very small, between 40 and 290 μ long, and cannot be removed by conventional screens. Veligers that pass through a screen have the potential to attach and mature in the piping downstream with the most abundant populations being near the intake. The downstream side of a screen often provides a much more suitable habitat for zebra mussels than the anoxic pipe farther downstream. Adult and juvenile zebra mussels can be restricted by screens. Screens will prevent adults from entering and fouling small-diameter downstream components, such as heat exchangers or fire protection systems.

c. Backwash the system. Many systems can be modified so that the piping and screens can be backwashed regularly. The backwash cycle can be designed to engage automatically for several minutes prior to activating the system.

d. Avoid the use of raw water in fire prevention systems. City or well water (chlorinated or isolated sources) are examples of water either toxic to mussels or devoid of zebra mussels.

e. Periodically treat with chemicals. A suitable quantity of chlorine or biocide could be injected into raw water systems. The system would then be sealed for a specific period of time (24 to 48 hr). The water in the system must then be treated to remove toxicants (McMahon 1990). When the water is no longer toxic, it could be disposed of using normal procedures. Shells of dead mussels can foul downstream components; in-line strainers can keep the downstream components from being clogged.

f. Use mechanical pigs. Mechanical in-line scrapers, known as pigs, propelled by gas or fluid pressures within various-sized pipes, can be used to remove zebra mussel infestations from specific lines. These are useful for all but extreme infestations such as total occlusions of a pipe.

g. Inject steam or hot water. Steam or hot water can be injected into part or all of the fire control systems periodically to kill zebra mussels. Zebra mussels are only moderately tolerant of elevated water temperatures. Exposure to 32.5 °C for 5 hr is lethal (Jenner 1983, Jenner and Janssen-Mommen 1989). This temperature is low enough to be obtainable often with minor modification. As part of this process, or as a separate control method, the system could be completely drained and exposed to the air for 7 to 10 days at temperatures above 15 °C. Any of these methods will kill adult and larval zebra mussels. When the system is reactivated, the released shells of dead mussels could be carried downstream and become lodged in nozzles and valves. In these cases, selected sections of pipes would have to be removed, cleaned, and then replaced. In-line strainers could be used to prevent fouling of downstream components by dead shells.

h. Replace existing pipe with galvanized or copper pipe. Zinc and copper are toxic to zebra mussels and will eliminate infestations. All or selected sections of standard iron or PVC pipe could be replaced with galvanized or copper pipe.

Gaging Systems Associated With Lock Operations

17. Many new locks, for example, the Melvin Price Locks and Dam on the Mississippi River near Alton, Illinois, use piezometric gages to measure water pressure for lock operation. They require small-diameter raw water lines which connect to sensor equipment. Meeting attendees suggested the following techniques for dealing with problems associated with these systems:

a. Localized chlorine treatment. A small quantity of chlorine, to maintain a concentration of 0.5 mg/ℓ, could be introduced into the downstream end (a small reservoir or well that is accessible from the lock wall) of the system. The chlorine could be further dispersed with water from a small-diameter hose or other physical methods. The chlorine must reach the submerged, small-diameter piezometer tap. During the growing season, when water temperatures are above 12 °C, lines could be treated every 3 weeks.

b. <u>Heating elements.</u> Heater strips, such as those used to keep unprotected water pipes from freezing, could be used to raise temperatures within the gages to levels high enough (>33 °C) to kill adult and immature zebra mussels. Care must be taken to ensure that sensitive equipment is not damaged.

PART III: GATED NAVIGATION DAMS

18. Gated dams provide a means of regulating water level in retained navigation pools through a wide range of flow. There are many types of regulating gates, but the most common encountered on the inland-waterway system are tainter and roller gates. Wicket gates are used when a navigable route is needed to bypass a lock during high-flow. The gates, gate seals, and lifting equipment are all susceptible to infestation.

