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Evaluation of UV Technology at Hoover Dam as Means of Eliminating Downstream Settlement of Dreissenid Mussel Veligers

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1.0 Introduction

Dreissenid mussels, the zebra and quagga mussels arrived in the eastern United States from Europe in the 1980s and quickly spread to many Eastern waterways, rivers, and lakes. These mussels are extremely prolific and can produce costly impacts by attaching to, and clogging water intakes, trashracks, pipes, fire control systems, cooling water systems, fish screens, and virtually all types of underwater infrastructure.

Since 2007, dreissenid mussels have been present in the lower Colorado River. The mussel populations have proliferated and mussels are now adversely affecting the Hoover, Davis, and Parker Dams. Adult zebra mussels were found at San Justo Reservoir in California in 2008. In addition to Arizona, California and Nevada, mussels are present in Kansas, Nebraska, and Oklahoma and have been detected in New Mexico, and Utah. Flow restriction is the foremost concern because it threatens water delivery and hydroelectric power reliability.

To address issues and impacts associated with invasive mussels, Reclamation is coordinating and conducting a diverse portfolio of research activities to improve monitoring and detection methods; to identify, develop and demonstrate promising control technologies and strategies for facilities protection; and to assess ecological impacts. While there are many chemical compounds that will control mussels, most are non-specific and have undesirable side effects on the receiving environment. Physical control strategies, such as use of UV lights to prevent settlement offer environmentally benign method of mussel settlement prevention.

Several studies carried out in the 1990's have shown that flow-through UV systems have the ability to prevent attachment of dreissenid veligers to downstream surfaces. Most of the trials were done on the Great Lakes and involved relatively small volumes of water (Lewis and Whitby 1993, Chalker-Scott *et al.* 1993, Chalker-Scott *et al.* 1994, Evans *et al.* 1995, Lewis and Whitby 1996, Lewis and Cairns 1998). The available body of evidence suggested that medium pressure lamps with UV wavelengths between 200 and 400nm will inhibit downstream settlement of dreissenids veligers if the veligers are exposed to a radiation dose of approximately 100 mW-s/cm^2.

In 1999, Ontario Power Generation (then called Ontario Hydro) embarked on a full size UV pilot installation to test the efficacy of UV under field conditions in an open, concrete channel. The flow treated was 760L/s (12,000 USgpm). The computed UV dose delivered to each particle passing through the UV system was between 70-100 mW-s/cm^2. The system was operational for one breeding season of the mussels. Despite numerous outages, there was an 85% reduction in settlement downstream of the UV system when compared to control chambers upstream (Pickles 2000).

Hoover Dam installed a UV system in late 2010 in a closed, steel pipe to protect a relatively small cooling water circuit on Unit A1. The system was monitored in 2011 and performance data was collected. The system was overhauled at the end of 2011 and two additional UV lamps were installed in order to deliver a higher dose. This report describes the results from the monitoring of the upgraded installation on its efficacy to prevent downstream veliger settlement. The monitoring was initiated on May 18, 2012 and continued until November 14, 2012.

2.0 Methodology

The primary objective of this project was to evaluate the efficacy of the existing UV system to prevent settlement of invasive mussels in Unit A1 cooling water system at Reclamation's Hoover Powerplant.

Water from the tailrace of Hoover Dam is lifted with a centrifugal pump, passes through a coarse strainer and then through a UV unit installed in the cooling water line (Fig.1).

Fig.1 UV system installation in the cooling line at Hoover Dam

The target dose the system was to deliver was 150 mW-s/cm². This dose was based on four lamps in the UV system, anticipated flow of approx. 900 USGPM ($3.4m^3/min$), and anticipated UVT of 94%. Two bioboxes were installed on the cooling water system using existing supply lines for water delivery. One biobox received raw water from upstream of the UV unit, the other received water that had passed through the UV unit. Each biobox was equipped with 8 settling plates. As the water from the tailrace (the source of the water) is very cold year around, two aquarium heaters were installed in each biobox in an effort to promote the growth of the Quagga mussels by providing higher ambient water temperature (Fig.2). The flow into each biobox was monitored with a flow totalizer to determine the total volume of water that flowed through each biobox in-between monitoring events. The outflow from each biobox was passed through dedicated 63-micron mesh plankton nets. The cumulative plankton sample from each net was collected, one each week. The total volume of water sieved (taken from the totalizer readings) was noted on each jar to allow calculations of veliger densities. Each sample was preserved with buffered ethyl alcohol and shipped for microscopic evaluation in our laboratory. In the laboratory, each sample was reduced to a volume of 120ml. A minimum of three 1mL replicate samples was examined using a Sedgwick-Rafter cell. Each subsample was examined using an American Optical compound scope equipped with a polarizer using 25x magnification. All umbonal and larger veligers were counted in each subsample.

At the time of the plankton sample collection at Hoover Dam, the temperature in each biobox was recorded and a UVT reading was taken using water from the biobox containing untreated water. The UVT readings were taken using RealTech handheld UVT meter. The UVT meter was calibrated prior to each use using distilled water. In addition, the flow in the raw water line was recorded from the display of the UV unit, as well as the lamp intensity and UV dose as displayed by the UVT unit.

