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Committee on Natural Resources Water and Power Subcommittee
Tuesday, June 24, 2008, 10:00 a.m.
Oversight hearing: The Silent Invasion: Finding solutions to minimize the impacts of invasive Quagga Mussels on Water rates, Water Infrastructure and the Environment

Summary Statement

I would like to thank the subcommittee for the opportunity to testify today.

Since the 1988 discovery of zebra mussels in Lake St. Clair, and the subsequent discovery of the related quagga mussel, the mussels have had profound physical and economic impacts on surface water dependent infrastructure. These mussels, which I will refer to generically as zebra mussels, impact water handling systems in such major infrastructure as electric power generation, public and private drinking water treatment, and industrial facilities that utilize fresh surface water for cooling, consumption, and industrial process uses.

Zebra mussels spawn outside of their bodies, with each female releasing up to one million eggs per season. The larvae are carried in water currents until they settle and attach to hard surfaces. In some warm, productive waters, the mussels can mature and spawn in the same year they themselves were spawned. It is these layers of millions of mussels that cause the impacts on infrastructure.

Physical impacts on water dependent infrastructure can extend from the mouths of intakes in lakes, reservoirs and rivers, through aqueducts and canals, through all internal water distribution components, to the point of any subsequent discharge back into surface waters. For facilities in proactive mode, expenses include monitoring and planning activities, as well as capital construction projects to prevent mussel fouling. In facilities unfortunate enough to be colonized by zebra mussels before undertaking preventive measures, physical impacts can include head loss, reduced water flow, clogged conduits, and damaged water system components. Economic impacts on infested infrastructure include lost production, time and effort expended to remediate clogged systems, the replacement of damaged components, capital retrofit projects to prevent future fouling, and long-term control and management activities.

The experience in states east of the Rockies has been that drinking water continues to flow at consumers' taps, the lights and air-conditioning still work, and products continue to be manufactured . . . but not without a significant cost – to the infrastructure owners and operators and to their customers as that additional cost of doing business is passed on to end users. In 1995, the National Aquatic Nuisance Species Clearinghouse undertook a detailed study of the economic impact of zebra mussels on infrastructure. We revisited the study in 2005 and have extrapolated the results to take into account the intervening years of control activities and expansion of the mussels' range. The economic bottom line for the period of 1989 through 2007 is a total impact of between $1 billion and $1.5 billion spread across 23 states, approximately one half of which has been borne by the electric power generation industry, with the drinking water treatment industry paying almost one third of the total. Industry, which is loath to talk publicly about economic impacts, is believed to have accounted for another 10 percent.

I would like to address what needs to be done in the western states to minimize the physical and economic impacts on water dependent infrastructure, based on the eastern experience.

First, monitoring of critically important waterbodies needs to be implemented immediately. Combined with the inspection of boats being transported into western waterbodies, particularly if they originated in eastern states, this will serve as infrastructure's first line of defense. Western states need to develop zebra mussel early detection and rapid response plans if such plans don't already exist.

Second, infrastructure owners need to be planning for and implementing both short-term, immediate preventive measures to keep the mussels out of their water systems and long-term capital projects aimed at keeping those systems open and operating throughout their expected service periods. To be totally candid, that planning should have been done years ago with response plans ready to be implemented today.

Western infrastructure owners need to learn from the eastern experience. There is no need to reinvent the wheel – there is already a wide range of proven prevention and control technologies that can be adapted to protect western power generation, water treatment and industrial facilities.

I cannot over-state the importance of education efforts. Infrastructure owners need to learn about the impacts of zebra mussels and how to prevent and manage them. An example of a proactive state is Utah where the Central Utah Water Conservation District is hosting a quagga mussel impact and control workshop for water treatment plants throughout the state. Boaters and other water resource users need to understand their role in preventing the spread of the mussels in the West. And the general public needs to learn how this aquatic invasive species can impact their pocketbook and enjoyment of western waters.

Finally, what is the federal government role? Technical assistance based on twenty years of experience is available from such national sources as the US Army Corps of Engineers and the National Sea Grant College Program. Coordination can be provided by the national Aquatic Nuisance Species Task Force and its Western Regional Panel, the 100th Meridian Project, and the National Invasive Species Council. And, of course, federal funding can help to stimulate and supplement state and local efforts to combat such invasive species.