Areas of Concern

19. The following are areas of concern with respect to gated dams:

a. Damage to side seals. Seals on dams are located along the sides to prevent leakage. Zebra mussels could adhere to rubber surfaces and, since water is flowing and well-oxygenated, colonize the seals. Zebra mussel infestations on side seals could prevent sealing, and overstress or otherwise damage the material during operation. For example, lifting the gate after it has been closed and infested could tear, dislodge, and destroy the seal.

b. Poor sealing of submersible gates. An infestation on the sides and bottom of gates could cause poor sealing, leakage, or vibration. The gate sill could become fouled with zebra mussels.

c. Increased weight on gates. Zebra mussels could increase the weight of a gate making it difficult to move. The added weight that can be lifted by existing equipment (hoists or electric motors) would have to be determined.

d. Problems on gate interiors. Zebra mussel larvae could enter the interior of the gate and then grow to adult size. They could cause corrosion as well as problems with sealing, increased weight, or unequal weight distribution.

e. Clogging of drains. Small drains associated with submersible gates could become clogged with zebra mussels and their shells.

f. Fouling of roller gates. The tracks that roller gates move on, as well as the chains or wire ropes that are used to lift them, could become fouled with adult zebra mussels. This could result in corrosion or cause the chain or wire rope to separate from the pulley wheels.

g. Debris accumulation on pier nose. Accumulation of debris and ice on the nose of the pier may be increased because of attached zebra mussels.

h. Fouled wickets. Structures associated with wickets could become fouled with zebra mussels. Lifting eyes and piston rods could become too heavy to lift, or held in place by byssal threads.

i. Clogged weep holes. Weep holes, which are small holes for drainage, could become clogged by zebra mussels.

Preventing Problem Infestations

20. The following were suggested control mechanisms for gated dams:

a. Use of coatings and paints. Exposed surfaces of gates, pulleys, and sills could be coated with antifouling compounds. Care should be taken to ensure that these compounds are not removed during normal operation.

b. Use of chain and wire rope. Zebra mussels will not attach to a chain or wire rope that is covered with grease. Where infestations are likely to be a problem, a scraper can be installed that will remove encrustations before the chain or rope reaches the pulley. Frequent use of the pulley could remove zebra mussels before the buildup becomes too severe. If necessary, manual scraping, hot water, or steam could be used to remove zebra mussels.

c. Cleaning/coating of seals. Manual cleaning may be one of the best methods for dealing with zebra mussels on seals. Coating the seal with grease would discourage zebra mussels.

d. Cleaning/coating of wickets. As with the seals, manual cleaning could be one of the best methods. A steam wand can be used to clean the underside. Antifouling coatings could be applied to help reduce the need for regular cleaning.

PART IV: RESERVOIR OUTLET WORKS

21. Outlet works are the concrete structures and associated components required to regulate water levels at reservoirs. Zebra mussels will probably be a problem in reservoirs in northern and central United States, where water levels are fairly stable. It is possible that zebra mussels will also be a problem in reservoirs in Arkansas, Tennessee, and north Mississippi. Zebra mussels are usually found in littoral zones and are not likely to survive if they are repeatedly exposed to the atmosphere. Large fluctuations do not occur every year in flood-control reservoirs, although seasonal drawdown will eliminate zebra mussels in shallow-water zones. Since zebra mussels are usually confined to the epilimnion (Mackie et al. 1989), structures that remove water from the hypolimnion should be unaffected. However, control mechanisms such as cables, rods, and stem guides could become fouled if the deep-level outlet is controlled through a wet well.

Areas of Concern

22. The following components are likely to be affected by zebra mussels:

a. Trash booms. These are placed upstream of an outlet works for safety purposes and to collect logs and other trash. Zebra mussels could cover the trash boom and, if sufficiently heavy, cause it to sink.

b. Trash rack. The trash racks could become clogged with zebra mussels. If these became clogged or partially clogged, it would be difficult to regulate water level.

c. Bulkheads. Bulkheads associated with reservoir outlet works are smaller and, consequently, lighter than those used in locks and dams. Infestations of zebra mussels in the guides could prevent placement of the bulkhead or binding that could prevent removal. Accumulation of shell debris at the bottom of the guides could prevent the bulkhead from fully closing. Failure of maintenance bulkheads could prevent removal of zebra mussels from other components of the outlet works.

d. Gates. Many types of gates, operated either hydraulically or with cables, are used at reservoirs. Zebra mussels could cause corrosion of cables and components and lead to equipment malfunctions. The additional weight caused by zebra mussels could stress existing machinery. Cavitation could occur if zebra mussels lodge in slots and gates cannot close properly.

e. Conduit. The conduit is the water passage that conveys reservoir release past the dam. That portion of the conduit upstream of the control gate is always full of water and is susceptible to infestations. The consequence would be increased roughness of the walls and possible corrosion to the steel liner. Problems are not likely to develop downstream of the control gate because of high velocity during ordinary operating conditions.

f. Water quality wet wells. Water quality outlets can consist of multiple intakes in a common wet well riser through a control gate located at the bottom or multiple pipes or conduits through the dam or outlet works structure. Zebra mussel infestations could restrict flow through the intake trash rack, wet well, or interfere with operation of intake and control gates. Corrosion could damage metal components.