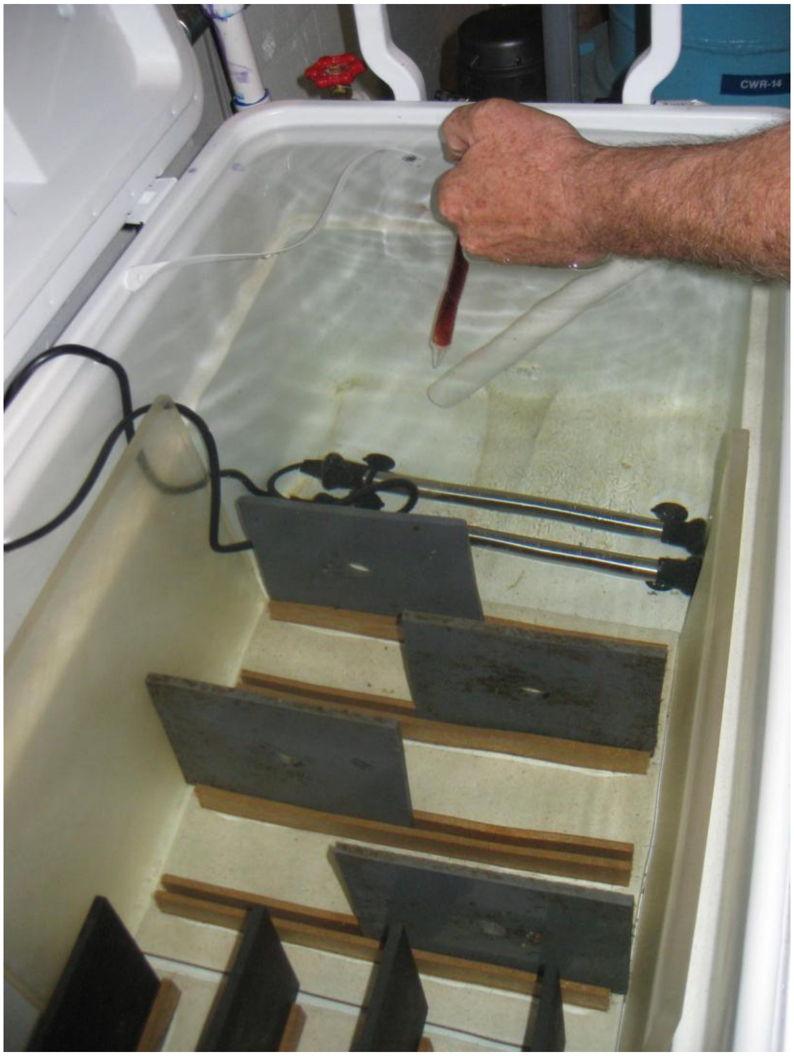

Fig.2 Biobox layout for settlement monitoring

To evaluate the power usage of the UV unit an EKM omnimeter power use data logger was installed on the UV power supply. The power usage was recorded at the same time as the other variables.

Every five to six weeks the settlement in the bioboxes was visually evaluated. The settlement plates were not cleaned in-between observations. The total settlement surface monitored was;

a) eight 6 x 6 inch plates monitored on both sides = 576 square inches
b) two 16 x 16 plates monitored on both sides = 1024 square inches

The total surface monitored was 1600 square inches or 11.1 square feet. The experiment was initiated on May 18, 2012. The settlement evaluation took place on June 26, August 14, September 24, and November 14, 2012.

3.0 Results

3.1 Dose delivered

UV lamp intensity output declines slowly with time. The intensity used for determining the average delivered dose is based on a lamp age of 5000 hrs. In UV irradiation studies, the average dose delivered (assuming steady output from the UV lamp) is based on light intensity multiplied by exposure time. The term ‘average dose’ is used here to draw attention to the fact that each particle which travels through the UV treatment unit receives slightly different UV dose depending on the proximity of that particle to the UV lamp. UV transmittance (UVT) affects the intensity of light that will reach a particular particle at a given distance from the lamp. The volume of water treated within the pipe will dictate the exposure time, the higher the volume, the lower the exposure time and the lower the dose delivered. In the UV system used at Hoover Dam, the UVT was fixed at the beginning of the experiment as UVT of 94%. The dose recorded from the display of the treatment unit is based on this UVT and on the input from the on-line flow meter on the raw water system treated. Therefore the dose displayed by the treatment unit changed only due to change in volume of water treated. When the volume of water decreased, the average delivered dose increased and that number was displayed on the UV system control screen.

Between May and November 2012 the actual UVT as measured with the handheld UVT meter consistently fell below the pre-set value (Fig.3).

