Zebra Mussel Control Costs in Surface Water Using Facilities

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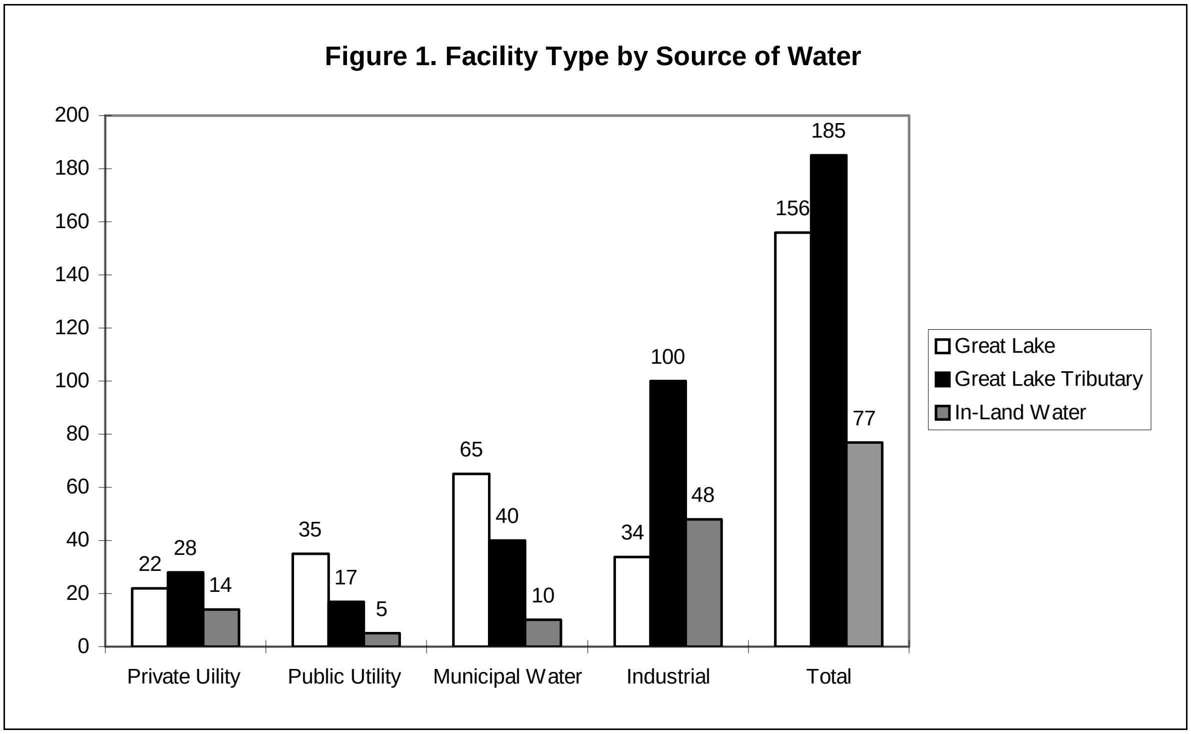
The zebra mussel infestation has imposed large costs on facilities that draw water from the Great Lakes: electric generating plants, municipal water systems, and industrial water users. For example, the largest fossil-fueled plant in the world, Detroit Edison's power plant in Monroe, Michigan had to shut down in 1989 because zebra mussels literally plugged up the water system. Since that time, this rapidly reproducing mollusk has spread throughout the Great Lakes, its tributaries, and many major rivers and inland lakes. The zebra mussel has reportedly infested hundreds of facilities that use raw water, such as municipalities' drinking water facilities, industries, and power generating plants. Despite these widespread damages, there has been little systematic information to identify the infested facilities, the costs of monitoring, cleaning and controlling the infestations, and whether the best methods are being used to minimize the costs. Research to determine surface water user expenditures on zebra mussel monitoring and control in the Great Lakes region was conducted by Ohio Sea Grant.

From 1994-1995, 1,490 companies consisting of power plants, water companies, golf courses, and other industries were surveyed about their annual costs of zebra mussel monitoring, control, and research to reduce zebra mussel costs. From this list, 326 water users surveys were returned due to incorrect addresses. A total of 1,164 companies actually received the survey. Among the 584 responses (a response rate of 50%) 420 questionnaires were from surface water users, about 36% of the sample population. The non-respondents consisted of 165 facilities that did not use raw surface water; they either used well-water or purchased water from a municipal water system and were not subject to zebra mussel infestation.

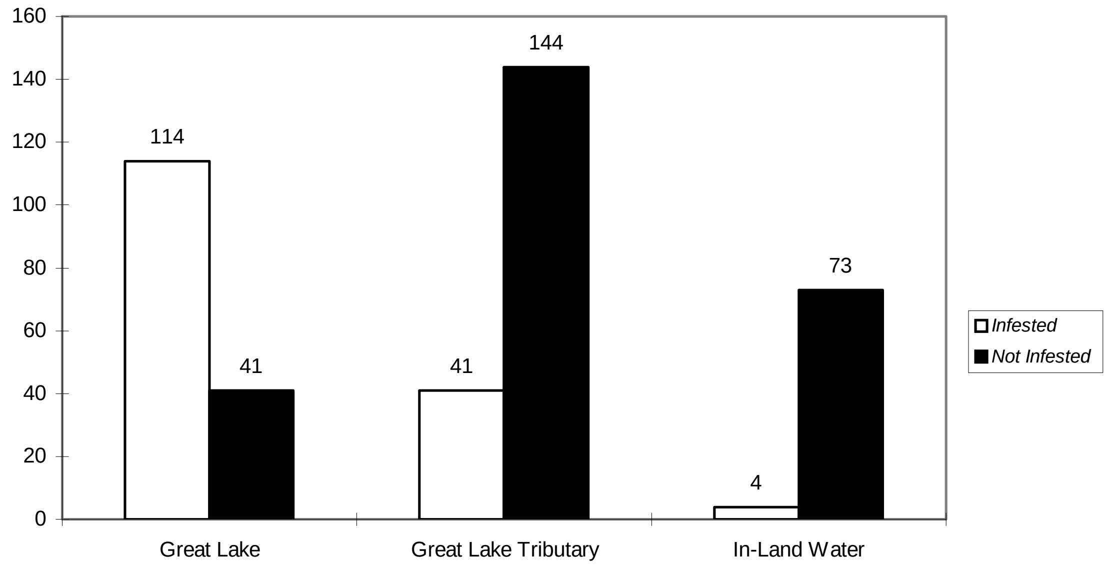
Source of surface water by type of facility is shown for 418 responding facilities in Figure 1; two respondents did not provide this information. Most respondents draw water from the Great Lakes (37%) and their tributaries (44%). About 44% of the respondents were industries (182), 28% municipal water plants (115), 15% private utilities (64), and 14% public utilities (57).



