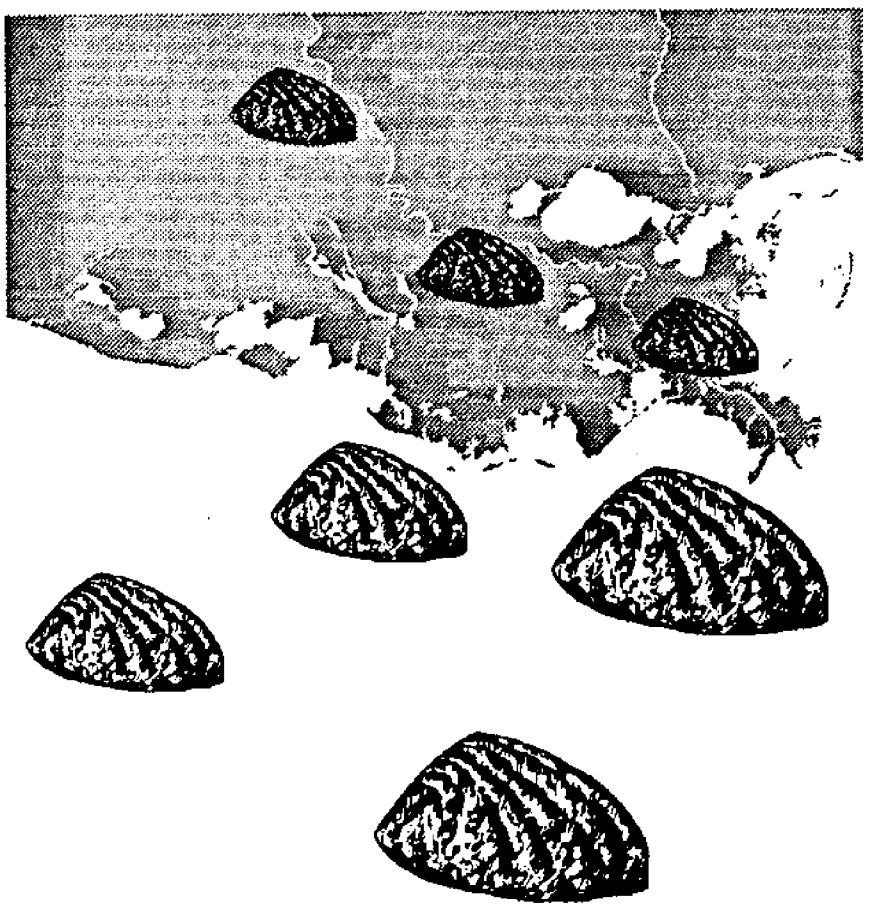
Summary of Proceedings of the Lower Mississippi Valley Zebra Mussel Information & Monitoring Workshop



SUMMARY OF PROCEEDINGS OF THE LOWER MISSISSIPPI VALLEY ZEBRA MUSSEL INFORMATION AND MONITORING WORKSHOP

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ABOUT THESE PROCEEDINGS:

Most of the presentations during the Lower Mississippi Zebra Mussel Information and Monitoring Workshop were accompanied by slides or other visual aids to further explain major points. Because these are not included in the proceedings, an exact transcription of the presentations would be incomplete or of reduced use to attendees. Therefore, this document contains summarized and condensed presentations designed to clarify the information for the reader. A copy of these summarized remarks was submitted to each presenter for approval before publication. All presenters except Charles O'Neill and Robert McMahon made final adjustments to the summarized text prior to publication. A list of attendees and presenters is included in this packet to facilitate direct contact.

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CONTROL STRATEGIES AND OPTIONS

INTRODUCTION AND RANGE EXPANSION OF THE ZEBRA MUSSEL IN NORTH AMERICA

Charles O'Neill, New York Sea Grant

We have been involved with zebra mussels in the Great Lakes since late 1988. This two-day workshop covers just about everything to do with the zebra mussel. We now know that we have two species in North America, *Dreissena polymorpha* , the zebra mussel, and *Dreissena bugensis*, which you may sometimes hear referred to as the false mussel or quagga mussel. In this workshop, we'll be talking about the introduction, the spread, the biology, and the ecology of the zebra mussel. We'll be talking about both infrastructure impacts and other impacts, how to monitor for zebra mussels, and how to control them.

Now that the zebra mussel has come into North American waters, we're finding not only that it affects one or two uses of surface water, but we are having a hard time identifying any uses of fresh surface water that aren't affected by the zebra mussel. If they get into your intakes or pipelines, you will feel that you have pretty much been muscled out of your uses of water as well.

For those of you who have never seen a zebra mussel, they are not particularly bizarre or threatening. The earliest mussels we saw typically had a herringbone striped pattern through the shell, although they can have a variety of colors and striping. Some coloring is almost all black, some almost all white. Some have a single stripe, which looks like a racing stripe. In Europe, these may be limited to one waterway or one drainage basin only. In North America, these have all been collected in the Great Lakes Region.

When you are looking for zebra mussels, you will not look for a large mussel. You will look for small mussels and also for things that may be the size of a head of a pin. Or if you are heavily monitoring, you'll be looking for their larvae, microscopic in size. You will get more information on that in a later session.

The zebra mussel's European range basically is the area around the Ural Mountains and the Caspian Sea in eastern Europe and western former Soviet Union. They spread across Europe around 200 years ago. Since they have been in Europe for so long, why haven't we learned from the European experience; why don't we know everything about them and how to control them? The first European introductions, in the late 1700s, early 1800s, were well ahead of the Industrial Revolution. In other words, water-using industries in Europe were built with the mussel in mind. However, here in North America, we never had to worry about a large macrofouler aside from *Corbicula* in our fresh surface waters. North American infrastructure is not designed with the mussel in mind, and now we must catch up.

We do not have a date when the zebra mussel was actually dropped off in North America, but we can deduct by its size when it was found in Lake St. Clair in June 1988, that the zebra mussels were probably dropped off sometime in mid 1986. We are pretty sure that they came to North America in fresh water ballast water from international ships originating at fresh water ports in Europe and the Soviet Union. These ships were likely traveling through the St. Lawrence Seaway

and the Great Lakes. Now some people think this group in Lake St. Clair was the first population in North America, however, there is probably a very good chance that there were other ones dropped off throughout the Great Lakes around the same time.

How does this happen? Many vessels enter the Great Lakes, and ships can hold up to 10 million gallons of ballast water. They come into the Great Lakes typically low on cargo, and start pumping out their ballast. Since approximately 240 different plant and animal life forms can live in fresh water ballast water, the zebra mussel was probably just one of many life forms in these ships' ballasts.

We expected a combination of both natural and human influence dispersal vectors to carry the mussels throughout the Great Lakes, and then into other fresh water in North America. But we didn't expect the speed with which the zebra mussel got out of the Great Lakes drainage basin and into other basins. This means that the human vector was very active in zebra mussel migration.

One year after the Lake St. Clair discovery, June 1989, virtually all of Lake St. Clair, which is basically a shallow rocky-bottomed warm water pond of Lake Erie, and the western basin of Lake Erie were pretty well infested with counts of about 5-7,000 zebra mussels per square meter of bottom. Six months later, January 1990, most of the shoreline of Lake Erie had zebra mussels, and they had also been sighted off the western basin of Lake Ontario near the mouth of the Niagara River. By January 1991, all of Lake Erie, most of the south shore of Lake Ontario, parts of the St. Lawrence River, Ottawa, and some places in the other Great Lakes, as well as in Lake Superior at Duluth-Superior Harbor had confirmed the presence of zebra mussels. These were probably transported on the outside or the inside of lake vessels, or possibly some were dropped off along the way earlier at the same time as those in Lake St. Clair.

In New York State, we have the dubious distinction of being the first place zebra mussels showed up outside of the Great Lakes drainage basin. They got into the Erie Canal in Buffalo (which is flooded with Lake Erie water) and spread eastward across New York State out of the drainage basin. By 1992, the mussels were in most of Lake Ontario, the Erie Canal, the Mohawk River, and down the Hudson River. Through the Chicago diversion, they started down the Illinois River and into the Mississippi River System, as well as up into part of the Tennessee River System.

January 1993, the density or number of locations increased in the Great Lakes and the Mississippi River System. They have now somehow migrated north to St. Paul, Minnesota, most likely because of barge and boat traffic. They are also throughout the Tennessee River System and down the Mississippi into the area of Greenville. We have found them in an up-current migration pattern on the Ohio River toward Pennsylvania. This would indicate that they are not limited to the natural currents. In January 1994 the mussels were confirmed in Tulsa, Oklahoma, on the Arkansas River. They were also confirmed all the way down to the Atchafalaya River in south Louisiana, and they have also made it down the Mississippi to New Orleans. We see them in Michigan and inland New York, and a few sightings in Ohio area.

We never expected to see them in these locations this rapidly. I want to emphasize that as far as aquatic introductions go, the zebra mussel has been transported throughout North America much

more rapidly than normal expectations, and mainly through human intervention.

We now have zebra mussels showing up on inland lakes that are not hydraulically connected to any of those other infested water bodies. We suspect that this is due to boat traffic on trailers. Zebra mussels can live for a certain amount of time out of water and can be transported on the hulls or in other parts of recreational boats.

To give you an idea of how fast the zebra mussels spread, lets take a look at the saga of barge GMT211B. When this barge was dry-docked in Hartford, Illinois, in April 1992, they found about 1,000 live zebra mussels on the bottom and sides of the barge. The mean shell length was about 17 mm per mussel. This gave us a pretty good opportunity to try and back date how that operated. Looking at that mussel size and looking at a growth rate of 1-1.5 cm per year, we were able to say these mussels were probably around a year old. Where was the barge the previous year when it could have gotten infested? It was probably around Spring Valley, Illinois, in the Illinois River. Between that time and the time it was dry-docked, GMT211B covered about 15,800 km of the Mississippi drainage system up and down various rivers, and this is only one barge. When we look at the Tennessee River System, the Arkansas River System, and a lot of other areas, we find the first mussels are showing up in lock and dam structures for commercial navigation. You talk about Typhoid Mary; this is probably the same thing — call it Zebra Mary.

How far can the mussel spread? Generally most of the U.S. is going to be able to pick up zebra mussels. When? No one can give a possible date.

Probably the North American site with zebra mussels furthest from the Great Lakes is the state of California. About a year ago, they added zebra mussels to their list of prohibited species so that their agriculture inspectors (at the state borders) could inspect trucks, trailers, boats coming into the state on the interstate highways. In November 1993, they found a boat that had dead zebra mussels on the hull, and they impounded it until they could confirm that all were dead. Late November, early December 1994, in the same location, they found zebra mussels on the hull of a large motor yacht being brought into California on a flat bed truck. It had been out of the water for two days, originating from Lake Erie or Lake Michigan. The inspectors pulled it over, kept it there at the location, and sent some of those mussels to their lab. Forty of those mussels turned out to be alive. That boat was heading for salt water, so they allowed it to be launched, assuming that the salt water would kill those mussels. The question is how many boats have traveled out of infested waters to other locations in fresh water systems? How many mussels does it take to reach critical mass to infest those systems? None of us can give you those answers.

RISK ASSESSMENT, DISPERSAL VECTORS, AND "MUSSEL MYTHS"

Dr. Ladd Johnson, University of California

The title of my talk is rather over ambitious given that risk assessments from the study of dispersal in natural populations are some of the most difficult topics with which to deal. But I would like to, at least, let you know what we do know about zebra mussel dispersal, the limitations on that knowledge, and warn you about some pitfalls that can occur by strictly relying on intuition. Finally, I would like to comment on educational programs in relationship to risk assessment and zebra mussel transmission.

Why study zebra mussel dispersal? (1)We can predict the rates and direction of spread which is important to all scientifically, as well as for management purposes. It is important to know when zebra mussels settle in an area and in what directions they are migrating. (2) We can identify the ways in which zebra mussels are transported from place to place. This is important for deciding if actions aimed at preventing dispersal can stop or slow the spread. (3)We can assess the success of existing containment efforts. Often people do what they think is the right thing, and, although, it probably doesn't hurt, it might not help either. Before people allocate scarce resources towards a particular education and intervention program, we should try to implement some way in which we can assess the efficacy of our efforts. (4) We estimate gene flow so we can predict how well a local population will be able to adapt to certain conditions. This might be a concern in the South near the limits of what we know to be the potential range of zebra mussels. (5) Finally, we can also use information on the spread of zebra mussels as a way of developing model systems to compare the dispersal of future aquatic pests. In fact, a current study is trying to use Eurasian water milfoil to predict areas where zebra mussels might migrate, because the milfoil is an exotic species that has preceded the zebra mussels and is dispersed by similar vectors.

There are various ways to contrast dispersal mechanisms. (1)By direction: downstream, upstream, and overland considerations; various vectors and mechanisms of dispersal can act differently in each of these situations. (2) By life stage: adults or larvae, some the mechanisms can selectively move one or the other of the life history stages. (3) By type of mechanism: natural versus human-mediated mechanisms.

Risk and the assessment of risk will depend on the relative importance of different dispersal mechanisms. For example, if zebra mussels are predominantly dispersed by natural means, there is very little we can do about it. Downstream dispersal of zebra mussels in a river would be such a situation. If natural causes lead to fast dispersal over a large area, even if human-mediated causes are also present, there is really no point in trying to slow down the spread of zebra mussels because we are helpless in that regard. However, if natural mechanisms are not fast or at least in some circumstances are not the dominant vector of spread, then we have the option of deciding whether it is worthwhile to try to intervene or to attempt educational efforts.

Known Factors About Zebra Mussel Dispersal

A map of zebra mussel locations in 1993 showed that zebra mussel dispersal seemed to be limited to commercially navigable waters of the Great Lakes and connected waterways and rivers. Basically we have seen a very rapid spread of the zebra mussels through contiguously connected

navigable waterways. The spread has resulted primarily from the natural downstream dispersal of the veliger stage (which is the larval stage of the life cycle in which the animal floats in the water for weeks at a time and can float basically wherever the water goes), and from the downstream and upstream dispersal of the adult state by movement of submerged objects such as commercial barges. From these observations, we have evidence for both natural and human-mediated dispersal, that in combination have lead to both upstream and downstream spread of zegbra mussels.

This suggests, intuitively, that the zebra mussel spread that occurs between connected waterways is probably accelerated by boating and shipping activities. Based on this intuitive idea, we could have done things early on to stop the transmission to the Mississippi River. I don't think politically or commercially it would have been a very good idea, but we could have stopped boat traffic, thereby greatly reducing the transport of zebra mussels between Lake Michigan and the Illinois River. Of course, we didn't. But I don't think zebra mussels would have gotten in the Mississippi River as quickly as they did without the human-mediated mechanisms.

Overland Dispersal Myths

Because the animal also appears to be spreding to waters not contiguously connected to infested water, we must focus on overland dispersal. But before we look at what might be happening, we must first look at some of the myths associated with overland dispersal. I say myths not in the sense that they are wrong, but in the sense that little or no scientific evidence for them exists. Until appropriate studies are conducted, intuition must play a part in this study of dispersal and range expansion because we have so little data on which to really understand how organisms are spread.

One myth, termed the "Noah Fallacy," says that it only takes two mussels to colonize a lake. It is unlikely that two mussels can colonize a lake, so some of the hyperbole you hear about very small inoculations infesting waters are unrealistic. Indeed, as Chuck O'Neill pointed out, there were probably many different introductions of zebra mussels in the Great Lakes that never "took." A second myth, that ducks will bring zebra mussels in anyway, is a favorite one to explain any pattern of dispersal that can't be accounted for otherwise. Some say that ducks will carry the tiny organisms on their feet, or eat a mussel and pass it through the duck's body, and then drop it into another lake. Finally, a third myth is that mussels can live outside of water for weeks. This is very true and has been well studied in the lab, but we don't know how well these laboratory findings apply to field situations. So, we have to try to temper our recommendations and not use facts out of context.

Dispersal Mechanisms

Natural overland mechanisms, then, could include the movement of birds, mammals, and waterspouts. Human-mediated overland mechanisms might include transient recreational boating (the use of boats in different waters and movement between them), fishing activities that can be associated with that boating, and movement of commercial equipment such as towboats, barges, and weed cutting equipment. Some of these mechanisms are unintentional; people are moving objects between watersheds and don't realize there are mussels on them. Some can be intentional introductions.

Dispersal Study in Michigan

How well can we predict dispersal? The Michigan Department of Natural Resources funded a project to predict dispersal in their state. The rapid spread of zebra mussels in contiguously connected

waters lead to the general impression that the inland waters of Michigan were ripe for invasion. However by 1993, the only known inland population in Michigan was found in a small lake in the southeast corner of the state. We selected lakes with predicted high risk characteristics of (1) public access, (2) large size, therefore attractive to large boats from the Great Lakes (nearby infested waters), and we selected some that (3) had navigable connections but weren't hydrographically connected, like a lock and dam system. We found evidence of zebra mussels populations in 10 of 33 lakes usually on plankton tows (towed plankton nets that scoop up veligers). Larval traps were much less effective in providing evidence — only 1 of 33 lakes. Examination of aquatic plants, which are a good indicator of mussels when there is high densities of them, showed us zebra mussels in only 1 out of 23. Looking at boat bottoms, we found 1 out of the 10 lakes with mussels on the bottom of people's pontoon boats, what we used as sort of a standard.

As I mentioned earlier, dispersal is difficult to clearly define. You can see that looking at each dispersal mechanism in these 33 lakes provided different results. Study experiences differ historically, too. Previous work had shown that plankton tows were not very effective because it is hard to find veligers at low densities. Actually, we found that the method used to examine the sample under the microscope makes a difference. We found that using cross-polarized light highlights zebra mussel larvae under the microscope. The veligers have birefringence or a refraction of the light that produces a very distinctive Maltese cross pattern so that the zebra mussel larvae stand out in a sample that is cluttered up with other organisms. By the way, this Maltese cross pattern also indicates other ostracods (calcareous zooplankton), so this is not a foolproof way of identifying bivalve larvae in water solution.

In the Michigan project, we concluded that zebra mussels are spreading to the inland lakes. How are they getting there? Remember the duck myth? We made a very conservative test of this duck foot mythology. There are certain types of zooplankton and algae that are certainly well documented as being carried on ducks feet. Some people have the idea that zebra mussels are being similarly transmitted. The result of this assumption is inaction because the regulatory agencies are not likely to take actions to prevent zebra mussel spread when they think it is going to happen anyway. Likewise, user groups such as fishermen and other boaters are not likely to be careful about moving from lake to pond if ducks are the vector anyway. And when someone puts a restriction on entering a lake, these same user groups want the restriction lifted because the ducks will bring zebra mussels there anyway.

So, can ducks move zebra mussels? We added veligers to a source pool, enclosed in a fence. We let the ducks play in there for a little while, then we chased them across an enclosed ramp to another, target pool, which contained clean water, with no veligers in it. We let the ducks frolic in the target pool for a few minutes, and then we examined the water for veligers. We did find some veligers by examining the target pool water under the microscope using the cross-polarized light. Thus, you can certainly say that ducks can transport zebra mussels, but keep in mind the rates of movement relative to other vectors. Ducks in our experiments moved less than one mussel each under ideal circumstances. In contrast, thousands of veligers were found in the live wells of recreational fishing boats, and hundreds to thousands of adult mussels can be transported by other mechanisms associated with boating. We did not test other considerations: do the mussels survive that transportation, are they delivered in enough numbers to produce effectively reproducing populations?

Remember the Noah Fallacy: Can the ducks transport enough zebra mussels to create a reproducing population? These mussels are dioecious — they have separate sexes, and they have external fertilization. Thus they have to be close enough to each other to have successful fertilization. The numbers necessary for this are unknown, but undoubtedly exceed the number that can be transported by ducks.

Is One Mechanism More Responsible Than Another?

Transient recreational boating (when people are taking boats from one body of water to another) is widely suspected of transporting zebra mussels overland. In Michigan, we had 800,000 registered recreational boats last year, 1 per 10 people. What are the possible mechanisms of dispersal through transient boating activity? Besides being attached to the boat's exterior surfaces, zebra mussels can be transmitted by vegetation entangled in the trailer from launching and retrieving the boat, on anchors, in bilge water, and in engine cooling water which collects in the engine. With fishing activities that are associated with boating, zebra mussels can also be transmitted in live wells and bait buckets. Larvae are likely to be transmitted by the latter four mechanisms whereas adults are more likely to be transmitted by the first three.

Note that the introduction of the larval stage is less likely to establish populations. They are fairly fragile, and, once they get in the water, they will drift away from each other, thereby reducing the chance of being close enough to mate after settlement.

Although we sampled about 2,000 recreational boats leaving Lake St. Clair (the origination point for this exotic species in North America), we rarely saw zebra mussels on the exterior of boats. Many of the people who are using their boats for recreation have them out of the water for long periods between uses. The boat typically sits in the water for too short a period of time for mussels to settle and grow on the boat. Unfortunately, most of our educational efforts have gone towards these short term-boaters and not towards the people who actually keep their boats tied up in the Great Lakes (or other infested waters) where mussels can accumulate on them. (Although these boats are not often moved between different bodies of water, they represent a great threat of establishing new populatins when they are moved to infested waters.) This is a good example of misdirected educational effort. We should have been trying to educate people who have long term wells or slips in infested waters. Instead, we have focused on people who aren't really as much of a concern.

In contrast, entangled vegetation can get on anybody's boat, and zebra mussels do attach to aquatic macrophytes. Bilge water is a suspected mechanism for larval stages. But bilge water is not a nice place to hang out, so this mechanism is not likely to transport large numbers. Although zebra mussels were found in small numbers in engine cooling systems, the density was low because these systems contain only a couple of pints of water. Zebra mussel veligers can almost always be found in live wells because the volume of water is high. Fewer are found in bait buckets, and many people don't reuse their bait or save it anyway.

The vision of people scraping tons and tons of mussels off the bottoms of boats is not real. The mechanism associated with most recreational boats is more likely to be aquatic macrophytes on the back of a boat trailer. A single strand of aquatic macrophyte covered with up to thousands of zebra

mussels per linear meter of strands could be a very effective way of introducing mussels into new systems. In summary, the dangers are certainly much higher of transmittal by boats than by waterfowl, but not all recreational boats are transporting zebra mussels in the same ways.

Prevention: Education and Intervention

A knowledge of the ways in which zebra mussels are dispersed overland between waterbodies permits us to make better decisions on the ways we might be able to prevent or slow the apread through either educational efforts or direct interventions. We regards to boaters, the vast number of boats that are stored out of the water and then used sequentially in unconnected bodies of water can, under some circumstances, disperse zebra mussels. Thus some educational efforts should be directed towards these "day users." Still, on a per trip basis, this populatin of boaters may be much less likely to cause further spread than the group of boaters who keep their boats moored in infested waters. Thus, it may be more important to target educational efforts towards marinas, lake associations, and lakeshore residents because these are associated with boaters who are most likely to moor their boats.

To intervene in zebra mussel dispersal, you can reduce or eliminate transient boating, depending on the type of control you have over the waters or the political capital you want to expend on this. Obviously these actions are an impingement on peoples' freedom to recreate. Providing cleaning stations for transient boats is a popular idea and is an option. Mandating proper boat hygiene is also an option; some states actually have laws that require certain procedures. In the state of Minnesota, for example, it is a civil crime to have aquatic macrophytes on your trailer or boat while you are transporting it over land. Minnesota can fine you up to $50 per fragment up to about $500.

Risk assessment is an important first step for prevention, be it intervention or education. Always try to determine whether something is a problem before trying to attack it. We have done this with simple surveys. For example, we have asked boaters leaving Lake St. Clair, "Do you ever go to inland waters?" In our studies, we found that over 50% of these boaters planned to use their boats in uninfested inland waters. To carefully assess the risk, we must learn something about the number of people doing this, the frequency during which they do it, the type of boating they do, the routes they take, and the types of waterbodies they use. Besides the numerical data, these will show patterns about transient boat movement. Intervention should address all of these factors.

Infestation results from cumulative introductions, not just a single mistake. Education must be cumulative too. For example, one of the most heavily used places at one Michigan boat ramp are the restrooms. Therefore, information about zebra mussel dispersal posted in this area, will be read by many, and some will read it more than once. Educational information about zebra mussels needs to be attractive, and present information efficiently. We live in a sound byte culture. Detailed text will be ignored.

Remember the golden rule of public advisories: if the desired actions are voluntary, then the request must be reasonable. For example, we could prevent zebra mussels from being transmitted by boats simply by burning the boats. And I guarantee that if everyone burned their boats after they used them, boats would never transmit zebra mussels. But this intervention method — burning boats — is not reasonable so people will not comply. We have to make reasonable requests that actually increase our compliance rate. If we make our request difficult or unreasonable, the probable success of any

particular dispersal mechanism increases, and the effect of intervention or education decreases. For example, removing tangled weeds is not hard. In fact, bass fishermen are generally fastidious about doing this. Flushing areas with cool tap water where veligers might collect is easy; it will reduce reduce the number of zebra mussels in an area. Don't flush it with chlorinated water which is dangerous to the environment. Hot water, which would be more effective at killing mussels, is generally not available. Don't move bait. That is pretty simple. Let the boat dry for at least two days before putting it into another waterbody. Two days actually gives the boat almost a week out of the water because most people boat on the weekend. But it is unreasonable to recommend leaving a boat out of the water for 3 weeks on the basis of lab evidence that three weeks is the longest we have seen zebra mussels live in air. In many areas, the boating season is probably only 2-3 months long anyway, so people aren't going to refrain from boating for three weeks at a time. Finally, don't forget resident boats (called live-aboards) can also transmit zebra mussels. They sit in the water for long periods of time so that mussels can settle and grow on the outside of the hull. Although they rarely move to new waters, it does happen and is likely to be a primary means of starting new populations.

In summary, zebra mussel dispersal in the U.S. is both natural and human-mediated, and is occurring upstream, downstream, and overland. But vectors are not equally responsible for zebra mussel dispersal. Some dispersal mechanisms present a higher risk to society. We have to try to modify policies and educational efforts to reach the high risk groups.

ZEBRA MUSSEL DISTRIBUTION IN THE LOWER MISSISSIPPI RIVER & TRIBUTARIES

Panel: Dr. John Lynn, LSU Department of Zoology and Physiology
Steve Filipek, Arkansas Game & Fish Commission
Dr. Bruce Thompson, LSU Coastal Fisheries Institute

LOWER MISSISSIPPI RIVER

Dr. John Lynn, Louisiana State University

We've been working on the idea that zebra mussels would be transported into Louisiana for about three years now. Three individuals, Dr. Tom Dietz, Dr. Harold Silverman and myself, began looking at this problem in late 1991-early '92 with the idea that we needed to consider that zebra mussels could migrate to and live in Louisiana despite the predictions that thermal temperatures would probably not allow them to survive. When we began looking for these mollusks about 2-2.5 years ago, we didn't see them at first. But in our research, we have followed them from their very first introduction until the populations discussed today. I think you will be very surprised at the types of populations that we are going to report to you.

It is important to recognize clearly that zebra mussels have moved from the Great Lakes region through the Mississippi River and its tributaries all the way to the Gulf of Mexico. They have also moved into the Atchafalaya Basin, and through it, to the intercoastal waterway. Zebra mussels have not been transported only into the Mississippi River.

The first confirmation of zebra mussels in Louisiana occurred at the Louisiana Hydroelectric Plant at the Old River Diversion Structure about 75-100 river miles north of Baton Rouge. To their dismay, plant personnel found zebra mussels in their firewater fighting system. In January, 1993, they had a reduction of pressure, cleaned out one of the screens, and found out that in fact they had zebra mussels in the population. In March of '93, we revisited, reexamined their fire system, and found a very small number of zebra mussels in their pipes at that time. They weren't particularly a problem. But, as we left, we saw a number of sportfishermen alongside the plant. They stayed for approximately 30-45 minutes, collecting bait. They didn't have any intention of staying in the Mississippi River; they were headed back to the Atchafalaya Basin to either fish or use the bait fish that they caught for catching crawfish. We already have the obvious transport vector in frequent occurrence right at the first place zebra mussels were confirmed in the state. And many others continue to do this, everyday.

Around May of 1993, we began a cooperative effort with Gulf States Utilities Riverbend Nuclear Plant in St. Francisville. Keith Stoma collected water samples from their cooling water system and analyzed them on a routine basis for larvae. He found larvae at that time by examining his samples under a microscope using the cross polarization technique. This technique allows you to quickly identify calcareous animals in your samples, and then you can easily identify whether they are *Dreissena* or another animal.

One month later, our second surprise was a barge that had been brought to dry dock to be

refitted and repaired. It was covered with adult zebra mussels. When I say covered, there were approximately 30-60 per meter^2. Although this is a low density by Great Lakes standards, the zebra mussels' presence was significant. This barge had never traveled the river system; it is an anchor barge or tie up barge, used to tie up other barges before they are moved either north or back down into the southern parts of the Mississippi River. It had been anchored for three years just north of the new Mississippi River Bridge at Baton Rouge, Louisiana. It had not moved at all. The animals that we saw were roughly 15 mm long (1.5 cm). They could have been anywhere from six months to a year old, suggesting that the adult animals were in this region possibly as early as the summer of '92. In the summer of 1993, we began looking more extensively and approximately 1/2 mile north of where we are sitting right now, at the new river bridge, in the rip rap along the shore, we were able to collect a number of zebra mussels. And, although their densities were spotty at that time, they were still ranging in the order of 60-100 per meter^2. This part of the summer is relatively warm, 28-30 ^{o}C. The zebra mussels were dealing with the Southern high temperatures (around 85 ^{o}F) just fine.

Let me summarize the kind of history we have seen during the monitoring process. In 1993 we saw one veliger or less per liter; in May-July of '94 the veliger count increased to about 20-30 per liter. That was, in fact, what we had predicted for 1994. The percentage of live veligers in those samples is also significant. Even though the number in '93 was only one or so per liter, a very low percentage was alive at the very high temperatures.

In the next summer, May-June of '94, as the temperatures began to rise, we started to see these slightly increasing numbers of larvae, but the live veligers were actually doing much better in this second group. We found between 50-100% of the veligers alive. Our real surprise came in late July-August of '94 when the density of veligers suddenly rose to 300 veligers per liter. This is a tremendous number.

To put this in perspective, the Mississippi River flow rate, a typical flow rate, would be about 12 million liters past a given point per second. That means that 3.6×10^9 veligers per second were flowing past the point in the Mississippi River where we collected our 300. Remember, these zebra mussel veligers were doing very well, even at the very high temperatures of roughly 29-30 ^{o}C (around 80 ^{o}F). They were not having problems surviving as they were in the previous year.

Typically the number of adults follow a similar pattern. We found less than a 100 per meter^2 up until July of '94. In August of '94, at the Dow Chemical Plant, we were surprised by the fact that we suddenly had a very large settlement of animals that increased to about 40,000 animals per meter^2. Later in 1994 (November, December), and early January prior to this seminar, we found settlers and adults up to 400,000 per meter^2 at Dow Chemical. These densities are similar to some in the Great Lakes region. In fact, the peak reported density in the country is about 750,000 (as of January 1995). The Southern waters don't have far to go.

Now one might say, "So what?" Maybe the zebra mussels won't survive, maybe they won't grow, maybe they won't settle in every place. But we have repeatedly seen these summer after summer. They are here, they are going to establish, and they are going to do well. They are growing. For example, in October, '94, the adults collected had a mean length of about 1 mm. They were obviously newly settled animals. By January 1995, the mean length of these animals shifted to about

3-4 mm. In fact we are now seeing a fairly large number of zebra mussels that are 5,6,7, and 8 mm long. These are all reproductively capable animals. It has taken a very short period of time to move from a 1 mm to a 3, 4, and 5 mm class. Although the river temperatures in January 1995 were down, they were still somewhat elevated during October and November. These animals are here, they can survive in our higher water temperatures, they are going to be a problem, and we need to recognize that very clearly.

MOVING UPSTREAM IN THE TRIBUTARIES

Steve Filipek, Arkansas Game & Fish Commission

I am going to discuss the spread of zebra mussels in Arkansas, primarily in the Arkansas River, from the point of view of a fisheries biologist. In October 1992, zebra mussels were first found in the Arkansas River at Lake Dardanelle. Later that year, some zebra mussels were also found downstream from the lake in the Arkansas River at Little Rock. The natural flow of the Mississippi did not carry these mussels into the Arkansas River, however, because the Arkansas River flows into the Mississippi River. This means the mussels somehow migrated upstream.

A biologist with Arkansas Power & Light, Charles Adams, actually found the first zebra mussels in a canal that runs into the Arkansas Nuclear One Plant. Power companies monitor for these animals because they can clog water intakes. The navigation people are concerned about the effect on locks and dams operation, as well as on the vessels themselves (weight drag, water intakes).

The Arkansas River has a series of locks and dams for navigation purposes, and by 1993, zebra mussels adults were found at almost every lock and dam on the Arkansas River. We believe they were spread via navigation. By 1994, zebra mussels were found all the way upriver to Tulsa, Oklahoma, and also in the White River in Arkansas which also flows into the Mississippi. The White River is joined by a navigation canal to the Arkansas River, too, so we knew this migration probably was going to occur. We really didn't want to see it because the White River is one of our better mussel, sturgeon, and paddlefish fisheries.

From a Game and Fish Commission or a state conservation agency perspective, our main concern was the effect on native unionids (freshwater mussels). We had heard about the problems generated in the Illinois River system from zebra mussels affecting the native mussel habitat by consuming the food, disrupting the food chain, and transmitting toxins to other animals in the food chain. We were also concerned with possible changes to the sport and commercial fisheries because of some changes that had been reported in Lake Erie and some other areas. We sensed a threat to hatcheries. We also realized that the state of Arkansas has over 30 state-owned fishing areas, one of the biggest systems in the nation. These are lakes that we have managed fairly intensively to boost production of sport and other fishes. We knew that the filtering capacity of zebra mussels could negate any management that was underway.