Preventing Problem Infestations

23. All of the previously described control strategies suitable for gated dams or conduits associated with locks would apply to reservoir outlet structures.

PART V: PUMPING STATIONS AND DRAINAGE STRUCTURES

Stormwater Pumping Stations

Description

24. Pumping stations are used to move water over or through a levee and into a river, upper end of a reservoir, or canal that leads to a river. Pumping stations are needed to remove standing water from land that is used for agricultural, commercial, or domestic purposes. These stations are usually on the landward side of the levee. A pumping station can be dry for months at a time, although certain pumping stations operate continuously.

Detection and control

25. If pumping stations are in stagnant water for long periods of time, zebra mussels will not survive. Zebra mussels will tolerate water with only 40 to 50 percent air oxygen saturation during the summer and near zero air oxygen saturation during the winter (Mackie et al. 1989, McMahon and Tsou 1990). Most storm water pumping stations should not experience zebra mussel infestations because they are separated from flowing water. However, a number of stations are an integral part of a floodwall or are located at the mouth of a larger tributary where there is frequent exchange of water from the receiving river.

26. Although zebra mussel larvae are motile, they usually only move vertically, not horizontally, and do not have the ability to move long distances along a pipe if there are no currents. Zebra mussels could attach to pump suction bells, or impellers if the pump is submerged in water that has free exchange with an infested river. Zebra mussels will probably not attach to blades of a large pump when it is operating.

27. If a discharge line runs over a levee, flap gates are installed on the outlet end to prevent drift or other debris from obstructing the opening. Other types of stations will discharge into a gate shaft connected to a gravity drain through a levee or directly through a floodwall. In the latter instance, the discharge line and outlet could be below the normal level of the receiving water. If the flap gate or other control gate became fouled and prevented from closing, water could enter protected areas at high river stages.

28. Zebra mussels could be removed from the flap gate and adjacent piping by brushing or scraping. Surfaces could also be coated with

antifoulant or toxic compounds or outfitted with copper or zinc inserts to reduce maintenance. During inspections, the suction bell should be checked, especially if it has been under water for more than several weeks. The sump walls should also be cleaned of shells and associated material. If an encrustation of zebra mussels is found on the impeller, the shaft and bearings should be inspected for damage caused by vibration and wobble.

Drainage Structures

29. Drainage structures include conduits or pipes through floodwalls and levees, the mechanism that controls flow, and other diversion control structures that carry water from a pumping plant or another waterway. Stop logs are susceptible to zebra mussel infestations as are inflatable dams associated with drainage structures or as part of habitat improvement on small streams. If inflatable dams are in operation for less than 2 months, zebra mussel infestations would probably be minor. As described previously, trash booms and culverts, especially those experiencing continuous base flow, could be affected by zebra mussels.

PART VI: HYDROPOWER FACILITIES

Background

30. The USACE is one of the largest operators of hydropower facilities in the United States. In the Nashville District approximately $30 million in revenue was returned to the United States treasury in 1990 from power generation.

Preventing Problem Infestations

31. Many of the structural components and possible solutions to zebra mussel infestations discussed above would apply to hydropower facilities. A unique feature of hydropower facilities is that water is used not only to move turbines and generate power, but also to cool electrical components and bearings. In addition, many power facilities operate intermittently; these peak power stations would be particularly susceptible. When they temporarily shut down, larvae could settle and become established. When the plant is operating, the water becomes oxygenated, and conditions will be more suitable for zebra mussels.

32. Control of zebra mussels in hydroelectric facilities is being developed both in Canada (Ontario Hydro) and the United States (Electric Power Research Institute). The USACE will adopt the most efficacious control strategies developed by these groups. Possible solutions include placing settlement screens in front of openings, thermal controls, molluscicides, manual cleaning, foul-resistant and toxic coatings, and frequent operation of all units.

