RECLAMATION

Managing Water in the West

Available Methods for Invasive Mussel Control

Quagga and Zebra Mussels

U.S. Department of the Interior
Bureau of Reclamation

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Available Methods for Invasive Mussel Control

The purpose of this report is to provide information on available methods for mussel control in accordance with the request specified on page 78 of the House of Representatives Energy and Water Development Appropriations Bill, 2014 (Report 113-135, July 2, 2013). The language states:

> "*Quagga and Zebra Mussels.*—The Bureau of Reclamation in its operations on the Colorado River shall report to Congress on the costs and benefits of various available methods, including chlorine and biopesticides, to address and mitigate the current problems posed by quagga and zebra mussels on Reclamation's infrastructure and mission. The report should include an analysis of the efficacy of each treatment system."

This report comprises a brief overview of the status of the mussel infestation, Reclamation's actions to minimize invasive mussel impacts, and information regarding available methods to control invasive mussels at impacted Reclamation facilities. The various methods can generally be categorized as: chemical and non-chemical methods, which include pesticides, coatings, ultraviolet (UV) light treatment, filtration, operational, and mechanical (removal or cleaning).

Reclamation has not undertaken efforts to test alternative methods side-by-side, except in a few cases. In most cases, the factors that determine use are only partly related to cost. Often, the controlling factors are the practicality of application within our complex hydropower infrastructure, plus issues relating to environmental impacts or permitting. This report, therefore, provides Reclamation's best information on practicality and effectiveness of various control methods available for the specific conditions and unique facilities associated with Reclamation's operations on the Colorado River, rather than direct cost comparisons.

Status of Invasive Mussel Infestation

Invasive mussels, including quagga and zebra, have the potential to block water intakes, clog piping and adversely affect hydraulic equipment associated with municipal water supplies, power plant systems, water delivery systems, and recreational facilities. Mussels are filter feeders and can form massive colonies causing a shift in the food chain, disrupting the ecological balance of infested water bodies and impacting native species.

Invasive mussel species have presumably been present in North American waters since the mid-1980s. The discovery of adult quagga mussels in Lake Mead in 2007 is the first known infestation west of the Rocky Mountains. Scientists believe, however, quagga mussels may have arrived in Lake Mead at least

3 to 5 years earlier, most likely on a boat trailered from an infested Midwestern or Western United States water body. Since 2007, mussel infestation has spread throughout the lower reaches of the Colorado River and into canals and lakes in southern California and Arizona.

The potential for mussels to adversely affect operations at Reclamation facilities is significant. Three major Reclamation facilities – Hoover, Davis, and Parker Dams/Power plants are currently impacted. Heavy infestations have occurred at all three facilities which represents the potential for interrupted water delivery and power generation functions as well as increased operations and maintenance (O&M) costs. Managing mussel shell debris has been particularly problematic because of the locations impacted and the increased O&M activity required. Action plans to address the presence of the mussels are in place for all three dams. The colonization has increased maintenance activities at the dams but, to date, has not affected the water delivery and power generation functions. Glen Canyon Dam/Power plant was recently infested with mussels and has the potential to be impacted, similar to these other three facilities, in the near future.

Reclamation's Response to Invasive Mussels

Following the 2007 discovery of mussels in Lake Mead, Federal, State and local natural resources and water management agencies began efforts to minimize impacts and control further spread. Reclamation established an invasive mussel task force to facilitate public outreach and education, research, monitoring and prevention, and control and mitigation.

Reclamation's Science & Technology (S&T) Program, managed by Reclamation's Research and Development (R&D) Office, has made invasive mussel research activities a priority since 2008. These activities have included the improving of early detection methods; identifying, developing, demonstrating, and implementing facilities protection technologies and strategies; and assessing ecological impacts. Through efforts between Reclamation's R&D Office, Lower Colorado (LC) Region – LC Dams Office (LCDO), and Technical Service Center (TSC), researchers remain actively engaged in a number of mussel-related research activities.