Within weeks of the first zebra mussels being found, we formed the Arkansas Zebra Mussel Task Force and built a team consisting of academics, power company officials, state fishery biolo-

gists, representatives from navigation, and the Corps of Engineers to slow the spread. The major thrust of the Zebra Mussel Task Force is to try to educate the public. We used the identification cards designed by Wisconsin Sea Grant, and developed some pamphlets that go into a little bit more detail about what each person can do to stop or slow down the spread of zebra mussels.

There has been some monitoring done. We started out at a relatively low level in the Arkansas and the White rivers. Arkansas Tech has also been doing some intensive sampling on Dardanelle Lake which is where they were first found (funded by Arkansas Power & Light). Just about 99% of zebra mussels in Arkansas has been associated with barge ramps and barge areas where they are stopping and waiting to lock through. From our perspective, the navigation vector has probably been the main one.

Researchers at Arkansas Tech (Dr. Gagen and Dr. Stoecker) have monitored in areas where the adults were found. In 1993, the veliger count varied anywhere from about 10 up to about 110 per liter. But in October 1993 we found 77,000 veligers per liter, so the mussels have made that ten-fold increase in veligers between '92 and '93. Obviously they are up and down the Mississippi River already. We know they are up and down the Arkansas and White rivers. There is barge traffic up to Newport on the White River. We also have barge traffic on the Ouachita River in south central Arkansas, so we anticipate that, in the near future, we are going to see more and more zebra mussels, and apparently, the migration is closely correlated with navigation.

ENTERING OTHER WATERBODIES

Dr. Bruce Thompson, LSU Coastal Fisheries Institute

We've worked in fisheries in the Mississippi River and Lake Pontchartrain now for over 20 years, and this past spring the U.S. Army Corps of Engineers proposed a test opening of one of the large floodway dispersal areas just north of New Orleans. This system is used to bleed off Mississippi River floodwater into the Lake Pontchartrain system. (Many rivers and fresh water streams flow into and out of Lake Pontchartrain.) A series of 125 lift gates take Mississippi River water and transport it about six miles north into Lake Pontchartrain. Since this was the first time that the Bonnet Carre Spillway had been opened since report of zebra mussels in the Lower Mississippi River, we wanted to see just exactly what happened — would zebra mussels move into the lake, would enough move in to settle?

When the gates are opened, we actually see white water. The Corps tried to hold flow to about 8,000 cubic feet per second for a test opening. We were filtering 100 liters of water in that high turbidity with a 63 micron net and we were looking for veligers and adults. The gates were only open about two days, but we continued to monitor in the lake. Our goal was to get some idea of what was going to happen with this potential transfer.

For most of these stations, the water changes slowly from fresh to low salinity. Here in southern Louisiana, we have a slight gradient all the way out to the Gulf of Mexico. The change from freshwater through brackish into marine water over several hundred of miles provides the potential for these animals to have to adapt to salinity changes over very, very slow, low gradients. To study this

possible adpatation, we also were taking a look at presence of Ca++, Na+ and other salts. Even after the gates closed, we studied survival of veligers. (And as you've heard several times already, we used polarized light under the microscope to identify zebra mussel veligers.) We don't think the zebra mussels colonized during this test opening.

We also found *Mytilopsis leucophaeata*. And, the next time they open the spillway, we are going to have zebra mussels and *Mytilopsis* happily coexisting on any number of regions within the floodway. We found a very large, massive freshwater population of *Mytilopsis* occurring about 1.5 miles inside the floodway right next to the newly emigrating zebra mussels. We are at the present time taking a look at the life history of this animal and making comparison of *Mytilopsis* and *Dreissena* because we are going to have the two, maybe not this year, maybe next year, living together and the coexistence will be very interesting. The dark false mussels' bars are much more irregular, and the shell is more elongated than in the *Dreissena*. And the *Mytilopsis* has the large apophysis inside that is relatively easy to find.

We found the same peak in veliger density and veliger survival in late 1994 summer that John Lynn just described. We were monitoring in water temperatures of 29-32 ° C and finding a very, very high percent of live to dead veligers. They are growing superbly above 30 ° C down here, they are having no problem.

We also attempted to make some estimates of growth rate. (We are now starting a project where we are going to be marking them with the four common chemicals that we use for fish otoliths to try to get some growth rates on some of this.) During our sampling on the Mississippi River, we found animals 5mm or less. Our experience was similar to John Lynn's at Dow Chemical. We found them out on the rip-rap rock that the Army Corps of Engineers uses to stabilize the river banks. Rip rap makes just about the best zebra mussels condos that you could ever imagine. They thrive on attaching to the rocks.

We would like to acknowledge the help of Sea Grant which let us take advantage of the opportunity to study on very short notice when we learned that the Bonnet Carre Spillway was going to be opened. The next time the Corps opens the spillway, millions of gallons of water are going to pass through from the Mississippi River into Lake Pontchartrain. We will be looking to see whether the water carries zebra mussels. We are going to study colonization rates because, at that particular point, these animals will have begun an eastward movement across Lake Pontchartrain into the systems that flow into the lake. It is an example of something that we are not going to be able to do anything about other than perhaps study it.

KNOW YOUR ENEMY

Dr. Robert McMahon, University of Texas at Arlington

The zebra mussel's scientific name is *Dreissena polymorpha. Polymorpha* in Latin means many forms. It gets its name because it has so many different color variants in the shell. Cilia on the end of the juvenile zebra mussel's foot, applied to the substrate, hardens to form the byssal thread. Zebra mussels can produce up to twelve byssal threads per day. Generally, adult animals have a range of 80-300 or 400 of these threads depending on the conditions they are living in. They make more threads in areas with greater currents. They can attach to any hard surface material. They don't really display a great deal of preference—plastics, rock, wood, metals. Generally the surface needs to be submerged for awhile and have a bacteria film growing over it before they will attach to it.

Zebra mussels can appear in your well water facilities almost anywhere where water flow is low enough for them to settle. They pile up and can develop very thick masses. We found a floating log in Lake Erie covered with zebra mussels. If this came up against trash racks at a water facility, the zebra mussels would either jump off the log or fall off it and go further in your plant. Sometimes a developing clump of mussels falls off. The clump can be carried, by flowing water, further into the plant. And the adults can be dispersed around as well as the juveniles.

Besides boat hulls, adults also attach to floating wood or floating plastic bottles and then they come against your trash racks and they can also detach. When they are detached, zebra mussels get carried further into the plant if you don't have fine filters. A large number of adults can be piled up on your intakes that way. And they can byssally attach to the shells of other zebra mussels. They don't mind living on top of each other. They can form very thick and crusty masses up to 6 inches or 12 inches thick. All they need is water. So they can take a three foot diameter pipe and reduce it to a one foot diameter pipe. Densities may reach 100-700,000 mussels per meter^2.

Byssal attachment and mussel accumulation on the shells of native unionids eventually leads to unionid death. We believe it starves them to death. The great concern is that zebra mussels can attach right over the native unionids' siphons, and starve them to death. All bivalves filter feed, drawing water in through an inhalant siphon that ventrally passes over the gills. These filter algae out and then the water is passed back out to an exhalant siphon. Zebra mussels, which also filter feed in the same way, often sit on top of the poor mussels siphons, and they probably remove all the food before the water gets into the unionids' gills. Evidence in Lake Erie is that the unionids slowly starve to death. Some unionids live burrowed in the substrate with only the posterior end of the shell sticking out and that is where the zebra mussels settle. But then the unionids get irritated by this and they begin to move around. If they back out of their burrows at all, the zebra mussels, which don't like being moved around, get off their byssal threads and move down the shell and reattach, and they slowly jack the unionid right out of the substrate. That may also lead to the natural unionid's death.

Zebra mussels filter feed on suspended algae and bacterial particles. In the old days, the filtered particle size range was 2-10 microns, but it is now known to be much lower than that. They can feed on bacteria, and even on small animals. Rotifers and Copepods that live in the plankton, the floating plant and animal life in the water, have been consumed by zebra mussels. The filtration rate varies with zebra mussel size, maybe the shell length. A 10 mm shell length mussel can filter about

17 ml per hour; a big zebra mussel filters about 40 mm (that is approximately half a liter per hour). A mixed population of 100 individuals can pump about 201 liters per hour, but populations in the range of 100,000 mussels per meter^2 averaging 15 mm long would pump 3,000 liters per meter^2 per hour. They can filter everything, including suspended silt. A zebra mussel is a massive filtration process. That is why they clarify waters.

This filter feeding process also can greatly increase sedimentation rates because what they don't eat, they bind up in mucus and it goes to the bottom. That can be a problem if they are in your plant because this will increase the sedimentation rates within the system. Their feces and pseudofeces (stuff they filter but don't actually eat) get bound up in mucus. So not only do zebra mussels increase sedimentation rate, but they make the sediments much more organic than they might have been, thus allowing for high levels of bacterial activity. This very high bacterial activity can result in rapid piping degradation of buried metallic pipes because the bacteria produce acids that eat away at the pipes.

After settlement, growth in North American zebra mussel populations (especially in the Great Lakes where they have been heavily studied) is generally faster than in European populations. In one year of life, some zebra mussels reached 10-25 mm in Lake Erie, whereas the maximum from Europe is about 5 mm. So growth is twice to five times as fast in the US. In Lake Erie, Jerry Nichols showed that growth in a 5 mm long juvenile was 0.21 mm per day, so a shell length of 20 mm at that growth rate could be achieved within a single summer growing season. This growth rate is one reason why complacency might be a mistake. If you have a lot of little tiny mussels that are no problems right now in your system, six months from now they are all going to be 15-20 mm long, and they are going to be all piled up on top of each other, and you are going to have a fouling problem.

Growth rate is influenced by water depth and flow rate. The rate decreases with increasing water depth. (They grow best near the surface.) The rate is stimulated by water velocities above 0.5-0.8 meters per second (the low flow areas of your plant), and it is inhibited above 1.5 meters per second.

Zebra mussels reportedly live for about 5 years in Europe, but remember these are slower growing mussels in Europe. A good guideline for mollusks: the slower they grow the longer they live. So far, we have found that a zebra mussel in North America rarely lives more than three years, that is due to the faster growth rate. In fact the majority of individuals do not survive 1-2 years of age in North American populations partly because in these dense populations, the old ones suffocate when the young ones cover them. The old ones die out underneath.

In terms of reproduction, zebra mussels have separate sexes, separate males and females. They shed sperm and eggs into the surrounding water so the sperm fertilizes the eggs externally. Spawning is initiated at temperatures above 10-12 °C, but massive spawning occurs above 18 °C (64 °F). They have a very high fecundity, but it is common that conditions in a typical habit will control the fecundity (the number of eggs produced). The average fecundity has been reported to be about 30-40,0000 eggs per female per year. But in Lake Erie, and other places where there is a lot more food, you are now looking at an average of about a million eggs per year in females, and in larger females, two million eggs per year. Not every egg is fertilized. Lake Erie reports up to 200,000

veligers per liter of intake waters. So you are going to have huge numbers of these juveniles or these veliger larvae coming into the plant. The initial stages after the sperm and egg fertilize and the eggs hatch are planktonic, that is, the larvae live in the water column, floating in the water. When these trochophores (pear-shaped, free swimming larvae) develop a shell, they become bivalve to form what is called the "D" shaped veliger because there is a straight hinge to the shell, which looks like a "D" and is planktonic. After metamorphosis to a umbonal veliger or postveliger which looks like a little swimming clam, the zebra mussel veliger has a little umbo (a prominence above the hinge) at the dorsal side of the shell.

The pediveliger gets its name because it has developed a foot to move around on during the settlement stage. It settles to appropriate substratum, makes a byssal thread attachment, and forms what is called the plantigrade, which is the settled stage (the shell becomes elongated and the animal develops siphons). The plantigrade, however, can be easily resuspended in water currents, can come off its byssal attachment but if it stays attached, the zebra mussel metamorphoses into a little juvenile mussel. It looks just like a tiny adult mussel but only a millimeter long or so. That is byssally attached. This tiny adult can also get off its byssal attachments and resuspend in the water column. We tend to call them translocators because they are translocated from one place to another on water currents. Then the adult remains byssally attached, and it may be carried upstream or downstream as individuals or byssally bound clumps of mussels. In other words, whole clumps of attached mussels can fall off areas and be carried in your water system as a big clump of mussels down through the system and then settle and foul a small diameter component such as the opening of heat exchanger tubes.

Temperature may affect settling. We have monitoring data on Lake Ontario that shows that when temperature reached about 18° C, the number of settling juveniles increased significantly, suggesting that reproduction, while it is low throughout the year, is greatest above 18° C. We also find veligers resuspended, not from reproduction, but these are veligers that have settled down for the winter and have been resuspended. I believe that 18° C is really the threshold point for massive spawning and that after the temperature reaches 18° C, you are going to get settlement.

Some of the characteristics of these larval stages: the egg is about 40 microns in diameter. It takes about 48 hours until the trochophore, which is also about 40 microns in diameter, develops. It lasts about 48 hours. Then it metamorphoses into the D shaped veliger, about 90-130 microns, which lasts 3-6 days. These are the most rapid development times. They can all be delayed to a certain extent depending on conditions such as temperature. The D shaped veliger develops into the umbonal veliger, which is about 100-110 microns in length. This stage lasts 4-7 days, although my suspicion is that if water temperatures are low or if feeding conditions are poor, the stage can last for weeks. Then the pediveliger, which develops the foot, is about 140-350 microns in length. This stage doesn't last very long because the zebra mussel settles. The stage can last longer if conditions are slow, but they rapidly transform after they make the byssal thread into the plantigrade, which is 230-460 microns in length. And the plantigrade rapidly transforms under good conditions into the adult. Under good conditions, a total of maybe two weeks passes from fertilization to settlement and development to the juvenile.

What about some of the tolerances of these larvae? European data show that the maximum

temperature for successful hatching and development of the veliger is around 18 °C with it dropping off towards zero above 24 °C. However, in North America that is not accurate. They are doing real well down here in the Mississippi River at 30 °C. Some data from mid-August shows both veligers and adults doing well in temperature around 31. Hatching and rearing success is low, below about 20% of normal air saturation levels. They won't do well on very low oxygen, and pH seems to be important. At pH below about 7.5 and above 9.5, there is zero hatching success.

Let's look at the physiological limits of zebra mussels and talk about some of their physiology at the same time. Generally, these animals don't live in acidic waters, pH limits greater than 7, nor in salinity above 8 parts per thousand. Although they appear to prefer low silt content, they are living in the Ohio and the Mississippi rivers, so silt doesn't preclude them. Apparently, only very high silt loads preclude them. In other words, organically rich waters don't limit zebra mussels as long as plenty of oxygen is present. The waters will just make them grow faster because there is more food. The maximum long term upper lethal limit on water temperatures is somewhere between 31-32 °C. Although they are usually not found in shallow waters, they are usually found in a water depth one meter below the surface, and they are not found below the thermacline, that is, the thermal discontinuity layer with the colder water under the warmer water. (Below the thermacline, the water is not exchanged so that the colder, deeper water has very low oxygen concentrations.) If you have really soft waters, less than 4 mg calcium per kilogram, you are very unlikely to have zebra mussels; and zebra mussels are seldom found in water with under 10 mg calcium per kilogram. In other words, we don't think that zebra mussels will occur in alkaline water, below 15 mg of calcium per kilogram.

According to some European data, in water below 7.5 pH, none of the lakes had zebra mussels. These are areas subject to acid mine drainages into rivers, streams, and lakes that would not support zebra mussels due to low pH. There are some drainages with naturally high salinity from which zebra mussels may be excluded, like portions of the highest salinity you can see here in west Texas where salt domes are drained. This condition exists in the Dakotas and near the Arkansas River, but zebra mussels are already in the Arkansas so salinity in drainage waters do not always preclude zebra mussels. Turbidity in the Ohio River is high but zebra mussels are living and doing very well there. Since those are among some of the most turbid waters in the U.S., I don't think turbidity is going to be a problem. (Some say that turbidity may affect filtration rate, a temporary phenomenon.) Temperature data accumulated in the U.S. shows zebra mussels to be about 3 or 4 times more thermally tolerant than they were reported in Europe. Our animals here are more tolerant than European. Some very recent data from our laboratory shows that the thermal tolerance increases in animals that have lived in warmer waters for awhile and this suggests that down here, if you are going to use thermal backflushing to get rid of zebra mussels, you are going to have to do it for a lot longer than they do it up north.

In most riverine and lake systems in the south, there is at least a five degree difference between daytime and nighttime temperatures. The lakes cool off. The surface waters cool off. For this reason, we have been looking at what happens when you take zebra mussels up to say 33° C and back down to 28° C over a 24-hour period, and they survive it much longer than if you keep them at 33 °C continually. Here it is too dry and parts of Texas are just too hot for them, but the rest of the U.S. is going to have to deal with them.

In U.S. waters, zebra mussels have been found at about 28 mg of calcium per liter and around 15 mg per liter, suggesting that zebra mussels like moderately hard waters or hard waters. They don't like really soft waters. Lake Superior has really soft waters, and zebra mussels are not in Lake Superior except in areas where harder waters come in from rivers. In terms of total hardness, zebra mussels certainly won't be found in waters with less than 20 mg of calcium carbonate per kilogram.

Zebra mussels are not very tolerant of low oxygen concentrations and waters that are chronically hypoxic. And in terms of desiccation, they survive less than one week at air temperatures above 20 ° C but below that temperature, they can live for very long times out of water. On average, they, like many native unionids, don't have very good tolerance of being in air, suggesting that they are unlikely to be successful in reservoirs that go through big variations in level such as water supply reservoirs or flood control reservoirs.

These mussels have little anoxia tolerance, that is, they can't be held without oxygen. Data shows that at 25 ° C, if you can take the oxygen out of the water (which is, by the way, something that the plants can do), you can kill them within a 100 hours. They don't like hypoxic (oxygen deficient) waters because they lose their ability to take up oxygen in it.

I will talk briefly about some geographic and hydrological factors that may affect zebra mussel distribution. (1) Navigable versus nonnavigable waterways: if you are on a navigable river where there is barge traffic, you are going to have a much better chance of getting zebra mussels than on one without barge traffic. Zebra mussels are carried around by barges. (2) Hard substratum is important for attachment. The more hard substratum that you have in the natural environment, the greater will be the population densities. However, recent data from the Great Lakes indicates that they now settle on sandy bottoms and spread out over them. It is assumed that the first zebra mussels in these lakes attached to some shell or hard object or place on the sandy bottom; then they attach to each other. It is a fact that they are covering the sandy bottoms of Lake Erie and Lake St. Clair, so hard substratum is relative. (3) Latitude: zebra mussels won't migrate north of North America. Temperatures have to be above 15 ° C for them to maintain really successful breeding and maybe even above 18° C in the summer. And they won't tolerate waters that are continually above 32 ° C or 90 ° F. So they won't be found in Mexico and probably southern Texas, but probably everywhere else. (4) Rainfall and water levels: areas with rainfall high enough to support continually flowing rivers and near constant lake levels most successfully support these animals because zebra mussels don't like big variations in water level. They love the Mississippi River because the lock and dam system to make it navigable has made the whole river essentially a giant long lake with constant water levels. Flooding and variable water levels in areas where there is very low rainfall results in changes in water levels that expose them and they will die fairly quickly. Stream size and flow volume, large permanent rivers and canals not prone to extensive water level variation will support them where as small, highly variable stream flows prone to extensive water level variation probably won't. Areas with very low precipitation, even with some major rivers are undesireable to zebra mussels when they go through major annual variations in flow and level. These freshwaters are more attractive to zebra mussels if they've been dammed to produce nice lakes or a lake-like effect. (5) pH: watersheds that have very soft water won't support zebra mussels. Acid mine drainage where the pH is less than 7 is very unlikely to support zebra mussels.

ENVIRONMENTAL TOLERANCES OF ZEBRA MUSSELS

Dr. Thomas Dietz, LSU Dept. of Zoology & Physiology

Since zebra mussels (*Dreissena polymorpha*) are freshwater bivalves, I want to introduce you to a freshwater bivalve and its relationship to the ions in its environment. These animals are really quite different compared to other animals; their blood contains a much lower amount of salt. Their blood is practically "distilled water." Blood ordinarily should taste salty. Your blood, like many animals' blood, is around 300 milliosmoles (mosm). You would expect to find something in the neighborhood of several hundred milliosmoles in bivalves by adding up all the solute. Instead, they are running at 10% to 20% (30-60 mosm); they are very, very dilute animals, a rather unusual characteristic of the bivalves.

Although the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena burgensis*) are within the range of a typical bivalve, *Corbicula* is different, with a salt content that is approximately 50% higher. What is there about *Corbicula* that is different from the rest of the bivalves? Looking into this difference provides insight into reasons why zebra mussels may tolerate some salt water.

Although sodium is the primary salt that is present in the blood, chloride is what you would expect would be the negative charge, the anion going along with sodium. And indeed for *Dreissena* and *Corbicula*, this is true; their blood is a sodium chloride type solution. Blood in the rest of the bivalves, however, share either equally chloride or bicarbonate or in some cases bicarbonate even exceeds the chloride on the negative charge. Under certain circumstances, we have actually exposed animals in such a way that chloride is virtually absent. Apparently, the chloride is not a critical ion.

By looking at this ion content of the blood, we can determine the stress an animal is experiencing. We have been doing this since 1993. The temperature ranged from about 30 °C down to about 4. In the heat of the summer, especially during '93, the animals were severely stressed. We saw this by the low, dilute, salt content of the blood. We brought animals into the lab that were so stressed that they were actually about ready to die. However, as stressed as they were and as low as the solute was, when we brought this group back into the lab, left them in the lab for 2-3 days at room temperature (22°C), they recovered. They did not die in the lab. Temperature and salinity work together; both influence the zebra mussel's survival.

The zebra mussels were dying in the field because temperature stressed them, and they could not retain enough salt to flourish. In the fall and winter, as the temperature went down, the animals recovered and the solute came back up. The animals' blood was higher in salt, in fact, at higher end of the fresh water bivalve range. In the summer 1994, we saw again a depression in the salt content of the blood, but none of the animals in 1994 fell into the "nearly dead" category. In one year these animals had adapted to the higher temperature so that heat did not exert as much stress and the animals did not lose salt, or they were more able to retain salt. Why does this happen?

Although salt ions are very low in the bivalves, they are not low because of any problem with the ion transport, ion uptake system. *Dreissena* (quagga and zebra) mussels have excellent transport systems. Compared to other unionid or native clam salt transport rates, *Corbicula* has a medium to

high transport rate, and the zebra mussel has a very high rate.

Salinity is important to the distribution of the zebra mussels. Although it is a fresh water animal, it cannot live in the freshest of water. It will die in distilled water in days. We made artificial pond water that had some sodium, potassium, calcium, magnesium, and a little bicarbonate. (Remember, chloride is not too important to formation of salt in their blood; carbonate works just as well.) In the various permutations we tried, the zebra mussels do not do very well in magnesium free pond water. This is the water that the rest of the bivalves that we have worked with can tolerate in the lab for years, but zebra mussels cannot tolerate it beyond a matter of days (two weeks to thirty days survival time). Only when you have magnesium present will the animals live. We found that the animals did very well under various combinations of sodium, potassium, calcium, and magnesium with both chloride and carbonate except for the groups that were deficient in potassium. Potassium was critical to the zebra mussel's ability to maintain the sodium and chloride balance. So potassium is an important ion to these animals. And in fact the magnesium, sodium, chloride and potassium are essential for long-term survival and they need to be in a reasonable balance. We found that the presence of an individual salt, such as sodium, is probably the best single salt.

Recently, one of the graduate students in the lab, Sean Wilcox, was looking at the potassium uptake and accumulation in the zebra mussel. (Potassium isotope has a very short half life, so in the laboratory, we use rubidium because they are atomically very similar.) Curiously zebra mussels tolerate rubidium much better than potassium even though it is nearly a substitute. Wilcox was looking for a saturation point: how much rubidium or potassium can the zebra mussel take; how much does it ultimately need? He found a saturation point at low potassium or rubidium concentrations, but when he continued to add more and more rubidium to see how they responded, he expected to see that saturation point maintained. It was not. At a remarkably low concentration of rubidium/potassium, there was a tremendous diffusive uptake which is almost unheard of in a fresh water animal. A zebra mussel, under normal circumstances in pond water, has the capacity to accumulate whatever salts it requires. Water will be coming in and the urine would then be expelled from the animal. Because the epithelia (primary animal tissue) usually do not have substantial leakiness, we thought substantial diffusive exchange is most likely going on. But as noted below, we were wrong in that assumption.

We challenged the zebra mussels by transferring them straight into 45 mM sodium chloride solution, about the same as a 10% sea water bath. If you transfer almost any freshwater bivalve into 10% sodium chloride, it is very tolerant of this solution. That is not a serious stress. The zebra mussels, however, immediately took up sodium, took up chloride. They died when exposed to a challenge of just sodium chloride. In another experiment, we put the animals in potassium. The animals cannot tolerate excess sodium or excess potassium as a single challenge. The sodium is probably going into the blood quickly, but if there is no additional potassium for the cells to regulate, the response of the cell would be to shrink, shrivel, and this leads to death. So a challenge of sodium will cause an imbalance in the cells to where they are going to shrink to a lethal level quickly. If however you put the animals in potassium (recall from the uptake studies that potassium would quickly get into the animal) and if the animal is already in balance, the potassium has no place to go. If it goes into the cell which is already in balance with the body fluids, more water would go into the cells, and the cell is going to swell. The animal is going to die. Cell swelling or shrinking is not good for most animals. The extra potassium in the blood is going to basically depolarize or ruin the electro-

chemical gradient between all of the excitable tissues (nerve, muscle, heart) that depend on a proper electrical chemical balance between the cell of the environment. If this is upset, the animal is dead. We again concluded that a critical balance of ions is very important to zebra mussels.

We then decided to see what would happen if we provided a range of combinations of ions in terms of the zebra mussels survival. We took the four minimum ions — the magnesium, sodium, chloride, and potassium — added sodium chloride, potassium chloride and kept magnesium constant. These are the minimum salts for zebra mussel survival. The results indicated that when challenged with just sodium chloride at 45 mM, the animals are dead in less than a week. If challenged with 45 mM sodium together with potassium over a range, the animals survived for 130-140 days. They are doing very well if you provide them with a balance of sodium and potassium. What kind of a balance? Well, 45:1 is what you would find in sea water. We get very good survival with this ratio so that if the balance is in the vicinity of sea water, sodium to potassium ratio or less, the animals do very well. Not only were they surviving, but 100% of the animals formed byssal attachments which is a good index of the lack of stress. If it produces a byssal thread, it is in reasonably good condition. The zebra mussels do very well in the vicinity of sea water sodium and potassium ratio.

When we transferred the animals to a single step acute or sudden exposure to dilutions of sea water, the pond water controls had 100% survival; 10% sea water, 100% survival. But as we stepwise increased the sea water concentration to 12, 14, 15%, we started seeing substantial mortality and at higher seawater percentages, rapid death from a single acute transfer. Zebra mussels can tolerate a certain low level of acute transfer but not any larger level. However, if you gradually increase the salinity such as in an area where there is a very slow tidal exchange or no tidal exchange, and fresh water that is sweeping the animal into a brackish water environment, and there is a slow mixing due to air or other kinds of stirring, very slow mixing, if you increase the salinity only 11 mosm per day, 30, 50, or a 100 per day, you can greatly extend their survival for months. If salinity is increased slowly, and the acclimation period is extended, you can extend survival. In other words, zebra mussel survival is good when their bodies are allowed time to make the transition and keep the salt balance between their blood and cells and when the ion resources are available (which they would be in sea water).

Curiously, half the animals died in the neighborhood of 350-500 mosm, about 50% sea water, but the other half of the animals remained alive and tolerated concentrations up to 700 mosm (70% seawater). *Polymorpha* is a good name for *Dreissena*'s structural appearance, but it is also a good name for its function. Some of these zebra mussels can resist up to 70% sea water, at least for a short period of time.

When the zebra mussels are transferred into sea water, they are exposed to both an ion change and a more concentrated environment. They are being subjected to a water change or change in water concentration, and change in ion concentration. We tried to see if we could separate water from ion movement. We did this by using what we were assuming was going to be a inert nonelectrolyte that we could add to the bathing medium and so we could raise the concentration of the bath and draw water out of the animal. The idea was good, but the experiment proved to be too difficult to secure reliable data from measuring loss of water from a whole bivalve.

But we salvaged the information because the material that we used to add some solute, some nonionic substance to the water was mannitol, a sugar analog not metabolized, not toxic, the animals tolerate it reasonably well. When we placed the animals in a 100 mM solution we expected the blood to become isoosmotic in about 12 hours, which they did. But when we measured the blood (assuming as water is drawn out of the animal the salts that are present in the blood will become concentrated), we hardly could find any salts. Salts were being lost at the same time that the animal was gaining a solute, and the solute was mannitol, something that was not supposed to get across the epithelia. We tried glucose and got the same results. These animals are incredibly leaky to a variety of molecules ranging all the way up to a molecular weight of 5,000.

For control purposes, this suggests that subjecting zebra mussels to an osmotic stress makes them vulnerable to absorbing toxic material during the challenge. What is happening then? When mannitol is added to the water, it rapidly goes into the zebra mussel at such a rate that the volume of water is not reduced. Although water might be coming out, as the mannitol goes in, it is going to carry water right back in. So we probably could never see any kind of real change in water.

In addition, despite an excellent ion transport system that continues to operate, they are now so leaky that their cells function like sieves. They are losing the body fluids. How is this possible? Well, we added another 140 molecular weight molecule, Lonthonum, that happens to be electron dense with the electron microscope. We added Lonthonum into the same bath, and noted that the Lonthonum penetrated between the epithelial cells all the way into the blood. These animals then are very open, sieve-like, when they are exposed in the laboratory to this kind of treatment.

In a natural setting, where you have the possibility of adding sea water to the fresh water as a river flows into a brackish water estuary setting, the challenge would be more natural. Under these conditions we actually found something a little more predictable. Going from pond water controls, adding the same level of osmotic challenge (about 100 mosm challenge, equivalent of a 10% sea water challenge based on ions), we saw what we expected the first time. Sodium and chloride were indeed concentrated as if the water was just simply drawn out of the animal. But, we could only account for half the amount of sodium and chloride. The animals are not only losing water and becoming dehydrated during this ionic based challenge, but they are now increasingly leaky to salts. Salts are leaking in and adding more salts into the body fluids of these particular animals. The leak in these animals even exceeds the excellent ion transport system. This kind of study demonstrates essentially all of the small ions are leaking in rather indiscriminately, but we found that the zebra mussel cells do become more selective when exposed to this sea water challenge. They don't accept large molecular weight molecules as readily.

To summarize, we have noted that the ion balances are critical to the survival of zebra mussels. (1) The inability to tolerate distilled water is really quite unique to the zebra mussels. The rest of the bivalves do very, very well. (2) Magnesium is absolutely required by zebra mussels. If you have no magnesium, the presence of calcium can actually throw the zebra mussel's body into a lethal imbalance. When magnesium is present, only a small amount of magnesium is needed. Those who have observed zebra mussel sensitivity to soft water must now investigate: is it really the lack of calcium or is it really the lack of the minimum amount of magnesium? This is important to control studies as well because if there is a minimum amount of magnesium, you could induce a toxic condi-

tion by elevating calcium. They cannot tolerate excess calcium in the absence of magnesium. (3) Sodium chloride challenge cannot be tolerated. (4) Potassium chloride challenge by itself cannot be tolerated because of the imbalances between blood and cells induced by sodium or potassium.

What can be tolerated, and tolerated for long periods of time is a balance between the sodium and potassium. That reasonable balance is present in a brackish water or sea water type setting. That natural balance in freshwater is very close to what they require. But, because the zebra mussel is very leaky, with these open sieve-like or pathways between the cells, they can retain very little salt in their blood although they have excellent transport rates. No matter how good their transport rate, zebra mussels cannot maintain a very high ion balance when salts continuously leak out of them.

Is the zebra mussel the only one that displays these characteristics? *Corbicula*, another pest, the Asian clam, also has very good ion transport rates, but they are not leaky. They have a very tight epithelium. Perhaps because of the good transport rate and their relatively none leaky skin, *Corbicula* is unique among the fresh water bivalves at being able to maintain a higher blood composition than the rest of the bivalves. Their salt concentration is as much as 50% above the rest of the bivalves. *Dreissena* has among the best ion transport rates but working against the leakiest of epithelia, it is simply unable to maintain a very high solute concentration.

The bottom line is that zebra mussels are quite capable of handling limited saline conditions. The slowly changing sea water, brackish water type of conditions that we have in Louisiana — a relatively constant inflow of fresh water against a nontidal type of brackish water system — is conducive to zebra mussel settlement. They will be able to perhaps do better in the Louisiana area than in a more open coastal setting with big tidal cycles and large changes in salinity. The animals cannot tolerate acute transfer to large tidal cycles, changes in salinity. The zebra mussels tolerate low or nontidal cycle very well.