The majority of both municipal water plants (57% of 115) and public utilities (61% of 57) draw water from the Great Lake whereas a majority of other industries (55% of 182) and private utilities (44% of 64) draw from one of the Great Lakes tributaries. Most of the facilities located on in-land water systems included other industries and private utilities, 62% and 18% of 77 in-land facilities, respectively. About 54% of 185 tributary water users comprise other industries, followed by municipal water plants (22%), and private utilities (15%); only 9% of the tributary facilities were public utilities. For the 156 facilities located on the Great Lakes, 42% were municipal water plants; 22% were public utilities and 22% were other industries.

In Figure 2, the responding facilities are arranged by zebra mussel infestation and source of water. Among the 159 water users which had detected the zebra mussel in their (water intake) systems, 114 facilities (72% of 159) were on the Great Lakes and 41 facilities (26% of 159) were on the tributaries. Only four out of 77 in-land water users (3% of 159) had detected the zebra mussel in their facilities. By source of water, 74% of Great Lake, 22% of Great Lake Tributaries, and 5% of in-land facilities were infested.

Figure 2. Zebra Mussel Infestation by Source of Water



Preventive Actions

- **44% of *infested* facilities took preventive actions prior to infestation**
- **9% of *uninfested* facilities were taking preventive actions when surveyed**

About 44% of infested facilities in our sample reported that they took preventive actions prior to infestation. However, only 9% of uninfested facilities were taking preventive actions when they were surveyed in late 1994 through early 1995. From this observation, we can say that, in general, the surface water users launched some monitoring or preventive actions after realizing that they had a certain possibility of infestation. In other words, they were "cost-conscious" or "cost-sensitive" even though the zebra mussel infestation is a very costly problem.

Monitoring and Control Costs

Water users in our sample have reported large amounts of expenditures for zebra mussel monitoring or control during the survey period. Total cost was defined as the sum of monitoring and control costs. The control cost, expenditures incurred to control zebra mussels, was the sum of [1] retrofitting costs, [2] physical removal or mechanical exclusion costs, [3] variable chemical treatment costs, and [4] other treatment costs.

Total Zebra Mussel Monitoring and Control Costs
1989-1994
$120 million

Annual Avg. Zebra Mussel Monitoring and Control Costs
1992-1994
$30 million

From the 420 surface water user respondents, 142 facilities spent a total of $60.7 million for either zebra mussel monitoring or control over the six year period, 1989 through 1994, which gave an average of $0.43 million for each facility. With a 50% response rate, total monitoring and control costs were estimated at about $120 million for this period. During 1989 to 1991, there was a rapid increase in the numbers of facilities infested by zebra mussels. By 1992, most responding facilities in the Great Lakes or their tributaries were infested. During 1992 to 1994, average annual zebra mussel costs were estimated at about $30 million.

Zebra Mussel Treatment Types	
• Monitoring or Treatment Costs	142
• Monitoring	117
• Retrofitting	92
• Physical Removal	36
• Chemical Treatment	
Oxidizing	85
(Chlorine = 60, Potassium Permanganate = 18)	
Non-oxidizing	14
(Mulluscicides = 11)	10
• Other	

Among these 142 facilities, 117 incurred expenditures for monitoring (for example, sampling or inspection) of zebra mussels. Monitoring costs included labor costs, equipment investment costs, training costs, and contractual service costs spent on monitoring for zebra mussel infestation. By treatment type, 92 facilities incurred costs for retrofitting, 36 for physical removal, 85 for oxidizing chemicals, 14 for non-oxidizing biocides, and 10 for other treatment methods. The 85 facilities using oxidizing chemicals were composed of 60 chlorine (Cl_2), 18 potassium permanganate ($KMnO_4$), four bromine, and one chlorine dioxide user. Most of the non-oxidizing facilities (11 of 14) were mulluscicides users. Many facilities used more than one method for zebra mussel control. For example, many electric utilities have physical removal and application of chemicals because chemical treatment is not possible in the large raw water intakes. Several plants used two chemicals simultaneously.

About 60% of the chemical users adopted chlorine (Cl_2) treatment for zebra mussel control. However, many of them (for example, water treatment plants) used chlorination as part of their operation before zebra mussels and no additional chlorine (Cl_2) costs were incurred for zebra mussel control. The major cost was to retrofit or move the injection point to the intake crib. The next most widely used zebra mussel control technologies (after Cl_2) were physical (or thermal) treatment and cleaning. Hot water was usually a by-product of normal operation. However, additional capital investments, such as new pipelines or other equipment, may be required for this control method. Potassium permanganate ($KMnO_4$) was also often used in water treatment plants. Few water plants used biocides, but mulluscicides were the second most widely used chemical for utility and industry. Bromine was another control method used in utility and industry for the control of the nuisances. No water treatment plant used either mulluscicides or bromine.

To compare the monitoring and control cost of these various types (especially, chemical treatments) of zebra mussel control methods, water users were divided into two groups: 68 municipal water treatment plants (Figures 3-8) and 67 utility and industry (Figures 9-15). This breaks the sample into establishments producing drinking water versus those using water for cooling.

For the purpose of this study, the municipal water plants were further classified into two subgroups by water intake capacity: [1] small (0-10 MGD), and [2] medium (11-300 MGD). The utility and industry was divided in three subgroups: [1] small (0-10MGD), [2] medium (11-300 MGD), and [3] large (300+ MGD). For every subgroup, chlorination (Cl_2) was the most widely used chemical treatment method.

Municipal Water

A total of 68 water treatment plants were monitoring or treating for zebra mussels during this period (1989-1994) in one or more years, and 51 of 68 gave us information on expenditures for chemical treatment. Figure 3 shows responding water treatment plants by size (water intake capacity) and type of chemical treatment. About 65% (33) of the 51 respondents used chlorine (Cl_2). The remaining 18 respondents used potassium permanganate ($KMnO_4$). A larger proportion of medium size facilities used chlorine than small facilities.