Reclamation has also been actively involved in assessing potential invasive mussel impacts to facilities. Facility vulnerability assessments, combined with monitoring for early detection that can potentially provide 3 to 5 years of lead time, assist with the planning and budgeting of response actions. Reclamation's Policy and Administration Office also developed an Equipment Inspection and Cleaning Manual that provides protocols to aid in prevention of invasive species spread through equipment use which can be found at Reclamation's website:
http://www.usbr.gov/mussels/prevention/docs/EquipmentInspectionandCleaningManual2012.pdf

Reclamation has been an active participant in the Western Regional Panel for Aquatic Nuisances Species, the 100th Meridian Initiative, the Columbia River Basin Rapid Response Plan, and the multi-agency Aquatic Nuisances Species Task Force. Reclamation has held numerous training sessions, and hosted the Western Invasive Mussel Management Workshop, May 5-6, 2009.

Various Available Control Methods

Reclamation's R&D Office has been working closely with Reclamation's Mussel Task Force including the LC Region – LCDO, Reclamation's TSC, managing partners, States, other Federal agencies, and private industry to address quagga mussel impacts at infested hydropower and water delivery facilities. Research activities are focused on identification, testing, and development of promising facility protection technologies and identifying strategies that are environmentally compliant or preferred. These activities include the evaluation of commercially available coatings to reduce or prevent mussel colony establishment on submerged surfaces (i.e., structures, trashracks, equipment, pipes, etc.); ultra-violet (UV) light treatment to prevent larval mussels (veligers) from settling in critical cooling, domestic, and service water systems; and filtration to exclude shell debris and veligers from piped systems.

The following various available control methods for invasive mussels are outlined relative to Reclamation's unique water and hydropower infrastructure and operations on the Colorado River. These methods have been grouped into two primary categories: chemical and non-chemical.

Chemical Control

The use of chemical controls requires knowledge of use permitting, labeling, and chemical specific application regulations. The Clean Water Act requires that all molluscicides and biocides discharged to waters of the United States be regulated. All pesticides and molluscicides registered by the United States Environmental Protection Agency (EPA) must be handled and applied within the limits of the label instructions

Chlorine
Chlorination in its various forms, including calcium hypochlorite [$Ca(OCl)_2$], sodium hypochlorite [NaOCl], potassium hypochlorite [KOCl], chlorine gas [Cl_2], chlorine dioxide [ClO_2], and chloramines [primarily monochloramine, NH_2Cl], is widely viewed as one of the most effective methods for controlling mussels. However, the chemicals produced from treatment (known as disinfection byproducts) and hazards associated with large-scale chlorination systems remain significant issues. As such, Reclamation has not used chlorine for mussel control. Mackie and Claudi (2010) provide information on chlorination[1] and information can also be found in the United States Army Corps of Engineers Zebra Mussel Chemical Control Guide: http://el.erdc.usace.army.mil/zebra/zmis/zmishelp3/zm_control_guide_chemical_control_of_the_zebra_mussel.htm

Limitations - Although chlorine treatments lose toxicity relatively quickly and do not bioaccumulate, carcinogenic compounds such as trihalomethanes may be formed as disinfection byproducts. There are concerns that cumulative effects of extensive chlorine use in rivers could cause toxicity to non-target organisms. The EPA effluent limitation guideline for chlorine use in power plants greater than 25 megawatt (MW) is 0.2 parts per million (ppm) for 2 hours per day, unless the need for use in combating

[1]Mackie, G.L. and R. Claudi, *Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems*, Second Edition, CRC Press (2010).

macrofouling is demonstrated or other discharge configurations are specifically permitted. Production of trihalomethanes must not exceed 80 ppb in drinking water. The oxidizing properties of chlorine may also corrode metal surfaces and chlorine does have some toxicity to fish (e.g., rainbow trout 48 hour LC50 [lethal concentration, 50%) is 0.07 ppm). Chlorine dioxide requires on-site generation equipment and may convert to chlorite which can create discharge limitation issues.

Ontario Power Group has estimated the use of chlorine to cost on the order of $1,000 per MW plus $50 per MW (annual O&M) to treat hydropower plant cooling water systems to control mussels. Although Reclamation does not consider chlorine a viable option at Davis Dam due to the limitations, cost estimates are approximately $250,000 per year to treat all of the cooling water subsystems for the five turbine-generator units at the power plant.