FEEDING EFFICIENCY OF THE ZEBRA MUSSEL

Dr. Harold Silverman, LSU Department of Zoology and Physiology

We haven't said much about volume or quantity so far. But lets think about volume: if you look in the western basin of Lake Erie and you are recording 300,000 zebra mussels per meter^2, you have a lot of biomass that should require a great deal ofnutrition. Large numbers of mussels began to be established in Lake Erie in 1988; 1995 just began and we are still measuring similar numbers of mussels. In six years, these animals must have done a great deal to the water column. The literature shows that *Dreissena* is a filter feeder that grazes on the phytoplankton in the lakes. A great many studies document the reduction in the phytoplankton as a result. *Dreissena* also grazes on zooplankton, and there are studies that indicate a reduction in certain species of zooplankton. As this occurs, many more changes are likely to occur in the ecology of the lake. I am not an ecologist or an expert on this process, but I must raise this question: How can lakes support large populations of zebra mussels over time if the amount of food present is going down?

That question led us to wonder about a zebra mussel's ability to use bacteria as a food source. As Dr. Bob McMahon indicated, these animals are very effective filtration feeders. And as they filter, they take the particulates that are in the water needed for nutrients, and ingest them. If they do not need nutrition at that particular time, they wrap particulates up in mucus and secrete it as something called pseudofeces. The nutrients that aren't utilized but have gone through the digestive tract are deposited as feces. Bob McMahon mentioned problems from these deposits in terms of corrosion on the pipes and so on. Some of this undoubtedly occurs.

To find out if the zebra mussel can filter bacteria, we had to look at the gill. It is the organ that moves water through the mussel's body and is responsible for filtering out particles for nutrition. Much of what I say today is not unique to *Dreissena*, but, in fact, generally describes some of the functional filtration characteristics of bivalves. The title of this talk is a little misleading since I will only focus on the ability of bivalves to trap or filter bacteria and convert bacterial nutrients into clam proteins.

Basically a bivalve has two gills on either side of the animal. Each gill is organized into a series of filaments on both sides. The animal brings water into the inhalant siphon and draws it across its gills. Water moves down through filaments into a series of small openings and down into a central water channel and then finally out the excurrent siphon. The force for most of this water movement is produced by cilia. These also trap food particles. As water moves, any particulate matter that would be in the water is filtered and moved up to the frontal surface. When we studied this pumping and filtering process under a microscope, we were able to define, in detail, the specialized method and the body parts used in this process. Close examination of some of a gill's architecture suggest that it is probably capable of filtering particles much smaller than those of the size of the phytoplankton. We made available to the mussels some radio-labeled *Escherichia coli* (*E. coli*) in the water column to see if the zebra mussels, unionids, and *Corbicula* would be able to ingest them. (*E. coli* are one of the normal gut bacteria that are probably one of the most studied organisms in the world.)

We found that both *Dreissena* and *Corbicula fluminea* were capable of taking radio-labeled

E. coli out of the water column very, very quickly. *Carunulina texasensis*, the example of the unionid we used, does it very poorly in relationship to the other two species. Close examination of the gill structure in the three bivalves suggested that a reduction in cirri structure in the gills of the *Carunculina* is probably responsible for its poorer ability to take up the bacteria.

We then asked: is the bacteria trapped somewhere in this zebra mussel being used as a nutritive source by the organism? Remember, we had radio-labeled the bacteria in the water column. First, we let the zebra mussels rest for a couple of days in cold water, and then examined their bodies for stored radio-labeled bacteria. We found some. Was it digested and used, or just stored? We chemically digested animals and bacteria in the laboratory and ran out their proteins on an electrophoretic gel so we could determine whether or not there were bacterial proteins located in and amongst the mussel tissue which would suggest trapping. Our data suggests that not only did these animals trap the bacteria, they basically moved them through the digestive tract and used them as nutrients to produce protein. Since this experiment used *E. coli* , a laboratory strain, we then tested a number of other, different bacteria. To date we have tested six different bacteria with size ranging from 1-4 microns, all of them are used relatively effectively.

Coming back to my original question: is there some way that *Dreissena* is using a food source other than the ones that are being reported which allow the *Dreissena* to buffer times when other nutrient sources are scarce? This is important to you in terms of whether these animals are going to be able to establish in large numbers across long periods of time. Invasive species tend to multiply quickly and then the population levels off somewhere. I am suggesting that in a river like the Mississippi, zebra mussels will not be using bacteria solely as a nutrition source. They may use bacteria to buffer reductions in other food sources across time.

So far, our research has concentrated on the filtration mode of the gill. We haven't concentrated much on the water fluid movement through the gill. Future research should examine this physiological process as well. Consider, that in your control efforts, you might decide to treat these animals with one or another noxious substance. If you have water flowing through the gill and through the animal, the concentration of noxious substance ought to be less than what you are using because this animal is free to close down. If you could prevent this reflex, perhaps the effective toxicant load could be reduced.

SURFACE WATER USE AND INFRASTRUCTURE IMPACTS OF THE ZEBRA MUSSEL

Charles O'Neill, New York Sea Grant

One of the questions that we get frequently, usually from folks who either control the purse strings or who have been elected to oversee the people who are controlling them, is "what are the economic impacts of zebra mussels." We can say millions and millions of dollars, probably hundreds of millions so far here in North America, but we can't quantify it any better because, so far, most of the basic research has been focused on trying to understand the animal itself, and, applied research, on how to control the animal. In very early 1989, the US Fish and Wildlife Service (USFWS) put together a forecast for the Great Lakes (and only that area) which estimated around $4.5-4.7 billion worth of impacts over 10 years. The largest of those, about $2.7 billion dollars for fisheries due to a disrupted ecosystem just hasn't happened. But power generation, public drinking water, industrial navigation, are areas that have already surpassed those numbers. When you start looking at non-Great Lakes impacts, the whole Mississippi River system, the Illinois River, Hudson River, Mohawk River, Ohio River and now in the south, those figures could spiral much higher.

In the Environment

Although I am not going to talk about the ecological impact, I will point out that the way the zebra mussel secures nourishment — filter feeding — does affect your infrastructure settings. Remember each of those little critters, once they get to be about a centimeter or so in size, is filtering 1-2 liters of water per day. We looked at the mean chlorophyll in Lake Erie's western basin between 1988 and 1991, and found a significant reduction in the chlorophyll content. Another way to describe it: The old joke was that if you were out in Lake Erie and stuck your hand overboard to the elbow and wiggled your fingers, you couldn't see them. In 1990 and 1991, we could see items down to a 2-2.5 meter depth on that same location. Some areas in Lake Erie right now, 1995, are being described by charter fishing captains as so clear that they can actually see bottom structure in 15-25 feet of water.

What does that do to your public drinking water facility? Many public drinking water facilities normally flocculate (accumulate and settle out solids in the water) by using a certain amount of particulate matter already in that water. In some cases, the zebra mussels have cleaned that water so much that there is not enough naturally occurring particulates to effectively settle the water out. Some have already had to change from treating with alum to treating with some of the polymers to effectively clean the water. A rather bizarre impact, but it is one that means an increase in operating expenses, and probably a little bit more time and effort.

In the Infrastructure

One of the strategies brought up at an early stage is: Which underwater structures are the most vulnerable and upon which materials do zebra mussels prefer to settle? These questions are related to the way the zebra mussel attaches to structures — the byssal threads. These tough, elastic threads are probably just about as tough as a strand of natural silk. Each of those threads is tipped with a small disk at which point a several part adhesive, very much like an epoxy, comes together and glues the critter to whatever hard substrate it happens to want to settle on. Typically they attach to stone (the cobble or rip rap under water or at the shoreline) and to wood, although they have been found on all

sorts of substrates, everything from concrete and various metals to plastics and fiberglass. We are also now seeing zebra mussels colonies on soft silted bottoms. At the beginning, the zebra mussels probably attached to a small piece of driftwood or shell, a unionid mussel sticking up, and then they start forming on top of one another, sort of like scabs. We have also seen very heavy colonization of macrophytes, rooted, aquatic vegetation, to the point that the vegetation collapsed to the silted bottom and then provide the nucleus for the colonization.

Zebra mussels do not like copper. At the water-metal interface, there is a lot of ionic transfer going on, and copper ions are lethal to many marine organisms. These ions are probably irritating to the little, drifting mussel, so it remains in the water column. Brass is very similar to that. Zinc in the coatings of galvanized surfaces probably has the same type of an effect. However, once that copper or brass becomes oxidized and you get that patina (characteristic green coating) on the surface, the ionic transfer decreases. A biofilm builds up and zebra mussels attach to it.

Do coatings prevent zebra mussels from attaching? Zebra mussels will attach to silicone-coated surfaces; however, once they are attached, it takes much less energy and effort to remove them from a silicone-coated surface than from uncoated surfaces. They like the older style Teflons, although I am told that there will soon be some new Teflons that have a different surface chemistry.

Is there a pattern to settlement? Let's take a look at some of that by considering the famous zebra mussels car. A disgruntled former owner from whom the car was repossessed pushed it off of a pier on the Canadian side of Lake Erie. It was pushed into the water in October, when there shouldn't have been a whole lot of zebra mussels spawning going on. It was pulled out of the water the next spring before the water had warmed up to the point where there was a lot of spawning going on. However, when it was pulled out, the car was covered with zebra mussels. Apparently juveniles living in the area, who at 2, 3, 4 mm, could still rip loose from their byssal threads, crawled around on their foot looking for the best habitat they could find, and they settled on the car. The zebra mussels had colonized in heavy numbers on everything — the metal components of the car, fiberglass bumpers, the wide oval tires, the wheels, inside the car on the seat belt webbing, the seats, dashboard — very heavy infestation. This indicates that, even during the winter when there isn't spawning going on, you do have juvenile translocation. Zebra mussels are still settling, even when you don't think there is any kind of spawning occurring.

The famous car also tells us something about zebra mussels out of water. Even after the car had been out of the water for several days, some mussels remained alive. Inside the car where it was very wet, very shaded, some mussels were alive about 10 days. Zebra mussels can therefore live on boats out of the water on trailers for more than a day.

How Do People Feel The Impact?

Zebra mussels can affect aquatic recreation. They do colonize near-shore cobble and rip rap from about a meter depth on out. In a lot of areas, that means that people wandering along and going swimming at recreational beaches will be walking on zebra mussels. In the Great Lakes, most of Lake Erie and Ontario right now, people do not walk barefoot in the water. People wear surf socks, beach booties, or other foot gear to keep their feet from being cut by zebra mussels' very thin, brittle, sharp shells. When storm waves scour the bottom, rip a lot of those mussels loose and throw them up

on the shoreline, they foul beaches. If you have ever smelled zebra mussels rotting in the noon day sun, you will not forget the experience. Also, the growth of bacteria in that decomposing flesh could be a public health problem. An example is a beach near Toledo, Ohio, which had almost a mile of shoreline littered with a 12-14 inch-deep band of rotting zebra mussels.

Commercial navigation and recreational boating are also affected. Once the mussels are in a waterway and start attaching to the hulls of boats, whether it is a commercial vessel or not, the more mussels, the less efficient that vessel is at cutting through the water. Zebra mussels cause an increased use of gasoline and decreased speed efficiency. More important, though, they clog engine components from the intake to the cooling jacket. On oceanic vessels, the cooling components are made very large bore because, between dry docking periods, that boat has got to be able to sustain barnacle growth. Freshwater vessels, on the other hand, have much smaller pipes. On recreational boats, those pipes may only be a tube the size of your small finger. Once that starts getting mussels growing in it, you have a system that can become clogged. It will be choked off for water. Your engine starts to overheat. If the zebra mussels break loose, they can break impeller blades as they pass through the system. From the cooling jacket out, you will not have mussels. We have seen a number of boats in Lake Erie stalled. The engines seize up while they are way out from shore, a couple of miles from shore, because a clump of zebra mussels broke loose, hit the impeller blades; no impeller, no cool water. We have seen navigational buoys sunken from the weight of zebra mussels.

But the big impacts are the biofouling of raw water intakes, and it doesn't matter what kind of raw water intake you are talking about. They are all at risk. Public drinking water treatment facilities, private residential facilities, and power plants of all kinds are affected. The intake mains, the pumping wells themselves, the screen house walls, even the traveling screens strainers, surface water lines — particularly the smaller lines, condensers and heat exchangers can be affected. We have seen traveling screens with so many mussels on them that they have jumped the sprockets and had to be taken out of commission for cleaning. Hydroplants, thought to be safe because of the velocity of water passing through the raceways to spin the turbines, are vulnerable from the water that is being used to cool and lubricate bearings and to cool transformers. Fossil fuel plants, nuclear plants that are using water for cooling and lubrication, and in firefighting are at risk. Industrial facilities using it for processed water, flushing water, firefighting water, and cooling are also at risk. Agricultural irrigation can be affected, particularly systems that are running a low amount of flow through a system from a raw water system. Golf courses have experienced major impacts up north because many draw their water from the Erie Canal. All of these had problems with the mussels plugging up their spray heads. Shells abrade the pump surfaces of firefighting systems, and the trucks become contaminated when they are filled from zebra mussel-infested water. When these are later pumped into a basin that doesn't have zebra mussels, the fire truck becomes a transmittal vector.

In dams and impoundments, some of the areas of particular concern are the outflow structures and the outflow tunnels themselves. Although the outflow structure on a dam is often large, it is not necessarily immune from zebra mussels activity. Enough zebra mussels on a valve seat, even a large 3-4 foot diameter butterfly valve, may not seat properly when it has been left open. If zebra mussels settle on the grooves that the stop logs have to drop down through, unless the stop logs are very heavy and extraordinarily large, the animals will keep those systems from sealing off properly. The intake structures in the infrastructure facility at power plants, anything from the intake crib in the trash racks

out to the lake or river can be covered. Trash racks, that once had spacing between the bars of up to six inches, appear to be solid.

Pipelines are homes as well as tunnels for zebra mussels. Generally speaking, if you have enough oxygen and still food in there, the mussels can live virtually throughout the pipeline as long as you are providing those basic needs. The pipeline leads to all of the pumping and handling facilities in the hydro plant. One layer of 1-2 mm zebra mussels on the inside of a pipe does destroy the laminar flow through the system. It gives you a very turbulent flow and can easily, on a pipe that is 2-4 foot diameter, cut your maximum pumping efficiency down by 10 or 15% before it starts choking down the diameter of the pipe. Why is a pipe so desirable to the zebra mussel? It is fairly simple. Zebra mussels in a water pipeline are protected from predation (fish, muskrats, raccoons, and the diving ducks), and from severe weather (storm waves, winter, cold water). You have given them a continuous source of new oxygen, food and you are washing away their waste by products. In other words, it is pig heaven inside a pipe for a zebra mussels colony. Even the smallest pipe is vulnerable. Low flow piping provides a long dwell time for the mussels to be able to settle, colonize, and allow their offspring to stay around to colonize as well. Dead end piping, particularly where the mussels aren't floating through, makes a great settlement spot. Once they do get in there, the zebra mussels will multiply quickly using a very high recruitment of their own larvae.

Fire protection systems using raw water from a lake or stream are particularly vulnerable. The mussels will colonize and make the valves and valve plates stick. We know of at least one facility in the Great Lakes that lost fire insurance temporarily when the insurance underwriter found out they had more zebra mussels than water in the system. An infestation would lead to loss of head and loss of pumping efficiency in those areas. Condenser tubes can be obstructed, too, although the flow through a condenser tube is usually fast enough that the mussels can't attach inside that tube while the system is operating. However, the mussels can still get into it. Zebra mussels break off in clumps called druses. These druses tend to be from about 1.5 inches to around 2.5 inches in diameter, based on the size of the mussels and the thickness of the colony that is starting to break apart. When these are drawn downstream into condensers, your system slowly loses efficiency until, sometimes, a maintenance shutdown is needed. Some facilities on the Great Lakes report that they have to slowly de-rate their units as they plug up until they reach a point where that unit is taken out of commission for a major clean out.

And not to leave those of you from water authorities and drinking water facilities out of the picture. If you let the situation get bad in your intakes, it is possible for rotting mussel meat to enter a public drinking water facility. Your customers will complain about bad tastes and smells.

There is no reason why anyone in North America should have to deal with those kinds of problems now. Back in 1988, 1989 up in the Great Lakes, we didn't have this kind of experience to benefit from. We knew the kinds of problems they had in Europe. We didn't think they would develop as quickly as they did over here. But with the knowledge we have now, we want to get this information out to people like you, in the Lower Mississippi River, so that it doesn't happen again.

THE NONINDIGENOUS AQUATIC NUISANCE SPECIES PREVENTION AND CONTROL ACT OF 1990

Charles O'Neill, New York Sea Grant

Congress reacted quite rapidly, rationally, and comprehensively, actually, with a national response to the zebra mussels invasion. The result was the Aquatic Nuisance Prevention and Control Act of 1990, public law 101-646. The primary sponsors in the House of Representatives were Congressman Henry Nowack of New York, Congressman Horton also of New York, and a handful of others. In the Senate, the persons who carried this act through to fruition was Senator John Glenn of Ohio and Senator Daniel Patrick Moynahan of New York. Basically this bill, although it is usually referred to as the Zebra Mussels Act, refers to the introduction of all nonindigenous aquatic nuisance species into the U.S., not just the zebra mussels. The bill's intent is to prevent future nonindigenous introductions, whether they are intentional or unintentional, and dispersal once they get here.

The bill provides a mechanism to coordinate the research, prevention, and the control aspects as well as information dissemination of aquatic nuisance species (ANS). The bill emphasizes developing aquatic introductions for control that are environmentally conscious, and environmentally sound responses. Also, the bill talks about minimizing the economic and the social impacts of such introductions as well as the economic impacts of control measures that are taken. It establishes and encourages the technology transfer and the research to address these issues, to be able to get that information done by the right people, whether it is at the federal, state, or university level, and facilitates getting that information out to the people in the real world who actually have to use it.

The act set up an ANS Task Force at the federal level which included a number of the major players who are going to have to be involved if such species are introduced in the U.S. The U.S. Fish & Wildlife Service (USFWS) is one of the co-chairs of the overall ANS Task Force. The Oceans and Atmospheres Division of the Dept. of Commerce, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency, and the U.S. Coast Guard are all represented on the task force. The Army Corps of Engineers is the strongest player in terms of public infrastructure and researching applications that utilize technology while protecting the infrastructure. Other federal agencies and programs are brought in by the ANS Task Force as needed.

The ANS Task Force has been doing some very good work on coordinating the federal response to nonindigenous aquatics. For example, the ballast water program, (the way zebra mussels and other nonidigenous species first entered North America) has been coordinated by the Department of Transportation. It looked at the environmental effects of ballast water exchange, not only on what it is bringing in, but on the diversity and the abundance of native species in the receiving waters. In other words, they took a look at what was already there, got the background data, so that when a nonindigenous species is introduced, we will know it happened and be able to predict the effect on the native ecosystem. It is very possible that some nonindigenous species may have very little effect.

The ballast water program gave the U.S. Coast Guard responsibility for developing guidelines for international shipping and local shipping coming into the Great Lakes. Before the law even passed, these first suggested dumping that ballast out in the ocean, and flooding the ballast chambers with salt water before entering the North America via the St. Lawrence Seaway. The voluntary

compliance was good. Over 90% of vessels coming into the Great Lakes complied. During the 12-month period following the passage of the law, a major educational technology transfer program was conducted for the shipping companies to get compliance, and at the 24-month point, the Coast Guard implemented enforceable regulations to prevent fresh water ballast introductions. Those regulations *are* enforced. They call primarily for offloading fresh water ballast at the 200 mile limit in the ocean and flooding with saltwater ballast unless it can be proven that a ship cannot safely do that kind of ballast transfer on the high seas. The bill allows for boarding of vessels for random checks on the ballast tanks to see if they are filled with saltwater or freshwater. There are provisions for civil and criminal penalties for ships that don't comply. Very early on, the Coast Guard did board several vessels that turned out to have fresh water still in their tanks. I believe one or two vessels were turned around and sent back out to exchange that ballast. When you look at the operating costs on an international ship, you are looking at about $10,000 a day in order to turn around and head back out the St. Lawrence, reflood and come back in. It made the point. Right now that compliance is up close to 100%.

Unfortunately, these regulations came a little bit late, and we have had a number of other species introduced into the Great Lakes along with the zebra mussels over the last several years. They are looking at the potential of extending these regulations to other waters of the U.S. as well.

The Act also set up research, technical assistance and education programs. Some of those research funds were administered through the Sea Grant programs and USFWS Cooperative Fishery and Wildlife Research Units. Technical assistance is provided to state and local governments in order to be able to enforce and implement the same types of things that the federal law calls for, and educational programs, primarily led up by the Sea Grant Marine Advisory Services programs as well as other agencies involved in public outreach like USFWS, in order to get this information out to the user audiences.

The bill also provided funds on a 75%-50% match for two types of state management plans. Generally a state can develop a plan for what they will do for public facilities to protect them, prevent introductions of aquatic nuisance species, and to remediate the problems caused by these introductions. A state can also submit comprehensive management plans to look at nonpublic facilities and impacts. Those plans must identify what problems might result from the introduction of nonindigenous aquatic species, describe specific management practices that could be implemented in the state by the state and federal governments and other partners to control those problems, and to undertake the remediation that might be necessary. Through the USFWS, assistance can be secured for prevention and protection programs for the nonpublic area, and the Army Corps of Engineers is involved primarily in remediation type activities for public infrastructure. Unfortunately we have not seen very much money coming down to do this.

The Great Lakes Panel was established since the zebra mussels and most of the other aquatic nuisances that fall under this law came into the Great Lakes first. This panel began making immediate recommendations to the ANS Task Force for implementation so that information can quickly be circulated to the rest of the country. They have done a pretty good job on that.

The task force has completed the generic aquatic risk assessment process. They have come up

with a research protocol which has been approved, and they are also looking at the control plan for the river ruffie which is in the upper Great Lakes. Generally, for fiscal 1995, the National Sea Grant Program was supposed to receive $2.8 million for zebra mussel research, outreach, and education. Research and education activities for the U.S. Army Corps of Engineers was set for around $3 million, USFWS, for a little over $4 million. Many other agencies are also funded to participate. The Act has never been fully appropriated. There has never been $35 million a year appropriations to match the authorizations.

Remember, the Act looks at unintentional and intentional introductions of these nonidigenous species. I bring this up because the lower Mississippi drainage basin tends to have a lot of aquaculture operations. Bait fish are being shipped out from the area throughout the entire U.S. and a lot of people are concerned with intentional and unintentional introductions through intentional activities such as aquaculture. The act provides for education and extension operations to make people more aware of the nonindigenous species issues and to understand the risks of unintentional introductions. It funds some research into those areas to determine or identify the associated risks, to try to develop ways to ensure that any kind of an introduction is pathogen free, and to try and use indigenous species wherever possible rather than bringing in nonindigenous species.

This last point, the use of indigenous rather than nonidigenous species, is very important in relation to zebra mussels control. A number of fish species have been identified that will eat zebra mussels. Some of those, the black carp and the red eared sunfish, could disrupt other lake ecosystems if they were intentionally introduced in order to control zebra mussels. This act tries to ensure that the "cure" is not as bad as the "disease" itself.

The bill provides for states and/or private industry, in this case it could be the aquaculture industry, coming up with their own codes, their own better business practices, and their own protocols for being able to ensure that they are shipping noninfested product. Private effort and industry self-regulation would work out a lot better than 50 individual state laws (none of which may coincide with others), and it would probably be a good marketing maneuver for the aquaculture industry as a whole to be able to say, "We can provide zebra mussels free product. We can certify it."

THE NEED FOR LOCAL AND REGIONAL MONITORING NETWORKS

Charles O'Neill, New York Sea Grant

Let's look at monitoring from the administrative perspective. Why do we need to do monitoring in the first place? I would like to set the stage for working as task groups and address questions like why should we standardize, why should we set up region-wide monitoring programs instead of limiting efforts to local ones at our own facilities, and I want to discuss why we should continue to monitor after we find zebra mussels in our facilities.

Why do we monitor? There are a number of different reasons for wanting to monitor. (1) If you are in a facility or any area that doesn't yet have a zebra mussels problem, early warning could make a difference. Monitoring before zebra mussels enter your area allows you to figure out when the mussels get to your area of the river, when they get to your waterbody, and of course when they get to your intake. It also helps you be able to notify people further on down or further inland to the fact that the mussels have arrived in your region. In the Mississippi River Basin, some of these early warning systems were ignored. I have been told by a number of facilities on the west side of the river that existed right across from facilities on the east shore that did have zebra mussels that they weren't taking any actions yet because they didn't know if it would ever really affect people on the west side of the river. Early warning systems and monitoring programs work better if everybody decides to buy into the issue.

(2) Responsible control programs, programs that are time-, cost-, and labor-efficient require a good ongoing knowledge of what the situation is, out in nature, out in your source water as well as in your facility itself. Regular monitoring provides information not only about the mussels' presence, but population density, animal size, etc. Are the veligers newly hatched or ready to settle? If you draw something into your facility that is not ready to settle yet, keep it in suspension as it goes through your facility, and it goes out of your discharge, you don't have a problem. The problem becomes your neighbor's down stream. They are sucked into his facility when they are a little bit older and ready to settle. With monitoring, you could share information with your neighbor. It also pays to know what the densities are. If you are drawing in water that is measuring zebra mussels veliger counts in fractions of veliger per liter, you have a different situation for your facility than if you are drawing water in containing 100 veligers per liter.

(3) Monitoring gives you a chance to evaluate the success of your control program, once you do institute it. If you know what you have coming in, staying and leaving, you are equipped to identify the best, most cost-effective control measures that you can use.

(4) It is important to know when your local populations begin to decline. Now we haven't seen any populations really declining yet here in North America. But at the time when we have gone through the exponential growth, have hit a very high plateau, and then hopefully see population crashes, it is going to be important to know when that takes place because, at that point, we may be able to modify our control programs to suit that new lower level. Zebra mussels probably won't ever entirely disappear.

Why monitor regionally instead of concentrating on your own facility? Everybody can work together. It gives you the big picture. Instead of knowing what is just happening out in front of your intake, it gives you a chance to know what is happening throughout that source body. The big picture provides realistic data for planning. And, if everyone is monitoring in the same way, researchers can get good reliable consistent data many places, giving them a chance to study the population and spread dynamics, and share that information with you. Regional monitoring maximizes the sampling sites. Rather than just having one or two sets of plates and perhaps a plankton tow periodically out in front of one pipe and bioboxes inside one facility, these are in place throughout the area. Zebra mussels veligers at times are unevenly distributed in the water column. If only one place is sampling, the veligers' presence might be missed. If you have got many sampling locations in the same waterbody, the chances of picking them up early are greatly enhanced. This is cost effective for everyone.

Monitoring networks are important. There are a couple of different ways of approaching a network. You can establish an industry-specific network. We have seen this in New York State when the Empire State Electric Energy Research Corp., a research arm of the New York Power Pool, hired one consulting firm to do statewide monitoring so that all power plants in the state on vulnerable waters were monitored in a uniform manner. We have also seen public drinking water facilities that have banded together and developed their own industry-specific protocols and monitoring networks. Another approach is the agency or multi-agency approach. For example, if an agency like U.S. Fish & Wildlife Service, state department of environmental conservation, or your fish commission, was working throughout a region, their field staff could monitor for zebra mussels in the course of their regular routine. The most efficient and effective way of doing this is a government-industry combination, when all who are monitoring work together. By standardizing the monitoring protocols, you maximize the effective use of field staff and money. Probably the largest nationwide monitoring and reporting networks are the one which is operated by the National Biological Service out of their Gainesville, Florida, office. They have developed a nationwide geographic information system for all types of nonindigenous species, not just zebra mussels. They have a very good, very comprehensive form to get all of the data on every introduction, and to be able to certify that each of those sightings is, in fact, an actual introduction. We operate the Zebra Mussel Information Clearinghouse through New York Sea Grant. Information on zebra mussels is shared on a monthly basis between the U.S. Fish & Wildlife Service, the U.S. Biological Service, and the Zebra Mussel Information Clearinghouse. You can share your sighting information with any of these.

Now why standardize the monitoring protocol? Although several different monitoring methods will work, the results are difficult to compare. The data is like trying to compare apples and oranges. The standard protocol gives us a way of being able to meet every user's needs for this information in a way that can be compared from sight to sight. It also allows researchers to be able to do a lot more quantification of the results rather than just having qualitative information. And if you follow the same kind of protocol each time you go out, you have a chance to replicate the results and be able to certify whether or not a result was accurate.

A minimum standard protocol looks at more than presence or absence of zebra mussels. For example, if you call us with a sighting, we'll probably ask you the date and location of the sample, the habitat type, what the water depth was at the time of the sampling, water temperature at that depth,

some of the limnology characteristics such as total salinity, dissolved oxygen, pH, and calcium. We would like to know turbidity, substrate and vegetation types at the location, and how the sample was collected (in other words was it a settlement plate, was it observation on natural or manmade substrates, was it a plankton tow or a pump sample).

Two ways of approaching monitoring are either presence/absence — do you have zebra mussels — and by actual density. In other words, you can gather qualitative or quantitative data. The type of monitoring program that you do depends on what use you have for that information, and the degree of infestation.

Presence/absence monitoring helps you define the mussel's location, and their actual presence in your facility or in your water source. Who has it, where is it coming from? From this, you can sometimes predict "when will it arrive?" (They don't always settle or migrate as predicted.) This type of monitoring also gives you a chance to look at the animal in different life stages, but it tells you nothing about quantity.

Density monitoring requires that you actually look at the population —whether it is settled, in what life stages (juveniles or adults), how many, and where? (in the water body, in front of the intakes, inside the facility). These data give you a chance to look at population dynamics. You have something with which to compare at a later time or at another location in your area.

Presence/absence monitoring can be done several ways. (1) Plankton monitoring, or veliger sightings, gives you a head start. Veligers are going to show up first before the juveniles and the adults. If you can find veligers coming in, you might have time to plan for the adults who will follow. But veliger distribution tends to be a little bit patchy. If you happen to sample in the wrong location, day, or hour, you may miss veligers. Veliger sampling is also much more time- and labor-intensive. A sample is taken on sight, then removed to the laboratory for examination. You will use a special net and you have to carefully take water samples. A technician should do this type of sampling, because you might have zebra mussels, or you might have other ostracods. Sampling the substrate for presence and absence of juveniles and adults is less labor intensive. Substrate can be monitored by anyone; in fact, you don't need a technician. Anybody can pull up the plates, put them in a Ziploc bag and then send them, on ice, to the laboratory to be verified. Generally it doesn't require specialized equipment. You can take a scraping from a large expanse of concrete or steel or whatever type of substrate is in your facility, or draw the water down, take a look at it, and take a scraping. Often that is going to be much more effective than suspending a six inch piece of Plexiglas someplace in that facility. Settled mussels are generally easier to identify than veligers, particularly in a very sediment-rich situation. These give you information about settling densities where the veliger count doesn't. A veliger may show you pediveligers, but your actual recruitment (the number that settle) is not shown by a veliger count. You need settling data from the substrate sampling.

Why continue monitoring after zebra mussels infest? We know that they are in the Lower Mississippi Basin, so why continue to monitor? One reason is to optimize your control. For example, in the Great Lakes where we generally do not have mussel veligers present year round, monitoring helps you determine when to use your chemical control methods most effectively. When you see the veliger numbers start to rise during the spawning season and until you start seeing organisms that are

of settling stage, you want to institute treatment. This also allows you to save money and be a little bit more environmentally friendly by using less chemical. Knowing densities, locations and numbers of zebra mussels in your facility will help you optimize the use of routine maintenance and maintenance shutdowns, adjust the operations program, so that the zebra mussels do not cause shut downs or serious losses. A number of facilities have chosen not to do chemical treatment, rather using physical controls which they include during other maintenance shutdowns.

In conclusion, monitoring can optimize treatment effectiveness. Without some data and a regular monitoring program, you won't know if you've removed or killed 100%, 90%, or only 50% of the mussels that are in your system. Monitoring region wide, or industry wide, can increase your knowledge about the mussel in your area and optimize the monitoring efforts by all in the network.

THE ZEBRA MUSSEL INFORMATION CLEARINGHOUSE

Charles O'Neill, New York Sea Grant

The Zebra Mussel Information Clearinghouse is a national project housed and operated by New York Sea Grant, but it is the nationwide zebra mussels clearinghouse project. The Clearinghouse was established in 1990 to be two things: a technical collection or technical library, and a newsletter publisher.

In 1990, as quickly as we could, we assembled as much of the European research as was available on zebra mussels. Now we are continuing to add all of the new work that is being done here in North America to a technical collection which, we believe, is the largest, most complete, and comprehensive collection in North America. This library is available for anyone who wants to make access to those materials. We've got a number of different things in it. *Dreissena polymorpha* papers cover everything from biology and ecology down through impacts and control, spread, and population dynamics. We have added a section for *Dreissena bugensis*, the quagga mussel, as well as other organisms (*Corbicula, Mytilopsis*) that are related closely enough so that we can learn something about zebra mussels and macrofouling from them. The technical collection numbers about 2,000; the bulk of these articles are in English, although there are a certain number of them that are in foreign languages. (Quite a few of those do have at least an English abstract or an English summary and the data tables are usually helpful, even in a foreign language.) This past fall, we started having certain papers translated; most were selected by a panel of researchers here in North America.

That technical collection is accessible to everyone. Our goal is to get the information into researchers hands as quickly as possible to save them research time and effort. Most are available in hard copy from the Clearinghouse as interlibrary loan items for a photocopying fee. We also have abstracted most of the English language articles, which are now being beta tested on an electronic database which currently resides in a small portion of the Internet. We expect to be able to get these articles on the Internet so anyone who has computer capability may access the entire collection, search through keywords, and review the abstracts to determine whether they want to get a copy via interlibrary loan.