PART VII: OTHER FACILITIES OF CONCERN

Gaging Systems Along Small Streams

Description

33. The USACE depends upon stage height data from rivers and streams to compute discharge and predict water levels throughout a watershed. This information is required to regulate dam operation on navigable and nonnavigable waterways. Possible control methods for these gaging stations could be similar to those previously suggested for water level sensing systems on locks. Appropriate control strategies for these gaging systems should be developed in cooperation with the U.S. Geological Survey.

Preventing problem infestations

34. The following strategies, in addition to those already described for lock gages, could be used to protect stream gaging stations:

a. Use of protective coating. Antifouling paints or thermal metallic sprays could be used to protect against buildup of zebra mussels on exposed surfaces.

b. Use of galvanized or copper pipe. Certain parts of the gaging station could be rebuilt with pipes that are resistant to zebra mussels. Copper or zinc inserts can be placed at the upstream end of pipes.

Cathodic Protection Systems

35. Cathodic protection systems are installed on metallic surfaces subject to corrosion such as miter gates. If zebra mussels adhere to the anodes of these devices, their ability to control corrosion is reduced. This has not been a problem in most power plants with zebra mussel infestations along the Great Lakes since these waters are noncorrosive. One possible solution would be to use anodes made from zinc, which is toxic to zebra mussels.

Navigation Aids

36. Buoys and mooring bitts can become inoperable because of the weight of attached mussels. Whenever these devices move in slots or use rollers, infestations could cause them to become inoperable. The combination of the water velocity, added resistance, and weight could cause a buoy to sink.

PART VIII: FUTURE CONSIDERATIONS

Disposal of Zebra Mussels

37. It could be difficult to find appropriate areas to dispose of large quantities of zebra mussels from a lock, dam, or other facility. Large volumes of zebra mussels should not be disposed of in a waterway. If they are to be disposed in a river, a National Pollutant Discharge Elimination System Permit, not a 404 Permit (zebra mussels should not be considered dredged material), would be required. Comparatively small numbers of zebra mussels that are scraped from underwater surfaces can be left in the water where they will eventually wash away. Landfill operators might not accept large amounts of zebra mussels because of odor. Under some conditions it could be possible to hold zebra mussels until the odor dissipates and then take them to a landfill.

Need for Innovative Procedures

38. The USACE, as well as those who design, maintain, and operate facilities along waterways, must be prepared to use innovative procedures to reduce interruptions in services and, ultimately, costs associated with zebra mussel infestations. For example, it appears that the specifications for types and application methods for painting surfaces will have to be amended. In areas that cannot be easily painted, consideration should be given to the use of copper inserts. The use of "dummy equipment" should be investigated. A false bulkhead with wedges, or water jets, could be lowered to prevent zebra mussel settlement. The Europeans frequently use disposable substrates to protect water intakes and pipes that are difficult to clean. These could include netting, hemp ropes, or PVC pipes that preferentially attract zebra mussels before they settle downstream. These substrates could be removed and disposed of when necessary. If their presence reduces maintenance requirements by even modest amounts (10 or 20 percent), their use would probably be justified.

Beneficial Uses of Zebra Mussels

39. Although this was not discussed in detail at the workshop, it is apparent that zebra mussels, like dredged material, can have some commercial

value. These beneficial uses, when fully evaluated, could be implemented to reduce the cost associated with disposal. It is possible that zebra mussels could be used as fertilizers, sources of calcium carbonate, or fill material. Reeders and de Vaate (1990) and Wisniewski (1990) describe the ability of zebra mussels as clarifiers of lake water and their possible use in biomanagement projects.

PART IX: CONCLUSION

40. The introduction and spread of zebra mussels in North America has captured the attention of the public more than all environmental issues of the past 30 years combined. Unlike the situation in much of Europe where zebra mussels have existed since the Industrial Revolution, equipment and facilities in North America were not designed to deal with this invasive pest. Unless preventative measures are initiated immediately, the possibility of temporary power outages, difficulties in obtaining water for cooling and waste removal, and interruption in the flow of bulk commodities exists. It is not likely that scientists and engineers will find one type of chemical, or one piece of equipment to rid navigable waterways of zebra mussels. A variety of methods and strategies will be needed to deal with this problem. Redesigning some facilities, purchasing and using new types of cleaning equipment, judiciously applying chemicals when needed, and investigating the use of coatings and sprays are all possible solutions.