Bromine

Bromine is another oxidizing chemical used in forms such as activated bromine, sodium bromide [NaBr2], and mixtures with chlorine or other chemicals. It is used as a chlorine enhancer, reducing the amount of chlorine needed.

Limitations - Non-target effects of bromine are similar to chlorine. Efficacy drops when water pH levels are below 8 and dehalogenating materials may be necessary to reduce halogen levels prior to discharge.

Quaternary and Polyquaternary Ammonium Compounds

Quaternary ammonium compounds (QAC) include CLAM-TROL and MACROTROL. Polyquaternary ammonium compounds (PQAC) include Calgon H-130M and BULAB 6002.
QAC and PQAC are cationic surfactants, achieving effects on mussels due to their surface-binding activity.

Limitations - Concentrations of up to 5 ppm must not exceed 21 days. Effluent limits for long-term discharges for potable water are 0.5 ppm (BULAB 6002) or are prohibited within ¼ mile of intakes (Calgon H-130M, CLAM-TROL, MACROTROL). Use of these compounds is also prohibited for food or feed crop irrigation. These products are toxic to fish and aquatic organisms at certain concentrations. Some QAC and PQAC are prohibited for sale and use in California. Furthermore, these products do not degrade rapidly and may accumulate. As such, deactivation is often necessary prior to discharge which typically involves application of bentonite clay at a 5:1 ratio.

Aromatic Hydrocarbons

Aromatic hydrocarbons are ringed organic compounds with surfactant activity. Formulations include BULAB 6009 (registration expired) and MEXEL 432. These products are primarily used as corrosion inhibitors and scale dispersants in addition to being toxic to mussels. Use is primarily as a proactive treatment in clean systems since they attach to treated surfaces, forming an anti-fouling film that prevents mussels from attaching

Limitations - These products are registered for use in non-potable closed-delivery water systems only, are toxic to fish, and cannot be discharged into the environment or public waters.

Copper
Copper has a long history of antifouling properties in aquatic environments and has been shown to have relatively high toxicity to invasive mussels. Research has shown several copper-containing compounds typically used for algae and weed control have molluscicidal properties. However, currently the only registered uses of copper for mussel control that Reclamation is aware of are the copper-based liquid formulation called EarthTec QZ and copper ion generator systems, such as MacroTech.

EarthTec QZ is registered and approved by EPA for use to control mussels and is approved for use by several states, including California. A recent University of Nevada Las Vegas study indicated that EarthTec QZ is effective in killing adult, juvenile, and veliger quagga mussels under conditions at Lake Mead and effective in preventing veliger settlement at product doses of 2.6 ppm (Wong and Watters, 2013).[2]

Copper sulfate is registered for mussel control, but labeled for curative application in lakes, ponds, lagoons, reservoirs, sedimentation basins, canals, and ditches. Application rates range from 0.18 to 1 ppm depending on whether treating established adults or juvenile mussels. Treatment durations of four days generally result in complete mortality.

Copper-ion generators are a continuous use application for both flow-through and recirculating systems. Anodes supply copper and aluminum ions to the water at toxic levels (5 to 10 parts per billion), while the addition of aluminum hydroxide acts as a flocculent and aids adsorption of copper to surfaces, inhibiting settlement.

Limitations - Concentrations of copper cannot exceed 1 ppm in potable water. Open water treatments of copper sulfate can be toxic to fish and other aquatic organisms. Accumulation of copper in sediments from prolonged use may cause concerns for non-target organisms. Low pH levels, organic carbon, and water hardness may influence efficacy. Copper sulfate is not registered for use in industrial systems or as a preventative treatment.

Endothall
Salts of endothall are commonly used for aquatic weed control. The amine salt is also registered under the trade name EVAC for the control of invasive mussels in industrial systems.

Limitations - This product is toxic to fish and discharge into lakes and rivers is prohibited unless in accordance with National Pollution Discharge Elimination System permit requirements. The permitting authority must be notified in writing prior to discharge. Furthermore, endothall cannot be discharged into sewage systems without prior notification to local sewage treatment authority.

