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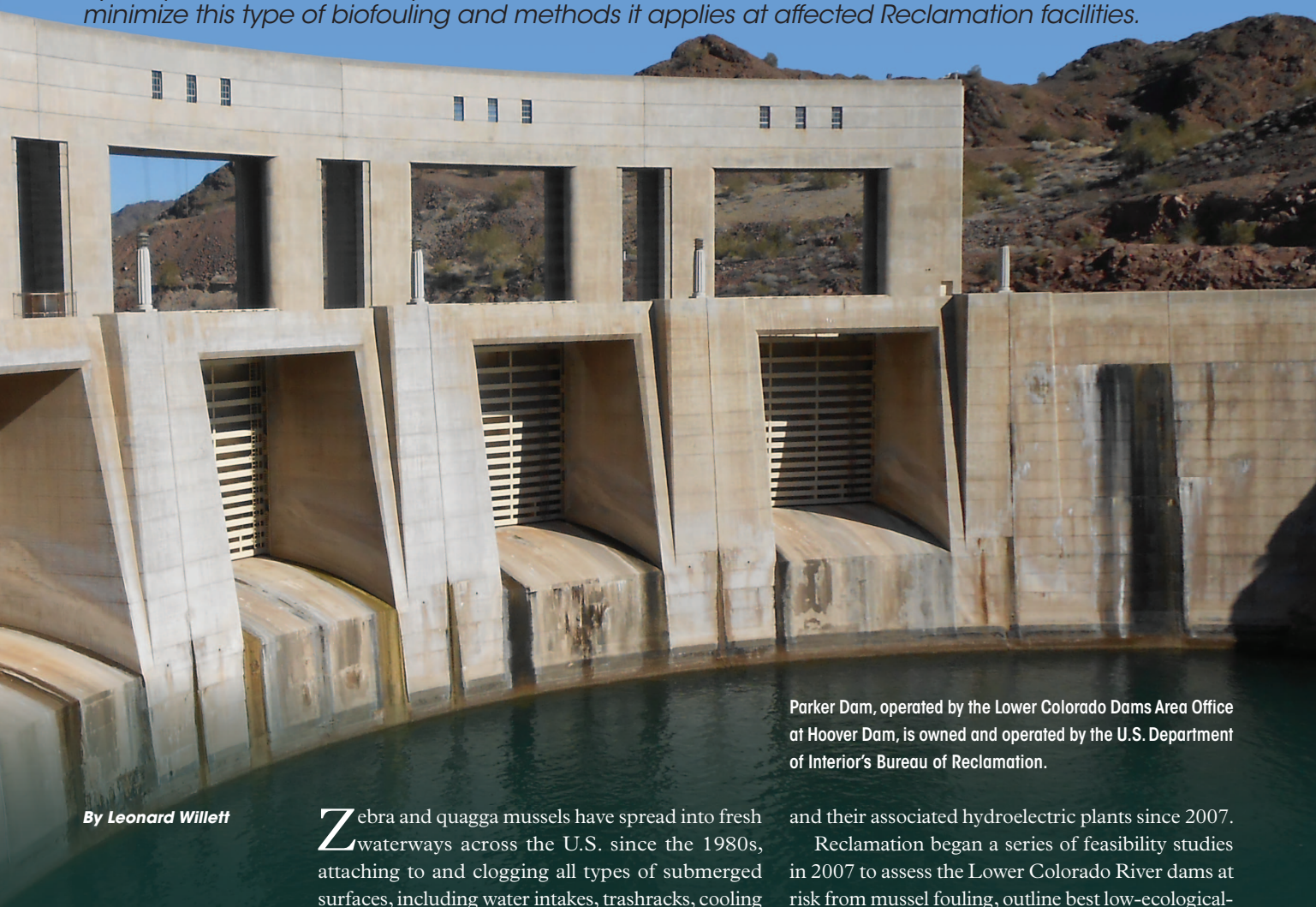
Environmental

How Reclamation is Dealing with Biofouling at Lower Colorado River Dams

Biofouling from invasive mussel species and their operational effects on the hydroelectric industry are profound. The U.S. Department of Interior's Bureau of Reclamation discusses its actions to minimize this type of biofouling and methods it applies at affected Reclamation facilities.



Parker Dam, operated by the Lower Colorado Dams Area Office at Hoover Dam, is owned and operated by the U.S. Department of Interior's Bureau of Reclamation.

By Leonard Willett

Zebra and quagga mussels have spread into fresh waterways across the U.S. since the 1980s, attaching to and clogging all types of submerged surfaces, including water intakes, trashracks, cooling water piping and fire control systems.