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APPENDIX A: MEETING AGENDA

STRATEGIES FOR THE ENVIRONMENTALLY SOUND CONTROL OF ZEBRA MUSSELS AT PUBLIC FACILITIES

Commonwealth Hilton Hotel
I-75 and Turfway Road, Ft. Mitchell, KY (Cincinnati Area)
16-18 September 1991

Session I: Introduction to the Problem

16 September

1300-1315	Welcome - Mr. Ron Yates, ORD
1315-1330	Introductions - All
1330-1345	Introduction and spread of zebra mussels in North America - Dr. Andrew Miller, WES
1345-1400	Legislation pertaining to zebra mussels - Dr. Ed Theriot, WES
1400-1415	Break
1415-1445	Development of strategies for the control of zebra mussels - Dr. Andrew Miller, WES
1445-1515	Biology and ecology of zebra mussels - Dr. Barry Payne, WES
1515-1545	Appropriate control methods for zebra mussels - Dr. Robert McMahon, Center for Biological Macrofouling Research, University of Texas, Arlington, Texas
1545-1600	Break
1600-1615	Recent experiences with zebra mussels in the Buffalo District - Mr. Frank Lewandowski, NCB
1615-1630	Zebra mussels at the Melvin Price Locks and Dam - Mike Kruckeberg and Billy Arthur, LMS
1630-1700	Identification of public facilities and associated structural components likely to be affected by zebra mussels - All
1630	Adjourn

Session II: Developing Environmentally Sound Control Strategies

17 September

0800-0815	Introductory Comments
0815-0930	Miter Gates on Locks - Dr. Frank Neilson, WES
0930-1000	Break
1000-1130	Gaging Structures, Fire Protection Systems, Cathodic Protection Systems - Dr. Frank Neilson, WES
1130-1300	Lunch

17 September (Continued)

1300-1400	Culverts - Mr. Glenn Drummond, OCE
1400-1430	Break
1430-1530	Navigation (Gated) Dams
1530-1600	Break
1600-1700	Reservoir Outlet Works - Mr. Glenn Drummond, OCE
1700	Adjourn

Session III: Summary and Conclusions

18 September

0800-0845	Pumping Stations - Dr. John Ingram, WES
0845-0900	Break
0900-0945	Drainage Structures - Dr. John Ingram, WES
0945-1000	Break
1000-1100	Discussion of Innovative Methods for Zebra Mussel Control, Sites for Future Meetings, Summary of WES Research on Zebra Mussels - Dr. Andrew C. Miller
1100-1115	Concluding Comments - All
1115	Adjourn

APPENDIX B: MEETING ATTENDEES

STRATEGIES FOR THE ENVIRONMENTALLY SOUND CONTROL OF ZEBRA MUSSELS AT PUBLIC FACILITIES

Commonwealth Hilton Hotel
I-75 and Turfway Road, Ft. Mitchell, KY (Cincinnati Area)
16-18 September 1991

List of Attendees

Name	Office	Telephone
Arthur, Billy	CELMS-ED-H	314/331-8333
Barrett, Daniel H.	CEORL-OR-R	606/666-8828
Bartelt, Gordon	CESWL-ED-HH	501/324-5442
Beatty, David	CEORL-ED	502/582-6740
Bhamidipaty, Surya	CEORH-ED-H	304/529-5606
Bivens, Tony	CEORN-OR-H	615/736-5863
Buelow, Dave	CEORD-PE-WW	513/684-3070
Collier, Mike	CESAM-OP-OE	205/690-3259
Drummond, Glen	CECW-EH-D	202/272-8502
Enterline, Tim	CEORH-OR-M	304/529-5448
Fowles, Mike	CEORP-OR-RL-L	412/639-3895
Freitag, Thomas	CENCE-PD-EA	313/226-6753
Gawarecki, Ed	CENCD-CO-OS	716/879-4293
Hannel, Wayne	CENCR-OD-SP	309/788-6361 (x6378)
Homborg, Roland	CENCS-CO-PO	612/220-0328
Houston, Len	CENAN-PL-ES	212/264-1275
Hoy, Doug	CENCS-ED-D	612/220-0525
Ingram, John	CEWES-EE-R	601/634-3048
Juhle, Pete	CECW-EH-W	202/272-8512
Kidby, Mike	CECW-OD	202/272-8839
Kinsel, Bob	CECW-EE	202/272-8616
Kruckeberg, Mike	CELMS-OD-NL	314/331-8588
Lapsley, Jim	CEORL-ED-D	502/582-5725
Lewandowski, Fran	CENCB-PE-SD	716/879-5454
McClellan, Gordon	CEORN-EP-D	615/736-5023
McMahon, Robert	UT, Arlington	817/273-2412
Miller, Andrew	CEWES-ER-A	601/634-2141
Neilson, Frank	CEWES-HS-H	601/634-2615