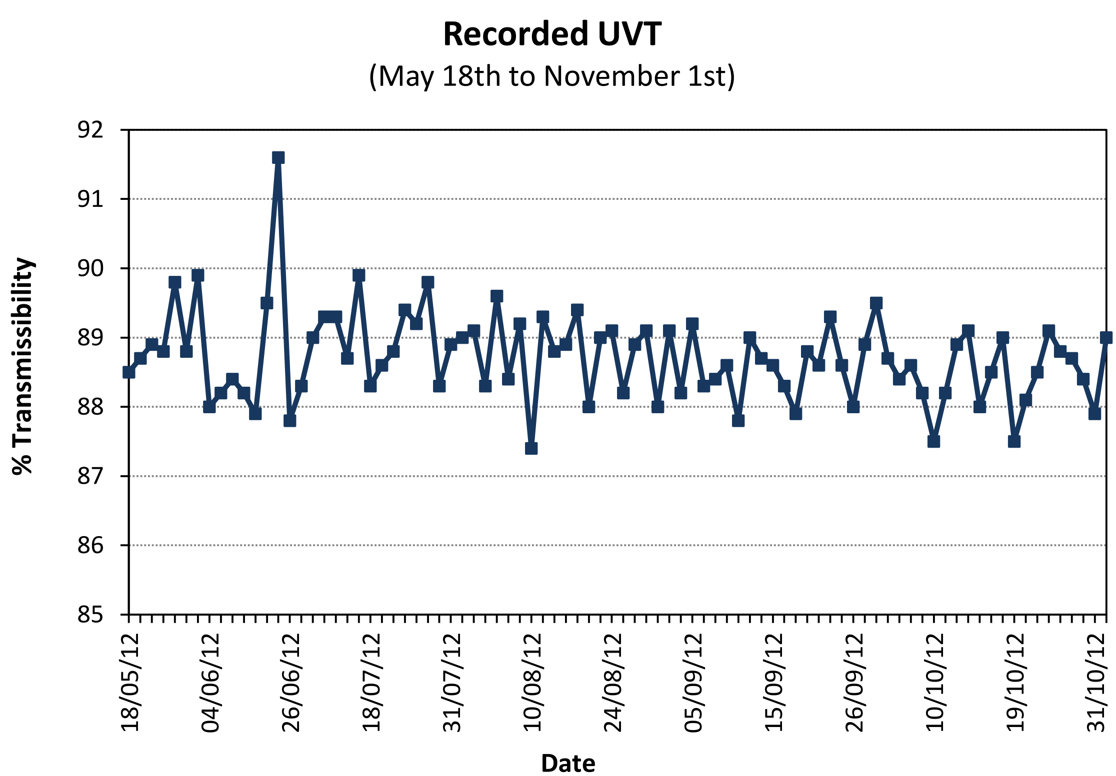

Fig.3 UV transmissibility between May and November

Using the above transmissibility data we corrected the average dose delivered during the experiment (based on the previously discussed parameters) and compared it to the dose that was displayed by the UV unit (based on 94% transmissibility, see Fig.4). The average dose delivered was corrected using dose curves provided by the UV equipment manufacturer. The curves show the estimated dose delivered by the UV unit under different conditions of flow and UVT (Appendix B). Appendix A contains raw data collected during the experiment as well as the corrected dose based on actual UVT measurements taken and the dose curves provided by the manufacturer.

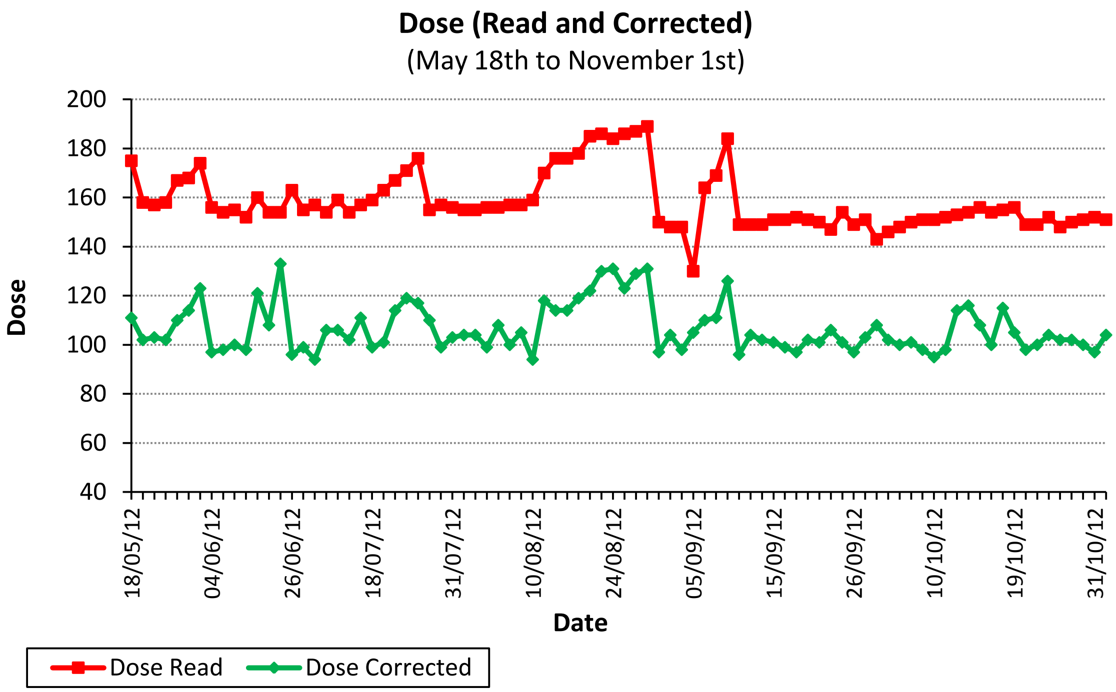

Fig.4 Displayed vs. Corrected Dose.