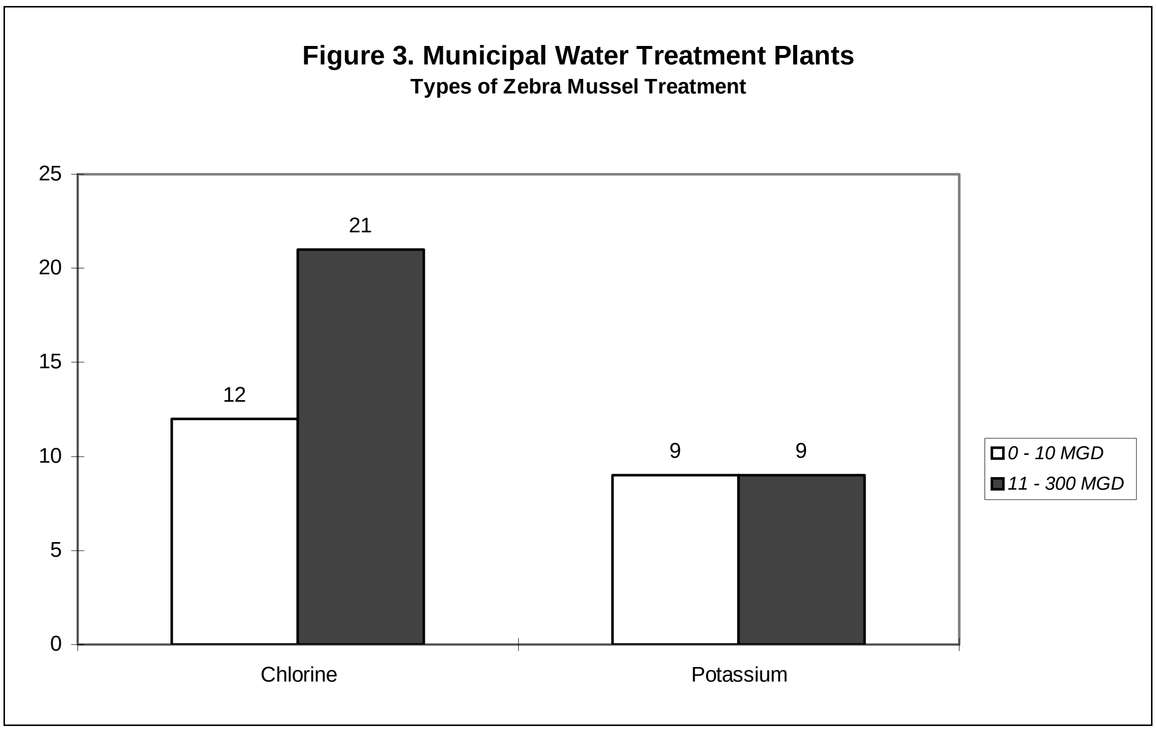
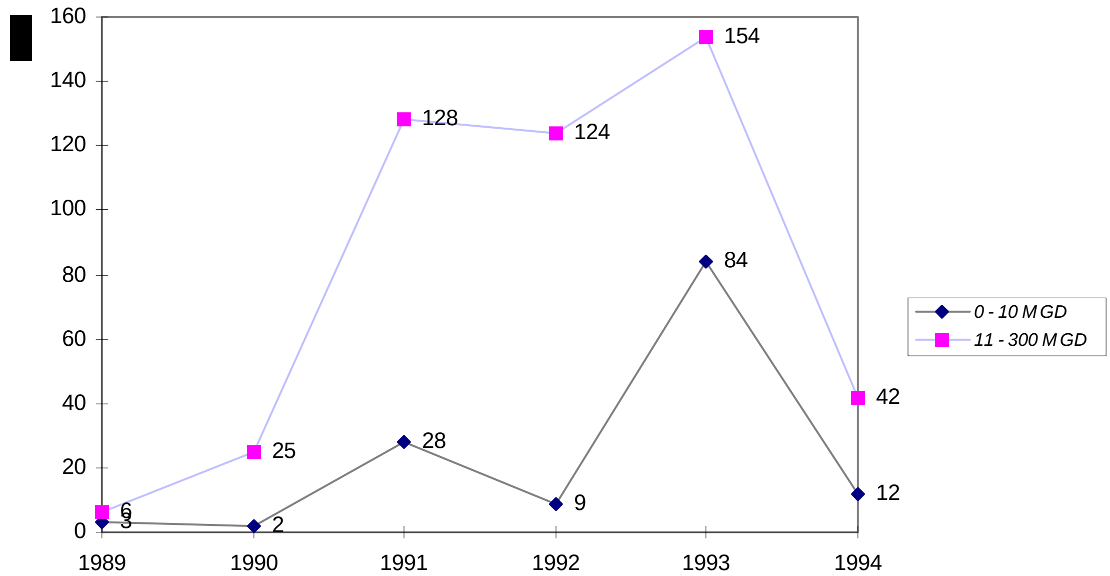


Figure 4 shows the average zebra mussel monitoring and control costs over the six year period (1989-1994) by year and size of facility. For both size groups, the average total costs were highest in 1993 ($154,000 for medium size plants and $84,000 for small plants), and 1991 was the second highest year ($128,000 for medium size and $28,000 for small size). Average total cost was derived by dividing the total cost, which was defined as the sum of monitoring and control costs, by the number of facilities reporting costs. In 1994, the average total costs dropped sharply to 27% and 14% of the average total expenditures in 1993 by medium and small facilities, respectively.

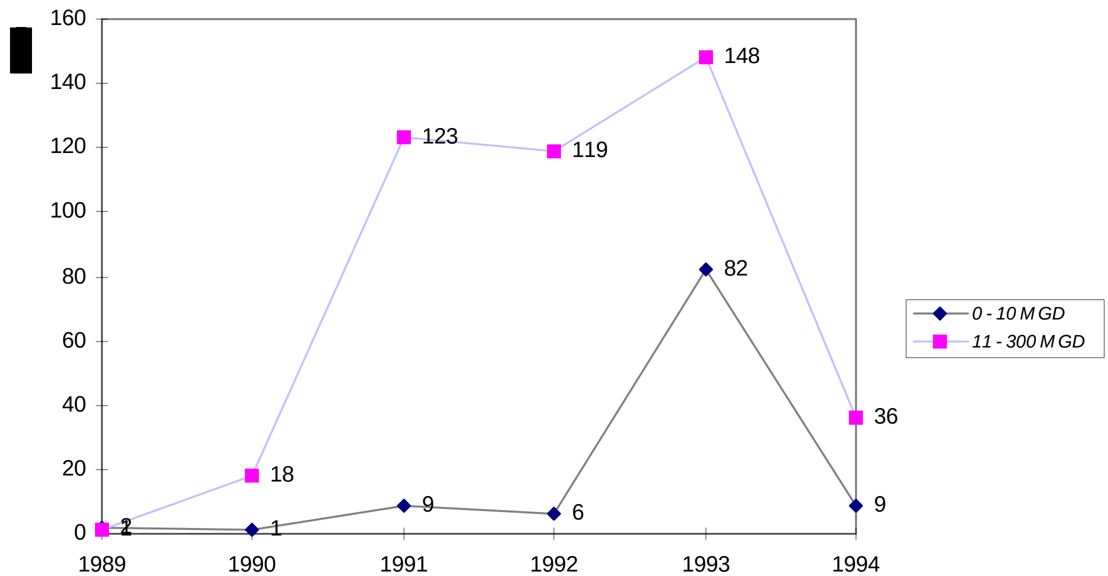
Figure 4. Municipal Water Treatment Plants