Name	Office	Telephone
Payne, Barry	CEWES-ER-A	601/634-3837
Peterson, Tim	CENCS-PD	612/220-0274
Pfeffer, Tom	CEMRD-CO-O	402/221-7289
Pickering, Glen	CEWES-HS	601/634-3343
Pletka, Joe	CEMRD-EP-TM	402/221-7313
Race, Tim	CERL-EMC	217/373-6769
Randolph, Billy D.	CEORH-OR-R	304/529-5613
Reuter, Claire	CENCD-CO-O	312/353-6375
Richardson, Lyn	CEORD-PE-WD	513/684-3035
Riley, Bruce C.	CEORP-ED-DS	412/644-4065
Roper, Bill	CERD-C	202/272-0257
Russell, Steve	CENCR-OD-MS	309/788-6361 (x6401)
Schliekelman, John	CENCR-HH	309/788-6361
Seals, Larry	CEORD-PE-TS	513/684-3034
Simpson, Maurice	CEORN-OR-R	615/736-5868
Sirak, John J., Jr.	CEORD-CO-OM	513/684-3418
Stewart, Henry	CENCD-ED-TT	312/886-2850
Szm, Chester	CENCC-ED	312/353-8465
Tar, Paul	CECW-ED	202/272-8671
Theriot, Ed	CEWES-ER	601/634-2678
Thomas, Claudy	CEORD-EW-D	513/684-3017
Vento, John	CENCD-PE-ED-T	312/353-2579
Willis, Bob	CEORL-OR-M	502/582-5600
Woods, Rodney	CEORD-CO-OF	513/684-6212
Yates, Ronald	CEORD-PE-W	513/684-3071

APPENDIX C: EXAMPLE MATRIX

ZEBRA MUSSEL CONTROL STRATEGIES FOR PUBLIC FACILITIES

Sheet___of_____

Date:_________________ **Location:**____

Participants:____

Facility of Concern:____

Structural Component:____

Potential Problem	Recommended Strategy*

*** Items for consideration:**

1. **Early detection**
2. **Prevent problem infestation**
3. **Reduce to nonproblem level**
4. **Design options (new or existing structures)**
5. **Season avoidance**
6. **Other considerations**

APPENDIX D: FACILITIES AND STRUCTURES LIKELY TO BE AFFECTED BY ZEBRA MUSSELS

Navigation (Gated) Locks

Chamber walls

Water intakes

Filling and emptying valves

Culvert walls

Lower and upper approaches (including navigation buoys)

Upper gates

Lower gates

Emergency closure

Navigation aids

Dewatering equipment (including bulkhead slots)

Monitoring equipment

Mooring bits

Ladders

Piping (including raw water facilities such as those used for fire protection)

Grating and screening

Navigation Dams

Control gates (opening and closing, as well as seals and crests)

Navigation pass (wickets and sills)

Dewatering and emergency closure

Maintenance equipment

Monitoring equipment

Reservoirs and Outlet Works

Spillways (crest, gates, and energy dissipaters)

Conduits (intakes, screens, emergency and regulating valves, and energy dissipaters)

Emergency closures and dewatering valves

Water quality release works (valves and monitoring equipment)

Associated recreation areas (docks, boat ramps, floating structures, beaches, and swimming areas)

Pumping Plants

Approach (trash racks, approach walls, and chamber)

Pump (propellers, propeller shafts, and suction bell)

Delivery line

Dewatering equipment

Monitoring equipment

Drainage Structures

Gaging Stations (staff gates, float gates, and bubble gages)

Flood walls and gates

Flap gates

Debris control structures

Grade control structures

Flow control and water level control structures (stop logs and rubber dams)

Hydropower

Turbines

Water distribution systems

Waterways Experiment Station Cataloging-in-Publication Data

Control strategies for zebra mussel infestations at public facilities / by Andrew C. Miller ... [et al] ; prepared for Department of the Army, US Army Corps of Engineers.
34 p. : ill. ; 28 cm. — (Technical report ; EL-92-25)
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TA7 W34 no.EL-92-25