While the displayed dose delivered fluctuated from a minimum of 130 mW-s/cm² to a maximum of 189 mW-s/cm², the corrected dose based on the measured UVT was as low as 94 mW-s/cm² and as high as 133 mW-s/cm². However, the majority of the time the corrected dose hovered around 100 mW-s/cm².

3.2 Power Consumption

The evaluation period was a total of 168 days (May 18 to Nov 1, 2012). During the evaluation period the average flow rate was 963 gpm (219m^3/hr). The total volume of water treated was recorded as 8.82 x 10^5 cubic meters. However, there was a period of approximately 1 week where the UV system shut itself down automatically as the lamps had reached their operating hours expiration time. The total flow above includes this outage for volume of water treated but not for energy consumption. The recorded energy use was 42,000 kWhr. For future comparison purposes this translates to 4.76 kWh/100m^3 (18 kWh/100,000 gallons). This value is an underestimate of the required treatment energy due to the unanticipated lamp shut down. Based on the nominal power use by the lamps of 12 kW total, the energy use can be corrected to be

5.48 kWh/100m^3(20.7 kWh/100,000 gallons).Very conservatively, the unit 1 UV system at Hoover would need to run for a maximum of 9 months of the year to capture the typical time veligers are present in the water. Based on the corrected electrical consumption value the total projected electricity use for nine month would be approximately 72,000 kWh. The cost of generating electricity is 3 to 5 cents per kWh. At Hoover the wholesale price of electricity is 3.5 cents per kWh so the generating cost is likely to be closer to 3 cents. Using the generating cost, the annual operating cost for power for the Hoover unit 1 UV system would then be approximately $2160. This is a conservative estimate as the actual window of settlement in this cooling water system is likely to be shorter, perhaps as little as four to five months.

3.3 Temperature in Bioboxes

To help maximize the potential settlement in both bioboxes, two aquarium heaters were installed in each biobox. The objective was to raise the temperature in the bioboxes to 20º C (68º F). Figure 5 shows the temperatures achieved in each biobox. The flow in the bioboxes was increased as much as possible during the experiment to maximize the number of incoming veligers. At the increased flow, the aquarium heaters were not able to raise the temp in the biobox by more than one or two degrees from the ambient. However, the temperature in both bioboxes was in the region which would allow for normal growth and development of settlers.