The Clearinghouse publishes the newsletter *Dreissena polymorpha Information Review.* Because we've recently recognized the value of information on *Dreissena bugensis,* and we didn't want to extend the newsletter title, the newest issues are just called *Dreissena.* It comes out in six regular issues per year and usually two special issues. There is usually a special conferences abstract issue and a bibliography issue. (That is usually a limited bibliography, not everything from the collection, but all of the *Dreissena* portion of the collection.) *Dreissena* is available from the Clearinghouse by subscription for $60 a year. That covers most of the production costs for the newsletter.

The newsletter contains a sightings map that is updated by the Clearinghouse every two months. We try to keep the publication research- and policy-based. We print a lot of research reviews in it, information on projects that haven't come to completion so they haven't been published in peer review journals yet, but interesting interim data is available. We also use the Corps of Engineers technical notes as bases for the control papers that we print.

We started out with quite a bit of industry funding to launch the newsletter. Some of our supporters are the ESEERCO (Empire State Electric Energy Research Corp.), private utility money; NSGCP (National Sea Grant College Program), federal money that has gone into mainly staffing the Clearinghouse; EPRI (Electric Power Research Institute), some public drinking water facilities, and Eastman Kodak.

THE LOWER MISSISSIPPI BASIN ZEBRA MUSSEL TASK FORCE & NEWSLETTER

John Forester, U.S. Fish & Wildlife Service

I would like to give you a brief history of how I got into zebra mussels sampling. In 1991, my office was located in north Louisiana on the campus of Northwestern State University. I was sampling fish populations on federal lands in Louisiana and a couple other states when the Atlanta regional office sent me down to the Mississippi River to sample for an animal I'd never heard of — the zebra mussel. So we set up sampling stations at river mile 540 which is near Greenville, Mississippi and sent all our samples to Ann Arbor, Michigan (At the time, it was the U.S. Fish & Wildlife Service Great Lakes Research Lab) and Dr. Susan (Jerry) Nichols. She detected no larvae in our samples during 1991. Late spring of 1992, we began sampling at the same site. We found nothing there until mid summer when larvae were discovered from our sampling plates. So we added a sampling station at Vicksburg (RM 440) and, during the summer, we started seeing larvae there, too. Additionally, scattered juveniles and adults were collected at both stations during summer and fall. We contacted the Zebra Mussel Clearinghouse in New York and the National Biological Survey (which at that time was a Fish & Wildlife Service as well) in Gainesville, Florida, and reported our findings. At the time, zebra mussels were still confined to the northeastern portion of the U.S. and there were no reports down where we were at the time.

We also had some placards produced by Sea Grant about the new discovery, and began distributing these to various industries and state agencies along the Mississippi River and tried to warn them about these little critters coming down the river.

The zebra mussels continued their expansion down river, and we began getting reports in areas above Baton Rouge in early 1993. We knew some industries were beginning to put out sample plates. They weren't finding anything in late 1992, but in early 1993 they began seeing just small quantities of zebra mussels on these plates.

In April of 1993 we had our first workshop — New York and Louisiana Sea Grants, the Cooperative Extension Service, and U.S. Fish & Wildlife Service, and in June of 1993, my office was moved down from Natchitoches to the LSU campus. Due to budget cuts, I had to stop sampling, and leave that to volunteers, researchers, and professional control companies. In January of 1994, we joined Louisiana Sea Grant to sponsor a meeting of 20-30 representatives from state and local governments as well as private industry and tried to establish some kind of a little group to pass information back and forth. We formed the Lower Mississippi Valley Zebra Mussel Task Force. I volunteered for the coordinator position. A little bit later I was actually named the Non-Indigenous Aquatic Nuisance Species Coordinator for our region of ten states. We began to exchange information through a newsletter written by Marilyn Barrett and me, and have been publishing twice a year, just after spawning, when activity is heavy. Our major goal is to try to pass information to people, especially those who are trying to treat this mussel at their facilities, trying to keep the cost down but also have an effective treatment to get rid of this little creature or at least keep its numbers down.

Marilyn and I are talking about the possibility of expanding the coverage of this newsletter. It

has been more or less Louisiana-based. We have had some input from the states of Arkansas and Mississippi, but this is happening so fast that we haven't been able to expand the way we would like.

My background causes me to be concerned about what may be happening out in the wild. I know that in the Atchafalaya Basin, which is a 320 square mile area just to the west of the Mississippi River (an outlet of the Mississippi, a distributary), a couple of months ago we found zebra mussels. They were attached to vegetation, hydrilla, and miles off the main stem of the Atchafalaya. There is quite a heavy infestation of zebra mussels in various parts of the Atchafalaya already, and this new find shows they have migrated laterally from the main stem of the Mississippi River faster than we had anticipated.

THE LOWER MISSISSIPPI BASIN: WHERE TO FROM HERE?

Marilyn Barrett, Louisiana Sea Grant

Two things keep coming to mind as I listen to the presentations and visit with you during the breaks. One is the desire on many peoples' part for a quick fix. You are asking: How can we get rid of these things and not have to spend much money? Second, everybody has a different idea, and everybody has a different monitoring protocol or monitoring form. It is pretty clear that this animal is migrating and adapting faster than anyone expected and in different ways than were expected. We need to work together to counter this.

Let's immediately dismiss from our minds the idea of a quick fix. Zebra mussels are not a disease that we can inoculate against or an infection to which we can quickly apply an antibiotic. We have to look at this situation as a long term change in our environment, a new animal that is coming to live in our plants, rivers, lakes and streams. We need to understand the animal in order to control it; we want to control it so it doesn't disrupt our business or our aquatic recreation. We may have to change our procedures to control it. We need to also think about the fact that this animal isn't just coming to one or two of us. It is not just coming to your power plant or your chemical plant, it is coming to all of us.

With these thoughts in mind, John Forester of the USFWS, Sea Grant's staff, and, in fact, a lot of industry people have been talking about coordinating our monitoring process. If we were all monitoring the same way, following the same protocol (the same procedure) during similar time intervals and recording similar information, and if we were all reporting that information to one place, scientists like Dr. Dietz, Dr. Lynn, Dr. Thompson and Dr. McMahon could look at a much larger volume of data and learn more about the animal. They could share that information with us in a timely fashion. It is important that data coming from different places be labeled about where it came from, when it came, and that it was sampled in a certain way.

I want you to think about the idea of coordinating your monitoring efforts in this way. LSU Sea Grant has started talking with one industry, Entergy, about starting a pilot program so that all of the Entergy plants will monitor in the same way and the data from monitoring will be coordinated and interpreted at LSU. But there is no reason why we have to limit this to Entergy. There is no reason why we cannot coordinate, work together with more than just the Entergy power plants. All of us will benefit.

This is a little different than many problems that we get in our industries and within our programs where we think, "It would be nice if the competition had the problem but we didn't." This animal will most likely try to settle in our plant and our competition's plant. We help ourselves by cooperating. So, with that in mind, I would like to ask you to give us your name, your company's name and phone number if you are interested in working on a coordinated effort, and we will get back in touch with you to work something out.

I would like to also propose to you that we expand the Lower Mississippi Valley Zebra

Mussel Task Force to include more than the original 30 members. This would mean that your company, if you decided to join the task force, would give us any information you had on where you found zebra mussels and when and in what density in both the veliger and the adult stage and we would include that in the newsletter. When you have a chance this evening to look at the newsletter, you will see that it is a very conversational newsletter. Each industry that has found something is listed, where they found it, how they found it, and a phone number is there. The reason for the newsletter is not just to disseminate information, it is to encourage different groups to talk with each other, to share, because the real way that we are going to help ourselves is to work together.

DEVELOPING ENVIRONMENTALLY SOUND METHODS AND STRATEGIES TO CONTROL ZEBRA MUSSELS AT PUBLIC FACILITIES

Dr. Andrew C. Miller, U.S. Army Engineer Waterways Experiment Station

(This article combines both of Dr. Miller's talks at the workshop: THE U.S. ARMY CORPS OF ENGINEERS ZEBRA MUSSEL RESEARCH PROGRAM and CONTROL ALTERNATIVES FOR COMMERCIAL NAVIGATION AND LOCK & DAM STRUCTURES. The reference given at the end of the article is part of a collection of information available from the U.S. Army Corps of Engineers on zebra mussels.)

The Zebra Mussel Research Program of the U.S. Army Engineer Waterways Experiment Station, authorized by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (PL 101-646), was designed to develop and demonstrate environmentally sound zebra mussel control methods at public facilities. Research is being facilitated by working groups that deal with: 1) locks and dams; 2) vessels and dredges; 3) power facilities; and 4) reservoirs, water intakes, gages, and pumping stations. Each working group consists of individuals with expertise in zebra mussel control, biology and ecology of zebra mussels, and design, construction, or operation of the facility of concern.

Today I will briefly describe results of selected demonstrations that are part of the program: 1) effects of reduced temperature and desiccation on mussel mortality at Black Rock Lock, Buffalo, NY; and 2) effectiveness of an air injection system in causing zebra mussels to release from the wall of a navigation lock in the Ohio River.

Potential odor problems from large numbers of dead zebra mussels and the need to comply with mandates of the National Environmental Policy Act when developing a zebra mussel control program will also be discussed.

Zebra mussels (*Dreissena polymorpha*), first reported in North America in 1988, have rapidly spread throughout waterways of the United States. Hulls of commercial navigation vessels are probably responsible for much of their rapid dispersal. It is likely that this species will negatively affect many facilities in the inland waterway system.

The U.S. Army Corps of Engineers (USACE) maintains and operates 195 locks, 75 hydropower stations, 461 reservoirs, and 2,260 vessels and dredges. With the exception of those located in brackish waters, most are susceptible to zebra mussel infestations.

In response to the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Public Law 101-646), the USACE initiated a research program to develop and demonstrate zebra mussel control methods and strategies at public facilities. "Public facilities" includes locks, dams, reservoirs, commercial dredges and vessels, as well as non-Corps structures such as intakes for power generation, potable water, and sewage treatment. The research program was designed to develop new and evaluate existing zebra mussel control methods, and to study the biology, ecology, and spread of this species. Studies are being conducted at the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi, and the U.S. Army Construction Engineering Research Laboratories in Champaign, Illinois.

Laboratory studies are being conducted on the effects of reduced and elevated temperature,

carbon dioxide, lowered dissolved oxygen, and desiccation on zebra mussel mortality. The effects of physical stress on stored energy reserves and reproductive output are being investigated, as are effects of high-density zebra mussel populations on water and sediment quality, native mussels, and other aquatic macroinvertebrates. Selected chemicals, antifoulant coatings, and cleaning techniques for zebra mussels are being evaluated.

Multi-disciplinary Working Groups

In September 1991, the USACE held a planning meeting on zebra mussels at Fort Mitchell, KY. Over 50 scientists and engineers with experience in the design, operation, or maintenance of locks, dams, and reservoirs attended. The purpose was to identify facilities and structural components likely to be affected by zebra mussels. In addition, attendees prepared a preliminary list of strategies to deal with infestations. A summary of the meeting was prepared that provided the basis for further research.

Following that meeting, four working groups were formed to deal specifically with facilities of concern. The approach was based on programs developed by Ontario Hydro, Toronto, Canada, and the U.S. Coast Guard. Facilities subject to infestation and of concern to the USACE were placed into the following categories: locks and dams, vessels and dredges, power facilities, and, reservoirs, water intakes, gages, and pumping stations.

Each working group consists of individuals with expertise in zebra mussel control, biology and ecology of zebra mussels, and design, construction or operation of the facility. A typical working group has approximately 20 members with representation from academia, state agencies, municipalities, Canada, the USACE, or other Federal agencies. Working group members are tasked with the same two objectives of the 1991 planning meeting: 1) identify components of the facility susceptible to infestation and 2) devise environmentally sound strategies to control zebra mussels.

Example of Working Group Procedure

The working group members that dealt with locks and dams made a list of particularly vulnerable components — (1) measurement systems (pressure transducers, gage wells, piezometers), (2) raw-water systems (screens, cooling systems, fire-prevention systems), (3) large gates and valves (miter gates, chamber and emergency vertical lift gates, tainter and vertical lift control gates, culvert valves, concrete surfaces and chamber walls), (4) navigation aids (buoys and trash booms, mooring bits, ladders), (5) submersible racks and gates (trash racks, wicket-type gates), and, (6) special devices (air vents and bubbler systems).

The group determined that trash racks can be protected by making them easily removable, by applying antifoulant coatings, or by mechanical cleaning. Regular inspection of many components, such as transducers, was considered critical. Transducers cannot be protected easily; protective screens that restrict water movement interfere with operation. Regular application of small quantities of biocide in the transducer well was considered to be a reasonable control strategy. The working group recommended that any component inaccessible to divers or that cannot be easily inspected should be monitored by observing an easily retrievable surface such as a tile, brick, or PVC pipe.

Meetings that dealt with other facilities were structured similarly. Group members with

knowledge of each facility identified components of concern and recommended methods and strategies. Recommendations included use of antifoulant paints and biocides, installation of screens, pigging (cleaning a pipe with a mechanical device), and treatment with desiccation, hot water, or steam.

Groups have met annually since 1991. At each meeting the spread of mussels and their impacts to facilities are discussed. Members suggest methods for dealing with specific components that are vulnerable. Recommendations are based on results of recent findings from the U.S. Coast Guard, Ontario Hydro, academic institutions under contract to USACE; and others studying zebra mussels. Since 1991, more than 300 individuals have participated in these working group meetings.

An important component of the Zebra Mussel Research Program is the demonstration project. Demonstrations are designed to apply findings from previously conducted research to a specific facility. In addition to determining the efficiency of control strategies or methods, information on cost, environmental compatibility, and application techniques is obtained. Here is a brief summary of two demonstrations:

Freezing to Kill Zebra Mussels at Black Rock Lock

Laboratory studies have shown that zebra mussels are relatively intolerant to aerial exposure at subfreezing temperatures . But, even in cold climates, during winter dewatering of a facility, it is possible that factors such as occasional warming of air, leaking water and ice formation, and clustering of mussels will increase tolerance times over those observed in the laboratory.

In January 1994, studies were conducted during winter drawdown of Black Rock Lock (U.S. Army Engineer District, Buffalo), in Black Rock Canal (a side channel of the Niagara River in Buffalo, NY) to determine experimental tolerance of zebra mussels to subfreezing temperatures. Constant recordings of air temperature were made at the top of the lock chamber during dewatering and at the bottom of the chamber after dewatering was complete. Zebra mussel samples were collected along a vertical transect down the lock chamber wall when dewatering was nearly complete, and again approximately 18 hours later. The shell length of each mussel was measured, and the animals were gently probed to determine if they were alive.

Near the end of dewatering a cold front moved through, and air temperature dropped from near freezing to less than -10 ^{o} C within 24 hours. This sustained subfreezing air rapidly killed all mussels on the chamber wall. There was close agreement between mortality observed in this field demonstration and laboratory studies.

This lock was also dewatered for maintenance and inspection during January and February 1992 and 1993. The lockmaster reported a slower kill of mussels in 1992, when it was warmer, than was observed in 1993. Nevertheless, samples taken from outside the chamber (i.e., at a location never exposed to air) and inside the chamber in January 1994 (i.e., exposed to air in early 1993 and again in early 1994) clearly indicated the effectiveness of the 1992 drawdown. Only settlers from the 1993 recruitment cohort (a group of individuals having a statistical factor in common) occurred in the lock chamber, whereas the population outside the lock chamber consisted of three cohorts.

Even very brief exposure, less than 24 hours, to air less than 3 ^{o}C is an effective method of

controlling zebra mussels. Sustained winter drawdown for several weeks is certainly sufficient to control mussels even if subfreezing temperatures are not consistently sustained.

Use of an Air Injection System to Control Zebra Mussels

In 1994 Dr. J. L. Kaster, University of Wisconsin at Milwaukee, conducted a preliminary study to demonstrate the possibility of using air injection for removing zebra mussels from substrates and intake orifices. This demonstration was directed at water-level monitoring devices, a critical component of navigation locks that are difficult to protect from zebra mussels. The operation relies upon creating an energetically inhospitable environment for the zebra mussels. Air bubbles agitate the animal's soft tissue siphon and prevent mussels from opening their valves and feeding. The two-phase alternating frictional force of water and air bubbles demands the animal's continual counteraction using its byssus-foot apparatus. The discomfort and exertion of trying to stay in place causes the animal to detach.

The ability of the air injection system to remove zebra mussels from both a float and a transducer-type measuring device was tested. Comparisons were made on an air diffuser with and without a facing plate. The purpose of the facing plate was to keep air bubbles close to the wall and the attached zebra mussels. The most effective configuration for the air injection system was a cylindrical facing plate with a circular diffuser at the bottom edge. The cylinder was about 3 inches in diameter larger than the area being cleaned, and the facing plate cylinder was long enough to exceed the amplitude of float movement. The air injection system was tested with full instrumentation to determine its effect on measurement accuracy.

An experiment was conducted in October 1993 to determine if operation of the system for fewer than five days (the standard time used in a previous test) would adequately remove mussels. This experiment was conducted at the Center for Great Lake Studies using two replicates and a foot-long air diffuser fitted with a facing plate at 1.7 square feet per minute. Underwater photographs were taken at 24-hour intervals during the 5-day period so that sequential removal of zebra mussels could be observed.

The results of sequential removal of zebra mussels indicated that approximately 93% had been eliminated by day 4 . The count for replicate 1 included a single individual (unextrapolated count) that appeared to be stuck in a crevice; however, this individual was dead, as indicated by its gaping valves. Regression analysis indicates a linear reduction of zebra mussels at a rate of about 45 individuals/hour. The product moment coefficient, r^2, was 0.928, indicating a very good correlation.

Air injection is practical for short-term abatement and as a long-term, cost-effective method for routine elimination of zebra mussels. Air injectors or diffusers can be implemented on a continuous or an intermittent basis to preclude colonization or to evacuate previously colonized zebra mussels from critical components of locks, dams, or other structures.

The air injection technique using the facing plate proved to be very efficient. The same technique without the facing plate proved to be totally ineffective. The time required to remove 100% of the mussels when the plate was used was between 96 and 120 hours.

Potential Odor Problems Associated with Decaying Zebra Mussels

As just described, zebra mussels can be eliminating by dewatering, then allowing the organisms to die by freezing and desiccation. However, dead mussels decay quickly and can produce a foul odor. If zebra mussels have to be removed from a confined area, workers could be exposed to high levels of obnoxious and dangerous gases. Odoriferous compounds that are likely to be produced as a result of decomposition include methane, hydrogen sulfide, and other organic sulfur compounds. Methane is of special concern because it is extremely flammable. If decaying zebra mussels are in a confined space without adequate ventilation, workers could be subjected to oxygen deprivation or exposed to high levels of gases . In these situations air samples should be taken to determine the concentration of oxygen and hydrogen sulfide. According to the Code of Federal Regulations; ANSI 1991, the permissible exposure level for hydrogen sulfide is 20 parts per million . This is the maximum level of hydrogen sulfide that a worker could be exposed to for periods of 15 minutes or less. Symptoms of exposure to hydrogen sulfide include eye irritation, dizziness, headache, gastrointestinal problems, photophobia, apnea, convulsions, and coma .

A variety of detection devices and personal monitors for toxic gases are available. For short-term use (8 to 24 hours), personal detector tubes that measure the exposure to hydrogen sulfide and other chemicals are available for approximately $100. Devices can be clipped to clothing and provide a direct reading without need for charts or calibration. Disposable personal oxygen monitors, which sound an alarm if the oxygen level drops below the minimum safe level of 19.5%, are available at a cost of approximately $400 each. These are also attached to clothing and can be used for up to one year. Battery-powered, nondisposable units can be obtained for both oxygen and hydrogen sulfide at a cost of approximately $1,000. Units of this type have a digital display with alarm.

Workers should wear protective clothing if they are to work in confined, poorly ventilated spaces for long periods of time. The degree of protection required will vary with each situation, but in cases of severe zebra mussel infestation, could require use of protective suits with respirators. A variety of respirators and protective clothing is available. Prices range from less than $25 for disposable products to over $1,000 for permanent devices.

Under some conditions it is possible to increase the amount of fresh air in confined areas with fans. Layers of sand or wood chips are a cost-effective way of reducing odor transmission by providing a temporary buffer zone between the odor source and ambient air. Odor modification by the use of chemicals such as lime, ferrous sulfate, potassium permanganate, and hydrogen peroxide has been attempted with varying success in land-based dredged material disposal operations. The use of chemicals for odor modification should be carefully evaluated, since the chemicals could cause adverse environmental effects if they inadvertently enter the water.

Control Methods Should Comply with the National Environmental Policy Act (NEPA)

Because of the spread of zebra mussels throughout inland waterways, many federal and state agencies will have to develop and implement a control program that is in compliance with the NEPA. The time to consider compliance with the NEPA process is during development or selection of a control method. Once an infestation is discovered, rapid control is often demanded. If a proposed method is not in compliance, valuable time will be lost adjusting the method or selecting another one.

To develop a zebra mussel control program that is in compliance with NEPA: (1) Identify individuals with expertise to address NEPA related issues. Select persons from several groups or disciplines because of the unique interaction of zebra mussels with engineered facilities. (2) Identify and include the operations people who must also address zebra mussel control. (3) Review existing permits to determine if modifications are needed. (4) Key state and Federal regulators should be identified and contacted. (5) Strategies for preparing environmental documents, such as environmental assessments, should be developed. Basin-wide rather than site-specific strategies should be developed.

Cooperation among area water resource agencies who must also comply with NEPA avoids duplication of effort and facilitates coordination. Any existing facility discharge permits should be examined to determine if modifications are required. The relative lack of freshwater biofoulers in North America prior to the arrival of zebra mussels probably means existing permits do not deal with chlorine or other treatment discharges associated with nuisance control at hydropower or navigation facilities. The cumulative effects of chlorine use for zebra mussel control in large rivers of the United States could be extensive. The Environmental Protection Agency and other control agencies in this country and Canada have expressed concern over increased use of biocides. Personnel in federal agencies must ensure that implementation of control methods is not delayed by lack of compliance with NEPA.

A complete and thorough analysis within the NEPA document will provide a good baseline of information that can aid in obtaining required permits from state regulatory agencies. The NEPA is an excellent vehicle for carrying out a public review of proposed actions. NEPA is dynamic and is always open to review and further iteration as situations change.

Environmentally sound control methods and strategies must be available for immediate use when zebra mussels are first detected at a facility. Control methods are based upon applied chemical, engineering, and biological studies. Those who design, operate, and maintain facilities are best able to develop strategies based on their own experience and research findings. As zebra mussels spread throughout the inland waterway system, control strategies will be tested at selected facilities. Success will be determined after evaluation of operational impacts, degree of control, and possible environmental effects. If successful, recommendations to other facility managers will be made. Otherwise, the problem will be reassessed and new techniques recommended.

No single control agent or method will eliminate zebra mussels from the inland waterway system. Facility-specific methods and strategies are needed that reduce zebra mussels locally. These must be economical, easy to use, and must not harm native aquatic organisms.

(This presentation was based upon a paper, "Developing Environmentally Sound Methods and Strategies to Control Zebra Mussels at Public Facilities," by Andrew C. Miller and Barry S. Payne, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180-6199.)

EVALUATING THE IMPLICATIONS FOR A MAJOR MUNICIPAL WATER SYSTEM: THE NEW YORK CITY STORY

Cameron Lange, Acres International

The objective of this presentation is to look at the significant biology (basically dispersal) of the zebra mussels as it pertains to the New York City Department of Environmental Protection (NYCDEP) Reservoir System. Then I will discuss the NYCDEP approach to zebra mussels control, and then, third, I want to provide more detail in conducting the initial systems vulnerability study, the first step that we took in this control approach.

The zebra mussel was introduced via ballast water into Lake St. Clair in about 1986. It was dispersed throughout Lake Erie by the end of 1989 and entered the inland waters of New York State by June of 1990. The range extension into the New York State inland waters placed the zebra mussels in close proximity to the New York City water supply reservoir system. It appears that the major route of zebra mussels in that area is the barge canal system. They had zebra mussels in close proximity to many of the area's reservoirs in the reservoir system.

Zebra mussels can cause several kinds of problems in water treatment facilities. First, the operational problems involve constriction or blockage of conduits and trash racks, the physical blockage. Even a thin layer of small zebra mussels in the intake system affects operations due to the increased roughness coefficient. This can decrease water flow by about 10%. The New York City Reservoir System right now, at certain times of the year, runs full out in terms of the water requirements to satisfy the needs of not only the New York city residents, but those living in upstate New York, places like Westchester County. Second, dead and dying mussels fouls up the systems in several ways. Filters and strainers can be physically blocked or damaged; the potential buildup of methane causes taste and odor problems. These taste and odor problems can be caused by methane buildup due to dead and dying mussels, or from the zebra mussels selective filtering of phytoplankton. When their feeding changes the phytoplankton base, an increase in the amount of blue green algae sometimes occurs. This algae contributes to the formation of other substances in the reservoir which contributes to taste and odor problems in the drinking water. Finally, some control technologies that are in use right now, such as chlorination, may actually increase disinfection byproduct formation, which is already a problem for drinking water facilities.

The New York City Reservoir System is comprised of 18 reservoirs and three controlled lakes. They occur in three drainages: the Delaware, the Catskill, and the Croton or East of Hudson drainage systems. The storage capacity in these reservoirs is about 550 billion gallons. The water from the reservoirs is conveyed from one to the other and to settling reservoirs through an extensive system of tunnels, aqueducts, and balancing reservoirs. Some of the tunnel systems are 16-foot wide tunnels. One tunnel system that connects two reservoirs is 276 miles long. Each one of these reservoirs has a variety of control structures, like head gate structures, that need protection. Naturally, the complexity of this system enhances the potential operational problems due to these zebra mussels. The officials recognized the presence of zebra mussels all around them.

What was New York City's approach to the zebra mussels control? The first step was a literature review in March 1991 on the behavior of zebra mussels (how do they live, how do they

reproduce, how do they move, why do they move, what do they like, what repels them) and possible limiting factors to migration. They educated themselves. They also consulted with the researchers and came to the general agreement that the zebra mussels could, in fact, be a very significant problem to the water system in New York City.

The second step was to develop a monitoring program. It was initiated in May of 1991, by monitoring five reservoirs. In 1992 and to the present, they have greatly expanded their program in terms of the monitoring techniques that were utilized and the reservoirs that were sampled. They now monitor 18 reservoirs, using about 54 different locations in these reservoirs. The city monitoring program includes veliger sampling and plate sampling, and also inspection of natural substrates.

The third step, called the Phase One Study, was taking a look at what control methods could be utilized, and trying to define the likelihood of zebra mussels getting into particular areas of the system. To do this, we conducted a complete evaluation of the New York City water supply system. We took a look at its infestation potential biologically (what reservoirs might likely be infested based on the likelihood of dispersal into that reservoir and the water quality of the particular reservoir) and, according to engineering components, tunnels or gates that might affect an uninfested reservoir, pumps that might prevent movement of water through the system. This was closely studied to determine what equipment was most vulnerable and what reservoirs may be more vulnerable than others. Based on this information, New York City developed an action plan. They determined what control would be best for each particular reservoir or location, how the control would be put in place, and the priorities for locations to have controls. This action plan was put together, approved and then submitted to the state of New York. The state of New York has come back with some concerns in certain reservoirs in terms of what controls are utilized. Negotiations are ongoing. This initial Phase One Study was conducted under emergency declaration, and the Phase One Report from award of contract to development of the report was done in under five months.

In the future, New York City will work on detailed design of the control systems. Then, hopefully within the next year, the construction and implementation management phase can be started. They will continue study and evaluation of the control technologies to monitor the effectiveness of the effort. Regular monitoring will also continue. New York is also conducting an education program for the public. It focuses on what people have to lose when zebra mussels are brought into a reservoir system, and on how people can help to minimize the chances that zebra mussels will be introduced into the New York system.

Let's now look, in depth, at conducting the reservoir vulnerability study. It is one of the initial steps that should be taken for any successful control program, whether control involves just a single intake line or a very complex system such as the New York City system. Remember, in New York, zebra mussels had not yet entered the system.

Basically, we analyzed the potential vulnerability of each component of, in this case, the reservoir system up to the initial invasion. How likely were zebra mussels to be introduced into a particular reservoir, and what is the likelihood of subsequent establishment of the zebra mussels? This study would also give us a prediction, an idea, of when zebra mussels were likely to get in— in the near term or long term — so the highest risk elements could be protected first.

We used the dispersal mechanisms. There are 23 potential mechanisms to disperse zebra mussels throughout North America. Three are natural mechanisms — birds or other animals— and 20 are human-mediated. We thought that by identifying the potential vectors associated with each reservoir or portion of the system, we could predict in which portions of the system and when impact would occur. I must stress that this is just a probability analysis. No one can predict ,with certainty, the month the zebra mussel is going to get in, even when it is going to get into a particular waterbody or if ever. You can only predict probability, only make a risk assessment. We assigned a relative likelihood of introduction factor to each of those potential vectors of introduction; we made a dispersal probability index. We assigned a number ranging from 0 to 4 based on a likelihood of introduction. Likelihood was based on the proximity of known populations of mussels, and the physical characteristics of each reservoir as it would pertain to introduction of mussels. We looked at the management practices of each reservoir and the interconnected water bodies, stocking programs, fisheries, traffic, etc. We took a look at the proximity of potential users (where there large metropolitan areas near the reservoirs), and the extent of public use. New York City reservoirs are utilized by the public to some extent. Although motorized boats are not allowed, some fishing boats and nonmotorized craft are allowed on the reservoirs, and other fisheries practices are allowed on the reservoirs. There was quite a bit of difference in the likelihood of dispersal of zebra mussels into the reservoirs. The uncontrolled reservoirs were the most likely to be infested with zebra mussels, followed by the more far flung reservoirs up in the Catskills.

Next we looked at the likelihood of zebra mussel settlement and colonization in the system. Will they stay? If so, where? Based on existing data and published research, we set 30 °C water temperature for extended periods as the upper limit of zebra mussels establishment. That limit might be set slightly higher in the South, based on your recent research findings. We decided a pH of between 6.5 and 9.5 is acceptable for adult zebra mussel existence, however reproduction and successful continuation of a population, based on European literature, would be about 7.4-9.4. About 20 parts per million calcium is ideal for zebra mussels to establish and flourish in an area, but between 12-20 is sort of the gray area. Some would probably establish, to what degree we cannot predict. Then we set 12 parts per million calcium to be severely limiting. We also determined chlorophyll (it's the measure of the nutrient levels in the reservoirs) of greater than two parts per billion would allow establishment. We didn't know where the lower limit was. It is interesting to note that in New York, and probably most of the northeastern reservoir systems, calcium is the most limiting factor. We found that a low level of calcium seemed to be present wherever we found another limiting factor such as pH or nutrient level. Thus, if you can't look at all of the parameters, and you have to make a choice, at least in the northern states, look at calcium. That will probably hold true in the southern states also, except down here, you must also look at temperature. By comparing these parameters with conditions in each reservoir, we developed a picture of the most vulnerable locations, and arranged them in a hierarchy based on water quality limitations. Then we combined the dispersal probability index (how likely the mussels would be to get into a particular area), used the multiplier of the likelihood of proliferation of zebra mussels based on water quality, and came up with a relative risk.

We found that some of the reservoirs are much more likely to have zebra mussels problems than others. Based on the water quality risk assessment and the study of engineering vulnerability, New York City determined which of the reservoirs needed to be protected first.

THE MONROE, MICHIGAN, EXPERIENCE: THERE IS LIFE AFTER ZEBRA MUSSELS

Wilfred LePage, Monroe, Michigan Water Authority

Unlike me, you've had time to prepare your defenses against zebra mussels because an awful lot has been written about the critters and a great deal of help is available today. That wasn't the case in 1989. They took us just totally by surprise. In fact, we were the first utility and probably the first installation in the U.S. to be hit by them and they hit us hard. At that time there wasn't one individual in the entire drinking water industry in the entire USA that had ever heard of a zebra mussel. We had no one to turn to for help.

If they haven't reached you yet, at least you know they are coming. If you don't get your shop in order before they show up and prepare your defense, you may experience living nightmare.

Never-the-less, it wasn't the end of the world. Now that we have the critters 100% under control, it is like waking up after that bad dream. I want to describe what we went through at my water plant on Lake Erie, what we did about it, and how successful we were.

In 1989, an undetected infestation of mussels began to restrict the flow of water through our raw water intake. By the end of the summer of 1989, that intake delivered only 80% of the water that it had delivered the year before. By the end of May 1990 when we cleaned that intake, the mussel infestation had reduced our raw water capacity by 25%, and without correction, that loss would have made it absolutely impossible for us to meet summer water demands. We know now that merely months after a spawning, millions of mussels can settle out. The time span between the egg and an absolutely crippling infestation can be incredibly brief. You don't have the luxury of time when these creatures move in. They want to take over the neighborhood immediately.

At the time this happened, my water plant had only one source of raw water, a 30-inch diameter concrete pipe protected by a timber crib, 6,100 feet offshore. Water flows by gravity through that pipeline and into the suction wells of the raw water pump station onshore. From there, it is pumped under pressure through 9 miles of 30-inch diameter concrete transmission main to the treatment plant in town.

On January 29, just six years ago, our ozonization system, which is at the head of our treatment train, was dewatered for a routine inspection. We found a rather large number of bivalves there that we had never seen before and couldn't ever identify. These were primarily located in the entry stages of the ozone contactor. We didn't pay a whole lot of attention to them at the time because it wasn't unusual for small crustacea to pass through our intake screens and make the nine mile trip to the treatment plant. We merely noted with satisfaction that these strange bivalves didn't exist in any of the areas where ozone was applied. We removed, disposed of, and largely forgot about them — except for one that curiosity made me keep around in a petri dish on my desk. It took me two months to really identify this animal and then all the frightening ramifications of his presence were revealed to us.