Zequanox®
Zequanox® appears to fall within the classification of biopesticide and is the only registered biopesticide for mussels that Reclamation is aware of under the EPA Office of Pesticide Programs Biopesticides and Pollution Prevention Division. This is as stated on the EPA website http://www.epa.gov/oppbppd1/biopesticides/whatarebiopesticides.htm:

[2]Wong, D. and A. Watters, "Effectiveness of EarthTec® on Killing Invasive Quagga Mussels in the Western U.S.," Department of Environmental and Occupational Health, University of Nevada at Las Vegas (2013).

> "Biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals. For example, canola oil and baking soda have pesticidal applications and are considered biopesticides."

Zequanox® is composed of dead cells of a naturally occurring microbe (Pseudomonas fluorescens), and is perceived as a food source by zebra and quagga mussels, which have been found to readily consume the product along with other food items. Once ingested, Zequanox® deteriorates the mussel's digestive lining, causing death.

Zequanox® appears relatively benign compared with conventional broad spectrum pesticides (e.g., chlorine) and Reclamation has considered its use in controlling mussels in cooling water systems at Davis and Hoover Dams. Reclamation's R&D Office and LC Region – LCDO collaborated with Marrone Bio Innovations, Inc. (MBI) to develop Zequanox® via testing at Reclamation's Davis Dam under a Cooperative Research and Development Agreement. More recently, biweekly demonstration treatments for a cooling water subsystem were completed by MBI at Reclamation's Hoover Dam. MBI's reported results from those treatments suggest that Zequanox® is capable of reducing mussel settlement in a treated cooling water subsystem at Hoover Dam by as much as 88% (Link, 2014).[3]

Limitations - While the product appears effective for control of mussels in cooling water systems, cost estimates provided by MBI to date are considered cost prohibitive by facilities management. Based on their 2014 report documenting trial testing at Hoover Dam, MBI's estimated cost for treating one cooling water subsystem using Zequanox® was $30,000 per year which equates to an annual cost of approximately $510,000 to treat all seventeen unit subsystems at Hoover Dam.

Reclamation's LCDO also determined that use of Zequanox® at Hoover Dam would require retrofit of the cooling water systems to install pumps for each unit which would draw water from the tailrace instead of the existing arrangement that uses reservoir water blended with tailrace water via a gravity driven system. The cost for retrofit of the cooling water systems was estimated by engineering staff at Hoover Dam to be $743,000 for 9 units (approximately $83,000 per unit, not including annual maintenance). This would amount to approximately $1.5 million for installation on all seventeen units at Hoover Dam and represents additional costs to enable the use of Zequanox®. Tailrace pumps are being installed in the next 2 years to reduce mussel shell debris and biofouling. The new arrangements will include connections for ultraviolet treatment equipment installation and diffusers for potential future chemical applications.

Non-Chemical Control

Coatings

Since 2008, Reclamation has continually evaluated the performance of various commercially available coatings systems for effectiveness in reducing or eliminating mussel fouling on submerged substrates. Potential applications include intake screens, trashracks, internal surfaces of large diameter piping, and

[3]Link, C., "Demonstration of Biweekly Zequanox Treatments to Control Invasive Mussel Populations at Hoover Dam," Marrone Bio Innovations, Inc. (2014).

associated hydraulic equipment. Results of the first 3 years of testing are available (Skaja, 2012).[4] To date several systems have performed well, but durability in all cases thus far is limited. The best performing systems are silicone-based and relatively soft which is expected to considerably reduce service life of the infrastructure over the conventional coatings systems typically used for corrosion protection.

Limitations – Durability continues to be a major concern. Pending improvements in durability, cost estimates are not yet available for use at impacted Reclamation facilities.

UV Light Treatment

Reclamation has evaluated the use of UV treatment for cooling water systems at both Hoover and Davis Dams. The results have shown that for correctly sized systems, UV treatment can reduce mussel settlement by more than 80%. Implementation of UV on the cooling water systems at Davis and Parker Dams is being considered to reduce mussel-related impacts.

Limitations – Although early results are promising, more information is needed on UV dosage rates, treatment costs, and impacts of environmental variables to optimize operating conditions.