Average Zebra Mussel Monitoring and Control Costs by Year and Size of Faciliy



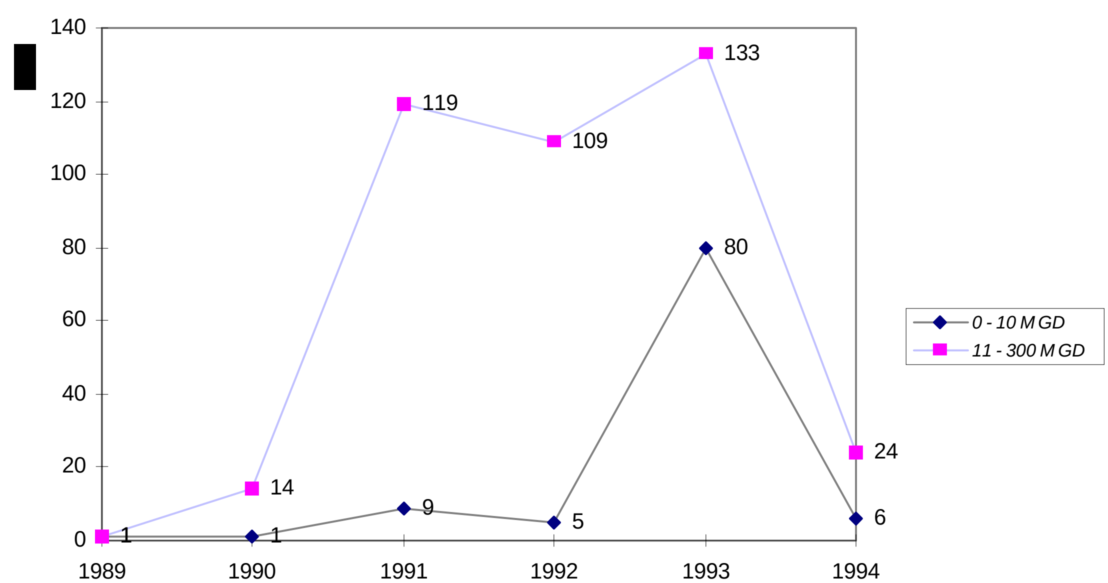
Control cost included retrofit costs, physical treatment costs, and variable chemical costs. Figure 5 shows that most of total cost was spent on treatment of the nuisances. In 1993, average medium size water treatment plants spent $148,000 (about 96% of average total cost) and small facilities spent $82,000 (about 98% of average total cost). The second highest control cost occurred in 1991; $123,000 (about 96% of average total cost) and $9,000 (about 32% of average total cost) for each size group. Monitoring costs averaged about $5,000 per year for 11-300 MGD and $3,000 for 0-10 MGD. These were only about 6% and 13% of total costs for each subgroup.

Figure 5. Municipal Water Treatment Plants
Average Zebra Mussel Control Costs by Year and Size of Facility



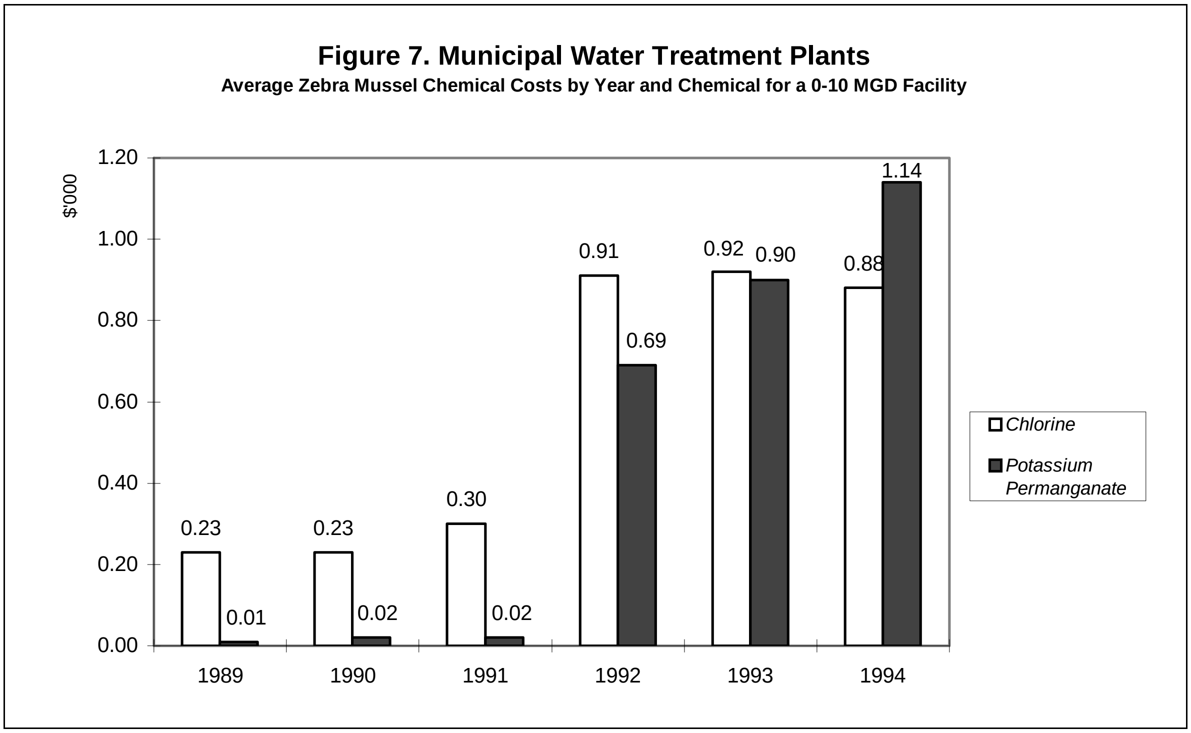
For municipal water treatment plants retrofit costs have run over 90% of total control cost (Figure 6). In 1993, the average retrofit costs were highest (about $133,000 and $80,000 for medium and small plants, respectively), which were 97% and 90% of total control costs, respectively. For water treatment plants, variable chemical costs were less than 10% of total control costs, because chemicals used for water treatment were nearly adequate for zebra mussel control.