It was almost the end of April before I learned what they were. We were already short of raw

water for peak summer demands, and any loss of capacity would certainly place our system in jeopardy. Then by early July, still 1989, it became evident that things were going wrong. Unprecedented head losses developed through our intake, and draw down in our suction wells seem to increase daily. More and more often, our raw water pumps were grabbing at air. More and more mussels in the one to two centimeter size range kept collecting on the traveling screens at the pump house.

In mid-July we sent a diver down to investigate conditions inside the crib and to penetrate the 30-inch diameter raw water intake pipe line. He reported that the rock ballast around the timber crib was heavily populated with mussels, a lesser population on the iron work, and only a sparse presence on the wood timbers of the crib. The interior of the upturned bell of the intake, which is 60 inches in diameter, was virtually covered with mussels that he estimated to be from infants to 2 cm long. He didn't have a camera so no underwater pictures were taken at that time, but he brought some rocks back to the surface for our examination. He also went about 80 feet inside the pipeline and reported that about the bottom one-third of the inside circumference was quite evenly populated with about one animal per square inch, and this population diminished up the sides and across the top of inside of the pipe. At each joint in the pipe, the animals were clustered up about three inches thick and to several inches on each side of each joint. As it turned out, what he thought on his first dive was a heavy infestation at that time was nothing to what he saw just weeks later when the rocks around the crib were very heavily covered and the animals inside the pipe had multiplied accordingly. When he inspected the screen chambers on the shore end and the adjacent raw water piping, the diver found a much lesser presence of the animals. That was encouraging but it didn't ease our concern for that single nine mile long transmission main to the treatment plant. The fact that we had discovered mussels at the entrance to the ozone contactor did, indeed, verify that some animals, veligers, or post veligers were surviving a trip through 10 miles of raw water system all the way to the treatment plant. We had little doubt whether some had taken up residence along the way.

We had already decided that chlorination at the pump station may serve to suppress any further growth in the transmission main by attacking any new arrivals in their presumably more vulnerable larval state, and cause the adults that were dwelling there to close up and either suffocate or starve to death or in some other manner succumbed to the biocide. So we immediately started construction on a chlorination facility at our raw water pump station. Meanwhile the clock was running, and the hydraulic capacity of the raw water intake continued to deteriorate almost daily.

Then on, September 1, 1989, our raw water suction was suddenly totally lost, like someone shut the valve. The discharge valves on the raw water pumps that were running stalled somewhere between open and shut because there was no hydraulic pressure to operate the cylinders. The flow dropped to a trickle, the pumps wouldn't respond to shut down commands because the cone checks were hung up somewhere off the limit switches, and you guys that are in the water business know the rule: all this had to happen 15 minutes before quitting time at the beginning of a long Labor Day weekend.

At the pump station, when we got out there, you could look down some 35 feet into those screen chambers and see that 30-inch diameter pipe running less that a third full. It took a lot of hours

of nursing that thing along — surging it and letting fill, pumping it down— until we could resume a decent flow. Vortexing and air ingestion caused by low suction-well-elevation occurred many, many times after that, but never with such severity and abruptness as occurred that day.

Even more serious ordeals followed. The worst of these occurred in December, 1989, when raw water flow was totally interrupted by muscles and "frazzle-ice". ("Frazzle-ice," or needle-ice, is a phenomena caused by a peculiar combination of conditions that create something closely resembling a huge snowcone right in the entrance of the pipe — tiny needles of ice that effectively block the flow of water). The mussel population had a lot to do with the formation of "frazzle-ice" that December 15, which totally interrupted the flow for 56 hours. Their colonization created a turbulence on the entrance of that intake pipe that flashed supercooled water into those troublesome shards of ice. We had to use trash pumps to obtain water from the river, and connected with a neighboring utility to supplement our supply. Even so, bars and restaurants were closed, schools and the college canceled classes, all businesses shut their doors and people, in general, were asked to conserve water. We imposed a boil order when our reserves were very nearly depleted, and it looked like we were going to lose pressure in some of the higher elevations of the system. That boil order turned out perhaps to be the best conservation measure of all because, apparently, people figured that if they had to boil the water, they weren't going to bother with it at all. They quit using it. We never lost pressure in any part of the system, thankfully.

On the third day, the sun came out and the super cooling of the surface water on the lake was interrupted. The water down at the intake warmed up, the ice dissipated, and flow resumed. All kinds of debris came flying through into the screen chambers of the pump station - mussels, sticks, ice — an unimaginable mess. Those simple little creatures brought our entire community to its knees.

I want to back up a few months now. That Labor Day incident prompted our decision to mechanically clean that intake. We wanted to do that before the end of 1989, but the bitter cold weather during that December forced us to put it off until spring when we would have a better chance of good weather. So we negotiated a deal with a marine contractor which required him to set up, operate, and maintain a temporary water supply for the city which would deliver sufficient water to maintain normal suction well elevations while pumping at a rate of at least an 8 million gallon/day rate while the intake was out of service for cleaning. He agreed to remove the mussels to the extent to which that intake would sustain normal elevations while pumping at a rate of 11 million gallons/day. The cost to the city for this effort would be $72,240 on a no cure/no pay basis. This was a real bargain that I don't think anyone will ever see again. That cleaning operation was a total success. I am going to describe that in a minute, but first I want to talk about a couple of other things.

Back to that nine-mile long transmission main. We finally started chlorinating at the pump station on October 9, 1989. The literature of that day on zebra mussel treatment was virtually non-existent. There was a little bit that originated in England reporting varying degrees of success with vastly differing doses of chlorine, from anywhere from about 2-250 parts per million (ppm). We were limited by the equipment we had available and by consumer tolerance because this water was ultimately going to the system. So we decided to apply just enough chlorine to produce a free residual of about 1 ppm at the end of the pipe at the treatment plant in town. When we did, things began to happen. When the residual at the end of the pipe got close to one part, we were literally inundated

with mussel guts — a tremendous influx of soft tissue — for days. It clogged strainers and rotameter tubes, flow raters, just about every small opening through which raw water had to flow. We even had to put screens under the raw water sample tap in the laboratory sample sink to collect the debris that came through. When the soft tissue stopped coming, we dewatered our ozone system again in order to take a look at the final 50 feet or so of the raw water main. Not a single mussel was found attached to the wall of the pipe. In fact, the only place at which any mussels remained attached was inside the riser box in the ozone contact chamber. And there, small numbers of six-month old animals were still attached to the walls. But on the floor, just across the baffle wall, in the corners of the riser box, the animals were heaped up over three feet deep, and, just over the baffle wall in stage two, empty mussel shells were piled up level with the tops of the diffusers, covering half of the floor area. We carried out about eight yards of empty mussel shells, bucket by bucket, handed over the baffle walls, carried up the steps, and dumped in the dumpster. These shells were all around 2-2.5 cm in length. The size implies that these guys were probably around two years old and undoubtedly already very prolific reproducers. We assumed they were too young to die of old age, which made us reasonably certain that our treatment was somewhat effective.

In retrospect, we concluded that after the death of the animal , the shell detached from the mussel, and, being very light, tumbled through the pipe and into the ozone contactor. Next the guts or the soft tissue, at an early stage of decomposition, followed and plugged up all the strainers and small openings. Whatever else remained behind undoubtedly decomposed over time.

We also looked at the other end of the transmission main after chlorination, and not a single animal was to be found anywhere. We were very much encouraged by this because, at least the time being, we had the situation under control all the way back to the raw water pump station, a distance of nearly nine miles. Barring any further "frazzle-ice" problems, the offshore portion of our raw water system, which we knew was fouled with mussels, should still deliver enough water to meet winter demands and it did. We still had a few problems with "frazzle-ice," enhanced by the mussel population, but these were not insurmountable.

The first order of business in the spring of 1990 was to clean that intake — 6,100 feet of 30-inch pipe buried in the bottom of Lake Erie. We needed a stable platform to do the offshore work. We used the barge *Illinois*. While the intake was shut down, we used the auxiliary system, consisting of twin intakes in the lake with two diesel engine-driven pumps situated on the lake shore and two 16-inch diameter plastic pipelines running over land to the raw water station. One of these would discharge into the west screen chamber of the pump station while the other would be used for wash water for the actual cleaning operation. This arrangement was supplemented by our pumps in the river at the plant in town and together they produced more water than that treatment plant had ever received before.

In the first step of the cleaning operation, a 3/8-inch polypropylene rope attached to a drogue was floated through the intake from the crib back to the clean-out fitting on the shore. Then the 3/8 inch rope was used to pull a 3/8 inch wire cable and that was, in turn, used to pull a 1/2 inch wire cable back to the barge anchored over the crib. The cleaning device or scrubbing device, as we call it, was built especially for our job by the King Company. It consisted of a tubular hole with spring-mounted scraper rings mounted forward and a combination squeegee-propulsion ring mounted aft. It

was also fitted with high pressure nozzles designed to wash debris ahead of the device and back into the lake. To make sure this thing would go around the two 45 degree bends in the pipeline, it was successfully passed through a 90 degree bend in the shop several times, and 1/2 inch steel cable was prudently attached to each end just in case the device got stuck. Even though this thing would pass around a 90 degree bend, it wouldn't go around the 45, so we hauled it back out and removed the squeegee ring. It then went around both bends smoothly, and ran with only one other incident, to the end. The people out on the barge said the debris was boiling up out of that crib like the eruption of an underwater volcano.

The job still wasn't finished. Because the modifications to the scrubber included the removal of the squeegee ring, undoubtedly a lot of loosened debris remained in the pipe. Since the contractor needed a few more days to fashion a device to sweep and squeegee the lines, we put the intake back in service. That proved to be a mistake because a tremendous amount of the loose debris, stacked up around the crib or left in the pipe line, washed back into the pipe and into the screen chambers and plugged everything up to the extent that we couldn't get as much water through the pipe as we did before we cleaned it.

The contractor's device to sweep and squeegee the line turned out to be an articulated contraption consisting of a couple of stiff wire brushes followed by a tight-fitting squeegee. This squeegee was made of about six layers of 3/4-inch thick reinforced industrial rubber belting backed by steel plates. When that thing came out the other end of the pipe intact, we were pretty sure that not much could be left behind. We were reasonably confident that the pipe, at last, was clean.

Preparations immediately got underway to pull a two-inch diameter, high density polyethylene hose through the interior of the pipe all the way to the crib, some 6,100 feet. This would ultimately be used to apply chlorine at the crib. The pull went smoothly until, at about half way, a thermally fused joint apparently separated, the stretched hose backlashed and apparently broke in a second place. It was late in the evening so the job was secured for the night, the pipe was returned to service, and everybody went home happy. But this time the happiness was short lived. Before midnight, flow through the east suction well nearly stopped. The operator had to shift the pumps on the other side of the station, and, by morning, that side was also plugged up tight. We found that the traveling screens were jammed solid with debris, the pins were sheared in the drive mechanism, and when they opened the doors on the trash hoppers, they were virtually inundated with the debris that gushed out onto the floor. I guess we are slow learners because we repeated the same mistake we made earlier: we should have never put that pipe back in service until the crib was vacuumed out. We had that huge pipe of debris out there around the crib and when we put the intake back in service, the debris tumbled back in and washed all the way through the intake. Again it took a lot of effort and several days to free the screens up and get the plant going again. That loose debris continued to wash through for about a week.

Full capacity of the intake was restored. When a diver went down to airlift the debris from the crib and redistribute it on the lake floor some safe distance away, he reported that the debris was stacked up like the cone of a volcano all the way around the crib. The diver estimated that he removed the equivalent of 7 or 8 large dump-truck loads of debris from the immediate area of the crib.

On the next attempt, the chlorine hose was successfully pulled through the pipeline and attached to the diffusion apparatus to chlorinate the 30-inch intake. (For information on this diffuser, write to Wil LePage.) We began chlorinating immediately.

Things went well for three days, until our screens again became clogged up. This material was unlike anything we had ever seen before. It was a nasty looking mess that formed a virtually impervious mat or cake on the screen. Apparently, this was the decomposing remains of the animals the scraper had left behind or that had washed back in after or before the crib was vacuumed. Fortunately, this material disappeared after a few days and, thankfully, it hasn't come back again.

Pretty soon our filters started air binding. This is very unusual in midsummer in 75 degree water. Massive gouts of air were expelled during a backwash process, tearing up the beds. We didn't think the trouble was air, however. Rather, we figured it was methane, carbon dioxide, and all the other noxious, gaseous, decomposition products of the rotting protein in our pipeline resulting from the decay of whatever remained of the animals. About the time we devised a way to capture some of those gases for analysis, they abruptly ceased. Strangely, the water did not taste or smell rotten. The only noticeable odor that we ever encountered was of chlorine when the residual ran a little high. Apparently our ozonization system at the treatment plant was still destroying the ugly tastes and odors that this stuff produced. Believe me, rotting mussels smell worse than decomposing fish.

In September of 1990, we sent the diver down, again, to inspect the crib and penetrate the pipe line. At first he reported a massive accumulation of living mussels extending in all directions from the crib and on the top of the crib. Areas that had been absolutely clean only three months earlier now were totally covered with mussels, 1/4 to 1/2 inch long. The rim of the bell of the intake and the ring to which the chlorine diffusers were attached supported a mussel colony approaching two inches thick. But from the chlorine diffuser inward, the pipe was totally free of mussels. After 1 and 1/2 years and over $300,000, conditions were restored to what they had been before the animal arrived.

Our next move was to fine tune our treatment strategy and complete the design and construction of our new raw water facilities. These include a second intake and a permanent mussel management system. We tried various patterns of chlorination during this time, all on a plant scale. We ruled out periodic treatment right from the start after our experiences with debris in 1989 and '90. We looked at intermittent chlorine applications too, but found too many survivors. The operators didn't like this method, also, because it upset operations at the treatment plant, so we decided on continuous chlorination applied to inflowing raw water at the intake offshore. It worked very well. Our engineers resumed the design of the second phase of our new intake, with instructions to include offshore chlorination as well as any other mussel management feature conceivable.

In the meantime we began to refine our chlorination practices to optimize mussel management and minimize impact on plant operations and infrastructure. This entailed operating to progressively lower terminal residuals and verifying the effectiveness of various levels of chlorination by underwater inspection. We decided to begin with a high dosage and come down, which we did progressively until our average terminal residual was down to 0.13 mg per liter. Our inspections verified that the treatment at this level was totally effective, and there were no mussels anywhere in the intake from the point of chlorination inward. Best of all though, aside from an effective mussel defense, was the lack

of adverse effects on the treatment processes downstream and on final water quality — aesthetically and with regard to compliance with water quality standards. As a matter of fact, with the chlorine program that we now use, our trihalo methanes (THMs) have actually gone down. Our total average THM for the year of 1994 was 31 micrograms per liter, which is a very comfortable level.

Construction was concluded and the new intake was ready for service in late 1992. The 42-inch concrete pipeline extends to an inlet structure that is 1,550 feet offshore in about 20 feet of water. The pipe is buried in a trench in the rock bottom of the lake with two sidestream lines buried right next to it in the same hole. The inlet structure is rather unique. It was designed specifically to accommodate chemical diffusion apparatus for mussel control and also to minimize conditions conducive to the formation of "frazzle-ice," one of those conditions being velocity of flow at the entry ports. The structure consists of a hooded funnel, 11 1/2 feet in diameter, that tapers over a distance of about 7 feet to 42 inch diameter at the throat. It is covered by a flat topped umbrella like structure that measures about 20 feet diameter with vertical sides extending downward some 4.5 feet to just slightly below the lip of the inlet funnel. Water has to flow upward to enter the system, then downward through the funnel and into the pipeline. Two-inch diameter diffusion rings are positioned around of the periphery of the hood and the lip of the funnel. These evenly distribute the chlorine solution to the inflowing water such that no water can enter the system without passing through the chemical plume. This entire structure is pinned to the bottom and is held in place by 55 tons of concrete poured into the base. It is also designed to be a break-away device in case the ice jams up in that area. (Contact Lepage for more information on these diffusion rings.)

Onshore we provided access points to accommodate the insertion of mechanical scrubbers if it should be necessary, and we included the capability for high capacity back flushing of either intake utilizing any number of our raw water pumps. This feature can be useful either for propelling scrubbers through the line (if necessary) or dealing with "frazzle-ice" or accumulated debris in the future.

We placed the new intake in service in December of 1992, and chemical application was initiated in January of 1993 using liquid chlorine feeding the gas. In July of 1993, the liquid chlorine system was placed in reserve, and control was shifted to the hypochlorination system for both intakes. Under this system, enough sodium hypochlorite is applied at each crib to produce a terminal chlorine residual of about 0.2 mg per liter in water arriving at the raw water pump station onshore. Then, in the transmission main leaving the raw water pump station, we apply enough hypochlorite to give us a desired residual of not to exceed 0.2 mg per liter arriving at the treatment plant in town.

The reason for this multipoint application is two-fold. First, we want to minimize the amount of chlorine arriving in the screen chambers to preclude the release of noxious and corrosive fumes into the pump station. Second, the neighboring township put a new treatment plant on stream that also receives water from the station. Because of its close proximity, any higher application would be too much for their operation. So far, they haven't had to chlorinate their transmission main at all, and are getting a residual of about .07 mg per liter arriving at their plant.

During our first six months of operation, in order to achieve the desired level of protection, our average hypochlorite application was about 2.1 mg per liter to produce the desired residual of 0.2 mg per liter in both of our intakes and terminated at .09 mg per liter in water arriving at the treatment

works. We improved on these numbers a good deal during 1994, applying only 1.97 mg per liter of hypochlorite which produced residuals of 0.14 at the end of each intake and .07 in water arriving at the plant nine miles away. Water arriving at the Frenchtown plant 2.5 miles away was .09.

This new system uses sodium hypochlorite instead of liquid chlorine out of safety considerations at the unmanned station, not because I like it. Individual hypochlorite metering pumps are provided for each of the four points of application. The operator at the treatment plant manually sets the desired rate of chlorination for each point of application, and thereafter it is paced to the water flow. The hypochlorite is diluted in a carrier sidestream that delivers the solution to the diffusers at each point of application. A sequestering agent also has to be added to preclude any precipitation as a result of the elevated pH in the side stream after the addition of the hypochlorite. All essential operating parameters of this system and all essential parameters dealing with the raw water station in general are transmitted to the main control room in the treatment plant. Deviation alarms alert the operator in the event that any critical function exceeds operating tolerance.

Although the results obtained with hypochlorite have been very satisfactory, it's much more expensive than chlorine. Mussel control with chlorine cost us $3.87 per million gallons during the six months that we ran the system on chlorine. Sodium hypochlorite, to do the same job, cost $6.83 per million gallons plus another $.33 per million gallons for the sequestering agent which drives the chemical cost to $7.16 per million gallons. Hypochlorite cost us 85% more for doing the same job.

A quick summary of the overall economics of this experience: our raw water system improvements package cost $4.9 million, more than $465,000 of that was exclusively for dealing with zebra mussels. Add that to the amount that we had spent previously, and the cost of mussel control so far is very close to $900,000.

The projected cost for operating the mussel control system was around $10 per million gallons. We have improved on that substantially, and right now the bottom line equates to about $8.50 per million gallons treated. We are still facing some fairly hefty expenditures to completely equip of that station (but those items are only remotely related to mussel control).

I hope this gives you some idea of the headaches and the financial burden that these animals can impose on a facility and a community. My advice: don't let this happen to you. There is just no excuse for this happening to anyone here is this room today. Because, if I had known in 1989 what you folks have learned at this workshop, this never would have happened.

INTRODUCTION TO CONTROL: PHYSICAL CONTROL ALTERNATIVES: EXCLUSION, PREVENTING SETTLING, MECHANICAL REMOVAL

Charles O'Neill New York Sea Grant

In the beginning, when we first started talking about zebra mussels and their impacts and controls, many people concluded that zebra mussels were invincible, that once they got into a system, it was doomed. We have learned, since then, that zebra mussel control is quite possible. Many technologies, off-the-shelf technologies that have been used in water handling industries for years, can be tweaked for use against zebra mussels, if not on an permanent basis, at least until some new types of technologies come on line.

A lot of people ask, "Is there a silver bullet, something that will work across the board in any kind of water intake system, in any kind of internal water handling system?" The answer is, "No, there will not be a single silver bullet that is going to work in all sorts of cases, however, there are many available technologies and more being developed every day."

The first intuitive measure is to conclude: "If we can keep zebra mussels out of our system to begin with, to prevent their entry, then we have got the battle won." Exclusion at the mouth of the intake pipe would prevent their entry by using some form of strainer, filter, or screening device. The effectiveness of these depends on the size of the mussels that you are trying to keep out and the size of the mesh, the porosity, of the kind of exclusion device that you decide to use. Many freshwater systems in North America use traveling screens to exclude materials that would normally flow in at the intake such as leaves, sticks, fish, or pieces of Styrofoam. Typically the traveling screens are going to be around 1/4 inch pore. We have seen 1 mm screens used on traveling systems. However, as you learned yesterday, zebra mussels are much smaller in early stages than 1 mm.

Some of the devices people look at when they consider exclusion are various types of buried intakes — infiltration gallery, or Ranney well, or shoreline sand filter. Strainer systems — fixed strainers — out at the end of the pipe will exclude up to about 60 microns or smaller, but consider how fast that is going to clog up from other debris. Inside the systems, fixed strainers, cyclones separators, and centripetal filters may be usable under some circumstances, but not when drawing in 1/2 million to 1 million gallons per minute.

Can the mussels be held in suspension, that is, prevented from settling? If you can keep the mussels floating, they can pass through your system and back out your discharge. The older European data tells us that a flow of about 2 meters per second on vertical surfaces is a threshold. Anything much lower than that is comfortable enough for the mussel to attach. On horizontal surfaces, European data suggests the flow layer should be set about 2.5 meters per second. Experience has shown this to be a little off. A researcher from the King Institute in the Netherlands has data to suggest that about 1 meter per second on most surfaces will prevent settling. Bob McMahon's work in this area shows that even these figures may be a little high. The general thought is if you can keep the water moving fast enough to prevent the mussels from stopping on a substrate, they will flow on.

There are some other ways to keep zebra mussels from attaching. Electrified surfaces may be possible. The Canadians are working with ionic/cationic installations to keep the mussels off the sides

of the walls. Some have had success with bubbling screens or air screens.

These prevention methods may not be possible because of pipe sizes, flow rates, conduit configuration, or systems that have water coming in at one rate at one time of the day and a slower rate at another. For example, some small systems may only pump for part of the day to fill their pipes. These prevention methods have not been used particularly effectively if they required retrofitting existing equipment, however, we have seen more success with prevention of settling when new infrastructure is installed.

Mechanical removal is another option. This would be removing the mussels at the most gross stage. People with hard hats and proper suits, armed with a scraping device (like a shovel), physically remove the zebra mussels from the infrastructure. You must be able to scrape or sandblast the system surface, and get the equipment and personnel into the system. You must be able to remove the piles of mussels from the system. A lot of freshwater systems don't have good access into the system. Can your system go off line? Divers will find it difficult to scrape during heavy duty pumping. This control method works best in the larger conduits where you do have access for personnel, and when you have large mussel stages to remove. This method is very labor intensive and expensive to get that labor into the system. Some have been able to remove mussels when a system goes off line intermittently, but generally we see most systems going off line at least temporarily to scrape or sandblast.

There are several control methods that can work with an intermittent offline schedule. Abrasive blast cleaning can be utilized in some circumstances but, after the blasting, you must remove the blasting material as well as the zebra mussels from the system as well. Carbon dioxide (CO_2) pellet blasting has been successful. The pellets of carbon dioxide act as both an abrasive and, being as cold as they are, make the zebra mussels more brittle and more removable from the walls of the conduit. Those CO_2 pellets tend to dissipate rapidly, leaving only mussels to remove. Dewatering and desiccation is another off-line, intermittent or less mechanical process. (See later talk by Dr. Robert McMahon)

So far most robotics are being used only for inspection of the systems although a few are trying to develop robotics to scrape smaller conduits. A problem is the amount of energy needed for a robot to operate and the kind of umbilical cord that must be attached to it. So far it is not practical. High pressure water jetting has been used extensively in power plants throughout the Great Lakes for removing zebra mussels. About 2,000 - 2,500 PSI of pressure are needed to remove them effectively.

An advantage to these off-line intermittent control methods as opposed to a mechanical retrofit is cost. These methods result in very limited environmental impact. There are no chemicals being discharged, nothing happening that requires regulations other than the method you use to dispose of the mussels. The disadvantage is an assumption you make that you will be able to sustain a certain amount of zebra mussel infestation and be able to remove it and allow it to grow back. You've got to have enough headroom in your system to afford to lose 10-15-20% of total flow capacity before clean outs. You either have to have downtime or a huge labor force to remove the mussels within the intermittent time period. This could be costly.

Disposal of the mussels can be a problem. You must work with your municipal landfill. It

must be willing to accept many cubic yards of very wet, highly calcified, putrescible organic material. Some will not take it. We have not yet seen too many rendering plants that will accept it either. There is the possibility of land disposals and plowing it under but this waste does contain some materials that you wouldn't want to use on vegetable crops, so that solution may be limited as well.

In smaller systems where you cannot get personnel in, you may be able to use pigging to clean those pipes. Polypigs from 4-6 inches in diameter up to a 72-inch diameter could be run through a conduit and could make it around some fairly good size bends. You still have to be able to get some access into that system to remove the mussel debris. If you have very tight bends or some major changes in pipeline conduit diameter, pigging may not work. Large infestations may block the pig, so you must run a small pig and then a larger pig, and then a final larger pig to just completely scrape the pipe. It has been done in a number of locations.

In all of these cases, access to the system is important. You may have to consider retrofitting your system to provide some access.

Now let's look at more advanced control methods. Oxygen deprivation is a possibility. Zebra mussels have to breathe just like any other animal. If you can cut off their source of oxygen and suffocate them, you can kill them and it becomes a mechanical removal program. Generally this means hermetically sealing the pipeline or the conduit or the pumping bay, allowing it to either naturally go anoxic or adding something like sodium metabisulfite or cobalt chloride as a catalyst to draw that oxygen out of the water. You may find that adding hydrogen sulfide can speed up the process as well. (See talk by Dr. Bob McMahon.)

Note that zebra mussels can hold their breath for at least a certain length of time. The duration depends upon water temperature. It is not effective to shut the system down and let them suffocate for an hour or so. It takes a prolonged period of time and your pipeline, in some way, has to be shut down so that you can seal it and let it go anoxic. You cannot just leave the system wide open.

Thermal treatment is also effective. If you cannot suffocate them, cook them. We are finding up north, where the animals are acclimated to cooler water, that thermal treatment can be a very effective way of dealing with mussel disposal. But this means that you are allowing some mussels to grow in your system and then killing them periodically. Thermal treatment is something that happens several times a year. Typically this method is for the cooler, northern waters. These schedules may not work out quite the same once you get down here in this part of the country.

If you want a completely clean system that never has any amount of mussels in it, all the technologies already discussed are not your solution.

When should these methods be implemented? In the Great Lakes, we typically use early summer treatment before the major part of the spawning event begins to clean out any mussels that may be left over from late spawning in the fall and to get those translocators (those that crawled in as juveniles and settled in the pipe). Then in the late summer (August maybe even into September) following the peak of the spawning season, another treatment is used to wipe out that major cohort of this year's spawn. A third treatment later on (October in the Great Lakes, November, maybe Decem-

ber in the South) to catch the late spawn and some of the early translocators that are coming into the system and to give you a clean system for the rest of the winter.

Desiccation, drying the zebra mussels out, always works. Although we talked about zebra mussels being able to survive up to 10 days out of water, that's in a very humid, very moist, very cool ideal laboratory setting. When it comes to natural real world, zebra mussels have little tolerance. If you can dewater and allow the area to completely dry out, the zebra mussels will die.

Among these are probably some technologies that will work in your system. But if your water treatment facility doesn't want any mussels at all in your system, these aren't going to work because these are treatments, not prevention and control type alternatives. For power plants, industrial settings, places particularly where you may not be operating at 100% of your pumping capacity but do have headroom to allow a certain amount of zebra mussel impact, these technologies may be applied. All of them are being used in one way or another in North America already.

FILTRATION AND MECHANICAL STRAINING DEVICES

Garry Smythe, Acres International

We will be talking about filtration or exclusion to control zebra mussels. I want to start off by talking about a few different terms we are going to be using. *Filtration* is the removal of particles from flowing water, in this case, mainly the eggs and the veligers, but also the adult stages . *Filtration efficiency* is usually presented as a percentage removal by a life stage. It is controlled by the filter media pore size and, in the case of the hard shelled critters, possibly the pore shape. *Filtration rate* is usually presented in volume filtered per unit time (e.g., million gallons per day, gallons per minute). It is also controlled by the filter media, but here it is the media surface area, and the line or head pressure that is developed across the filter media, and the particulate load and the particulate type. Particulate load leads to a clogging rate and the surface open area ratio.

What are your objectives for filtration? The most demanding objective is to expect 100% efficiency (i.e., remove all zebra mussel life stages from the smallest viable egg up through to the adult). This objective might be necessary in a fire protection system or possibly in a make up water system. In these cases, you draw in water that is going to be held for a reasonable length of time within the facility. During that time period, if the water quality remains constant and promotes additional zebra mussel growth, mussels will grow, settle, colonize, and plug the system if allowed to get in.

Another filtration approach is to look for 95-100% efficiency for the zebra mussel settling stages. This situation might be appropriate in a service water system with continuous flow. You might look for 50-60% efficiency for the settling stage or for the eggs for that matter, but you would have to use some other reactive approach that would take care of the mussels that would get through the filtration system. If more than 50% of the viable mussels pass the filter, this is probably not a practical method.

Why might you be able to set 95-100% exclusion for the settling stage? You must look at the life cycle. The smallest viable zebra mussel life stage, the egg, is typically around 40 microns, maybe a little bit smaller than that for the quagga mussel. The "D" form veliger stage reaches about 100 microns on the long axis, and the post-veliger or umbonal stages are on the order of 130 to 180 microns as they begin to move into the settling stage. At the settling stage they form the byssal threads and begin to attach, they begin to foul. All the rest of the life stages, from the egg on through to the settling stage, are going to pass through your system just like any other detritus as long as the water flows. So if you can filter out the settling stages, you won't have to worry about all the earlier stages. They're not going to cause any problem in the plant, they are going to be carried right on through. To do that you are going to need a filter with an absolute rating of about 70 to 100 absolute microns. If you want to filter out the egg, however, you are going to have to use small porosity — about 40 microns and, being conservative, going as low as 20-25 micron. These filter sizes are quite different in cost, and in the losses they cause to the water head.

What are the different kinds of filters? Filters can be described by location: intake filters and in line filters. Intake filters include any filter positioned right at the intake. The filter media here is

typically the natural aquifer, or some kind of man-made infiltration bed. One type of intake filter is the standard well where ground water is used as source water, and a natural aquifer is used as the filter media. These can be very good at protecting water systems, however, in many states such as Arkansas, Florida, and New York, state agencies are worried about the ground water supply and depressing that ground water table which is being used in many cases for drinking water supplies. To produce a standard well, a typical drilling rig comes in, drills possibly an 8-inch hole, maybe 100-200-300 feet into the ground depending on the aquifer and the ground water level. After you finish drilling, you put a pump on top and start pumping away and hope that you get a high enough production for the needs of your water system. If it turns out that you don't have enough production, you can use hydrofracturing to improve production. The hole is sealed around an injector and water is pumped in under high pressure, along with some sand or silica particles. This causes small fractures to open up in the aquifer. The sand or silica particles hold open all those fractures. When you take the pressure off, you'll get more production through those fissures. It is important to complete the correct hydrogeological survey before you drill to assure success. One utility in New York state did not do their survey first, spent about $100,000 for six wells, and got useful production out of only half of them.

Shoreline infiltration is a type of intake filter. These, also known as a lake shore galleries, river bank galleries, or collector wells, use the natural aquifer as the filter media. Sometimes these are also called sand filters because the shore line may be very sandy and the water runs through the sand. Construction of this type of filter is similar to the standard well — a vertical shaft and in some cases a horizontal shaft are drilled or trenched — but most of the time, shafts are shallower than in the standard well. These collector wells are usually 50, 60, or 80 feet in depth, and they're located somewhere near a water supply such as a river or lake that helps to recharge the ground water the filter draws upon.

A Ranney well, also known as a radial or collector well, is also placed near surface water and uses a natural aquifer as the filter media. The hole going down into the ground is, in this case, much larger (15-18 feet in diameter). The shaft may be 50, 60, 70, or 80 feet down in the ground, based on hydrogeology. Radial collectors — basically perforated pipes — are placed at the base of the caisson used in this large diameter hole. Water begins to percolate through the aquifer and into the perforated pipes, into the caisson and then pumped away. It takes advantage of the surface water supply to quickly recharge the ground water that it is using as the water for your pumping activities.

Another shoreline filter would be the lake shore gallery, also know as bed intake or bed gallery. These use manmade infiltration beds or filtration units. In these, perforated pipe is laid underwater on, or in, the bottom of the lake or river. Gravel or sand is placed over the pipe. Depending on how deep in the water column you have to go, these beds can be trenched on site from a rig on the surface, or they can be built on land, floated into place, then sunk. The perforated pipes come back to a header which goes, on shore, to a pump station. The surface area of a particular gallery can be large (even acres), depending on how much water you need. This filtration system needs some kind of a backwash used intermittently, maybe once or twice a month, depending upon the suspended load in the raw water. Be sure to determine the suspended load and backwash capability. A small drinking water supplier in Ontario, Canada, spent over $1 million on an infiltration gallery, but didn't

take into account the actual suspended loads they had. Their filter plugged up so that the system is no longer in service. They spent their money on a zebra mussel control system that they can't use.