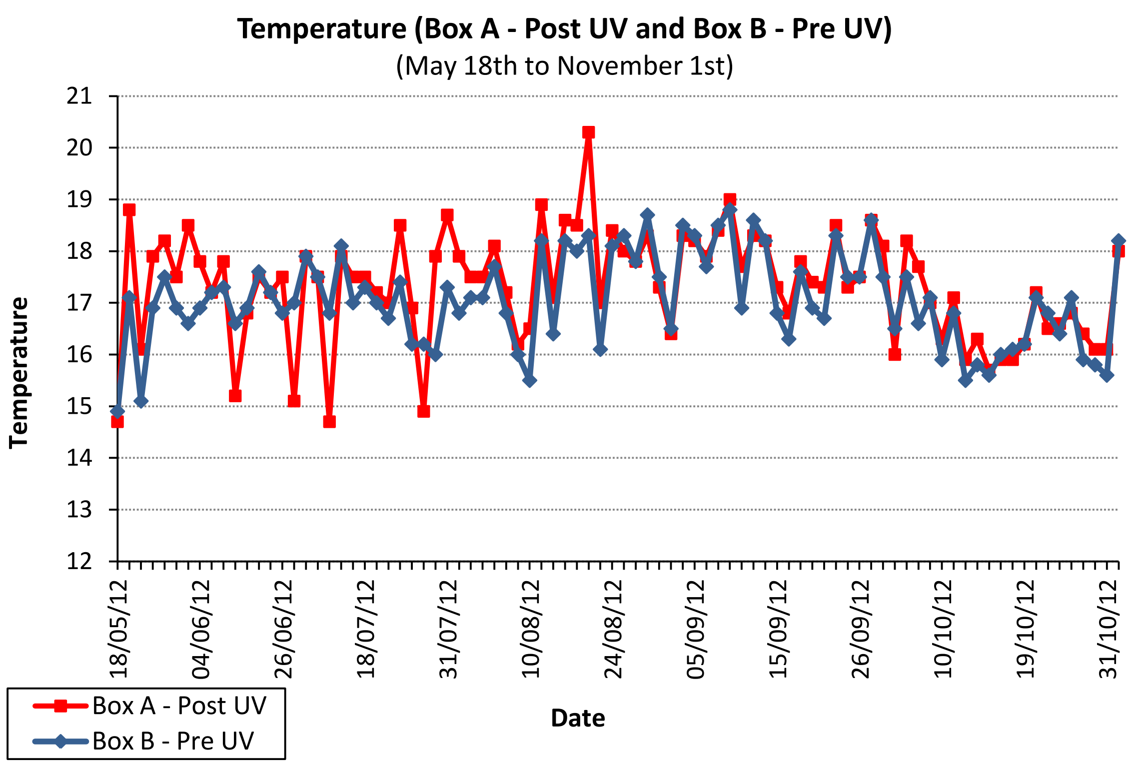

Fig.5 Temperature in bioboxes

3.4 Plankton Samples

The weekly plankton samples collected from each biobox represented the cumulative collection of plankton for each week. As the cumulative flow through each biobox was recorded at the time of each sample collection, we were able to establish the presence of veligers per volume of water for each week of the experiment (Fig.6). Only umbonal or larger veligers were counted as they represent the earliest possible stage capable of settlement. The veliger numbers recorded in both bioboxes were in the same order of magnitude. The variation between the absolute numbers recorded in each biobox was not unusual as profound variations in veliger numbers are commonly seen in field experiments. Dreissenid veligers tend to clump together in space and time rather than displaying an even distribution in the incoming water. The presence of zooplankton and phytoplankton was noted in all of the samples collected (Appendix C). However, given the huge volume of water filtered for each sample (approx.10,000 gal) the overall plankton densities were low. The lack of plankton was also noted during the collection of the plankton as plankton nets could filter water unattended for a week without plugging up.

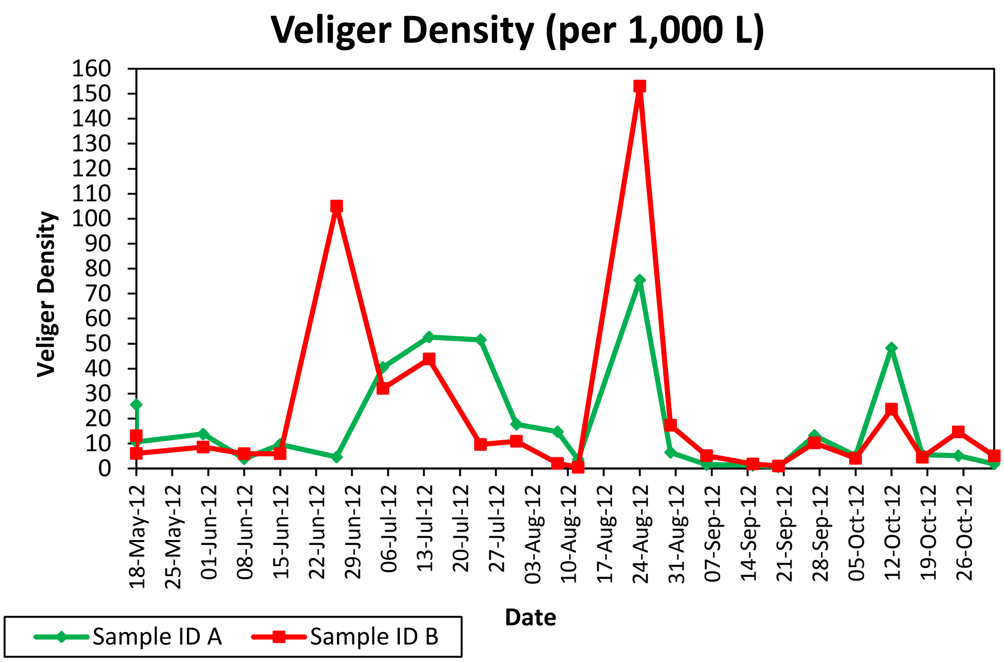

Fig.6 Number of umbonal and larger veligers passing through biobox A and B

3.5 Settlement

No settlement was detected on June 26th, 2012 in either of the bioboxes. On August 14, 2012, two settlers were found on one of the large plexiglass plates in the biobox with untreated water. No settlers were found in the biobox with UV treated water. On September 24, 2012 the settlement in the untreated biobox was 479 individuals. Most of the individuals counted were between 500 microns and 1mm in length. One individual was 2mm and one was 4mm long. There were no settlers detected in the treated biobox.

Settlement September 24th 2012					
Untreated Biobox					
		Smooth	Rough	Edge	Total
Plate 1 ABS	1	17	35	18	70
	2	15	21	2	38
	3	12	13	4	29
	4	17	15	1	33
		Side1	Side2	Edge	Total
Plate2 ABS	5	3	3	2	8
	6	25	15	2	42
	7	8	3	0	11
	8	18	26	3	47
Plate 3 Plexiglas		Wall side	Cooler	Edge	Total
	1	142	33	0	175
	2	20	6	0	26
Total					479

On November 14, 2012 the settlement in the untreated biobox was 552 individuals. This number represents cumulative settlement from August 14 to November 14, 2012 and translates to a density of approximately 50 individuals/square foot or 538/m². This density was calculated based on total settlement area examined for settlement during each monitoring event as follows:

- 4 ABS plates of type Plate 1, 6x6 inches. Both sides were counted representing 288 square inches.
- 4 ABS plates of type Plate 2, 6x6 inches Both sides were counted representing 288 square inches.
- 2 Plexiglas plates of Type Plate 3, 16x16 inches. Both sides were counted representing 1,024 square inches.
- Total surface area examined, 1600 square inches or 11.1 square feet.