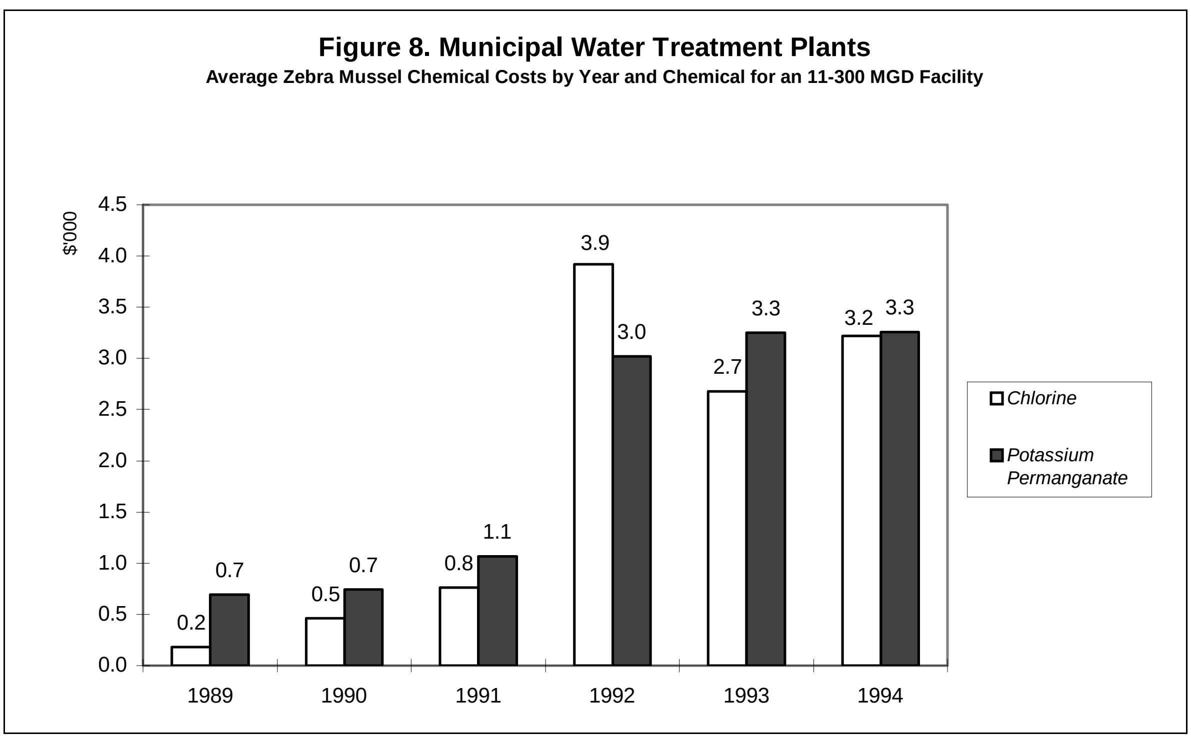
Figure 6. Municipal Water Treatment Plant
Average Zebra Mussel Retrofit Costs by Year and Size of Facility



The average retrofit costs dropped in 1994 after having increased steadily into 1993. In 1994, the medium facilities spent only 18% of 1993 retrofit expenditures and small facilities spent less than 10% of 1993 retrofit expenditures.

Figures 7 and 8 show chemical costs by year and by chemical. For small plants (Figure 7), the average cost of potassium permanganate ($KmnO_4$) and chlorine (Cl_2) were similar after 1992.





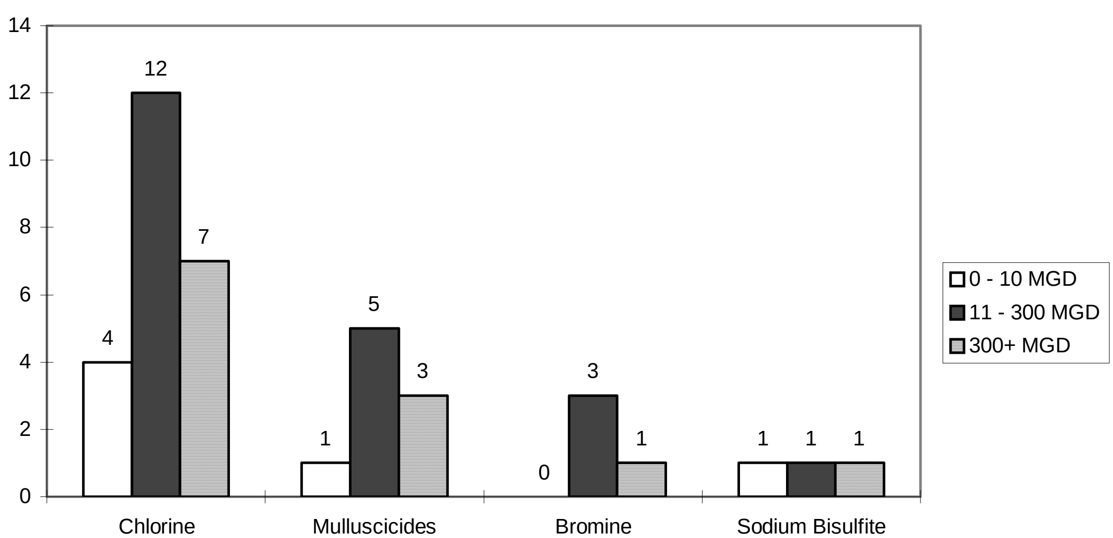
For the larger facilities (11-300 MGD), average chemical costs were similar for chlorine and potassium. In 1994, 21 plants used chlorine with average costs of $3,218 while nine used potassium ($KmnO_4$) with average cost of $3,263.

Based on a statistical analysis of alternative control technologies (Deng, 1996; Hushak and Deng, 1997), the simulated cost of replacing chlorine by potassium permanganate in water treatment plants was $13,258 per facility if the plant was using chlorine prior to the zebra mussel infestation and purchased potassium permanganate explicitly to control zebra mussels. Most of the plants using chlorine were using it prior to arrival of the zebra mussel and the marginal or additional costs of using chlorine to kill zebra mussels were very small. If such a plant wanted to use potassium permanganate for zebra mussel control but retain chlorine for water purification, the cost of potassium permanganate was substantial. For water plants that adopted chlorine explicitly to kill zebra mussels, the costs of using potassium permanganate as an alternative resulted in small simulated savings of $1,612 per facility.

Utility and Industry

Figure 9 shows responding utility and industry establishments by size and chemical treatment method for 39 out of 66 plants that used at least one chemical treatment method. Sixty-six plants reported zebra mussel control costs of which 39 were using at least one chemical treatment method. Several were using exclusively physical removal. About 54% of the 39 were medium (11-300 MGD), 31% (300+ MGD) were large, and 15% were small (0-10 MGD) in size. Chlorine (Cl_2) was the most used (59% of 39), followed by mulluscicides (23% of 39). Both bromine and sodium bisulfite were used by 18% of the 39 chemical-using utility and industry respondents.

Figure 9. Utility and Industry Facilities
Types of Zebra Mussel Treatment



Figures 10-15 show average costs of the monitoring or control of zebra mussels by utility and industry. Figure 10 shows average total cost by year and size of the facility.