Backwash is less needed, and possibly seldom needed, if river flow continually cleans the bed surface. For example, a system was designed for the Columbia River, where some of the water from the river is to be diverted over top of filter beds. One caution about this type of "backwash" design: if, at certain times of the year, you take too much water from a river, you may end up having a dry reach between the point of the inlet and outlet. Also, at the outlet point, you might have a point discharge of higher turbidity than the normal loads of the river and some agencies frown upon that.

The intake filter can handle a variety of water volumes measured in million gallons per day (mgd; 1 mgd= about 694 gallons/minute). Ranney wells are operating in North America providing over 140 mgd; infiltration galleries in North America typically provide around 15 mgd per day. Other conceptual designs provide over 900 mgds.

What is the advantage of intake filters? The primary advantage is the absence of chemicals (disinfection byproducts — DBPs) necessary to control the mussel. The lack of DBPs is important for drinking water suppliers because it allows protection of the entire system from the intake without putting any added toxin, taste, or smell into the product. This gives overall improved water quality, and in some cases, may lead to reduced operational costs. If designed and installed properly, intake systems should have low maintenance and longevity as evident by systems set up in Europe and England that have been in operation for decades providing protection from zebra mussels.

The major disadvantage can be cost. You need to do some sort of an up front hydrogeologic survey before you install filters. The larger the flow rate you need, the larger the infiltration area, and again these can be on the order of several acres. You can have a very high initial cost, probably some of the highest capital cost for zebra mussel control. Operational costs should be low, however.

What types of systems can use intake filters? Many industries and agricultural suppliers can use these types of intake filters. Some medium to small municipalities can use them, and many utilities can use them for service water systems.

The three major types of in line filters (also called on line filters) are (1) manual clean or basket strainers (sometimes called duplex strainers if they are side by side), (2) slow and rapid sand filters, and (3) automatic or continuous backwash filters. A basket strainer can catch the adults and the debris coming in a system. These can be effective in keeping out mussels that might otherwise go into the condenser tubes and plug up a cooler. Traditional in-line filters are the slow and rapid sand filters. These are pressurized or gravity fed. They both require effective backwash systems. Municipal drinking water suppliers usually use a gravity filter. It is basically a concrete basin with collector pipes on the bottom that is filled with gravel and sand. The water flows through the sand. The sand filters out the particles, and hopefully, zebra mussels. Most sand filters are the down flow type in which water flows into the top of the sand filter, and through the sand media underneath. As the water flows through the filter media (it doesn't necessarily have to be sand but typically is), the particulates in the water are filtered on to the upper two or three centimeters of the filter bed, slowly forming what is called a filter cake. When the pressure differential across the filter bed gets so high

that the water is not moving at the correct rate anymore, the filter goes into a backwash cycle.

Typically in a single media filter, whether sand or other media (like anthracite), particles orient from the smallest particle on top to the largest on the bottom. This presents a problem. As water flows in the top in the down flow filter, most of the filtration occurs in the first few centimeters of the filter media because the pore sizes are smallest there, removing most particles from largest to smallest particles. This can lead to very short filtration runs depending on suspended load in your water. It would be much better if you could turn that system upside down, so that the water comes into the larger filter particles first. To solve the problem, you can use an up flow filter. In it, water is pumped in from the bottom, taking advantage of the pore size gradient, bottom to top. Unfortunately these systems are complex, fairly expensive, and are typically proprietary as well.

An alternative solution is the dual media or multimedia filters in a down flow system. We mix together a large size, low density particle with a medium size, medium density particle and a small size, high density particle. They will orient with the larger particles on top and the smallest ones on the bottom, giving a more effective filtration and longer filtration runs. These materials may be silica or sand, ilmenite, garnet, or anthracite.

What's the difference between rapid sand filters and slow sand filters? Typically, the slow sand filter gives you infiltration rates of .04 to .08 gallons/minute/ft^2 of filter surface area. A biofilm on the surface of the filter media provides the fine filtration. The slow sand filter should be able to filter out zebra mussel life stages if it is operating properly. On the other hand, the rapid sand filter provides infiltration rates much higher — 2 to 8 gallons/minute/ft^2 of surface area. However, you're not going to get the high efficiency as far as the zebra mussel life stages. You should be able to get most of the D-form postlarval stage with the standard grain size sand filter.

To get the smaller larvae and retain higher flow rates, use a flocculant such as alum or one of the polymers. You can significantly boost efficiency in the sand filter system with the flocculant, and, if you happen to be using one of the polymers such as DMDAC (dimethol-dialyl ammonium chloride), you may also get a biocidal effect. Thus, you will get increased efficiency through flocculation as well as cause mortalities in the zebra mussels that are exposed to the treatment.

Automatic backwash and continuous backwash filters are also in-line filters. They are much smaller than the other filters, and in most cases, they are placed in line with flanges. The filter and media are much smaller in size than any so far discussed; you must have a very efficient backwash system to keep the filter from plugging.

Ontario Hydro has tested several filters from Filomat and Linden. They tested a 20-micron and a 40-micron nominal mesh — one with a continuous backwash and one with an automatic backwash — and found 100% exclusion of the D-form postlarvae and larger. They may have been getting 100% exclusion of all life stages, but they weren't looking at the egg to trochophore life stages in their study. Commonwealth Edison in Chicago is looking at an absolute 70 micron mesh, and they don't have any data yet for the system. Last summer and fall we tested an Amiad filter at Mississippi Power and Light's plant in Greenville, Mississippi. We tested an absolute 70 micron, 36-40 micron, and 25 micron. This study was funded by U.S. Army Corps of Engineers Waterway's Experiment

Station in Vicksburg, USDA, and Mudcreek Irrigation District in Michigan, and the Gerald Andrus Mississippi Power & Light/Entergy plant in Greenville, Mississippi. In the Greenville project, we found that the 36-40 micron mesh was giving us effectively 100% exclusion of all life stages with some minor reservations. The 70 micron mesh would have been acceptable in keeping out the settling stage mussels. Unfortunately, the 25 micron mesh, which was the one we had really hoped to test in great detail, was compromised when we started testing so we didn't get any useful data on it.

We tested nominal 100 micron meshes and 60 micron meshes in a Bromm filter for New York State Electric and Gas (NYSEG) and the Empire State Electric Energy Corp. (ESEERCO) in 1992. We found the 60 micron polypropylene mesh was giving us about 97% efficiency in removing the zebra mussel settling stages. Kinny strainers were also tested with 142, 95, and 40 nominal micron meshes. The 40 micron mesh reduced the density of ready-to-settle veligers in the filtrate by 98%.

A New York Power Authority small hydro facility has installed two banks of Ronningen Petter filters, one protecting the seal water and the other protecting the bearing cooling water. They are using 20 micron mesh and 40 micron mesh. In field sampling, we are not seeing any mussels coming through. They do have very low density of mussels, however, and so we conducted bubble tests to verify pore size. We predict, based on the bubble test, that these filters should provide all the protection they need, probably taking out particles down to the egg stage.

Filter media used for the in-line, automatic backwash, and continuous backwash filters are not designed specifically for zebra mussel control. In fact, industrial filter media manufactures are not used to working with biological systems. They do a good job and understand very well how to remove solid, non-living objects like sand and small particles. These manufacturers typically don't understand, however, that if you want zero mussels inside the plant, you have to be able to exclude the animal in its smallest life stages. Therefore, you need to be an educated filter media consumer when talking to filter sales people. Ask for an absolute mesh rating rather than a nominal rating. An absolute rating is going to tell you, fairly well, what size particle can get through. It may be wise to ask if bubble tests, typically conducted to ASTM standards, were conducted and ask for the documentation when you are buying filter media.

The major problem with mesh is physical: minor variations in the sizes of these pores or openings can quickly effect the efficiency of a filter. One way around this problem is called sintering. Each crosspoint of the weave is fused to reduce fiber movement.

There are various types of filter media, among them, the wedge wire screens. These particular types of filter media, to my knowledge, have been tested but not yet used for zebra mussel control. However there is reason to believe they will work. Some manufacturers are Kroal Reynolds, R. P. Adams, and Ronningen Petter.

Another type of filter media, manufactured by Amiad, is a cylinder made from a sandwich of fine, stainless meshes. Polypropylene mesh used by Ronningen Petter and Braum. Stainless steel sheets molded into small modules are used by Kinny. These are examples of some of the mesh types.

Backwash methods used by the various manufacturers are similar in that they use the filtered water. Some filtered water is put in reverse flow to either wash an entire filter module or part of a filter mesh. Most all seem effective. If you have large solids like fish and sticks, you may need to use your backwash system as a grinder. I would suggest you look at hydrocyclone or some type of an in line emulsifier rather than try to use your filter as the grinder. If you have high suspended solid loads, you nay need a very effective backwash to clean the mesh. The backwash operation is as important as the mesh size, especially where fine filtration is needed.

During our research when we have monitored flow continuously, we noticed that the flow rate is at its lowest just before a backwash cycle. That is because you are beginning to build up a filter cake and the flow through the filter media is slowing down. Most automatic systems are set up so that the pressure differential is monitored until it gets to maybe 5 or 8 PSI. At that point, an automatic system starts the backwash.

Each filter manufacturer treats the backwash system a little differently mechanically. Ronningen Petter has one unique system. Remember that most of filter systems used the clean or filtered water to backwash through and clean off the filter media in a backwash cycle. Ronningen Petter also has the option of using outside water to backwash a given module. If outside hot water at about 180° F is used to backwash the system, it will protect that filter from zebra mussels .

Filtration rates vary, and the number and size of filter units you put in line depends upon your need, the space available, and your budget. The advantages to in line filtration are reduced chemical need, improved water quality, less sediment build up in your piping, relatively low capital cost operational costs. and familiar, available technology. Filtration has been used for years in industrial and utility situations. The disadvantages are that you have an intake that remains unprotected, and there may be some pressure losses. Increased clogging with fine meshes and maintenance are certainly possible.

Another type of filtration device, that is really not a filter but meets the definition, is known as a hydroclone. One of these is the Kreb's desander. We found the Kreb's desander was providing about 50-60% efficiency in removing the settling stage mussel. As water flows into the device, it is forced to go into a spiral motion heading down the cone towards the apex of the system, and, because it flows in a spiral motion, it creates a centrifugal force. Centrifugal force will act on any particle that has a specific gravity greater than water's. Because the unbonol zebra mussels in a shell form are going to be more dense than the water (or have a higher specific gravity), they should tend to be forced to the outside of the spiraling mass of water. The water is moved down towards the separator apex due to the constant incoming flow from the top. At the apex of the cone, flow momentarily slows down and the sediment and the zebra mussel load that is being carried by that water is dropped into the grit chamber. The cleaner water then continues to move up to the central vortex and out to the top. This system has no filter media. There is nothing to plug up. These might be used to replace basket strainers, or to take out the shells after chemical treatment, or as a prefilter for an in line filter.

The last type of filter is the retractable shoreline intake filter. A rotating drum screen is located in the water on the end of a pipe going to a pump on the shore. If the drum screen is small enough in mesh size and doesn't plug up, it will filter out all the zebra mussel stages. It will provide

complete control. The advantage is access to the intake: if your filter plugs up, you can pull up the filter and use hydroblasting to clean it. If the level of protection you seek isn't provided by a rotating drum screen, use a multiple control approach — put several of these retractable shoreline filters down in the water, maybe all of them are operating, maybe one at a time. The water is then pumped up to the surface on the shoreline and into some secondary control such as an in-line filter, steam, chemical, whatever you might want to choose can be used to control the mussel.

In conclusion, I would just like to say that given the regulatory emphasis on clean water and the number of steps one must take to assure safety with chemicals, I think you are going to find more and more utilities using filters to control zebra mussels.

OXYGEN DEPRIVATION, THERMAL SHOCKING, DESICCATION

Dr. Robert McMahon, University of Texas at Arlington

I am going to talk about the nonchemical means of control of zebra mussels. This may eventually be very important for many of you. While you may initially use chemical controls — either oxidizing or nonoxidizing molluscicides — the regulatory climate is such that pressure will increase to move away from biocides or molluscicides to control zebra mussels or Asian clam macrofouling in white water systems and toward nonchemical controls. The rapid increase of zebra mussels in the Mississippi drainage basin is going to accelerate this process because, as many small industries and other raw water users start using biocides on the Mississippi drainage area, the biocide load in the Mississippi drainage area is going to increase significantly. The EPA is already aware of this and, even up in the Great Lakes, the EPA has started to regulate the use of some biocides in systems where there are multiple users drawing water even though no one user is outside of its limits. EPA officials fear that the large number of users will bring chemical levels in that body of source water above normal or acceptable levels. The work described today is all done in my laboratory at the University of Texas at Arlington and is supported by the U.S. Army Corps of Engineers Waterways Experiments Station Environmental Laboratory, the Aquatic Ecology Branch which is located in Vicksburg, Mississippi. I work very closely there with Dr. Andrew Miller, and Dr. Barry Paine. They are closely involved with the experiments you are going to hear about today.

Let's look in three areas for possible methodologies that can be used in raw water systems to control zebra mussel macrofouling. In particular, our goal is to mitigate zebra mussel macrofouling after the zebra mussels have entered the system by using technologies that are already used in the wallwater treatment — all readily applicable and having very low or no impact on the environment when discharged into the water system.

First we studied anoxia/hypoxia. "Anoxia" means lacking oxygen, and "hypoxia" means low levels of oxygen. You can remove oxygen from moving water in a number of ways: application of hydrogen sulfide or sodium metabisulfite, or stripping oxygen in low flow systems with nitrogen bubbling machines. We studied zebra mussels' tolerance for low oxygen in the laboratory by measuring the mean survival time in anoxia, which was generated by bubbling the media with nitrogen gas and stripping all the oxygen out. We tested both *Dreissena* and *Corbicula*, another macrofouling organism, especially in the south. To provide water with no oxygen to the system without using chemicals, you could put oxygen scavengers in, or, if your system is off line, you can simply lock up the system and let the zebra mussels use up the oxygen themselves.

This is already being used up on the Great Lakes. A water treatment plant with multiple intakes, in the winter, covers their mushroom-type openings to block off the whole system. They also inject sodium metabisulfite into the system to scavenge oxygen. The treatment plant keeps the system closed up for a month, long enough to kill all the mussels. They do this annually.

The temperature affects the mean survival time — length of time needed for the mussels to die — under these conditions. We noted that using hydrogen sulfide or sodium metabisulfite as an oxygen scavenger in a closed system or the accumulation of naturally produced toxic anaerobic products plus sulfide from dying mussels in a static system will greatly decrease the time required to kill them. In terms of developing a control method: if you had animals in your system at 15°C, but

you could warm your system up to 25°C and make it anoxic, then you know you would have to use about 200 hours to kill the mussels in the system. We have not yet had a test of this in a real system, but we are hoping to work with the U.S. Army Corps of Engineers to do that in the near future.

We are now also working on hypoxia, low oxygen tensions. As the oxygen tension in the environment drops, the respiration rate drops. So in summer, the aerobic portion of the animal's metabolism is declining with decreasing oxygen concentration. But the overall metabolic rate is not declining. The portion of the metabolism that is supported by oxygen uptake decreases and the portion that is supported anaerobically, without oxygen, increases and the products of anaerobic metabolism are produced in increasing volume. Some of these products are toxic to the animal and somewhere along this line, enough are produced to kill the animal. We suspect that this may start to occur, at least at warm temperatures, somewhere around 50% of full air saturation, and right now there are experiments being initiated in my laboratory to look at what levels of hypoxia, that is partial removal of oxygen, will kill the mussels, and what level of hypoxia do zebra mussels tolerate. A lot of waters are hypoxic, and this study will help people predict whether or not zebra mussels can live in these systems.

Our conclusions are that zebra mussels are about 2 to 7 times less tolerant of anoxia than Asian clams. Asian clams are among the most anoxia intolerant freshwater bivalves, so zebra mussels now set the record. This flags anoxia as a reasonable control measure. Neither zebra mussels nor Asian clams species therefore are as tolerant as other freshwater bivalves. Acclimating zebra mussels to warm temperature increases the tolerance to zebra mussels; in other words, if you try to do this with animals that have been at summer temperatures, they already have more tolerance for high temperatures than animals that have been living at colder temperatures. A decreased temperature increases tolerance so that doing this at colder temperatures will require longer exposure times. We believe that exposure to anoxia is a viable nonchemical means of mitigation control for zebra mussels.

For zebra mussels, a mean of about 3.5 days of anoxia at 25°C will kill them, and for Asian clams you will need 11.8 days and 25°C. This can be achieved by static layup; that is, if you have a system which you can close — valve off — the animals will continue to grow while bacteria will remove all the oxygen, and the animals will die. You could get the same result by injecting hydrogen sulfide or sodium metabisulfite into the system to remove and scavenge the oxygen.

In a flowing water system, use hypolimnetic water in the summer. (In lakes, water below the thermal discontinuity layer doesn't exchange with the surface; thus it becomes very hypoxic, often anoxic, without oxygen.) If you build a second piping system down to that lower part of the lake, draw water for relatively short periods in the summer time from that oxygen-deprived water, and run it through your system, you could kill zebra mussels in the system. Most existing plants can't do this, but a small water user might consider this idea for new construction. Europeans do use hypolimnetic water.

Now I want to talk about chronic and acute thermal treatments. Power plants produce hot water which they often discharge back into the raw water system. With thermal treatment, you take a portion of that water and recirculate it through the intakes. Many plants, especially up north, are already built to do this because they warm the water to get rid of "frazzle ice" in the system. You can

use this same process to raise the temperatures above the upper thermal limits of the mussels and kill them. This also has application in non-power plant systems where you might have a component which is particularly sensitive to falling temperatures. You might just want to deliver hot water to it now and then to kill the mussels or, in an intake, you may inject steam just to heat the intake ambient temperature as a nonchemical means of controlling mussels falling in the intake environment.

What is the difference between chronic and acute thermal treatments?

Acute thermal treatment is used to increase the temperature at some rate until it goes beyond the threshold for instantaneous death. You increase the temperature until you reach a temperature in which 100% of the mussels die, then you return the system immediately to the operating temperature. This threshold temperature is dependent on the acclimation of the animal. This depends upon the actual temperature of the water being drawn into the system and the rate at which the temperature is increased.

In chronic thermal treatment, you increase the temperature within the system to a lethal level and then hold the system at that temperature until you get 100% kill, then you return the system to operating temperature. It is not an instantaneous kill.

The actual temperature for acute thermal treatment is usually higher than for chronic thermal treatment because you do not hold the temperature up in acute thermal treatment.

The advantages of acute thermal treatment are fairly obvious. It is quick, and you don't have to do a lot of control. To maintain a high temperature for a long period of time, a power plant will have to do a lot of operational things to run above normal operating temperatures; just bringing the system up and then back down takes a lot less operational complexity. Acute thermal treatment is possible in relatively smaller systems. You can inject steam into an inbankment; just bring the temperature up to a temperature that will induce kill and bring it right back down. You can inject steam or heated water in a specific set of piping or in a specific component of your system.

The main problem with acute thermal treatment involves fairly high temperatures. Systems that are discharging water, like a power plant, may not be able to easily increase temperatures because these may exceed the operating limits for the equipment in the plant and/or they may exceed what the EPA (Environmental Protection Agency) will allow that plant to discharge back to the receiving water. Another problem, especially in a very heavily infested system, is fouling from waste. All of the zebra mussels die at once and they begin to release (detach) in large numbers, get carried down, and plug up small diameter components including heat exchangers, filtering systems or trash removal systems.

What temperature is the lethal temperature for 100% kill? We have developed models that predict this temperature, based on the size range of the mussels you want to kill, the rate at which temperature is increased, and the acclimation temperature of the animals. To give you an idea of how this might work, if you had a operating temperature of 20°C and you could raise the temperature one degree every 30 minutes, you would need to reach a temperature of 37° to achieve 100% kill, or roughly 98°F. You can use these models then to decide what temperature you need to achieve kill. It

eliminates wasted time with experimentation and prevent damage to your system during that experimentation. (Contact Dr. McMahon directly to secure models.)

What are the advantages of chronic thermal temperature? The temperatures required to get kills are lower than with the acute control methods. The mussels are released (detach) into the system at a lower rate and it takes a longer time to kill the mussels. The temperatures probably won't exceed discharge limitations, and the temperatures may remain in the equipment's operating ranges so you don't damage your equipment.

But it is difficult to use chronic thermal temperature in small systems or at single components because the temperature must be maintained at a constant level for long periods. In power plants, for instance, operating at very high temperatures will cause loss of capacity and therefore, lost operating efficiency. Regulating high temperatures in a raw water system can be difficult and you need a lot more personnel on operation control. We found that the higher the temperature that you keep them at before you expose them to these increasing temperatures, the longer zebra mussels survive. We also found an exponential increase in survivalship at higher holding temperature. In other words, the higher the acclimation temperature, the longer the holding time while they are dying; the higher the treatment temperature, the shorter the holding time to kill them. For example, if your in current water temperature was 20°C and you were going to treat the zebra mussels with around 33°C, it would take about 100 hours or maybe less to kill them, but as you go to higher temperatures, around 34 or 35°C you can get relatively instantaneous kills.

Shell length is also significant. We have found that the larger the animal, the less tolerant it is. Larger zebra mussels tend to be less tolerant of high temperatures and I will predict that in our southern waters, as temperatures approach upper lethal temperatures, it will sweep away larger animals so that we may have populations dominated by smaller animals in the South.

In conclusion on thermal treatment: in chronic treatment, you will use lower temperature but maintain it for an extended period in order to get 100% kill; in acute thermal treatment, you will apply very high temperatures to a specific area and immediately reduce the temperature to normal. Remember that the higher the temperature they were experiencing prior to the treatment, the greater their tolerance time for any particular lethal temperature and 31°C is the approximate, long-term, incipient upper lethal temperature. This means they will tolerate anything below 31° C indefinitely. Either treatment (chronic or acute) may be efficacious, depending on the capacity to regulate temperature in the system. If you can regulate it well, you may want to go with the chronic treatment. Remember also, if you have a population dominated by smaller mussels, a longer application of heat or higher temperature may be required to get 100% kill.

Now I want to talk about desiccation, another nonchemical treatment. This is a case where you can dewater the inbankment and expose the animals to air. We wanted to see how long it would take to kill mussels under different conditions in order to dewater during summer months in order to induce lethal drying. Under these conditions I will show that it requires days of exposure, and in many cases, long shutdown time. Then we looked at what happened if you dewatered and, instead of letting them dry at ambient air temperature, you inject the area with heated air. Lethal drying, or thermal kill occurs much more quickly at higher temperatures. You can achieve 100% kills within hours rather

than days. Dewatering during winter months and exposing the animals to freezing air temperatures has also been done up north. Anything less than -3°C is lethal to zebra mussels and 100% kill occurs within hours. This may be difficult in the South but could work up north. Even so, the high temperature method with dewatering allows you to achieve mitigation without molluscicides.

We looked at zebra mussel physiology in relation to this control method: At all the relative humidities regardless of the air temperature, the zebra mussels were exposed at up to 75% relative humidity, and all lost about 60% of their water at death. That means death was due to desiccation. We noted that at the high relative humidities, water loss was very slow, and they actually were dying at much lower values of water losses. We concluded that the zebra mussels were not dying at this higher relative humidity due to desiccation (the actual drying and concentration of the tissues), but probably these animals are anaerobic in air, they cannot respire very well from air, and they build up anaerobic products at toxic levels in their mussel tissue. For example, if you have zebra mussels at an exposure temperature of 20°C in about 80% relative humidity, it is going to take about 250 hours of exposure to achieve a kill.

What if you could take an inbankment or a piping system, dewater it, and pump heated air through, could you speed the process? We looked at 35°C which is just five degrees above the upper lethal limit and we got a rather amazing result. Against and across all the relative humidities, just a slight increase in air temperature results in 100% kill at less than 30 hours. You can generate heated air easily and cheaply. We found, in this case, the higher the relative humidity, the faster the kill rate. Remember in normal conditions, you would expect it to be the other way around, the higher the relative humidity the longer zebra mussels last because they are losing water, desiccating at lower rate. What is the reason for this? As you might expect, in the higher relative humidities, the rate at which the animals lose water decreases. When animals evaporate waters from their surfaces, just like when you sweat, the evaporative water loss cools the tissues. So when you put heated air into a wet system in which the relative humidity is high, the heated air is above the upper lethal temperature and, if the animals cannot cool their tissues by evaporation, they are actually going to respond and die more quickly. They are going to reach a lethal temperature faster. Heated air, and especially if you went up to 40 and 50°C, which is easy to generate heated air, you could have very rapid kills in your system.

We also looked at freezing at temperatures ranging from 0°C to -10°C. Exposed zebra mussels neither in clusters of 10 animals representing a dense population piled up on each other nor single animals, can tolerate -1.5°C for no longer than 15 hours. Kills are almost instantaneous at -10°C. When they are clustered, they survive about three times as long and they do survive greater than our 48 hour test time at -1.5°C. Therefore, if you dewater in the winter, freezing could be a very excellent way to get rid of these animals.

Why do the clustered zebra mussels last longer? It takes longer for them to totally freeze. To be certain, we looked at the amount of mantle cavity water present in the zebra mussels. The mantle cavity water is the water outside the body trapped in the valves. We found that it didn't make any difference whether the zebra mussels had that water inside the mantle cavity or not. The big difference was the longer time it took for a cluster of animals to freeze at any tested temperature, and the

longer it takes to freeze, the greater the tolerance time.

Tolerance time increases exponentially as temperature of freezing increases. We tested this at Black Rock Lock on the Niagara River in Buffalo, New York, where they dewatered two years in a row. After they dewatered, we sampled up and down the lock wall. It was just above freezing so all the mussels were alive. That night, the air temperature dropped to a -5°C, and when we sampled the same wall the next morning, not one animal was alive. There were some living animals left where there were leaks — water running over the zebra mussels to keep them from freezing. Had the temperature dropped overnight to just freezing or just a degree below freezing, it would have taken several days exposure for an effective kill.

In conclusion, desiccation is an efficacious nonchemical zebra mussel control method but emergent desiccation, that is applying heated or freezing air to the animals right after they have emerged from water (during dewatering), achieves a rapid kill. Slower kills are achieved by emergent desiccation in the summer. This may be useful for control in raw water sources because many of these, such as artificial lakes, can be drawn down.

Remember zebra mussels tend to live in surface waters. If you draw down the water periodically, you would then expose them to air. This method is not efficacious below 15-20°C, however, because the tolerance times are too long. Acute and chronic thermal treatments are efficacious. Acute treatment may be used for small or large scale treatment, and chronic treatment is best on a large scale like a power plant where you can actually control temperatures. Remember that the acclimation temperature or prior operating temperatures of the water in which the zebra mussels are living, and the rate of temperature increase, will affect the success of the kill. Note what you have learned today: zebra mussels can live continually at 30°C, they are living in the Mississippi River at 31°C. We are looking at fluctuating temperatures now which suggest, in a normal day-night situation where a river might fluctuate between 30°C in the day and drop to 28 or 27°C during the evening, zebra mussels can live for weeks if not months. So the zebra mussels are essentially going to extend throughout the United States. No one in the south is certainly safe from this animal.

USE OF OXIDIZING BIOCIDES, COATINGS, AND HIGH TECH ALTERNATIVES

Charles O'Neill, New York Sea Grant

Up to this point, with the exception of the filtration devices that Garry Smythe talked about, we have been talking about ways of treating facilities that already have mussels infestations. Since chemical treatments have the ability to be able to control or prevent mussel infestations, we will now discuss control or treatment methods that may be applied in facilities that do not yet have mussel infestations as well as those that do. Therefore, a drinking water facility that doesn't want to have any mussels, any time, any place in the system could use these, or any type of facility with some critical small pipe or area where none of these other methodologies can be applied, chemical treatment may be a way of taking care of the problem, whether you currently have mussels in the critical place or not. We'll be looking at nonoxidizing molluscicides, oxidizing molluscicides, and a few others.

Oxidizing biocides have turned out to be the chemicals of choice for public drinking water facilities, and they've been used extensively throughout infrastructure in industrial processes or electrical generation. Oxidizing biocides are familiar and already used in most circumstances, definitely in drinking water facilities. For example, chlorine has been used at low levels, at very short treatment intervals, for slime control. Most of the typical oxidizing compounds can be used against the zebra mussel, but those that are probably used the most often are chlorine and chlorine dioxide. Now chlorine in any of its forms is going to be very effective at killing zebra mussel, but I haven't seen too many facilities that use gaseous chlorine. Most public drinking water facilities are using chlorine dioxide, sodium hypochlorite, and ozone. Potassium permanganate, which is used for taste and odor control, is used quite often.

Chlorine can combine with various organic compounds to form trihalomethanes (THMs), particularly in the warmer water intake, shallow intake, more organic rich waters. THMs do present a problem, particularly since the EPA is reducing the limits of THMs allowed in the water. THMs are considered carcinogenic.

Most regulatory agencies permit chlorine (sodium hypochlorite) inflow through systems, although they have a residual requirement at the discharge. Sometimes facilities must dechlorinate the treated water before it can be discharged. For this reason, we see chlorine dioxide and ozone used for zebra mussel control more often, although chlorine dioxide seems to be the preferred oxidizing agent. Quite a few people have shifted over to it in the Great Lakes, particularly as their primary oxidant. Chlorine dioxide is safer and less expensive to generate on site than ozone. Chlorine dioxide, a common disinfectant that acts on aerobic and anaerobic bacteria, does not lead directly to the formation of THMs although its generation requires the use of sodium chloride, sodium hypochlorite, and hypochloric acid, special equipment and stringent safety measures.

Because ozone dissipates in raw water, it works best when applied locally. To deliver it a distance or into a piping system requires supersaturation. This can be quite difficult. You wind up having to change from plastic to stainless steel piping. We don't see an awful lot of ozone systems being put on line yet. Potassium permanganate gets away from the THM issue. If you are feeding

permanganate in water that is not particularly turbid or cold, good results are possible. But we have seen facilities that have had good results with potassium permanganate for a couple of years; then, suddenly, zebra mussels appeared in their systems in a year when the water was slightly cooler and a little more turbid from a lot of rain.

Some plants have looked at hydrogen peroxide; some have considered or tried chloroamines. Both are effective to an extent at killing zebra mussels. They are more effective against veligers than adults, and the kill rates are not 100% kill rates in the facilities.

Injecting strategies for these compounds vary, depending on your facility type and what it is you are trying to accomplish. Intermittent treatment would be a system where you do allow some mussel growth and then kill with treatment, and then allow growth and, after a couple of months, treat again. The timing is based upon how much mussel infestation your system can tolerate and how long you want to be able to treat to get rid of those mussels. Periodic treatment tends to be a system where you don't want much growth between treatments at all. Instead of treating only once every couple of months, you may be treating once every several days or actually once every several hours. Continuous treatment is exactly as it states. You turn the system on and start treating as soon as you know you've got spawning and active veligers in your waterbody. Active treatment continues whenever you draw water. You don't stop until the spawning season is over.

The Canadians developed a new technology in injecting strategies called continuous pulsed. Basically, they have watched zebra mussels respond to oxidizing chemicals. They have observed that zebra mussels can detect chlorine concentrations as low as about six parts per billion, and when they detect it, they flush the mantle water out as much as they can, seal their valves, and basically hold their breath. Periodically they will open back up and sip water. If they still detect that oxidant in there, they will clam up again. At some point they have to open up, regardless of the presence of the oxidant, and start filtering again. That point takes less time for younger, smaller mussels than it does for older mussels, and for warmer water than colder water. Once they open up, you've got them. You've killed them. The Canadians have timed the valve openings and figured out how often the zebra mussels open up to respire at given temperatures. In other words, the treatment is applied for 15 or 20 minutes, the mussels clam up; the treatment system is shut off, you figure out when the mussels are going to open up again, and start treating just before they open up. When the mussels open up, they sense the oxidant, they clam up again, the system is shut off. At some point the mussels are going to have to stay open. At that time, they get oxidized. Basically you are fooling the mussels into thinking that they are continually in oxidized water. You're minimizing the amount of chemical you have to use, which minimizes your expenses, and it also minimizes your environmental discharges in a "once-through" system.

A researcher in the Netherlands developed some data using continuous pulse chlorine injection. To get to a 100% mortality by injecting one part per million (ppm), the treatment takes about two weeks (up to about 14 days). If the concentration of chlorine is reduced to 0.5 ppm, it will take around 17 or 18 days; 0.25 ppm takes about 21 days, three weeks. That would be for all sizes of mussels. In other words, if you started to treat a system that had 2 or 2.5 cm long mussels in it at 0.25 ppm residual and treated continuously for three weeks, you would most likely kill 100% of all life stages of all sizes of mussels in the system. If you're treating smaller mussels, you may be able to cut

back to a point where you are killing them in a lot shorter amount of time. Again this is for chlorine. The numbers are similar for chlorine dioxide and for ozone in that 1 ppm down to 0.25 ppm will be efficacious against all life sizes after about three weeks.

Once you've got a clean pipe and you're treating at 0.25 ppm continually, you will keep a clean pipe unless your water temperature drops considerably to the point where you may have to start increasing that chlorine level. It is very effective.