Thank you.

Colonization Process of Zebra and Quagga Mussels

Zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) have a reproductive strategy unique among freshwater bivalves, which is largely responsible for their rapid population expansion in North America and their extreme impact on water dependent infrastructure. Mature females can produce 40,000 to 1,000,000 eggs per year. Spawning occurs outside the adults' bodies and results in planktonic veligers (larvae) capable of active swimming for one to two weeks. These veligers are transported by water currents, enabling them to disperse considerable distances from parent colonies. Within two to five weeks of hatching, the larval mussels become too large and heavy to remain planktonic and begin to settle out of the water column. At this stage, the mussels must find a hard, natural or manmade substrate on which they can attach. Sexual maturity is typically reached by the end of the first year with a shell length of approximately one half inch. In the warm, productive waters of the American South and West, zebra mussels can reach maturity in the same year in which they were spawned and go on to spawn hundreds of thousands of larvae themselves.

In nature, the mussels will colonize lakeshores and riverbanks where they attach to natural substrates, forming broad reef-like mats. In some areas of Lake Erie, colony densities of 20,000 to more mussels per square meter of lakebed have been reported, with six-inch deep layers of shells accumulating within two years.

Zebra mussels secrete durable elastic strands, called byssal threads, and an epoxy-like adhesive, by which they can securely attach to nearly any solid surface. In nature this would be rocks, submerged wood or plant materials, or even the shells of native clams or mussels; they also attach in large number to such manmade surfaces such as concrete, metal, and plastics. Because of an affinity for settlement in areas exposed to low velocity water currents, the mussels tend to be drawn into and extensively colonize water pipelines and canals.

Physical Impacts On Infrastructure

The major impact of zebra mussels on which I will focus is the fouling of raw water intakes, distribution lines, and other components at such surface water-dependent infrastructure as public and private drinking water treatment, electric power generation, and industrial facilities. This includes both large-scale municipal and small-scale private drinking water intakes; all types of electric power generation facilities (fossil, nuclear, and hydro) that have raw surface water circulating (cooling) water and service water (fire fighting, transformer cooling, lubricating) systems; and, industrial facilities utilizing raw surface water for cooling, flushing, or process water; although water impoundment and navigation facilities, agricultural and golf course irrigation systems, and untreated fire fighting (hydrant) distribution systems. Dams and impoundments, including inflow and outflow conduits and water level control mechanisms are also at risk. Water intake structures serve as an excellent habitat for mussel colonization. The continuous flow of water into intakes carries with it a continuous source of food and oxygen and carries away the mussels' wastes, while the structures themselves protect the mussels from predation, siltation, and wave and ice scour. Such intakes make ideal zebra mussel habitat.

Biofouling of raw water systems begins at the point of intake and can extend throughout a facility to any discharge. At the point of intake, submerged intake cribs, trash racks, pipelines and tunnels, and shoreline forebays and pumping wells are subject to severe fouling (up to 750,000 or more mussels per square meter have been reported in Great Lakes facilities, forming layers one foot or more thick (Figure 1).

The presence of zebra mussels within a facility's raw water intake is usually first detected by the discharge of shells or shell fragments into a pumping well or forebay, often accompanied by a noticeable decrease in head or pumping ability. As the mussels line the pipeline or tunnel, friction and turbulence are increased, disrupting laminar flow within the conduit – even before the mussels significantly reduce the effective diameter of the conduit a single layer of 0.1-inch mussels throughout a pipeline can decrease that conduit's water carrying efficiency by five to ten percent. As more mussels settle in the conduit the mussels and continue to grow, the reduction of effective diameter becomes a major consideration in moving water through the conduit.

Unlike saltwater or estuarine raw water systems which are designed to cope with the presence of such macrofouling organisms as barnacles, blue mussels, and sponges, most inland, freshwater raw water systems in the past have only had to consider biofilms as their major biofouling threat. With the exception of the Asian clam (*Corbicula fluminea*), any large organisms that can impact flows have been removed by screening. Zebra mussel veligers, however, are capable of passing through such screens to gain access to downstream components, attaching and growing into large fouling colonies within a facility' internal piping systems.