Most of the individuals counted were 1mm in length. There were no settlers detected in the treated biobox.

Settlement November 14th, 2012					
		Untreated Biobox			
		Smooth	Rough	Edge	Total
Plate 1 ABS	1	18	56	16	90
	2	16	33	3	52
	3	14	18	8	40
	4	7	12	2	21
		Side1	Side2	Edge	Total
Plate2 ABS	5	6	18	3	27
	6	19	12	0	31
	7	22	16	10	48
	8	35	41	30	106
Plate 3 Plexiglas		Wall side	Cooler	Edge	Total
	1	77	45	0	122
	2	9	6	0	15
Total					552

4.0 Discussion

The Aquafine UV system performed flawlessly during the entire monitoring period. The corrected dose, although lower than anticipated, prevented the settlement of quagga mussel veligers downstream of the UV system. From the data collected during the monitoring period, an average dose of approximately 100 mW-s/cm² prevented all downstream settlement. With such a clear result, no particular statistical analysis was warranted or possible.

The original research protocol anticipated early settlement in the spring that would have allowed for repetition of this experiment every five or six weeks adding to the robustness of the observations. As early settlement did not occur, multiple repetitions of settlement observations were not possible. However, in a parallel with the work at Hoover Dam, in an experiment carried out by the authors using a proprietary UV system and similar experimental design, 99% inhibition of settlement was achieved using doses substantially lower than 100 mW-s/cm² in three separate experiments. This finding supports and strengthens the findings in this report.

In some facilities the management team may feel that absolute settlement prevention is not necessary. Many of these facilities have been dealing with some small level of macrofouling for a number of years and have concluded that their systems are not vulnerable to a small number of shells. In such instances a lower UV dose may be adequate for settlement reduction by 90% or even 85%. A lower UV dose would mean smaller UV unit, lower capital costs and lower operating costs. The use of lower dose should be tested on a system that receives a high number of veligers and therefore experiences greater settlement than observed in the current location.

Although there was a steady influx of veligers into both bioboxes, in terms of absolute numbers, the count of individuals was very low. This in itself is an important finding that was not anticipated. The minimum number recorded was 5 individuals/1,000L and the peak occurred in August with 150 individuals/1,000L. For comparison, Gerstenberger *et al.* 2011 report maximum density of veligers from the Boulder Basin in 2008/2009 season as 28,000/1,000L and a minimum density of 1,000/1,000L. These numbers reflect all veliger sizes, not just pediveligers. However, in November 2008 the authors note the highest number of pediveligers observed; 60% of all veligers counted. The authors further noted that umbonal veligers and pediveligers constituted larger proportion of all veligers from August 2008 to January 2009.

The low numbers of ready to settle veligers passing through the system were reflected in the low settlement found in the control biobox. First significant settlement was noted at the end of September, following the August peak in veliger numbers. This agrees with the findings in Gerstenberger *et al.* 2011. Some additional settlement took place between September and November translating to a seasonal cumulative settlement of 50 individuals per square foot or 500/m². Compare this settlement to that documented by Mueting *et al.* 2010 in Lake Mead. The authors recorded settlement rates from August to September 2008 as 8,062/ m² and from October to November 2008 as 28,926/ m². This would represent a cumulative settlement of 36,988/ m². This settlement is almost two orders of magnitude higher than the settlement in the UV control biobox.

The presence of zooplankton and phytoplankton was noted in all of the samples collected. However, given the huge volume of water filtered for each sample (approx.10,000 gal) the overall plankton densities were low. The lack of plankton was also noted during the collection of the plankton as plankton nets could filter water unattended for a week without plugging up.

The growth rates of settled individuals appeared very slow despite the use of aquarium heaters in the bioboxes. From September 28th to November 14, a period of almost 47 days the growth of settled individuals appears to be at best 500 microns, or approx. 10 microns per day. Maximum growth rate under favourable condition can be as high as 100 microns per day (Mackie & Claudi 2010).

The lack of ready to settle veligers in the tailrace may well be the result of the phenomenon frequently observed in long pipelines. In long pipelines most of the mussel settlement occurs in the first 300 to 500 feet with sporadic settlement thereafter. This is thought to be the result of immediate settlement of ready to settle veliger on first available substrate. It therefore likely that all ready to settle veligers which come into contact with the walls of the penstock settle, leaving only those ready to settle veligers travelling through the middle of the penstock to reach the tailrace. The veligers that have reached the tailrace have travelled through the turbines, experiencing turbulence and other stress factors. This may decrease their fitness to settle.

In addition, the pump that delivers the water from the tailrace to the cooling water system we monitored may also contribute to decreased fitness to settle of the veligers passing through that pump. To assess this possibility, an additional biobox could be installed prior to the pump. Settlement numbers could then be compared from the biobox before the pump and the biobox before the UV system. If the pump is contributing to veliger mortality or lack of fitness, the settlement numbers between the two bioboxes could be radically different.