But in a once-through system, you are still going to have a lot of chlorine in that water. You are going to have to dechlorinate chemically or by an airstripping tower. For drinking water systems, this works quite nicely. Power plants use this control method in the sensitive systems — those service water lines that are used for fire control or transformer cooling bearing operations where it is preferred that no mussels get in or live in. We do see this kind of treatment on a continual basis and on a pulse basis. Most of the regulatory agencies are still allowing service water lines in "once-through" systems to be chlorinated and then be mixed into the water stream from the circulating water systems for dilution with a discharge rate of somewhere in the six parts per billion range. In Canada and in the U.S., we are now seeing some pressure to start measuring that residual, not at the point where it is mixed in with circulating water, but where the actual service water enters the circulating water. The movement is toward chlorine minimization. That is the reason for the Canadian research on the continual pulse regime. Even at 1 ppm, if you can charge a system and let it sit for a couple of days, particularly firefighting lines and things like that, and allow the residual to build down, you can be very effective.

One drawback of chlorination at the discharge of the "once-through" type system is the need for dechlorinization or a large amount of dilution. Some of the environmental organizations are starting to recognize that no matter how much you dilute it, millions of gallons of six parts per billion water chlorine mixtures going into the receiving streams still adds up considerably, particularly if a number of facilities are all discharging at that rate. Chlorinated water in areas that were never planned to be chlorinated may have a negative effect on operating equipment and of course, with drinking water plants, excessive concentrations may cause some TRO (total residual oxidant) problems as well as THM problems.

Ozone is a good alternative if you've got the money and the ability to transmit it out to the end of the pipeline. It helps get around the THM production although the EPA is studying some of the byproducts of ozonization. This process is very expensive, and you must comply with some additional OSHA regulations when generating ozone on site. Wil LePage showed you his system with the defusers. In the typical technology for drinking water facilities, a pipe is run inside your intake pipe out to the mouth of the intake pipe. Someplace just inside the mouth of that pipe, a defuser injects the chlorine or other oxidant so that you are oxidizing all the water that is drawn or that flows in. There are bar defusers, cross defusers, and single or double circular defusers. The idea is to make sure that you have enough residual oxidant at the shore end of the pipe to keep the mussels from settling throughout that entire system.

In the Great Lakes, we have seen problems with diffusers where we have low water temperatures. The diffusers themselves may cause cavitation at the mouth of the pipe, and, if you have

supercooled water, you can have "frazzle ice" development. I don't think you will have those types of problems very often in the South.

Can you treat the crib or the meshes over the mouth of an intake? Most regulatory agencies require that you chlorinate inside the mouth of the pipe, and have interlock systems so that, if your pumps go down and the backup pumps don't come on, you're chlorination-feed stops immediately. Most of these systems have a positive siphoning effect toward the shore from the water body, at least for a certain length of time, so that a sudden pump shutdown does not stimulate immediate flushing of the entire pipeline back into the lake. In cases where you can't run a pipe inside your intake pipe, for instance if you don't have enough head room to lose that much diameter loss, pipes on the outside are allowed. Wil LePage shows that alternative in the Monroe, Michigan, new systems. Those pipes are laid in the same trench as the intake pipe. An exposed intake pipe has to be grouted onto the outside of the intake and completely covered or it must be double- or triple-wall piping with filtration devices in the insides of those pipes and sensors to detect a breach of the internal pipe. In other words, regulatory agencies do not want any chemical getting out into the source water.

We have seen a few facilities that have stainless steel grates over the mouths of their intake which would not be getting treated if they had the diffuser inside the intake. Since these facilities had problems with fish entering the system at uncovered intakes, they did not want to sacrifice the stainless steel meshes, but they realized that those meshes would become infested by zebra mussels over time. One major facility brought their diffusers outside the pipe so that they were actually chlorinating the stainless steel grate. To prevent the water from escaping to the environment, they built huge fiberglass shrouds that fit over the outside of the pipe. If you look at a diagram, it almost looks like an intercontinental ballast missile sitting there with a big nose cone over it. The water is being treated inside the nose cone and then it is being drawn right into the pipe. They had to install equipment to make sure of immediate shutdown when the pumps shut off and to guarantee that no chlorine would leak out. They had to prove that the water in the nose cone inside the shroud would be drawn into the pipe upon shutdown, and not leaked back out into the environment. This expensive equipment added about 50% to the cost of the construction of the project, but they are happy, so far, with the results.

Coatings on the market are two types, antifouling and fouling-release. Antifouling coatings are highly toxic paint-on chemicals like the old tributyltin oxide (TBTO) used on the hulls of boats to kill things like barnacles. Because they killed a lot of things in the marine environment as well, those paints have been prohibited now. We still see various copper-based hull paints which are still very effective in an aquatic, navigation type environment. They are 50% or more powdered copper mixed in with the paint. Some of these antifoulants and the hard epoxy coatings that are coming on the market may work on industrial settings like the trash racks at a power generation facility, but they are not going to be able to be used in a drinking water setting.

Fouling-release coatings allow the mussels to attach, but the mussels come off more easily with scrubbing since the surface tension is so different (lower). Sometimes the mussels may wash off at lower water velocity. So instead of that 2 meters per second (mps) or 1.5 mps, you may be able to keep the flow rates down below 1 mps and prevent the mussels from permanently attaching. These include the silicones, the wearlons, and the teflons. These are also limited to industrial settings, not drinking water settings. Although the silicones are biologically inert, they are very soft and can

slough off a surface. They have not been certified for drinking water usages, although they may be soon. They are very expensive, probably $10 per square foot for application. All of these must be applied to a clean dry surface to begin with, and since they're soft, they have a fairly limited service life.

Do some of the high tech approaches work? These include acoustic energy, ultra sound. Some lab experiments in a static situation have found that you can kill zebra mussel or stun zebra mussel veligers with sound. Unfortunately, when you try to inject sound into an entire section of a pipe, the amount of energy necessary is still prohibitive. Can sound stun the zebra mussel veligers enough to discourage attachment? Maybe. They can stun them, probably not kill them. You don't kill them until you get up to energy levels that actually cause cavitation in the water. The amount of the equipment and the expenses of operating these are still prohibitive.

Ultraviolet (UV) radiation does work very nicely on veligers in areas where the water has a long dwell time (measured in minutes as opposed to seconds). A low flow system that can support a high intensity of UV bulbs placed in it may kill veligers. However, once they start to form a shell which is pigmented, the shell can absorb the UV rays. The ultraviolet never touches the mussel's living tissue.

Electrical fields haven't proven to be terribly effective yet. I think within the next year we will have information that will be useful on the cathodic protection area.

Isn't there some beneficial use for zebra mussels? The Dutch have been watching the valve opening and closing mechanisms on the mussels. They found that if you plot that on a computer graph, the opening and closing cycles differs according to the varying chemicals that are in the water. In other words their valve opens at a different rate in the presence of chlorine than in the presence of permanganate or some different pollutants. They suggest monitoring the mussels with a computer so that they serve as a little living biomonitor out in a water stream. This monitored colony could tell you what pollutants are coming downstream, providing early warning to sensitive systems. Since zebra mussels can measure down into the parts per billion range, they may be a little bit better than electronic monitoring equipment. This has been patented in Europe. They have sold quite a few of them in the Netherlands, France, and Germany. They now have received patents here in the U.S. and have sold a few of these devices in the U.S. to actually put the little devils to work for us rather than against us!

USE OF NONOXIDIZING BIOCIDES

Dr. Robert McMahon, University of Texas at Arlington

We have studied nonoxidizing biocides and nonoxidizers that are the newer generation of molluscicides for control of zebra mussels and Asian clams. Some of these might be considered in developing a zebra mussel control program.

To distinguish these from oxidizing molluscicides that have been tested, I'm going to review Chuck O'Neill's talk briefly. Chlorine: at 0.5 ppm for seven days gives you 75% adult kill. At 0.3 ppm, it takes about 21 days; 0.2 ppm continuous will prevent veliger settling. Chlorine dioxide: 0.25 ppm for 11 days gives you 100% adult kill, 0.5 ppm for 4.1 days will give you 100% adult kill, 0.5 ppm for 24 hours gives a 100% veliger kill. Chloramine: similar levels for 100% adult kills and veliger kills.

Two other oxidizers not yet mentioned are bromine and carbon dioxide. Bromine and chlorine in 1:1 ratios: 0.1 ppm for 18 days will give you 35-65% adult kill; bromine alone also is effective and may be used at somewhat lower concentrations than chlorine. Carbon dioxide (which is an acid so an oxidizer) at very high concentrations of about 196 ppm for 48 hours at 18° C will give you 50% adult kill and will eventually give you 100% adult kill. It's being used right now as a pretreatment to induce shell gaping in zebra mussel. Carbon dioxide increases the efficacy of chlorine, but in fact we believe that it is toxic itself. We have some new data that shows that holding zebra mussels in water bubbled with a gas made up of 10% carbon dioxide, which is not a whole lot of carbon dioxide, making it hypercapnic (high carbon dioxide levels), will begin killing zebra mussels in about five or six days; by about 21 days, you'll have 100% kill. Carbon dioxide, on discharge, of course is used up by photosynthetic organisms, essentially having no impact on the environment. An injection of carbon dioxide has been used for controlling high pH in raw water systems for a long time.

Some of the nonoxidizers included in this discussion are the metallic molluscicides. You can't use the tributyltin oxides in stationary systems although they were used as hull coatings on boats. They cause sex changes, sex reversals, and all sorts of poor shell formations on mollusks so they are not used anymore. But they inhibited settlement. Zinc in paint or galvanization as surface coatings will inhibit settlement for quite a long time. The problem with zinc galvanization is it eventually loses effectiveness. You have to clean it off now and then. Potassium ions turn out to be very effective. Potassium chloride, a relatively cheap compound, will give you 100% adult kill by using 50 ppm for 48 hours. Dr. Tom Dietz alluded to what happens when you add potassium — you upset the potassium/sodium balance and that's lethal to the zebra mussel. Copper ions embedded in paints and epoxy coatings will probably irritate the veligers and prevent settlement, and copper ions at a concentration of 5 ppm for 24 hours gives you 100% kill. Silver ions, although expensive, also work for a 72% kill; mercury ions are a little less effective. Zinc, at 5 ppm for 24 hours, only gives a 5% adult kill, yet zinc is very effective at preventing settlement. So it must be irritating to veligers. Zinc coatings probably don't kill the zebra mussels. Rather, the zinc in them prevents zebra mussels from settling in the system. Aluminum sulfate, if used continuously at concentrations used for flocculation and water treatment, inhibits settlement and kills adults. So if you move the point at which you apply it to the end of your pipeline, and you're moving water fast enough through the pipeline to

prevent a lot of settlement of flocculated material there, you'll keep the zebra mussel out of the pipeline. Very high concentrations of copper sulfate, 100-300 ppm for five hours at relatively high temperatures works, but not well. It doesn't achieve a very good kill.

Now, let's talk about the nonmetallic forms of nonoxidizing molluscicides. These are all organic molecules. Some of them are very commonly used to control zebra mussel and *Corbicula* in the U.S. They are all relatively new so you may not know them as well. A molluscicide by Bayer, called Bayliside, is used against Lamprey eels. As little as 0.05 ppm for 24 hours will induce 70% adult kill, 0.1 ppm for 24 hours will produce 100% adult kill. These have not been approved yet for zebra mussels, but they are trying to. Using 0.9 ppm Frescon, another Lamprey-cide, for 24 hours, will produce 100% kill. These are being used to control lampreys' larvae up north. Because the product is fairly nasty, toxins that work very fast, the manufacturers are trying to secure regulatory approval for these.

Approved nonmetallic forms include a cationic polyquaternary ammonium compound produced by Buckman Laboratories, BuLab 6002, a surfactant. It has a lot of positive charges and is attracted to negative charge on surface proteins so it's too big to be absorbed. This product lays down on the surface of the bivalve. (Bivalves have the biggest relative surface areas because of the huge gill and mantle exposure areas of almost all meristic organisms.) So they are particularly susceptible to this. Even 0.3 ppm continuously applied, produces 100% kill in about 826 hours. The kill rates drops very rapidly, so that at 4.8 ppm, it only takes 197 hours to achieve an adult kill. This product does have "once-through" approval from EPA. It is not very potent against fish so it has EPA discharge limits of 10 ppm. Without any treatment it can be put back into the environment at 10 ppm. You can manage to wipe out a zebra mussel at continuously 0.3 ppm level. This is one of the nonmetallic oxidizing agents that are very good against bivalves.

Another Buckman Laboratories product, an aromatic hydrocarbon, is called BuLab 6009. In continuous exposures, at relatively low concentrations, it can produce 100% kills. Clamtrol CT1, Betts Laboratory's industrial product, is a quaternary ammonium compound. Buckman Laboratories adds this same polyquaternary ammonium compound to dodecyl-guanidine hydrochloride to produce a very potent nonoxidizing agent against zebra mussels. For example, 1.95 ppm for 48 hours at 20 ° C gives 100% kill. It is also approved in "once-through" systems. A product not yet approved but proven to be a good molluscicide is known as Buckman 5001. All these compounds are currently in use, either as algaecides or something else.

An organic flocculant which is approved for use in drinking water systems is a crosslink polyquaternary ammonium compound that works a little bit slower than BuLab 6002. It still achieves 100% kills at fairly low levels, 0.57 ppm for 1,295 hours will kill 100% juveniles, 0.75 for 1,295 hours will also kill 100% adults. If you are moving water through you intake structure fast enough to flocculate out in front of your normal location, this product will keep the whole pipe clean.

One ppm of Calgon's polyquaternary ammonium compound call H130, for 24 hours will give you 100% kill. A combination of two polyquaternaries, called MacTrol 7326 by Nalco, achieves 100% adult kill with 5 ppm for 140 hours, 55% in 48 hours, or use 20 ppm for 72 hours for 100% kill. Both the Calgon product and the Nalco product have EPA approvals for "once-through" systems.

A saponine extracted from the African soap berry plant, called Endod, is used by Africans as medicine. It is particularly useful for getting rid of tapeworms, but it also kills mollusks. Although this product does not yet have regulatory approval, we found that 15 ppm continuously applied gives 100% kill. I don't know if that will ever get approval.

My favorite, capsicin, which is the alkaloid extract from the seeds of capsic pepper plants which you would call jalapeno plants, hot peppers. Someone suggested putting it in the surface coatings of paints, so that it irritates the veligers and inhibits settlement. People have tested this and while they got a lot of press for a while, it doesn't work.

However, primary and secondary ammoniated carbon chains do work. When you ammoniate a carbon chain, you make it into a detergent that will take apart the membranes of the living, exposed epithelia, and bivalves have a lot of it. They tend not to tolerate these chains very well. The product Mexel 432, applied in a concentration of 2 ppm for 1.5 hours a day for 30 days, will kill 40% of the adults. And finally, benzalkonium chloride, fish culture disinfectant, will also produce fairly effective veliger kills, but at fairly high concentrations.

These compounds have some advantages over oxidizing molluscicides. Fewer precautions are required for on-site storage. They are not very dangerous. You can pour most of them right on top of you and they won't do anything. People have drunk them by mistake, full concentration, and survived. There are few safety hazards to humans associated with handling and use, but many have high toxicity to macrofouling bivalves at allowable application concentrations. Unlike the oxidizing molluscicides which actually irritate the zebra mussel and cause them to close up, non-oxidizing molluscicides are not easily recognized by the zebra mussel so the animal stay's open in spite of the fact that they are being poisoned. Some may be less toxic to nontarget organisms, particularly those that work as surfactants, because the relative surface area of the nontarget organisms is not as big as the relative surface area of freshwater bivalves. The application technology is relatively simple and inexpensive. The products are neither flammable nor gaseous. You simply put together PVC tubing and pumps to deliver them. You can set up a delivery system very quickly.

In addition, nonoxidizing molluscicides are generally not corrosive to metallic compounds. Oxidizing compounds, by their very nature, will oxidize metallic compounds. Ozone is not very good to rubber seals. So using oxidizing compounds will increase the rate of corrosion within the system, you will lose wall thickness at a faster rate, and your piping will have to be replaced sooner. Nonoxidizing compounds don't do that.

The disadvantage of nonoxidizing molluscicides is cost. Generally these compounds are more costly to apply than oxidizing molluscicides, certainly than chlorine where you use some very high dosages for short term kills. But with chlorine, you may have to detoxify the water before discharge, which adds an expense.

Right now only a few nonoxidizing agents have received federal and state approval for once through and potable water systems because they are new . You may have to struggle to get them approved with your state regulatory agencies. Most agencies know and understand chlorine. If

chlorine was to undergo the same RCCRA examination now that these other compounds do, I guarantee you it would not be approved by the EPA for use. The EPA is still concerned with determining the environmental impact of these compounds: How quickly do they break down? They are organic materials. Bacteria do eventually break them down. The EPA wants to know if that rate of breakdown is fast enough to prevent any major buildup in the environment.

Strategies are important with nonoxidizing biocides. Continuous application (where you apply at low levels continuously) or semicontinuous applications (where you essentially interrupt application for very short periods—on for half an hour then off for an hour) are most economical in terms of the amount of biocide used. Much larger doses of biocide are needed for intermittent application (where you slug in doses for two hours every day, or two 2-hour periods every 24 hours) allows periodic mitigation — the mussels can build back up in the system — and then you hit them again before they become a problem. The kill is rapid with intermittent application.

In periodic mitigation, you add molluscicide for a short time to mitigate established fouling mussel populations. Betts ClamTrol and Calgon H130 are used that way. You apply at a frequency which prevents fouling from degrading the system operation, letting the zebra mussels settle and you kill them frequently enough to prevent them from hurting the system. You apply at high concentrations and effect a short term mussel kill. You use a relatively lethal compound at relatively high concentration applied for a day or two or even 12 hours, clean out the system and wait until it gets bad again before you treat again. The method results in the lowest annual usage of molluscicides. Although you are using high concentrations, you are only using it periodically. The total molluscicide going into the environment during a year is low. This is the most economical way for you to use molluscicide, because the total amount used over the year is low.

There are a number of disadvantages, though. A molluscicide must be continuously adjusted to site-specific spawning, settlement, and growth cycles. You must have extensive monitoring to know when to apply. Timing is essential to effectiveness. If you apply it the year before the mussels all settle, the molluscicide will not kill any zebra mussels. Instead, those mussels will stay in the system, grow, and cause problems before you do your next treatment.

Molluscicide use does allow mussel fouling to be re-established in the system. The system may experience some degradation between treatments because even small levels of mussel fouling can cause problems with heat exchangers. When you kill all these mussels at once, all the bodies and shells are released into the system at one time. This can cause strainers to plug up, and other system fouling. The discharge with a molluscicide usually requires detoxification, which is an added expense. We have gathered data on many of these molluscicides to predict the best concentrations for a kill.

Temperature affects the mortality rate with these biocides. The lower the temperature, the longer it's going to take to kill the animals. You will have to expose them to the molluscicide for a longer period or at a higher concentration in low temperatures. The cutoff point seems to be around 15°C which is about the point at which the mussels become metabolically relatively inactive. If you are applying biocides, they should be applied, especially if you are going to mitigate periodically, during summer months or when temperatures are high enough so that they are metabolically active.

Continuous application of very low concentrations can inhibit pediveliger and translocating juveniles settlement. This prevents establishment of mussels in the system. The application technology is relatively simple — with nonoxidizing biocides you just turn it on and leave it on. The discharge concentration of the molluscicides into the source water remains extremely low because you are using the lowest possible concentrations. You won't have problems at the detox end because someone made a mistake and added a large amount of biocide, because you don't have to detox. Some of these nonoxidizing molluscicides also reduce microbially influenced corrosion when applied continuously.

Over a year, however, continuous application uses a relatively large amount of molluscicides even though you are applying at low levels. High chemical usage may be costly, but since this prevents mussels from ever getting into the system, it's probably the safest way to use molluscicides.

Intermittent application of nonoxidizing molluscicides means daily, bi-daily or tri-daily. You apply for short periods, half an hour to 2 hours, 1 to 3 times per day. This application will inhibit pediveliger and juvenile settlement. The concentrations are higher than those used in continuous treatments, and you can limit the process to spawning periods because you are preventing pediveliger settlement. You can also use this type of strategy with oxidizing biocides to prevent the establishment of mussel fouling. The advantage of this strategy is that it reduces the discharge of molluscicide while reducing microbes in the system. The disadvantage is that it will not mitigate established zebra mussel fouling or prevent fouling by translocating juveniles because, as with nonoxidizing chemicals, the bigger adults and juveniles that get carried in the system with intake currents learn to recognize those materials and shut down during the period you are applying it. Then they open up and become active when you are not applying it. While it inhibits veliger settlement, it won't remove an established population of zebra mussels, and it will allow the translocating juveniles to reestablish a population.

We are just beginning to evaluate the semicontinuous application of nonoxidizing molluscicide. This is the rapid on and off cycling of molluscicide addition — application at low concentrations for 15 to 30 minutes followed by off periods of 15 to 45 minutes. The mussels experience a rapid on-off addition of the molluscicide. We think it will inhibit pediveliger and juvenile settlement completely. The concentrations to use are very low, similar to continuous application. You can limit this to spawning periods. The advantage of semicontinuous application is prevention of mussel establishment in the system while greatly reducing the discharge of molluscicide into the source water. Compared to continuous application, the concentration of molluscicide is low, but less volume of the molluscicide is being used to do the same job. You greatly reduce molluscicide usage and costs. This strategy also may reduce microbial influence from corrosion. It will still involve relatively larger amounts of molluscicide than if you used periodic mitigation and the application technology may be a little more complex. This strategy is still in early stages of development.

We have done a test in the lab where we applied a molluscicide to zebra mussels for a half hour and then turned it off for 45 minutes, reducing the volume used over time by about one half. We also applied the same molluscicide in continuous strategy for comparison. The result surprised us. With the semicontinuous application, the mussels opened up when they were in clean water, and they

stayed open for a while when we added back molluscicide. Whereas, when they were continually in the molluscicide, they became irritated and closed up. Thus, in the lab we found that using the exact same concentrations, having a half hour exposure, followed by a 40 minute exposure in clean water, actually induced death as quickly or more quickly than continuous exposure. This semicontinuous application strategy may prove highly efficacious with some of these nonoxidizing molluscicides.

A final word: remember that zebra mussels are almost always more tolerant to biocides than Asian clams. Don't base your control of zebra mussel on what you are doing for Asian clams, because zebra mussel removal will be a lot tougher. Also, remember that it always takes a higher concentration and longer application to kill adults than it does to kill juveniles. If you are periodically mitigating zebra mussel in your system, you want to do it often enough to prevent the animals from reaching adulthood because adults are more resistant to treatment.

WHEN TO IMPLEMENT TREATMENT

Garry Smythe, Acres International

Let's look at a strategy for the selection and implementation of controls for macrofouling organisms. The organisms to worry about here are the zebra mussel and the quagga mussel. In this strategy we want to synthesize specific factors related to site water quality parameters, monitoring, biological data, facility design, and operations and possible control options, all of which you have heard in this workshop. I want to combine all those different specific pieces of information for managers and operations with the perceived risks that they see from zebra mussels. I want to help managers develop a strategy and reduce the gambling element in the effort to control zebra mussels.

What is at risk? The potential risks are dollars through premature or inappropriate control selection, equipment fouling, and facility outage. What do I mean by premature control selection? If you act too quickly and select a control, and put it in place, you may then find out through monitoring that you don't have the mussels. Given that situation, you may have spent a lot of money in capital expenses that you didn't have to spend. On the other hand, if you select an inappropriate control, maybe one of the chemical treatments that are going to be outlawed in the next 2, 3, or 4 years, you may have to replace it with something else. Again you have spent money inappropriately. On the other hand, if you hang around too long doing nothing, you may end up with some equipment fouling and facility outages. As you can see, we're actually gambling with money and time.

There are five main tasks that we work with in this strategy. The first task is going to be to conduct a site-specific environmental evaluation and facility component vulnerability assessment. The next one will be to look at the controls and make some control selections. The third task would be to look at the complete conceptual and detailed control designs; task four to schedule and implement the controls, and five to conduct post installation field testing.

In task one, the site-specific evaluation and vulnerability assessment, we want to determine the probability of infestation by looking at mussel dispersal mechanisms, systems water quality, and system flow rate. You also want to evaluate the sensitivity of individual systems within your plant to zebra mussels. You are going to look at your intake structure. How quickly is that going to foul? What about your make-up water system? What about the service water systems? What about your condenser tubes? Monitoring results and information from your upstream neighbors on the status of zebra mussels at their location are important elements in this assessment. Then look at available control options in relationship to plant design and operation. Every plant is going to be a little different. Don't forget the federal and state control restrictions that may already exist or may be brought into play in the very near future.

Task two involves reviewing available controls and selecting those that appear to be appropriate to the evaluation. You may find that more than one control would work for your particular facility; or you may find that more than one control is needed at different systems within your facility. For example, you may see a place where chemical application is needed, and you may use

that in combination with a foul release coating of some kind or maybe filtration. During this process, you are looking for control options that reflect sound biological engineering and environmental methods. You want to look at proven methods. By "proven," I mean an option that is in full operation in another plant, and that you have complete confidence in. If that's not possible, then look at something that has been studied in full scale — over a long period maybe at a site or in a laboratory — instead of something that has been studied once for two months. Look at control methods in relation to cost effectiveness for your particular plant. Then prioritize the control options that are suitable for your plant and the systems to be protected. For example, you might be able to say, "I don't have to worry about my intake structure right now. I don't think that's going to foul in the first year or the second year to the point where I can't operate. However, my service water systems may be in jeopardy right away, and I'm going to have to put some kind of control in there right away." Thus, we want to consider the facility fouling rate and the implementation window to get that particular control into place. Here you are gambling a little bit. If it is possible that your facility could foul in a shorter period than it takes to implement the selected controls, you may need a contingency control plan in place, or you may scrap that particular control and select a quicker option. You are gambling with time.

Task three, you want to go into conceptual design and detail design in relationship to your plant or the particular system which needs zebra mussel control. If you select a molluscicide treatment, typically the vendor/manufacturer includes service to come on site, puts in the molluscicide, and go off site. You really don't have to do much as far as a conceptual and detail design. But, if you choose another control method like filtration, or application of a chemical like chlorine, you may have to spend some time designing.

It's important to design on the basis of results from your monitoring program and on information you have received from people upstream of your facility. Remember you are developing a probability for when life stages of the animal will arrive on your site, and probability for the locations in your plant where the zebra mussels will settle. If the mussels have not yet infested your plant or your neighbor's plant, you may be able to pause after the conceptual design. You are gambling with time.

Task four, schedule and implement the selected controls, is going to be site specific. You must determine this in relation to operations, production, and maintenance schedules as well as the imminence zebra mussel infestation. I can't help you with this one.

Task five, post installation field testing, is the way you find out if your control method is working. It will help you evaluate the biological effectiveness and the mechanical effectiveness of the control plan. When you put the control process in place, don't walk away and assume your zebra mussel problem is now over. If your goal was a kill, make sure the system is doing the job biologically. If it's a filter, is it filtering out what you want or is it missing the mussels. Is the chemical you have chosen going to do the job for the adults, for the juveniles, for the veligers. Is the control method working mechanically as anticipated? If you don't have any mussels yet, let it run for a while, use it as if mussels were present to check the mechanics of the system so it will work properly when mussels come. How is the control program affecting the entire system? Are possible side effects appearing in other areas of the plant or in your product from the control process? (Because you have

planned carefully, your control process should not result in affects to other parts of the plant. But remember Wil LePage's experience. Waste from killed zebra mussels might foul other systems; chemicals from a control program might require a change at the discharge point.)

In closing, the most important part of this strategy revolves around the people that develop it, select controls, and implement them. Try to keep the group small, but use knowledgeable people. This will probably include facility operators, facility management, corporate management, and then your engineering and biological staff, and consultants, if you are using them. Get these people together during the control selection process and then at regular intervals thereafter. Continue your monitoring program as a further check on your control process. That's the best and most efficient way to get this kind of effort underway, operational, and blended into the plant operations.

SYSTEMS APPROACH FOR ZEBRA MUSSEL CONTROL: DESIGN CONSIDERATIONS FOR NEW INFRASTRUCTURE

Charles O'Neill, New York Sea Grant

We've reviewed a fairly long list of control methods that work pretty well for retrofit — to treat your facility in a timely fashion during a zebra mussel invasion. But when you look at long term, building new infrastructure, a slightly different approach can be taken. Zebra mussels have migrated to the U.S. They are here to stay.

Many of the topics discussed so far in this workshop will also have a role to play in this approach to new infrastructure, but from what happened with zebra mussels in Europe, particularly in Western Germany and in the Netherlands, we have learned that planning, or at least awareness, for future construction is important. Applying the systems approach at existing sites or designing infrastructure at new sites is quite different from the infrastructure design methods we currently use on freshwater in the U.S. (This approach has been used in the U.S. on saltwater, however.)

How do you design new infrastructure to handle zebra mussels? How do we, 50 years from now, say, "That plant never had a zebra mussels problem because we designed it with zebra mussels in mind." I'm going to discuss a holistic approach.

You will look at the existing plants and study intake design, pumping strategy, water velocity, onshore structures, and how the water actually gets into the facility at that point. You will study your overall water flow in the facility as well as your surface water and your service water systems to discover how you can adapt those to prevent zebra mussel infestation. You will examine your system from far out in the surface waterbody through every point in the system and out your discharge, if you operate a once-through system, and out to your big filter beds, if it is a drinking water facility. How do you wish this existing plant had been built? Then you will apply those conclusions to your new design. Let's look at a few critical points in any new system.

The intake can be configured in a couple of ways. Europeans are surprised that our intake cribs are sometimes over a mile and a half offshore. They favor very short intakes — either a short single intake designed to be pigged easily or to be dewatered. In the latter case, the intake has cleanouts built into it so that when you take the unit down, for whatever reason, you can routinely pig or dewater the line and go in and remove the mussels manually. Europeans also favor dual short intakes. Each intake can operate the plant in itself. Each can be sealed off at both ends to be dewatered or hermetically sealed and have the oxygen scavenged out of it. In these plants, water can be pumped through one of these lines until zebra mussel settlement becomes a problem and it has to be cleaned out. Then that pipe can be sealed, the other pipe can be opened and used while the first pipe is allowed to become anoxic and the zebra mussels are flushed out. The dual pipe system gives added benefit to meet excessive water demand or as a backup if the first pipe is damaged.

Another approach that Europeans use is to install shore line pumping bays instead of one big, long intake pipe or a couple of short ones. These shore line pumping bays will not work for an intake at drinking water facilities, but for some industrial and some power facilities, the approach will work.

Access to a shore line pumping bay is much easier than to a pipe. The system doesn't have to be hermetically sealed, and it can be designed so you can clean it out mechanically — sometimes even while the system is still on line.

Regardless of which one of those approaches you select, the intake specifications fall into two related categories: the intake surfaces and the piping layout. First, build intakes with smooth walls in order to lower the friction coefficient on the surface as much as you possibly can. You want (a) the water to flow through the intake nice and smooth, and (b) the zebra mussels to have difficulty attaching. When they try to attach to a very smooth surface, their glue beads up like water on the hood of your car after you Simonize it. The pipe surface should promote a very good flow with little turbulence. At the water surface-pipe interface, at the sheer zone, that good flow will keep the zebra mussels from attaching to the walls. If you've got a nice smooth flow with that well defined sheer zone, the zebra mussels are discouraged. If flow is broken (by pitting, a bad weld, a misaligned joint, any kind of roughness) and causing a bit of turbulence (this happens with old pipes as well as new pipes), mussels will attach although the flow rate would normally have kept the zebra mussels moving. Once a few mussels attach, other ones can start growing around them and a colony can get started.

The other category, linked to the first by the need for uninterrupted flows, has to do with the pipe layout and assembly. Avoid tight turns, particularly 90 degree turns (not necessarily 90 degrees on a horizontal plane, but on any plane). This includes areas where the water comes into the shore or some sort of bay, and then is pumped vertically upward. That circumstance will result in eddying. At that point, zebra mussels can and will attach. Changing pipe diameters will have the same result. You don't want anything in the layout or assembly that will interrupt this nice smooth rapid flow of water through the facility and you want to minimize those vertical sections as much as possible. A lot of folks on the Great Lakes object to this plan, because it leads to fish entrainment problems. They are worried about sucking in more fish than the Fish and Game Commission will permit. What can be done about that? You might change the design of the mouth of the intake and let it funnel down as described below.

New designs should take into account pumping and water velocity throughout the system. Ideal water velocity to keep zebra mussels from settling, according to the Europeans, is two meters per second. Here in North America, some of our research suggests a slightly lower velocity will also work. The ideal velocity, to some extent, depends upon the surface. Whereas we, in North America, tend to use large pipe and pump at a slow velocity, Europeans choke down the pipe diameter and use a humongous pump that's moving an awful lot of water at a high velocity. The pump and the fast water suck in the fish. However, if you design your intake either with bifurcated or trifurcated mouths, or, as Wil LePage demonstrated with his funnel shaped intake, the velocity at the mouth of the intake is probably going to be low — close to a regular pipe intake — enough to reduce fish entrainment. The design will then have to choke the pipe down into a narrower pipe where your velocity does pick up. An alternative, used in Norway and the other Scandinavian countries for fish farming, is to install ultrasonic fish fences around the mouth of the intake. In summary, the concept is to shrink the diameter of the pipe, keep it smooth, keep the water flowing, increase the rates, go with very high velocity water flowing through it, and help minimize the attachment of the zebra mussels.