Once inside a drinking water treatment facility, the mussels can colonize any surface up to the first oxidation or filtration stage where they are either killed or filtered from the water. This includes intake mains, fish traps, testing equipment, raw wells, traveling and stationary screens, screen house walls, pump bells and impellers, strainers and settling tanks, and other hard surfaces (Figure 2). Impacts associated with this colonization include loss of intake head, obstruction of valves, blockage of screens, cavitation wear on pump bells and impellers, putrefactive decay of proteinaceous mussel flesh and related production of methane gas resulting in taste and odor problems, and increased corrosion of steel and cast iron pipelines resulting from bacterial growth around the mussels' byssal attachments.

Similar fouling occurs in electric power generation plants and industrial water systems that use infested waters as a raw water supply. Circulating (cooling) water systems suffer loss of head and increased pumping resistance. Condenser and heat exchanger tubing become clogged (Figure 3), leading to loss of cooling efficiency and component overheating. Service water lines (*e.g.*, fire protection, bearing lubrication/cooling, transformer cooling, etc.) clog, resulting in damage to vital components and possible safety hazards. Raw water circulating and service water systems of particular concern are shown in Figure 4. Impacts on water handling system components are presented in Table 1.

Zebra mussels also result in nonfouling impacts on drinking water treatment. Zebra mussels feed by filtering plankton from the water (up to one liter per day per adult under ideal circumstances). One effect of the resulting water clarification is that not enough particulate matter remains for effective coagulation to take place with standard methodologies in water treatment plants, necessitating changes in treatment technology, often at an increased expense. Changes in algal populations resulting from the mussels' filtration is believed to be contributing to an increase in geosmin and MIB, compounds which, while harmless, impart disagreeable tastes and odors to water, further increasing treatment costs. Finally, mussel filtration may be increasing the portion of cyanobacteria versus green algae in the water, potentially resulting in the production of waterborne neurotoxins that must be filtered from drinking water to prevent public health impacts.

Economic Impacts on Infrastructure

The figure of a $4.7 billion impact of zebra mussels from 1989 to 1999 has been frequently cited. This figure is incorrect in such usage. In actuality, this was a worst-case forecast of what *could* occur for that 10-year period *if* zebra mussels resulted in the need to completely rebuild the water intake systems in public drinking water treatment plants in nine major cities, 11 small cities, and 50 towns throughout the Great Lakes. Also included was the redesign and rebuilding of the water intake and distribution systems at 18 nuclear and 54 fossil fuel electric power generation plants in that region. In addition, the number incorporated the redesign and retrofit of the water systems in industrial facilities in the region. Also, mussel related impacts on the 67-ship Great Lakes merchant marine fleet and 2,500 private recreational boats were added in. The estimate also included a 10-year maintenance figure. This was only an estimate, developed before the mussels had moved out of Lake St. Clair. We now know that in almost all cases, the cost of actions undertaken to remediate infested facilities and protect those that are not yet infested is actually far less than that 1989 worst-case estimate. The estimate also included more than $2.7 billion of impacts to Great Lakes sport and commercial fisheries. While there have been economic impacts to those fisheries, they have yet to be quantified.

In 1995, to address the reality of the economic question, the National Aquatic Nuisance Species Clearinghouse (a special national education and technology transfer project funded by the National Oceanic and Atmospheric Administration and operated by New York Sea Grant) undertook a detailed study of the economic impact of zebra mussels on infrastructure in North America. The documented economic impact in that study for the period of 1989 through 1995 was $69+ million (7-year total, not per year) for 339 facilities throughout the Great Lakes and Upper Mississippi Basin region which had incurred mussel-related impacts (an average of about $204,000 per facility). Not all impacted facilities responded formally to the study, in many cases due to confidentiality concerns – unofficial (personal communication) information from non-reporting facilities, and careful extrapolation based upon the numbers of facilities known to be infested yielded a 1989 - 1995 figure for the infested Great Lakes and Mississippi Basin regions of $300 million to $500 million.