Flow restrictions caused by mussels threaten water delivery and can significantly reduce generation from hydroelectric, water conveyance systems such as canals, fire suppression systems, pumping plants and other facilities and lower associated revenue.

The presence of quagga mussels in Lake Mead is a primary concern to the Lower Colorado Dam Office of the Department of Interior's Bureau of Reclamation. This office has been responsible for maintaining the Hoover, Davis and Parker dams and their associated hydroelectric plants since 2007.

Reclamation began a series of feasibility studies in 2007 to assess the Lower Colorado River dams at risk from mussel fouling, outline best low-ecological-impact management practices for coping with invasion, and identify control options for raw water systems to prevent invasion and infestation.

Coating systems were evaluated to address exterior biofouling and various control methodologies, categorized as chemical and non-chemical approaches, were evaluated to address interior concerns.

After completing research, Reclamation began to use a variety of proactive and reactive techniques that help control invasive mussel biofouling at Hoover, Davis and Parker dams.

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Coating systems on exterior surfaces

Since 2008, Reclamation has evaluated the performance of commercially available coating systems in reducing or eliminating mussel biofouling on submerged substrates. Potential applications include intake screens, trashracks, internal surfaces of large-diameter piping, and associated hydraulic equipment. Results of the testing are available up to 2015. The best-performing systems are silicone-based, which are relatively soft and expected to considerably reduce service life of the infrastructure as compared to conventional coating systems typically used for corrosion protection.

Another issue that has a potential effect on exterior surfaces is the fact that source waters experiencing mussel infestation encounter an increase in aquatic weeds due to the decrease of plankton (which the mussels feed upon) and resulting increased sunlight penetration. Aquatic weeds can reach heights of 8 feet and, when broken, can plug the power plant trashracks. Additionally, submerged surfaces such as intake structures, equipment, instrumentation and pipes will experience biofouling as a result of the mussel infestation.

Reclamation's Materials Engineering Research Lab in Denver initiated a coatings research project in 2008 to identify and develop solutions to mitigate mussel-related problems on trashrack panels. Parker Dam, where mussels reproduce almost year round, was selected as the test site to evaluate coatings in static and dynamic exposure conditions. Parker Dam on the Colorado River between California and Arizona creates Lake Havasu and provides water to a 120-MW powerhouse.

More than 100 coatings and materials for mussel control have been evaluated. During the first year, anti-fouling paints typically used in the marine industry were studied, but they did not prevent mussel attachment in dynamic water conditions. The focus then shifted to finding foul-release coatings that would prevent mussel attachment and demonstrate acceptable durability for Reclamation's specific site conditions. Nineteen materials and coatings, all of which are silicone-based, were found to prevent mussel attachment or allow affected items to be easily cleaned.

Mussels have infested the penstock belly drain at a Lower Colorado River dam (see video at HydroWorld.com).

Silicone-based foul-release coatings do not contain biocides and are non-toxic and rely on physical properties to prevent attachment, provided the coatings remain intact and are not mechanically damaged. They are UV stable and appropriate for immersion or alternating immersion and atmospheric service.

Unfortunately, commercially available abrasion- and gouge-resistant silicone-based foul-release coatings that prevent mussel attachment have not yet been found.

Control methodologies for interior biofouling concerns

With few exceptions, Reclamation did not conduct side-by-side test comparisons of alternative control methodologies to address mussel infestation at its impacted facilities. Research activities focused on identification, testing and development of promising facility protection technologies and identifying environmentally compliant or preferred strategies.

Algaecide/pesticide control measures

Estimating setup and ongoing costs for chemical control of mussels is highly variable, depending on the system application. Setup costs include application equipment, regulatory support for permitting and certification, and technical support to produce the most effective and safest application possible. Case studies on specific scenarios of implementation of chemical mussel control may provide some insight but may not be applicable to other facilities.

With the assistance of RNT Consulting Inc., Reclamation evaluated a variety of algaecides — at concentrations normally used for the control of aquatic weeds and algae — for their ability to control zebra and quagga mussels. The experiments were carried out in mobile flow through laboratories located at Davis Dam (for quagga mussels) and the San Justo Reservoir (for zebra mussels) in California.

Algaecides: Endothall formulations

Two endothall formulations, di-potassium salt (Cascade®) and amine salt (Teton®) of endothall, were evaluated. Adult mussels were exposed to different concentrations of both formulations at ambient water temperatures of 20 degrees Celsius and 25 C for 96 hours. Mortalities were recorded every 12 hours. Short-term exposure and recovery testing to determine post-exposure mortality rates was also conducted. There was greater efficacy at higher temperatures.