Filtration

Filtration was one of the first technologies evaluated by Reclamation for protecting piped raw water systems from mussels. A number of reputable filtration vendors exist and the technology is considered mature. Testing in 2009 at Reclamation's Parker Dam demonstrated very good performance with up to 99% exclusion of mussel veligers using 40-micron filter media and over 90% exclusion using 80-micron filter media.

Limitations - Although, highly effective for excluding mussels from cooling water systems, the technology has since proven maintenance intensive according to power plant staff.

Mechanical and Operational

Some mussel control can be achieved by performing mechanical activities such as jetting, scraping, and cleaning which physically remove the mussels from facility structures. Mechanical activities are also necessary to remove mussel shell debris resulting from other control methods. In addition, operational activities such as drawdowns/desiccation will also reduce mussel populations.

Limitations - Operational activities have to be performed repeatedly to maintain the desired level of mussel control.

Systems Retrofit

In addition to tailrace pumping, which has been previously mentioned, the conversion of single-pass cooling water systems to closed loop systems is a potential option for minimizing or eliminating mussel-related impacts to cooling water systems. However, doing so would generally require a complete redesign of existing systems. Conventional single-pass cooling water systems are typically gravity driven and utilize raw reservoir water routed through heat exchangers to cool equipment.

[4]Skaja, A.D., *Coatings for Mussel Control – Three Years of Laboratory and Field Testing*, Technical Memorandum No. MERL-2012-11, Bureau of Reclamation (2012).

Limitations - Retrofit to incorporate closed-loop cooling would basically require integration of pumping to recirculate cooling water and additional heat exchangers or chillers to remove heat during the cooling cycle. For most large power plants, cooling water systems are comprised of extensive piping and equipment to cool various components which typically include generators, bearing oil, packing boxes, compressors, transformers, heating, ventilation, and air conditioning systems and in some cases supervisory control systems electronics. While Reclamation recognizes closed-loop cooling as a potential option, redesign and modification of existing systems is very expensive.

Costs and Benefits

Reclamation has primarily utilized filtration and mechanical methods to control mussel infestations and reduce the associated risk of water and power delivery interruptions. Both of these methods require increased O&M efforts and costs. As such, Reclamation continues to pursue other effective options that can augment these available methods, are compliant with State and Federal regulations, and are cost effective for applications specific to Reclamation infrastructure.

Costs and benefits of implementing mussel-related facilities protection at Reclamation facilities are complex and depend on factors such as levels of infestation, facilities complexity, operating conditions, and design requirements. Infestation levels and locations determine the degree of impacts and associated corrective actions to minimize or eliminate those impacts. Dealing with mussels at complex facilities (e.g., large pumping plants and multi-unit power plants) is expected to be more costly than at less complex facilities (e.g., storage reservoirs with outlet works). Design requirements are inherently linked with the level of complexity while implementation may be driven by other factors including operations. For example, it may only be possible to phase in protection of cooling water systems at large, multi-unit power plants in order to avoid shutting the entire plant down for retrofit of installation of control equipment. Furthermore, facilities that do not operate year-round may experience fewer impacts than those that remain in service continuously. While intermittent operations can provide opportunities for maintenance to remove mussels from infested systems, it can also compound problems by allowing mussels to infest systems that would otherwise (due to high water velocities that prevent mussel colony establishment) be minimally impacted. In addition to mussels settling in distribution piping, to a large degree, many of the impacts experienced at Reclamation facilities involve mussel shell debris. Heavy shell debris loads from acute mussel die-off events can result in significant impacts potentially affecting function of water delivery and power generation facilities.

Estimating setup and ongoing costs for chemical control of mussels is highly variable depending on the system in which it is applied. Setup costs include application equipment, regulatory support for permitting and certification, and technical support to produce the most effective and safe application possible. Additional costs to consider include facility downtime, equipment maintenance, safety, monitoring, and mitigation of environmental impacts. For this reason, it is not meaningful to use per-volume costs of chemical control products for the purpose of cost comparisons. Case studies on specific scenarios of implementation of chemical mussel control may provide some insight, but may not be applicable to other facilities.