We revisited the study in 2005. Comparing the results of the two studies and, again, extrapolating the results to take into account non-response of facilities using raw surface water throughout the mussels' current range of colonization, an estimated cost of capital projects for mussel control, and the intervening years of continued maintenance in facilities which had implemented control projects in the early years of the mussel invasion, we now estimate a total economic impact for the period of 1989 through 2007 of between $1 billion and $1.5 billion spread across 23 states. Although this figure is based somewhat on educated extrapolation, I am quite confident that it is a realistic estimate of the actual cost of the mussels on US infrastructure. [It should be noted, however, that industries, because of confidentiality issues and a fear that an admission to mussel impacts within their facilities, even if under control, might result in negative stock value impacts, have continually not provided sufficient information to be statistically relevant. Approximately ten percent of the $1 billion to $1.5 billion impact is estimated to include direct impacts on industry.] Details on infrastructure economic impact on specific facility categories and mean economic impact expenditures by prevention, control, and management category are presented in Tables 2 and 3.

The following observations and recommendations regarding what ideally should be undertaken in the western states to minimize the physical and economic impacts of zebra and quagga mussels on water dependent infrastructure are based on the eastern experience and upon my 20 years of experience working with regional, state and local governments on zebra mussel and aquatic invasive species planning and with the electric power generation and drinking water treatment industries on zebra mussel prevention, control and management planning and implementation.

Monitoring for the presence of zebra mussels, both pre- and post-treatment is essential to any zebra mussel prevention and control program. If a facility is not yet infested by mussels, a monitoring program should be the first step taken in developing a comprehensive mussel response plan. Just because a lake, reservoir or river has not yet been shown to be colonized by zebra mussels does not mean that the mussels are not there; often the first indication of the presence of mussels is when they are found inside a facility's water intake. The same holds true for states that do not have any known mussel infestations – small infestations may already exist that simply are too small or in too remote a site to have been found. [The discovery of *Dreissena polymorpha*, in San Justo Reservoir in San Benito County, California in January 2008 – the only known infestation the original North American species of zebra mussel west of the continental divide is a good example of how just because the mussels haven't been found locally or in a nearby state doesn't mean that they aren't already there waiting to be discovered].

Monitoring efforts should, ideally, be undertaken both at facilities' water sources as well as within the facilities water intake systems. Efforts to monitor source waterbodies should be standardized and ideally should be undertaken in coordination with other raw water system operators and with local/regional/state resource management agencies. Why standardize and why develop monitoring networks? It is important that regional monitoring efforts be standardized and coordinated because this allows all involved parties to compare the data from different locations within and between watersheds, to compare data from one time period to another, to benefit from the "big picture" rather than just from local "snapshots in time", to maximize the number of sampling sites to provide more comprehensive coverage, to allow for replication of sampling results, and to minimize duplication of effort. The ideal standard monitoring protocol is one that meets a broad range of stakeholder information needs and is easy for staff that may not be trained biologists, to implement and maintain efficiently.

Such source water monitoring programs can provide an early warning of the mussels' arrival, and can serve to alert downstream facilities of impending infestation. Responsible in-plant zebra mussel prevention and management programs require real-time knowledge of local source water mussel population dynamics and life stages in order to allow for the most effective implementation of control activities within the facility. Monitoring can also be used to determine when source water temperature and veliger counts begin to drop signaling the end of the spawning season (short-term) and when source water population densities begin to decline (long-term). Monitoring of critically important waterbodies should be implemented immediately if it is not already in place.

Tracking transient boat traffic within and between western states and inspecting boats known (or suspected) to have originated from infested (or potentially infested) waters is also an important component of a western zebra mussel prevention and response program. The 100th Meridian Initiative is a cooperative effort between state, provincial, and federal agencies to prevent and track the westward spread of zebra mussels and other aquatic invasive species in North America. Two very important components of the Initiative are voluntary boat inspections and boater surveys, and the establishment of monitoring sites on waters west of the 100th meridian to determine the presence or absence of zebra mussels. If they are not already participating with the Initiative, western states should initiate immediate contact with the program to being implementing these objectives locally and regionally.

Western states need to develop zebra mussel early detection and rapid response plans if such plans don't already exist. Regional, coordinated zebra/quagga mussel monitoring networks, combined with transient boat inspections can serve as an important early warning system and first line of defense.