What are you going to do about this smooth flow to get it into your facility? Your planning should include a survey of wet wells, low lifts, pump houses, always with the goal to keep the flow of the water very smooth. Avoid small volume structures, as well as very large pumping bays where the water comes in and stands in a lot of areas, hardly moving. Keep away from those square corners. To reduce eddying, European pumping bays are capsule- or spherical-shaped instead of rectangular. By keeping those areas smooth, you will minimize the amount of zebra mussels that are going to be able to attach. Water velocity continues to be very important. Your internal water flow and your circulation water systems also need to flow as fast and as smoothly as possible. Your system and the way you're using the water will put some limits on maintaining these high flows. If you can't maintain the high flow, get creative with materials. Copper or brass piping and galvanized pipes are comparatively irritating to zebra mussels. Perhaps coat the pipe with one of the copper-entrained epoxies or with some of the polymer surfaces that the mussels can't attach to as well. Those types of materials may be utilized in the circulation water systems as well. A condenser box is a possible colonizing point because it encourages eddies. I've seen many condenser boxes with very good velocity going through the condenser tubes but the water box itself is just one big eddy along the sides.

If your facility generates heat of any sort, and if your production process can accept places where the heat is recirculated, design it right in there. The high temperature discourages settlement and very high temperatures kill/cook them. Some Great Lakes power plants are now scrambling to figure out how they can rechannel waste heat back through. If you're designing a new facility that will have heated water in it, design a way to use the heated water as a free source of zebra mussels killing power.

Use creativity on your service water lines. The creative piping materials, like copper or polymer surfaces, may work. Fire fighting lines, ideally, should be designed so that they absolutely, positively do not have water flowing through them except in an emergency. Backflushable, centrifugal filters (such as Garry Smythe described) are ideal for service water lines. It is very easy and cost effective, from the designing stage, to incorporate ultrafiltration into the system that will be able to keep the mussels out of those service water lines.

Design good access into your circulating water system or your service water system — to get people in with scrapping equipment, and skids for bucket loaders, to be able to feed a pig through a system. Access sites are necessary for cleanouts, dewatering, and mussel removal. If your pipe layout has to have step up-step down diameters or real tight bends (and those are sometimes unavoidable), you may need to design in multiple access sites for cleanouts.

Dewatering and mussel removal or just mussel removal should be incorporated into your operating plan. Design so that scheduled maintenance shutdowns include zebra mussel control. Utilize your waste heat, recirculate it. Over design where possible. Instead of designing with 50% headroom in a system, plan out 25 years and design with 75% headroom. If you feel that you can afford to have mussels in your system, and you know they cut about 15% off your efficiency, then design an extra 30% of efficiency in. If you plan to control the mussels with chemical feed lines, consider future replacement of those pipes; they do wear out. Don't cast them in 10-feet of concrete. An alternative is to design 2 or 3 spare feed lines that you can switch over when you start to have one line break down.

Plan ahead. Look at the long term, 50-year life of a facility during the conceptual phase, design like they did in Europe, with the mussel in mind. Facilities along America's salt water coast are already designed with pest-wildlife in mind. Now we are going to have to consider animals in our freshwater infrastructure here in the U.S. In the next generation folks operating these facilities are going to look back at 1990s, scratch their heads, and say, "What was the big deal all about?"

THE NEED FOR IN-PLANT SIDE STREAM MONITORING

Cameron Lange, Acres International

So far we have looked at different controls to protect against zebra mussels. I'm going to talk about a rather inexpensive yet effective methodology of verifying that the control works, and also how to optimize that control. The key to this is monitoring.

Whether it takes place inside a plant or outside in a water body, every monitoring program should include substrate monitoring, which, in effect, is side stream monitoring in a plant. It should include veliger collections to determine the imminence of settlement. It should include (especially inside a plant) direct inspection, and education. If many people know what you are looking for, you will have fewer surprises. The frequency of each of these depends upon your particular needs, but all should be included.

What are side stream monitors? Side stream monitors simply are a means to sample the raw water flow for settlement. It's a means of gaining easy access to know what's inside the pipes in your facility, and allows sampling for veligers in your plant in order to determine veliger densities. You use a 63-micron net to gather evidence of veligers and a biobox to gather evidence of juvenile and adult settlement.

First, let's look at side stream monitoring design. There are two styles of side stream monitoring in general. The first style is called the canister style; the first one in place that was brought over from Europe. A pipe or a raw water flow is tapped into the inflow at the bottom of the side stream monitoring. The water passes through a number of diffusers or baffles in order to calibrate flow, and then the water flows over the substrate plates or other material like a bridal veil sampler to detect veliger settlement, and finally through the outflow that runs into a drain. Substrate plates are usually made of the same materials as the substrates in your plant, or of some hard surface zebra mussels like to settle on.

In the south, another component of a side stream monitor is a bleeder valve to remove sediment. Since you have a high sediment load in a lot of the waterbodies down here, and you want a low flow condition in the monitor that is conducive for zebra mussels settlement (lower flow than what's in the pipe that you are tapping from), sediments will rapidly build up over the substrate plates without this valve. Zebra mussels don't settle in sediment. So a bleeder valve is something to be considered for side stream monitoring or biobox design.

A biobox has the inflow and the outflow, with substrate plates inside. It is nonpressurized. Some of the first bioboxes tried to mimic exactly what was going on inside their pipes so they developed a pressurized biobox. By experimentation and observation, we found out that the biobox works just as well, whether it is pressurized or not pressurized. More important is the rate of flow that passes over the substrate plates.

Why install bioboxes? They can help you determine the best time for your control program because they will give you data to determine the seasonal and annual variability of mussels in your system . If your plant uses continuous control, you may not have to use the biobox all year long,

although down south here you may find out that you will have to use a control 12 months of the year. A biobox is also used to measure the success of the control.

When do you want to initiate the sampling? Initiate when ambient water temperature approaches 8°C in the spring. Because of your climate, your water temperatures do not go down as far as those in the north, so you may want to consider sampling all year. Even in the north, because the translocation of juveniles occurs year round, many facilities maintain their bioboxes year round, and, in fact, sample them all year long.

How frequently should you sample? Most folks will look at their bioboxes every other week. Frequency depends on the sensitivity of the system defouling, and also the type of control to be used. You don't want to be overzealous and pull your substrate plates on a daily basis and replace them with new substrate plates. The plates must have a biofilm built up on them, and that takes a number of days to build up. There is a least one circumstance on the Niagara River in New York where an overzealous technician pulled the plates every day and replaced them with new plates. At the end of the year he turned to his boss and said that they had no settlement in the plant. They sent a diver down who found that they had about 3-inch layer of zebra mussels throughout their plant!

Where do you want to set up your bioboxes? Generally you want to place one upstream of your point of control. This acts as a biological control to compare to your in-plant control method. This way, you can see if your control is being effective in your plant or something that's happening out in the waterbody. In 1992 —the year without a summer up in the Great Lakes — there was virtually no settlement anywhere in the Great Lakes due to the slightly cooler water temperatures. In that year a number of facilities decided that they would turn on their chlorination or potassium permanganate controls, and at the end of the year, their inspections showed that they didn't have any zebra mussels in their systems. The control method had "worked." They were surprised the following year when the water temperatures went back to normal, that settlement rates were similar to those two years ago, and they found that their controls weren't effective.

Put another one in any sensitive area and one at each of the furthest points that the control effectiveness is desired. It's not necessary to set the bioboxes or the side stream monitoring up after your condensers because the water is going to be too hot. The zebra mussels veligers will be killed going through the condensers and there won't be any settlement. But just before the condensers would be a good place to put a biobox. A biobox near water quality metering equipment gives you a feedback mechanism. That is important if you decide to go with some chemical application, especially continuous oxidation.

If you remember nothing else in this talk, remember side stream monitoring techniques are indicators of fouling but are not necessarily indicative of the fouling that is occurring in your plant. In a biobox, you are looking at a relatively small substrate, you are looking at only one micro-environment (micro-habitat) that is in your plant. It may not show what's happening throughout your plant. If there is a massive settlement of zebra mussels, and you have your biobox set up correctly, you will probably get some degree of settlement in that biobox, but the degree of settlement may not duplicate what's happening in various areas of the plant. Don't use side stream monitoring as the sole means of determining what's happening in your plant. Use direct inspection, wherever possible, as the primary

means to detect zebra mussels.

Side stream monitoring allows you to look at areas or get an idea of what's going on in areas that you can't access, places where it's much easier to access the side stream monitoring on a continuous basis. But once a plant goes off line, don't forget to inspect other areas where you have not been monitoring. Check the traveling screens, that's an easily accessible area. Check the screen wash if you can, back flush your filters periodically. Take a look at your filter back wash; see if you have shells in your system. If you look for zebra mussels wherever and whenever you can, you are going to minimize the chance that zebra mussels are going to catch you by surprise.

Some general methodologies should be followed when conducting a side stream monitoring program. All substrate plates should be the same size and material, so you can compare them. It is important to have the biological control substrates upstream of your physical control or your zebra mussels the same as those in the plant. Flow rates in the monitors should be comparable to each other. A rate of about 10 liter per minute creates a flow with the diffuser plates that's conducive to zebra mussels settlement. We always provide a veliger tap at the incurrent line of the side stream monitoring. Without a tap on that line, you may overestimate the densities of veligers in your plant because the biobox is a sink for veligers, they tend to congregate at the bottom. Monitor frequently because the incurrent pipes may become clogged with zebra mussels which can shut down your bioboxes. When bioboxes shut down, they go anoxic. They are not indicative of what's going on in your particular facility.

Don't limit examination to only the substrates plates in the biobox. Although it is easy to pull those, take them back to the laboratory and look under the microscope for early fouling, zebra mussels settle everywhere. Look at other areas in your biobox. Just as you want to look at other areas in the plant. Look all over the biobox at anything that comes in contact with your raw water. In this way, you will maximize the chance of picking up settlements events.

If you have a prudent monitoring program where you look every two weeks or so, you're not going to see the large organisms. In fact you may look at substrate plates and see nothing but when you can rub your hand across them, the plates feel gritty or sandy. You may have zebra mussels there, but you are not going to be able to make a positive identification with your eye. You are going to have to take the plates back to the lab and look under a microscope.

Your side stream program has to be tailored to the type of control you are using. If you decide to use continuous chemical control like chlorination or another oxidant, or perhaps a nonoxidizing chemical on a continuous basis, you can utilize monitoring to determine when the controls should be started in the spring and end in fall (although in the south, we're not sure you can start and stop), and the effectiveness of the control. You look for settlement upstream and downstream of your control regularly to optimize control efforts. If you see that the animals are settling even though you are treating continuously, you can increase the concentration of your chemical.

If you place the monitors near residual analyzers, you have an idea what's going on in that particular system. By inspecting the substrate plates frequently, you can make adjustments to the residual if needed.

Those using continuous chemical control can conduct veliger sampling to determine mortality. You don't have to get 100% mortality even in the water you sample downstream of your control. We have found that a 50% difference in the veliger mortality in the side stream monitors before and after the control can be considered effective because it is not necessary to kill the veligers. Your goal is to irritate them so they don't settle.

If you are using a periodic chemical control (such as a molluscicide or chlorination) or some periodic treatment (such as thermal control), you can utilize the bioboxes to determine when control should be scheduled. If you start having a massive settlement event, begin treatment as soon as possible because you don't want the mussels to grow so large that they resist or avoid treatment and you don't want any disposal or any clogging problems.

Monitor frequently in order to determine these settlement events. Inspect all substrates prior to control application to determine the densities of zebra mussels. You can then predict whether your controls are going to be effective. If you don't have a lot of juveniles or adults on your substrate plates, you may want to spike the monitor. That means, plant some zebra mussels in there in order to determine the effectiveness of the control. After the control is conducted, inspect the monitors at regular intervals, post treatment, because there is some latent mortality. All the zebra mussels don't die immediately. Be patient. Look at your spiked sample over a number of days just to make sure the treatment, in fact, was successful.

Timing is very important and monitoring will help you determine if your timing was right. If you haven't timed control application exactly right, look for additional build up and consider scheduling another treatment.

For periodic treatment and thermal control, veliger sampling is usually not required, although you may want to do some low level veliger monitoring to look for pediveligers. It depends on the amount of lead time you need to get the control. If you are using an outside service where your control program has to be scheduled around those at other facilities, you may need lead time. In that case, veliger sampling can help you be sure you have enough lead time.

If you use barrier filtration (such as Garry Smythe described), monitoring will help you compare substrates upstream and downstream of the filter quite frequently to determine if any zebra mussels are passing through. Collect veliger samples frequently. Once the veligers get in, if they are a settling size, they may settle. If you do use barrier filtration, think about a backup control methodology in case side stream monitoring proves the filter was not effective.

Finally in summary, the biological monitoring program should be an integral part of any zebra mussels control program. It will save the plant a lot of money in the long run, especially if you find out your control doesn't work or you decide to use a concentration that turns out to be more than was needed. When you are setting up the program, place these biological monitors strategically with the control assessment in mind. Tailor your monitoring program to the type of control being utilized and also the specifics of your plant. And finally and probably most importantly, remember that monitoring is just an indication of what's happening in the raw water system. It may not be totally indicative of what's actually occurring.

CASE STUDY #1: CHLORINE CONTROL IN THE LOWER MISSISSIPPI VALLEY

Harold Chagnard, Dow Chemical Company

Before I begin, I would like to make a comment about chlorine. Many of us are here today because we had chlorine in our drinking water. Although there is pressure to limit the use of chlorine, in essence, it's a lifesaving chemical.

My topic today is the chlorine control for zebra mussels. To put our particular case into perspective, we have a 300,000 gallon per minute flow of river water that is used for once through cooling. This is quite a large flow of river water. Our plant is fairly old, but it is well maintained plant. Utility companies use about the same amount of water as we do. Much of our water is used to produce chlorine, which takes electricity.

There are some subtle differences in chlorine control for our sites in the Great Lakes area and our sites in the Mississippi Valley. The first thing one must do is to look at all the various ways to control zebra mussels. In our plant in Canada, they went through a long list of different types of options to control zebra mussels including heating, desiccating. Basically, they decided that chemical control was the only viable option. We are facing the same situation here in Baton Rouge, Louisiana. We have to find something that is toxic to the zebra mussels, that will kill a large percentage of them, possibly 90% or more. This may be toxic to the waterbody receiving our discharge, so we also have to arrange for detoxification.

We decided that some of the compounds described by Dr. McMahon may not be totally out of the aquatic environment when they are detoxified. When one uses a solid adsorbent to remove an organic, often the organic remains with the solid. The EPA has already recognized that problem, and they are concerned about sediment toxicities. On the other hand, chlorine is easy to detoxify. In Canada, to meet a 10 part per billion limit on discharge, we (Dow Chemical Co.) use excess of sulfite solution to neutralize the chlorine. The chlorine is reduced to chloride ion.

After you have decided on a chemical control agent, the next two important considerations are capital costs and operating costs. Every penny that we use for capital, we must pay interest on. That is our criteria. When you are evaluating capital costs, you must add interest to the cost of that capital.

Operating costs include people issues and process issues. Safety is a people issue. In our Louisiana plant, we handle a lot of chlorine. Our employees already know how to handle chlorine. Safety is already built into the system so we know the safety cost of using chlorine as a control agent. Many plants resort to using sodium hypochlorite solutions to avoid the possible contact and release of chlorine gas. Sodium hypochlorite is a more expensive method, but a safer method, of putting chlorine into the system.

Some of the operating decisions we have to make are: What time of year do you want to treat with the chlorine? Where do you want to add the chlorine? Where do you want to dechlorinate? What's the dosage level? How often do you want to treat? Do you want to cycle this treatment? Do you want to use 15 minutes on, 45 minutes off type of approach? We looked at a number of different

approaches that could be used in applying the chlorine; most of these were described by earlier speakers.

This one wasn't mentioned. You can actually program the dosage level. In other words you could start with a real trace — 0.2 parts per million (ppm) chlorine, and then increase to 0.4, 0.6 ppm, and so forth and actually program up the chlorine dosage level. This can save chlorine and also have less impact on the environment. There are all kinds of scenarios you can devise with the chlorination. However, if you finally get to the point where the zebra mussels population is too high, chlorination through the whole period may be required; the options of periodic or intermittent approaches may be gone.

In our plant near Baton Rouge, Louisiana, we generally classify zebra mussels by size. We look at the veligers, we look at the attached settlers, and we look at the adults. In particular, we are interested in populations on all these, some environmental tolerances for the settlers, and the growth rate for the adults.

Dr. Dietz's group sampled for veligers at our plant. In 1993 we had roughly about one veliger per liter; by 1994 we had over 300 veligers per liter. This is a phenomenal increase in veligers. This is just as high as what we (Dow Chemical Co.) encountered in our plant in the Great Lakes.

The data that set off an alarm for us showed up in our biobox. We installed an aquarium style biobox, with one foot square plates, three inches apart, with a five gallon per minute flow rate. The water velocity is 0.044 feet per second passing the vertical plates. The water velocity is the real key on how effective you are going to be on catching the settlers. From March to July we had about one zebra mussel per plate. An inspection 12 days later showed 50 on that place that we were easily able to count and see visually. Then Dr. Dietz examined the plate and counted 200. That showed us that what we thought might be a slow growth in population from year to year, maybe double each year, was not going to be the case. This indicated to us that the growth rate was exponential.

Additional observations show that in September, we could get in roughly another 200 settlers per week. We confirmed these biobox results on some of our screen frames. We also confirmed these with some of substrate samplers that we built ourselves. We find that if we drop substrate samplers right into the flow, we will only get the settlers on the plates that are shielded from the flow. We may get a few on the ones that the flow impacts, but always on the shielded plates. Velocity is simply the key item when you are trying to sample zebra mussels.

In the beginning of 1993, we were seeing five zebra mussels per foot^2, 150 per foot^2 later on that year. In early 1994, they were counted at about 150 per foot^2. In the second half of 1994, we examined pump housings. On the outside, where we have low velocity, we found 2,000-4,000 per foot^2.

On these housings, we could actually see zebra mussels over an 1 1/2 inch in size spaced out about every three inches. These were 1993 mussels. The 1994 mussels that were found, the young

adults, numbered about 20 to 1 compared to the older ones. In fact some of the young ones actually grew on top of the older ones. We estimated there to be 2,000-4,000 per foot^2; if you put that in terms of square meters, you just multiply roughly by 10, and we come out very closely to the number that Keith Stoma reported (for River Bend Power Plant upriver) the other day, about 35,000 meter^2.

The level of veligers, settlers, and adults together is the reason that we decided to take some action. How to go about setting up the dosage levels and the times and process? This particular reference book: *Zebra Mussels Biology, Impacts, and Control*, edited by T.F. Nalepa and D.W. Schloesser (Lewis Publishers) had all the information in it that we needed and that was recommended by several people. In my opinion, it is the best reference for chlorine control.

We selected for our target 0.5 ppm of residual chlorine for 21 days. We extended the published envelope a little bit for safety, but not a whole lot. We decided to chlorinate at 12-15 ^{o}C, a little bit cool, but there are some good reasons we'll talk about later.

If you wanted to compare different oxidants. The data is available in that same reference book edited by Nalepa and Schloesser. Someone asked about permanganate effectiveness. All of the oxidant chemicals require several days of contact to achieve a good kill.

One of the biggest differences in chlorination effectiveness is temperature. If we used higher temperature, in the 20 ^{o} C range, we can get to 100% kill level in only 10 days.

We looked at the temperature data for the Mississippi River at our plant and found that if we wanted to start our treatment after the water warmed up past 55 ^{o}F, we would have to wait until about April. If we discontinue treatment when the water gets too cold, we will do that in November.

A moment ago, I said we chose to use a temperature on the low side — around 12^{o}C. In our system, we must convert the chlorine gas into aqueous solution. If the weather gets too cold or there is a temperature inversion, our system can vaporize the chlorine. We used quite a bit of chlorine in this plan so there's actually two chlorinators in parallel to provide this amount of chlorine. We chose Wallace and Tiernan V2000 V-notch gas chlorinators.

This is an injector provided with the system. A process water line creates a vacuum in the injector, and the chlorine is drawn into the process water. A pressure indicator is hooked to a computer. If the pressure comes up in the line, it will shut off the emergency block valves. There are also pressure indicators on the water flow and there are emergency shut offs via a computer to shut the control process off if you lose the water flow. Although if you loose the water flow, you lose the vacuum. We have a double safe system. I must emphasize that it is very important that the chlorine is introduced into an aqueous solution. If you try to inject straight chlorine gas directly, more than likely you are going to get chlorine vapors into the air.

We discharge the resulting solution of chlorine and water into a canal system. Our plan has redundant analyzers in the intake and the return canals to control the level of chlorine at 0.5 and to be certain that the residual is not too high. These, of course, will all go to the same control computer and can shut down the system if we have a high level in either the intake or return canal.

To summarize: we do not think that this treatment will control our zebra mussels forever. We believe that 0.5 ppm of chlorine, for 21 days, twice per year will protect our plant for a couple of years. If the zebra mussels keep multiplying and settling like they have in the last two years, we may need to go to a system that was discussed where we chlorinate through the entire veliger season — from April to November.

CASE STUDY #2: EXCLUSION FILTER IN THE LOWER MISSISSIPPI VALLEY

Martha Brown Hester, Mississippi Power & Light Co., Gerald Andrus Plant (Entergy Corp.)

The Mississippi Power & Light company, Gerald Andrus Plant is A 761 MW single, supercritical, oil/gas fired unit, located five miles west of Greenville, Mississippi. The water used for once-through cooling (circulating water system) and closed cooling water are taken from a small oxbow lake called Lake Ferguson that receives water from the Mississippi River.

Located inside the plant's intake structure are the circulating water and the service water pumps. There are two circulating water pumps, which have a capacity of 90,500 gallons per minute (gpm) each, that pump water through a 96-inch pipe. Also inside that intake structure are two 12,500-gpm service water pumps that are used for the closed cooling water system and the raw water filtration systems. These pump water through a 36-inch pipe. One service water pump is kept on standby. Water for cooling purposes is taken from Lake Ferguson and discharged into the Mississippi River.

With confirmation from the U.S. Fish and Wildlife Service that zebra mussels were present in Lake Ferguson (1992) and based on various workshops and seminars related to zebra mussels, substrate samples were placed at the facility's marine terminal as a proactive approach in November 1992. Our substrate samples consisted of a 4-inch by 12-inch piece of PVC piping that we just hung over the side of a barge. Substrate samples were placed on each corner of the barge, giving us a total of four substrate samples.

After approximately two months, the substrate samples were inspected, but no signs of zebra mussels were found. Periodic inspection of the substrate samples continued with no zebra mussels sighted until July 30, 1993. At this time, Entergy Corporation established a Zebra Mussel Working Group to evaluate the potential impacts resulting from zebra mussel infestation. The working group was tasked with developing a consistent system wide strategy for monitoring and control. The initial recommendation from the working group included inspections of closed cooling water systems and surveillance documentation. It was after the zebra mussel sighting in July 1993 that the plant initiated a monitoring program for zebra mussels. Acres International Corp. was hired in October 1993 to assist the facility in developing a site-specific zebra mussel monitoring program. The monitoring program included: (1) identifying areas that could be vulnerable to zebra mussel infestation and installing side stream monitors in those areas; (2) instituting zebra mussel veliger sampling on a monthly basis with FTN Associates; (3) meeting with plant personnel to review control strategies that could be applicable to the facility; and (4) developing and implementing a control strategy.

The most vulnerable area identified at the Gerald Andrus Plant was on the plant's service water system. The service water cooling system supplies water not only to the plant cooler, but also to the demineralizer units and firewater protection system. This is filtered river water that is stored in two 400,000 gallon storage tanks. A total of six side stream monitors were stationed at various areas on the service water system, and one side stream monitor was placed on the circulating water system. In November 1993, the plant began zebra mussel veliger sampling. Although the veliger counts were relatively low, the presence of zebra mussels in any life stage was not a good sign. By the end of the sampling period in December 1994, the plant had seen veliger counts up to 44,000 veligers per

meter^3. In October 1994, a veliger count of 380 per meter^3 was found in our fire protection system, which was a major concern to plant personnel. During the entire monitoring period, veliger counts fluctuated from month to month with data showing the majority of the zebra mussels had not reached the settling stage.

In March and April 1994, during a scheduled maintenance outage, the stator cooling water coolers, the bearing cooling water heat exchanger, and circulating water condenser water box were inspected. Approximately 15 adult mussels were found in the bearing cooling water piping, but none were found elsewhere. In early July 1994, the maintenance personnel were cleaning coolers almost on a daily basis. Once the coolers were inspected, the majority of the fouling was found to be zebra mussels. During a forced outage from July 8, 1994 to July 23, 1994, the decision was made to use a molluscicide treatment as a reactive approach to the zebra mussel infestation. The plant maintenance department fabricated a basket strainer in an effort to catch mussels going to the cooler in order to save time on cooler cleaning. The design of the strainer did not allow for a snug fit against the cooler and, with high volume flow rates, the zebra mussels washed over the side of the strainer.

During the fourth quarter of 1994, the plant had the opportunity to work on a filtration study in conjunction with the USDA, the Corps of Engineers, and with Acres International. Our 500 gpm auxiliary service water pump was used during the course of the test. Flow meters were installed on both the control side and the treated side of the filter. The test screen was an 8-inch self-cleaning stainless steel mesh wire filter that was supplied by the Amiad Filtration. The filter screen tested was rated at 36 microns (according to the German manufacturers of the filter), although Amiad Filtration called the filter an absolute 40 micron filter. This 40 micron filter excluded all shell forms of zebra mussels. A small percentage of preshell zebra mussels and larvae were present in the treatment sample, but were all damaged and were considered not to be viable. Based on the test results of the filter, a comparable Amiad filter could be used, fitted with a 40 micron mesh filter, to exclude viable zebra mussels from water systems.

In conjunction with the 40 micron filter, the existing upflow filter system can be used to protect a 400,000 gallon filter water storage tank that is used for raw water makeup and for our fire protection. The upflow filters contain different grades of sand (filter media), that are used with a polymer for water clarity. Documentation exists that proves the effectiveness of polymers for control of zebra mussels. Based on using the 40 micron filter in our service water system and then passing the water through the upflow filter sand media, we will be able to exclude viable life stages of zebra mussels from the filtered water tanks. This form of control is a benefit to the Gerald Andrus Plant, because using chemical treatment as a control method could possibly affect the performance of the ion exchange system.

CASE STUDY #3: MOLLUSCICIDE TREATMENT IN THE LOWER MISSISSIPPI VALLEY

Keith Stoma, Entrgy Operations Inc.

I first learned of zebra mussels in 1990 at an EPRI macrofouling conference. Being a microbiologist by education, I took great interest in tracking the spread of the zebra mussels throughout the Mississippi River Basin. I studied the rapid reproduction of the mussel and how fast they can spread. Looking at the range of geographical areas and how fast they were being infested with zebra mussels prompted the proactive approach taken at River Bend Station.

River Bend Station is located at river mile 262 on the west bank of the Mississippi River, about 25 miles north of Baton Rouge. We produce electricity with a 934 megawatt boiling water reactor. We have four mechanical draft cooling towers with makeup water taken from the Mississippi River. About 2 1/2 miles of 36-inch header piping carries water to our clarifier system. this piping is buried and very susceptible to zebra mussel infestation. Just across the river is another power plant, coal driven Big Cajun. As you've heard in some of the other talks, one of the possible vectors for moving zebra mussels from one area to the other is barge traffic. This plant receives the coal to produce power by barge. This could possibly be one of the sources of adult zebra mussels that we see in our area.

In 1992 we modified service to a closed loop system. A separate cooling tower (five cell system) services the closed system, taking water from deep water wells at our 1,800 foot aquifers as makeup.

Our intake system houses two makeup water pumps. Dual intake lines come into the makeup pump structure combined at a 36-inch header pipe which is routed underground 2 1/2 miles to the clarifier system. This header pipe extends some 400 feet out into the river with fixed intake screens attached to each. They are stainless steel with about a one-inch opening mesh providing another very likely place for zebra mussel infestation. The screens are about 4 feet in height and 12 feet in diameter at the top. By backwashing these lines, and we are able to flush large debris which collects on the screens.

As of November 1994 we have performed three molluscicide treatments at River Bend Station. We are using Calgon's H130M which you heard described in another presentation. Initially we treated for about 16 hours in January 1994, but only achieved a 17% mortality. The water temperature was approximately 54°. From this pilot project and we learned a lot of valuable information that would be used in future treatments.

Again in August, we treated after identifying peak settlement at River Bend in May and June. At that time, with the water temperature approaching 20 °C, we achieved a 100% mortality. Another peak spawning was identified in September and October of 1994 and another treatment was scheduled for November in which 100% mortality was achieved. The water temperature during the treatment was approximately 65°F.

Through our monitoring program, we identified two peak spawning periods in June and October, both in 1993 and '94. (Of course, the density was a lot less in '93.) We also observed settling densities in June of '94 of around 35,000 per meter^2, about the same densities as Dr. Dietz was observing at the Dow plant down river. Our density monitoring was performed using substrate deployed in the river on a buoy. As we explored the river bank, we found that the Army Corps of Engineers mats, with which they line the embankment of the Mississippi River, is very popular with settling zebra mussels. They seem to like to settle in between the mats along the edges where there is low flow. The river bank is a very good place to collect live zebra mussels if you need live specimens for control bioboxes.

How did we get to the treatment stage? A zebra mussels task force was formed in 1992 in an effort to take a very proactive approach after seeing those horror pictures of zebra mussel infestations in the Great Lakes area. We decided that we didn't want to get to that point. We wanted to prevent any infestation. We learned that we won't prevent infestation but we can minimize or mitigate the infestation by periodic or intermittent treatment. At that time we reviewed control strategies, ranked and presented them to senior management in the fall of 1992. A cost benefits study of control methodologies was done. We developed a preliminary treatment facility design in the spring of 1993. Originally a chlorine-bromine continuous treatment system at that river intake system was proposed. The cost study proved that alternative to be very expensive and maintenance intensive in our application. The intake is 2.5 miles away from the plant, making it difficult to maintain because of inaccessibility.

Based on our initial interest and other available studies, we began our monitoring in January of 1993. Veligers were first sighted in May of 1993 at very low densities, approximately 1 veliger per gallon. We reevaluated the control strategies in the summer of 1993 and our water discharge permit modifications and treatment schedules were completed in the fall of 1993. Although the DEQ/EPA were concerned about the toxicity of nonoxidizing molluscicides, they did give us a "go ahead" to use H130M with a letter of "no objection." During treatment, he EPA required toxicity testing, which proved that we were removing all of the free available molluscicide before we discharged into the Mississippi River. Toxicity tests were performed with benthic feeders as well as cerodaphnia.

The task force set some goals and objectives to minimize infestation of the River Bend Station water intake system by the biological agent *Dreissena polymorpha* and to ensure plant reliability by preventing macrofouling in vital systems. The objectives were (1) to anticipate mass infestations through a continuous monitoring program, and (2) initiate treatment based on monitoring results. The monitoring program includes continuous veliger monitoring coupled with veliger settling density studies during spawning periods. To meet this objective, we installed a side stream monitor in the clarifier building. We monitored temperature, pH, dissolved oxygen, and calcium level for hardness. We also installed settling plates to monitor mussel settling densities during spawning. Some are left in all season while others are checked weekly. A drain valve located in the box also provided a good place to sample for veligers.

We chose to monitor at the clarifier system because of the easy access to both influent and efffluent lines so that plankton net sampling (to monitor veligers) could be performed as well as residual testing during treatment of both clarifier influent and effluent water.

The task force examined many of the available options presented during this workshop. We examined chemical options with oxidizing and nonoxidizing biocides as well as oxygen scavengers, thermal mechanical filtration and mechanical cleaning. The recommendations of the task force in River Bend's application was to perform intermittent treatments with nonoxidizing biocides based on identified spawning seasons by continuous monitoring. Calgon H130M molluscicide was chosen to be used.

We are pleased with the results we are getting with H130M molluscicide. We initiated treatment within three months of the spawning season and injected the chemical for an eight-hour period at 3-5 parts per million to achieve a 1-2 part per million active chemical at the end of the pipe. Mortality rates were measured with the use of side stream monitors, and toxicity tests were performed during the treatment for the NPDES compliance monitoring. We performed effluent monitoring during the tests at one hour intervals for total residual chemical with a minumum detection limit of 10 parts per billion. The Louisiana Department of Environmental Quality issued a letter of no-objection for a one-time treatment which allowed us to perform this activity in each application (three total).

We actually designed our own injection quills for the treatment system, which were installed at the intake screens by divers. These were made out of 5/8-inch stainless steel tubing to which we would attach tygon tubing to facilitate controlled chemical injection. Chemical was pumped from a boat. We treated both lines simultaneously.

At the plant, we established a lab to accumulate zebra mussels for study. We use them in the bioboxes to measure the efficacy of the kill. I've kept mussels alive in the lab for three weeks with regular change-outs of Mississippi River water.

In conclusion, we postulated that the advantages of nonoxidizing biocides in our application made it the most cost effective control method. We used a small amount of chemical resulting in minimal discharge concerns. In our application, we found that the residual chemical was being removed out of the clarifier system with the heavy silt and sediment load that is normally removed at that point in the system. We achieved natural detoxification with this process. Bentonite clay was not required, which made the whole treatment very economical. This application is noncorrosive to piping, requires a small chemical volume at the 50% concentration, is non-hazardous, and easy to handle. State and federal regulatory approval was obtained for these treatments. We are in the process of securing a new, five-year state permit and are beginning the process to renew our federal water discharge permits which are due in 1996. We are anticipating that these will both include the verbiage to use H130M for future intermittent treatments.