The average costs of monitoring and control steadily increased into 1993. In 1993, the average monitoring and control cost was about $439,000 for large, $92,000 for medium, and $10,000 for small size establishments of utility and industry. The subgroups have 21, 26, and 20 facilities, respectively. From this figure, we see that utility and industry spent 97%, 61%, and 85% of 1993 expenditures in 1994. This was a quite different result from the case of water treatment plants, where in 1994, average water treatment plants spent only 27% (medium) and 14% (small) of 1993 expenditures.

Figure 10. Utility and Industry Facilities

Average Zebra Mussel Monitoring and Control Costs by Year and Size of Facility

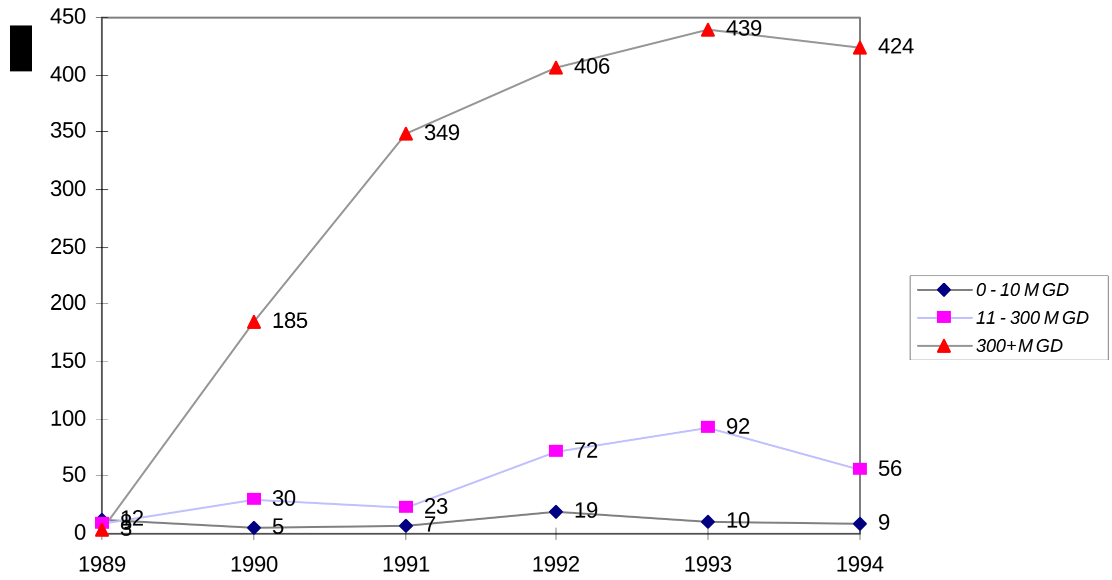


Figure 11 shows control cost only. For large plants, the highest cost was incurred in 1993, about $434,000 (nearly 99% of the control and monitoring cost in 1993). The highest control cost for medium and small size facilities occurred in 1992, about $62,000 (86% of total cost) and $15,000 (79% of total cost), respectively. For small size facilities, the second highest control cost occurred in 1993 - about $6,000; for medium size facilities $52,000 in 1993; and for large size facilities $420,000 in 1994. The major part of total cost was control cost, similar to water treatment plants. Average monitoring costs were about $5,000 per year for large utility and industry and $4,000 for small. The average monitoring cost spent by medium utility and industry was much higher than other groups, about $10,000.

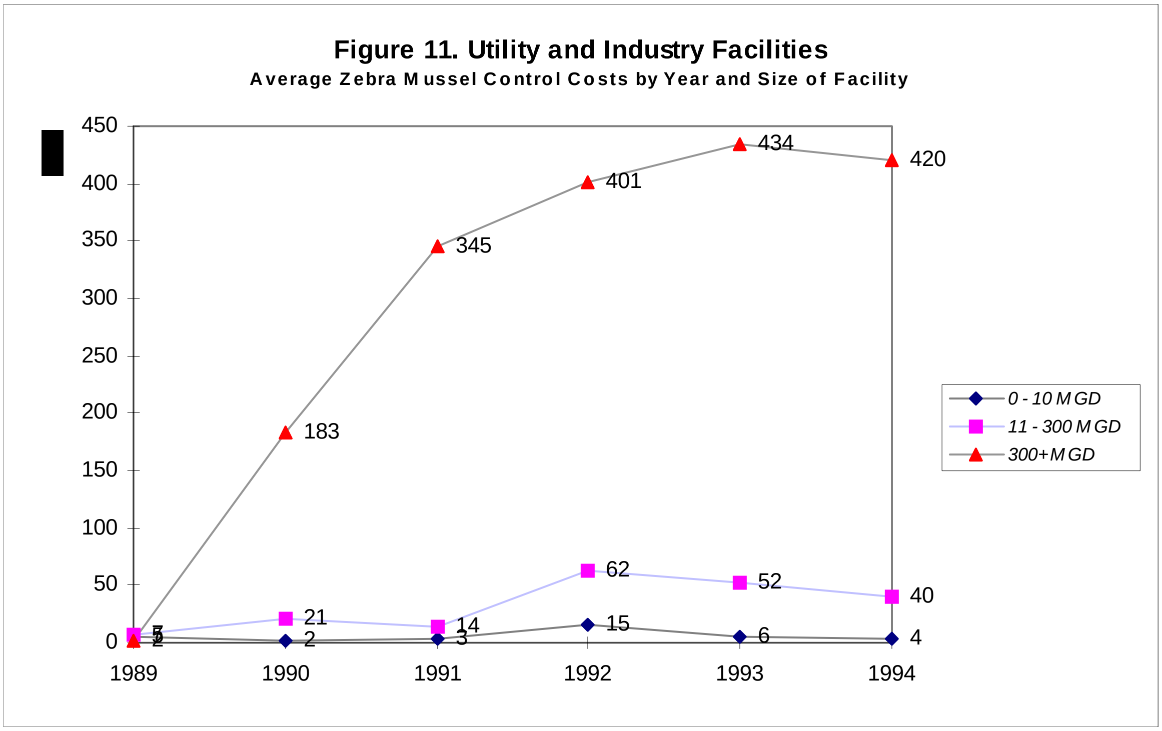


Figure 12 captures the part of control cost spent on retrofit or reconstruction. For the large utility and industry facilities, retrofitting cost was about 50% of total control cost each year. The highest retrofitting cost for large size occurred in 1993 (about $230,000) and it did not decrease much in 1994. The retrofit costs of medium size facilities varied widely from year to year - the retrofit costs reported in 1994 were only 14% of 1992 costs, roughly $37,000. Small size facilities spent $2,700 per year in the period 1989 through 1994, which was about 49% of annual average total control cost of $5,600.