Infrastructure owners need to be proactively planning for and implementing both short-term, immediate preventive measures to keep the mussels out of their water systems and long-term capital retrofit projects aimed at keeping those systems open and operating throughout their expected service periods. To be totally candid, given that the potential impacts on western infrastructure should have been recognized in light of what was happening to Great Lakes and other eastern infrastructure as a result of the early decade of the zebra mussel invasion, such planning should have been undertaken years ago with response plans ready to be implemented today. A wait-and-see approach is simply not supportable and can, in the long run, result in lost production and disruption of services to customers, expensive reactive remediation projects, and greater costs to facility owners and end users.

Infrastructure owners throughout the West can learn from the Great Lakes and eastern experience. There is no immediate need to reinvent the wheel – there is already a wide range of proven prevention and control technologies that have been developed here and abroad that can be adapted to best suit specific western power generation, water treatment and industrial facilities. Table 4 lists the available, effective, adaptable zebra mussel control technologies already available to western infrastructure owners.

I cannot overstate the importance of education efforts to all segments of western water use stakeholders. Infrastructure owners, if they are not already up-to-speed, need to learn about the potential impacts of the mussels and how to prevent and manage them. Again, ignoring the situation is not a viable option. Beginning almost immediately upon the initial discovery of zebra mussels in the Great Lakes, the National Sea Grant College Program of the National Oceanic and Atmospheric Administration (US Department of Commerce) developed and implemented stakeholder education programs pertaining to all facets of the zebra mussel invasion. Educational workshops were held throughout the East and, via the Sea Grant Nationwide Zebra Mussel Outreach Project, in a number of western states, as well. Most of these programs still exist, as do programs in Pacific coastal states. Two long-term web-based zebra mussel education and technology transfer programs still exist that can assist western stakeholders in learning about the mussels: the National Aquatic Nuisance Species Clearinghouse (www.aquaticinvaders.org) and the Sea Grant Nonindigenous Species project (www.sgnis.org). [Note: while many of the informational resources of these programs are still accessible, some have been cut back as a result of cuts in federal aquatic invasive species funding over the past several years.]

An example of a state being proactive in water-dependent infrastructure education is Utah, where the Central Utah Water Conservancy District is hosting a quagga mussel impact and control workshop for water treatment plant operators throughout the state. New York Sea Grant is coordinating the agenda and “faculty” for this July 2008 workshop. I would recommend that a major regional workshop for water-dependent infrastructure be planned and implemented as soon as possible.

In addition to infrastructure owners and operators, recreational boaters and other water resource users need to learn about the potential impacts of zebra and quagga mussels on their use of those resources and their role in preventing the further spread of the mussels throughout the West. And, the media and general public need to learn how this aquatic invasive species (and invasive species in general) can impact western water resources, ecosystems, and their pocketbooks.

Finally, what is the federal government role in responding to the Dreissenid invasion of the West? Technical assistance based on twenty years of experience and research is available from such national sources as the US Army Corps of Engineers’ Zebra Mussel Research Program, the Bureau of Reclamation (which has addressed the issue for federal lands and projects under their jurisdiction), the Aquatic Invasions Research Directory at the Smithsonian Environmental Research Center (a database of current information on people, research, technology, policy and management issues relevant to aquatic invasions), the Nonindigenous Aquatic Species Information Resource of the United States Geological Survey (a central repository for spatially referenced biogeographic accounts of nonindigenous aquatic species in the US), and the National Sea Grant College Program, particularly the National Aquatic Nuisance Species Clearinghouse.

Regional coordination of, and support for zebra and quagga mussel programs could be provided by such federal programs as the national Aquatic Nuisance Species Task Force and its Western Regional Panel, the aforementioned 100th Meridian Project, and the National Invasive Species Council. Other federal programs, particularly those under the Departments of Interior and Agriculture (such as Interior’s US Geological Survey and National Park Service, and Agriculture’s Animal and Plant Health Inspection Service (APHIS) and Cooperative State Research, Education and Extension Service) all have important roles to play in responding to the zebra and quagga mussel invasion of the West.

In the end, national, regional, state and local efforts to prevent and combat invasive species like the zebra mussel are suffering from a lack of resources. Increased federal funding is of utmost importance to protect America’s natural resources, economy and human health from the tremendous negative impacts of invasive species.