- Cascade: Very low mortalities were detected when quagga or zebra mussels were exposed to any concentration of Cascade in either ambient temperature condition.
- Teton: High mortalities were detected when quagga mussels were exposed to Teton at both temperatures. Zebra mussels were much less susceptible to Teton, but they exhibited increased

mortality with elevated ambient temperatures. The use of Teton as an algaecide may offer significant benefits in areas with both problematic algae and quagga mussels. An algaecide treatment may result in control in the body of water treated by direct toxicity to quagga mussels.

Algaecides: Copper-based

Five copper-based algaecide solutions — including GreenClean sodium carbonate peroxyhydrate powder and GreenClean liquid, copper sulfate (CuSO4), Natrix™ copper carbonate ethanolamine complex, Captain™ double chelated copper compound, and EarthTec® copper pentahydrate — were evaluated.

Adult mussels were exposed to a high (1 mg/L) and low (0.5 mg/L) concentration of copper for 96 hours with ambient temperatures between 16.5 C and 19.5 C at concentrations normally used for the control of aquatic weeds and algae. The exception was copper sulfate, which was used at a high value of 0.5 mg/L cubic meter (Cu) and low value of 0.25 mg/L Cu. Generally, copper-based algaecides have greater efficacy at higher temperatures. Mortalities were recorded every 12 hours. Short-term exposure and recovery testing to determine post-exposure mortality rates was also conducted.

With the exception of EarthTec, which was equally effective at inducing mortality on both species, copper-based algaecides were more effective at inducing mortality in quagga mussels than zebra mussels.

Temperature variations were found to be insignificant for quagga mussels, while higher temperatures may have contributed to increased mortality for zebra mussels.

Bio-Pesticide: Zequanox®

With the assistance of Marrone Bio Innovations Inc., Reclamation conducted a series of quagga mussel control treatments at Davis Dam using its naturally derived aquatic biopesticide called Zequanox. Zequanox is made from a naturally occurring strain of the bacteria *Psuedomonas fluorescens.*

A cooling water subsystem at Davis Dam was used to complete three treatments of Zequanox in June, September and November 2011. The mortality results were acceptable when taking into account the raw water flow was 2.2 times greater than the system was designed to treat. The results were 43.3%, 77.0% and 43.5% for the June, September and November treatments, respectively. Repeated treatments could be used to achieve mortality goals by taking advantage of the cumulative effects of Zequanox. As an environmentally friendly solution, Zequanox showed little to no impact on other aquatic species. Despite the efficacy of Zequanox, using the product bi-weekly on our flow-through system resulted in high monthly and annual costs, making it cost-prohibitive to use. A static system where the cooling water could be shut down for six to eight hours would allow for less Zequanox to be used, providing some flexibility in overall costs.

Filtration

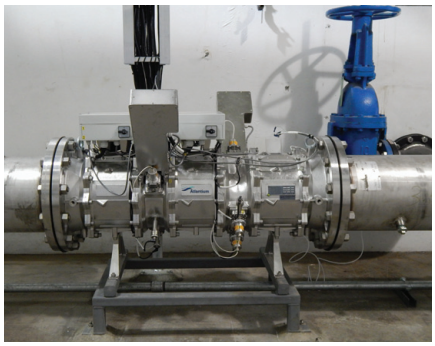
Reclamation uses micro-filtration to exclude shell debris and veligers (larval mussels) from piped systems at its impacted facilities. While the technology works well, the high capital costs and labor-intensive process creates limitations to the concept of micro-filtration being the primary treatment to mitigate mussel infestation through the cooling water system. Using micro-filtration as a self -cleaning strainer on cooling water for mussels and weed control seems to be a much better fit.

UV treatment

While UV is a viable treatment option to prevent mussel fouling, all UV systems are not alike. System-specific operating principles and associated UV dose rates regulate how a system will perform in full-scale installation.

UV treatment does not introduce a residual disinfectant (i.e., chemical) and, as a result, neutralization is not required to meet National Pollutant Discharge Elimination System requirements.

In "Monitoring and Control of Macrofouling Mollusks in Fresh Water System," Gerald Mackie and Renata Claudi posit UV wavelengths between 200 and 400 nanometers inhibit downstream settlement if the veligers were exposed to about 100 millijoules per cm^2 (mJ/cm^2). Their data is currently the accepted



This photo shows an Atlantium Hydro-Optic™ UV system installed at Parker Dam.

industry standard for UV treatment.