The 2007 Vulnerability Report (Claudi and Prescott 2007) suggested the closing of all intake louvers except those closest to the bottom of Lake Mead. This suggestion was based on low veliger counts and cold water in that region. This strategy would have minimized fouling of penstocks and all other systems at Hoover Dam. The potential for losses in power production however outweighed the benefits of decreased mussel fouling at that time. The use of tailrace water for cooling loads appears to have some of the same benefits as using the deepest layer of water from Lake Mead in terms of low veliger counts. Therefore, the use of water from the tailrace is an excellent option of minimizing the impact of quagga mussels on the cooling water systems of the Hoover Dam.

Various water quality parameters for Lake Mead are available primarily from Southern Nevada Water Authority. However, the most important parameter for the performance of the UV system is the water transmissibility to UV radiation (UVT). This parameter was not available and was therefore measured weekly at the biobox containing untreated water. The UVT was generally much lower than anticipated. This has implications for any future UV systems that may be installed on the Lower Colorado River as their design will have to take into account the low UVT values.

5.0 Conclusions

UV treatment of raw water with a continuous average dose of 100 mW-s/cm^2 appears to prevent all downstream settlement of quagga mussel veligers at the Hoover Dam cooling water circuit of Unit A1. This finding is supported by concurrent UV experiments carried out by the authors in 2012, using proprietary UV technology and similar experimental design.

The cooling water obtained from the tailrace appears to have very low numbers of ready to settle veligers.

6.0 Recommendations

Given the low density of settlement, the use of water from the tailrace is an excellent option for minimizing the impact of quagga mussels on the cooling water systems of the Hoover Dam. Additionally, the use of water from the tailrace rather than from the penstock would eliminate the transport of shells into the cooling water system from the penstock. Completion of year-long veliger monitoring in the tailrace water started during this monitoring effort would be beneficial to confirm the presence and quantity of veligers present. Continued monitoring of settlement in the installed bioboxes is also recommended provided the UV system continues to operate.

The use of lower UV dose should be tested on a system that receives a high number of veligers and therefore experiences greater settlement than observed in the current location. UV dose values for inhibition of 90% and 85% of settlement should be established to minimize future capital and operating costs of UV systems.

Installation of a biobox before and after the pump to evaluate settlement would help to determine if the pump is affecting downstream settlement of veligers