Figures 13-15 report chemical or variable costs. Chemical costs for zebra mussel control were higher for utility and industry than for municipal water because there was little use of chemicals prior to the zebra mussel infestation. For large size utility and industry (Figure 13), there was a move from mulluscicides to chlorination during the period. In 1991 and 1992, mulluscicides were used by six large utility and industry facilities and chlorine by three. However, in 1993, seven of nine large facilities chose chlorination over mulluscicides and in 1994 seven of eight used chlorination while only one used mulluscicides. Average chlorination costs in 1993 and 1994 were about $132,000 per year and were about 31% of total control cost. In 1992, large facilities spent about 29% ($115,000) of total control cost on one or both chemical treatments.

Figure 12. Utility and Industry Facilities

Average Zebra Mussel Retrofit Costs by Year and Size of Facility

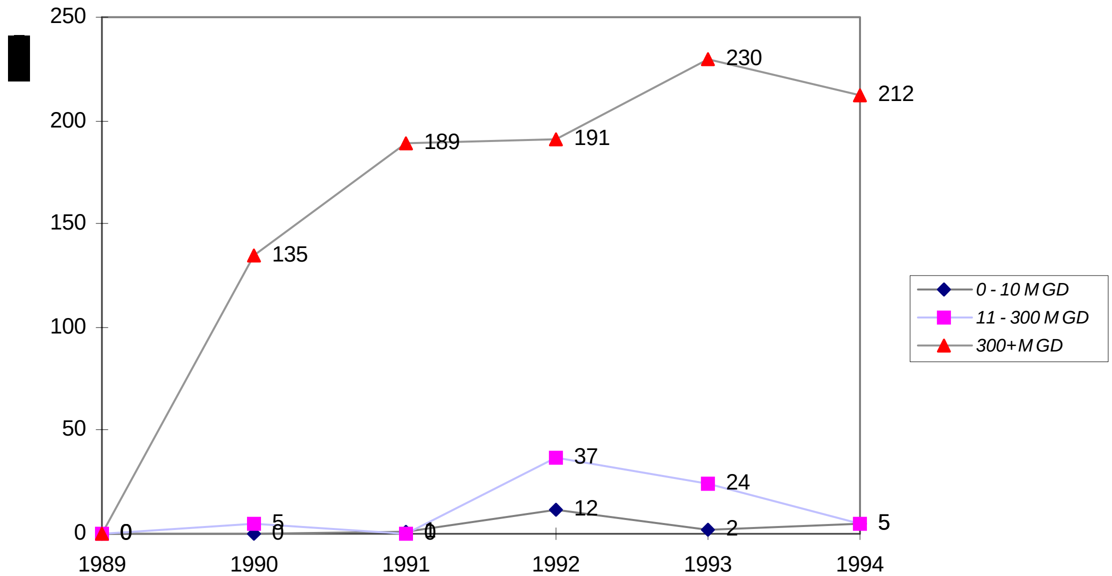
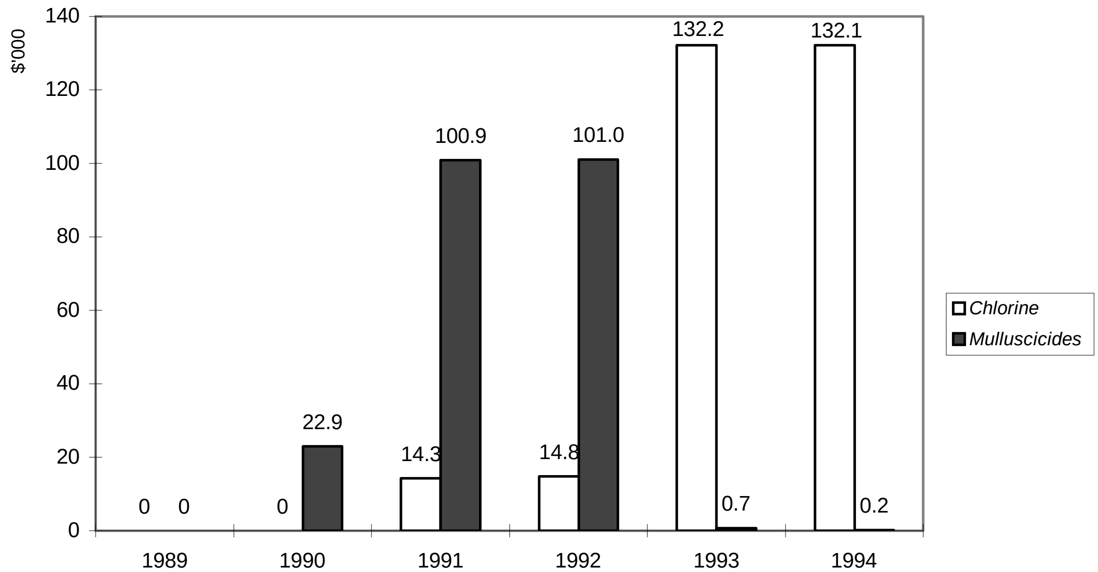


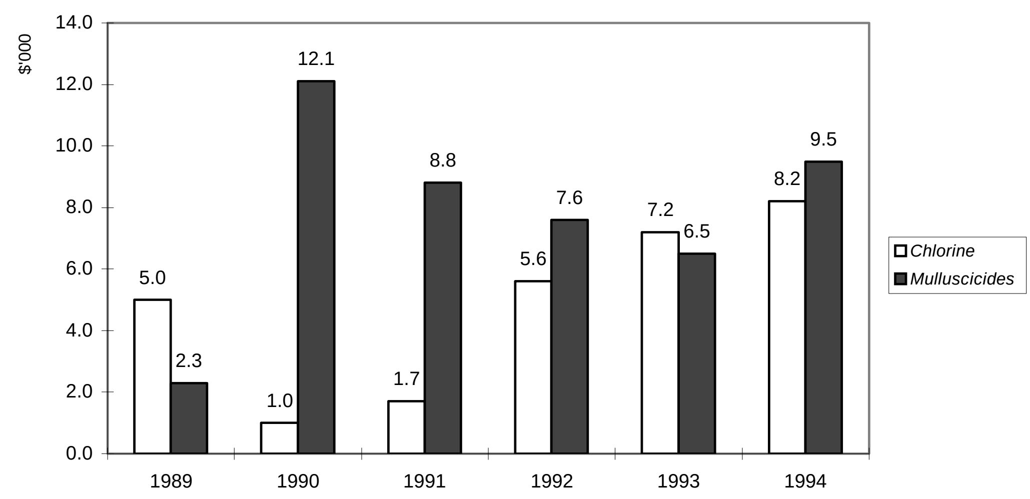
Figure 13. Utility and Industry Facilities