Attachment 1: Figures 1 through 4
Attachment 2: Tables 1 through 4

Figure 1 – Pumping bay at Detroit Edison Monroe, MI, electric power generation facility

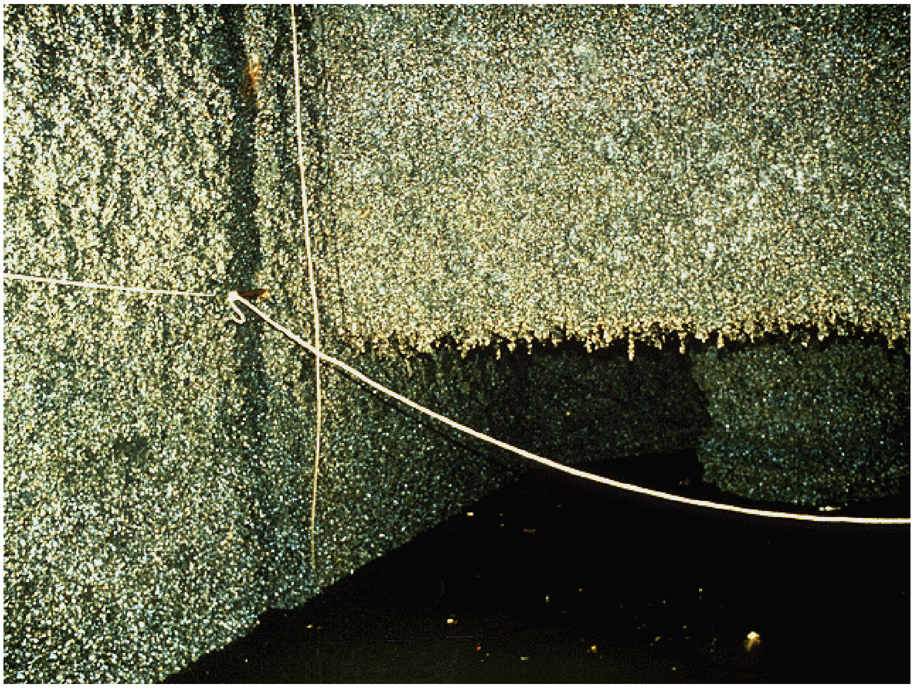

Figure 2 – Zebra mussel fouled trash rack

Figure 3 – Fouled electric power generation facility condenser tube sheet

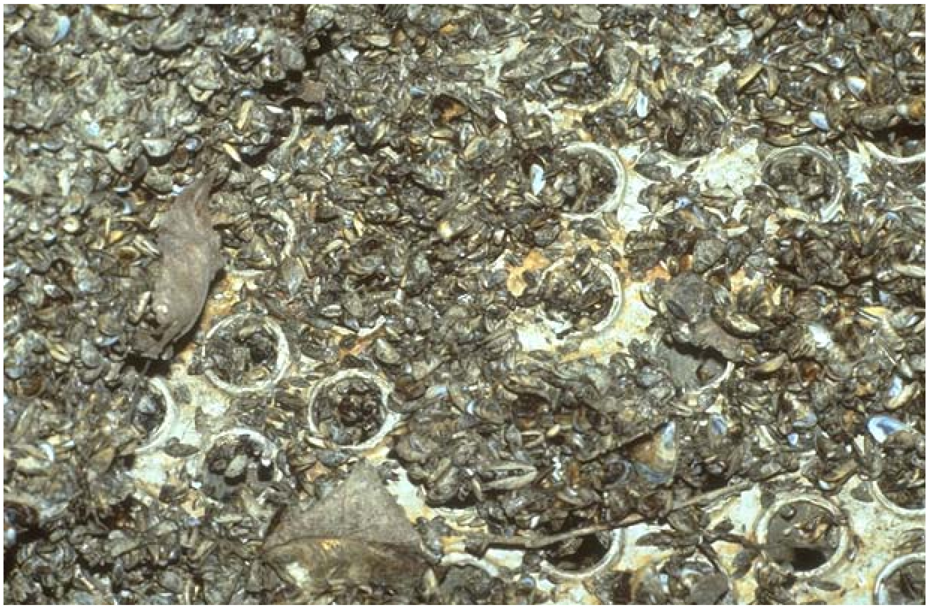

Table 1 – Fouling problems associated with zebra/quagga mussel colonization for various categories of water-dependent infrastructure components