Several studies carried out in the 1990s showed UV systems have the ability to prevent attachment of dreissenid veligers to downstream surfaces.

RNT Consulting, as the primary researcher for Reclamation, evaluated two types of UV treatment systems designed to prevent veligers from settling in critical cooling, domestic and service water systems. Traditional and Hydro-Optic UV treatment was found to be effective in reducing *mussel settlement* (veligers attaching themselves to a surface). However, the Hydro-Optic UV system was able to provide effective treatment using a much lower dose on dirtier water. Results are detailed below.

Industry UV standard vs. lower dosage

The cost of power is a significant operating expense associated with UV disinfection systems, and power usage is directly related to the UV dose being delivered.

The Aquafine® UV treatment system, evaluated in 2012, used the industry standard dose of about 100 mJ/cm^2, which prevented 99% settlement of quagga mussel veligers downstream of the UV system.

The Atlantium Technologies Hydro-Optic UV system, tested in 2014, used a substantially lower UV dose to achieve a 99% inhibition of quagga mussel veligers settling downstream of the system. Because lower dosages mean less heat being produced by the bulbs, a lower UV dose correlates to reduced capital and operating costs.

Total Internal Reflection is an optical phenomenon applied in the field of fiber optics where quartz or glass is used to guide/extend the paths taken by UV light photons. The core of the Hydro-Optic UV

system is its water disinfection chamber made of high quality quartz surrounded by an air block instead of traditional stainless steel. This configuration uses fiber optic principles to trap the UV light photons and recycle their light energy. The photons repeatedly bounce through the quartz surface back into the chamber, effectively lengthening their paths and their opportunities to inactivate microorganisms.

The Hydro-Optic UV system was unique in its ability to consistently monitor water quality and UV intensity and to adjust the UV dose rate accordingly to meet application-specific needs. The technology has the ability to "recycle" a required dose throughout the reaction chamber using a patented internal reflection system similar to fiber optic technology. Proprietary software, logic, sensors and controls enable real-time, automatic dose adjustment according to changing water quality conditions, to consistently maintain the required dose.

Following the conclusion of the two studies conducted by RNT Consulting, Reclamation-led researcher, Sherri F. Pucherelli, evaluated the impacts of Hydro-Optic UV doses at 100, 50, 40, and 20 mJ/cm^2. For each dosage level, the research measured the effects on veliger behavior, physical damage and/or immediate or delayed mortality.

The impact of UV exposure was analyzed for each veliger life-stage to determine if one is more impacted than another. All of the doses tested in this study produced delayed veliger mortality. Post-exposure mortality rates appear to vary based on the UV dose, month/water temperature, and veliger size. UV treatment in this test was found to be effective in reducing mussel settlement. This information can also help determine if UV can be effective in other mussel management applications like biofilming common in raw water systems. UV can also be used on wash down water/fire systems, transformer, compressors, and oil coolers using raw water as supply.

Additional considerations

Infestation level and location determine the degree of impact and associated corrective action to minimize or eliminate impact. Dealing with mussels at complex facilities such as large pumping plants and multi-unit power plants is expected to cost more than at less complex facilities, including 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. Source water selection is especially important when lake water is used for cooling water systems at hydroelectric facilities because of the possibility of high levels of debris that may be present.

Tailbay water is preferred over forebay water because tailbay water contains lower levels of debris that can obstruct and damage packing and cooling water systems. Trashracks and strainers on intakes of the tailbay water system provide initial protection from mussel shell debris. It is logical to phase in protection of cooling water systems at large, multi-unit power plants to avoid shutting down the entire plant for retrofit or installation of control equipment. Furthermore, non-continuous facilities may experience fewer impacts than those that remain in continuous service annually.

While intermittent operations can provide opportunities for maintenance personnel to remove mussels from infested systems, the lack of high water velocities, which help prevent mussel colonization, can also compound problems by allowing mussels to infest systems.

Conclusion

Following the evaluation of various chemical and non-chemical control methodologies, the Hydro-Optic UV system was selected as the preferred treatment to supplement operational and mechanical activities already in place at Hoover, Davis and Parker dams.

One Hydro-Optic UV system is installed at Davis Dam and has been used for the three years of research. The results have been impressive with 99% removal of mussel settlement, low maintenance costs, and low energy usage. The Hydro-Optic system consistently monitors water quality and has the ability to adjust the UV dose to meet application specific conditions. As a result, the system operates at the lowest energy needed for treatment. Four remaining Hydro-Optic UV systems are scheduled for installation in 2018. At Parker Dam, five installations were completed in March 2016, and Hoover Dam installations are planned for 2016 and 2017. ■