Average Zebra Mussel Chemical Costs by Year and Chemical for a 300+ MGD Facility



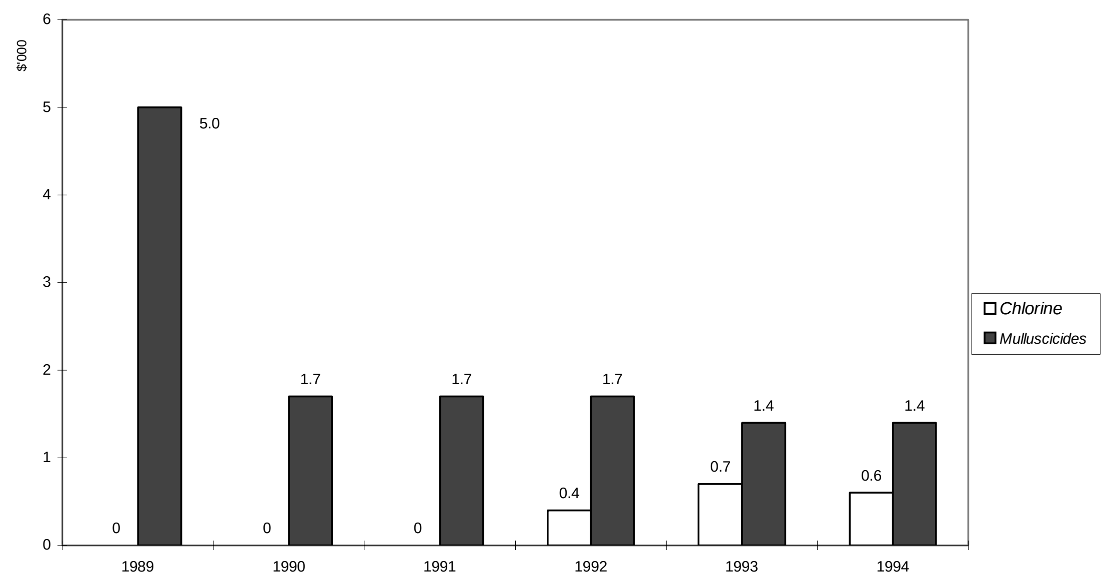
For medium size facilities (Figure 14), average costs of chlorine and mulluscicides were similar beginning in 1992. In 1994, 12 of 17 facilities used chlorine and spent $8,100 on average. The remaining five facilities used mulluscicides and spent $9,400 on average.

Figure 14. Utility and Industry Facilities
Avg. Zebra Mussel Chemical Costs by Year and Chemical for an 11 - 300 MGD Facility



In 1993 and 1994, four of five small facilities used chlorine with an average cost of about $650. One facility used mulluscicides at a cost of about $1,400.

Figure 15. Utility and Industry Facilities
Avg. Zebra Mussel Chemical Costs by Year and Chemical for a 0 - 10 MGD Facility



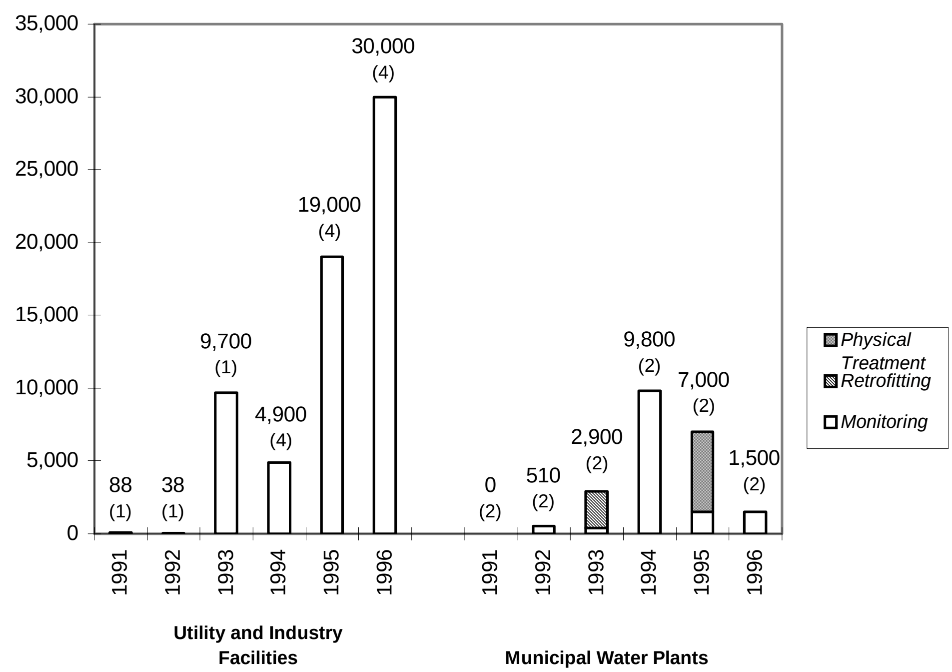
Based on Deng (1996) and Hushak and Deng (1997), biocides or bromine were the primary alternatives to chlorine for electric utility and industry facilities. Replacing chlorine by biocides or bromine resulted in lower simulated control costs of $21,792 and $26,067 per facility, respectively. If chlorine control was replaced entirely by physical cleaning, simulated costs increased by $3,774 per facility. In both subgroups, the results were subject to the caution that the substitute technologies may not be feasible at a particular facility.

In-land Water Users

A survey of in-land water users attending the St. Louis zebra mussel control conference in 1996 suggests that in-land facilities reporting monitoring and control costs spent an average of $6,816 over 1991 to 1996, municipal water plants spent $3,618, and utility and industry facilities $10,013. Figure 16 shows the average zebra mussel monitoring and control costs over the period by year and type of facility. For utility and industry, the average costs of monitoring and control steadily increased into 1996; for municipal water plants, the average costs were highest in 1994. The numbers of responding facilities are listed in the parenthesis.

Figure 16. In-land Water Users

Average Zebra Mussel Costs by Year and Type of Facility



For municipal water plants, the major cost was retrofitting and physical treatment; no additional chemical cost was required after relocating existing chemical treatment points. Utility and industry facilities spent all of the costs on monitoring of zebra mussels. The monitoring costs of the utility and industry group were very large compared to those of water treatment plants. The survey showed chlorine and potassium permanganate were preferred by municipal plants. For utility and industry, anoxia or cationic polymer were the primary alternatives to chlorine.

These data and conversations with other in-land surface water users suggest that the zebra mussel is not likely to cause large damages in many facilities. Large river systems, such as the Mississippi or Ohio, have zebra mussels, but populations are small or are confined to rather small pockets. Zebra mussel populations do not increase steadily over time as was the case in the Great Lakes. Zebra mussel infestations need to be monitored, but populations may remain small and treatment unnecessary.

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