System	Components	Impacts
Intake	Trash racks	Blocked flow
	Trash booms	Corrosion of metal surfaces
	Intake cribs	Increased structure weight
	Intake conduits	Poor flow distribution
	Bulkhead slots	Increased maintenance
	Exposed surfaces	Sinking of floating structures
	Stop-log slots	Increased loads on pumps
		Erosion/abrasion of components
		Prevention of operation
		Disposal of removed mussels
Circulating Water	Large-diameter piping	Reduction in pipe bore
	Low-flow piping	Restriction/blockage of flow
	Pipe bends	Corrosion of metal surfaces
	Pipe joints	Poor valve operation/seating
	Heat exchangers	Erosion of surfaces
	Condensers	Abrasion of components
	Tube sheets	Increased weight
	Water boxes	Reduced heat transfer efficiency
	Valve plates/seats	Increased maintenance
	Distribution piping	Prevention of operation
	Traveling screens	Disposal of removed mussels
	Exposed surfaces	
Service Water	Fire fighting systems	Blockage of flow
	Coolers	Corrosion of metal surfaces
	Air conditioners	Poor valve operation/seating
	Makeup water systems	Abrasion of components
	Low-flow piping	Reduced heat transfer efficiency
	Dead-end piping	Increased maintenance
	Valve plates/seats	Prevention of operation
	Pipe bends	Disposal of removed mussels
	Storage reservoir/tanks	
	Sprinkler systems	
	Small-diameter pipes	

Table 2 - Economic impact of zebra and quagga mussels on specific infrastructure categories

Industrial Facilities				
Minimum:	$2,000		Maximum:	$1.6 million
		10% of total reported impact		
Water Treatment Plants				
Minimum:	$1,000		Maximum:	$3.66 million
		31% of total reported impact		
Electric Power Generation				
Minimum:	$1,000		Maximum:	$5.95 million
		51% of total reported impact		

Table 3 - Mean per facility economic impact expenditures by prevention, control, and management category

Expenditure category	Mean per facility with some type of expenditures
Prevention efforts	$186,557
Lost production and revenues	$124,110
Chemical treatment	$63,049
Planning, design, and engineering	$58,459
Retrofit and/or reconstruction	$48,314
Filtration or other mechanical exclusion	$22,061
Monitoring and inspection	$21,398
Mechanical removal	$13,897
Nonchemical treatment	$9,786
Research and development	$4,208
Personnel training	$2,976
Customer education	$1,831
Other	$14,360

Table 4 - General categories of zebra/quagga mussel control technologies

- **Exclusion (prevention of entry)**
  - Sand filter intakes
    - Wells with bank infiltration
    - Infiltration galleries
    - Raised sand filter beds
  - Groundwater wells
  - Public (treated) water
- **Preventing settling**
  - High-velocity flows
  - Non-fouling metal piping (copper, bronze, galvanized)
  - Coatings
    - Anti-fouling
    - Fouling-release
  - Electrified surfaces and electrostatic shock
  - Cathodic (electrolytic) protection
  - Acoustics
  - Cavitation
  - Air bubble curtains
- **Mechanical control methods**
  - Manual scraping
  - “Pigging”
  - High-pressure water jetting
  - Abrasive blast cleaning (sand and shot blasting)
  - Carbon dioxide pellet blasting
  - Mechanical filtration
  - Hydro-cyclonic separation
  - Disposable substrates
- **Chemical control alternatives**
  - Metallic salts
  - Nonoxidizing biocides
  - Oxidizing biocides
  - Metallic ionization
- **Oxygen deprivation**
  - Hypoxia (low level of dissolved oxygen in water)
  - Anoxia (no dissolved oxygen in water)
- **Thermal treatment alternatives**
  - Heat shocking
  - Exposure and desiccation
    - Desiccation at nonfreezing temperatures
    - Desiccation at freezing and subfreezing temperatures
- **Ultraviolet irradiation**
- **Biological controls methods**
- **Long-term design strategies for new construction (systems approach)**