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8.0 Appendices

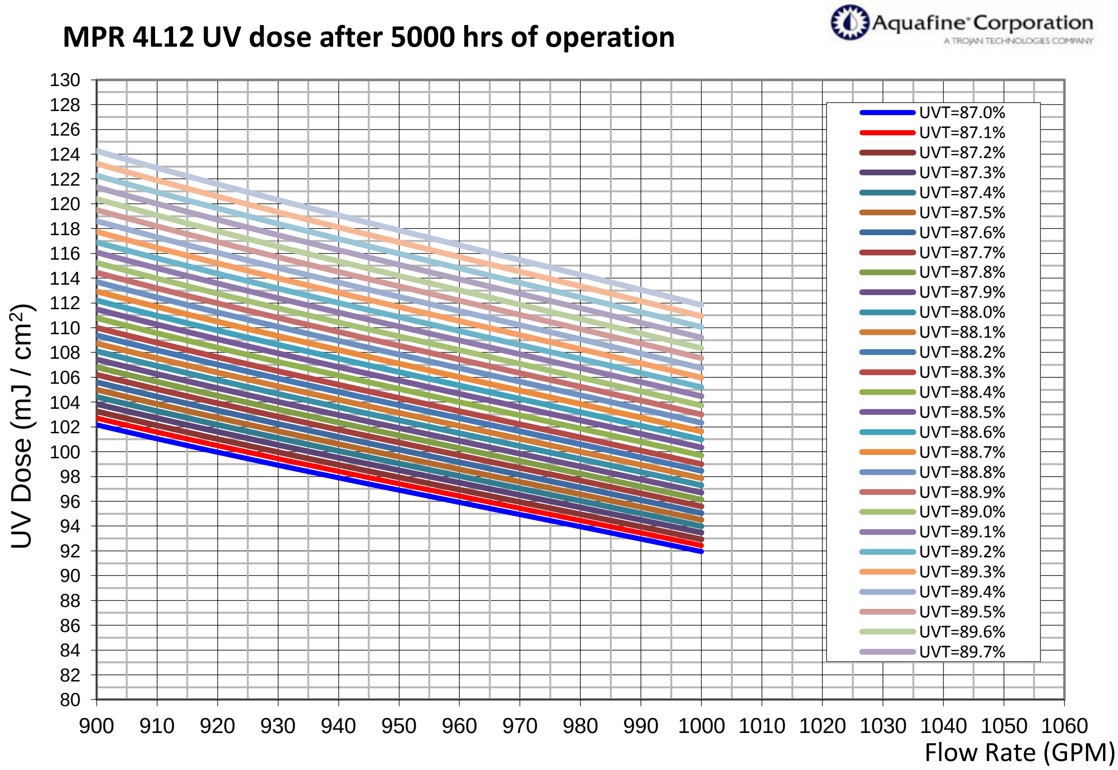
8.1 Appendix A: Raw Data

		UV System					Box A - Post UV	Box B - Pre UV
Date	Flow	kW/hrs	Intensity	Dose	UVT	Corrected Dose	Temp A	Temp B
18/05/12	882	360.0	2,781	175	88.5	111	14.7	14.9
24/05/12	988	1,085.3	2,821	158	88.7	102	18.8	17.1
25/05/12	983	1,201.5	2,797	157	88.9	103	16.1	15.1
29/05/12	980	1,709.9	2,499	158	88.8	102	17.9	16.9
30/05/12	954	1,830.9	2,876	167	89.8	110	18.2	17.5
31/05/12	945	1,955.6	2,886	168	88.8	114	17.5	16.9
01/06/12	915	2,074.3	2,878	174	89.9	123	18.5	16.6
04/06/12	1,025	2,448.5	2,894	156	88.0	97	17.8	16.9
05/06/12	1,036	2,576.9	2,894	154	88.2	98	17.2	17.2
06/06/12	1,036	2,699.5	2,894	155	88.4	100	17.8	17.3
08/06/12	1,048	2,943.9	2,886	152	88.2	98	15.2	16.6
12/06/12	849	3,412.1	2,878	160	87.9	121	16.8	16.9
13/06/12	1,000	3,564.6	2,898	154	89.5	108	17.5	17.6
14/06/12	1,000	3,686.3	2,878	154	91.6	133	17.2	17.2
26/06/12	970	5,134.3	2,853	163	87.8	96	17.5	16.8
29/06/12	1,020	5,514.6	2,861	155	88.3	99	15.1	17.0
02/07/12	1,050	5,886.4	2,861	157	89.0	94	17.9	17.9
05/07/12	1,024	6,262.9	2,853	154	89.3	106	17.5	17.5
06/07/12	994	6,361.4	2,853	159	89.3	106	14.7	16.8
16/07/12	1,012	7,626.8	2,837	154	88.7	102	17.9	18.1
17/07/12	997	7,740.7	2,821	157	89.9	111	17.5	17.0
18/07/12	988	7,871.1	2,837	159	88.3	99	17.5	17.3
19/07/12	969	7,981.5	2,831	163	88.6	101	17.2	17.0
20/07/12	934	8,099.2	2,829	167	88.8	114	17.0	16.7
23/07/12	915	8,496.9	2,837	171	89.4	119	18.5	17.4
24/07/12	886	8,606.5	2,813	176	89.2	117	16.9	16.2
27/07/12	1,000	8,979.0	2,797	155	89.8	110	14.9	16.2
30/07/12	993	9,341.3	2,813	157	88.3	99	17.9	16.0
31/07/12	1,000	9,469.5	2,829	156	88.9	103	18.7	17.3
01/08/12	998	9,588.6	2,797	155	89.0	104	17.9	16.8
02/08/12	1,003	9,716.7	2,829	155	89.1	104	17.5	17.1
03/08/12	1,002	9,833.5	2,821	156	88.3	99	17.5	17.1
08/08/12	983	10,448.7	2,789	157	88.4	100	17.2	16.8
09/08/12	985	10,578.2	2,797	157	89.2	105	16.2	16.0
10/08/12	969	10,680.7	2,789	159	87.4	94	16.5	15.5

		UV System					Box A - Post UV	Box B - Pre UV
Date	Flow	kW/hrs	Intensity	Dose	UVT	Corrected Dose	Temp A	Temp B
13/08/12	917	11,072.1	2,813	170	89.3	118	18.9	18.2
15/08/12	880	11,314.9	2,781	176	88.8	114	17.1	16.4
16/08/12	877	11,441.9	2,789	176	88.9	114	18.6	18.2
17/08/12	864	11,565.3	2,772	178	89.4	119	18.5	18.0
21/08/12	829	12,050.8	2,772	185	88.0	122	20.3	18.3
22/08/12	816	12,168.1	2,748	186	89.0	130	17.0	16.1
24/08/12	833	12,428.4	2,764	184	89.1	131	18.4	18.1
27/08/12	835	12,808.5	2,764	186	88.2	123	18.0	18.3
28/08/12	811	12,924.8	2,748	187	88.9	129	17.8	17.8
29/08/12	801	13,051.0	2,732	189	89.1	131	18.3	18.7
30/08/12	1,024	13,169.9	2,764	150	88.0	97	17.3	17.5
31/08/12	1,026	13,293.1	2,748	148	89.1	104	16.4	16.5
04/09/12	1,031	13,792.3	2,764	148	88.2	98	18.3	18.5
05/09/12	1,014	13,906.3	2,756	130	89.2	105	18.2	18.3
06/09/12	927	14,029.2	2,748	164	88.3	110	17.9	17.7
07/09/12	901	14,150.9	2,756	169	88.4	111	18.4	18.5
10/09/12	811	14,522.7	2,708	184	88.6	126	19.0	18.8
11/09/12	1,012	14,649.4	2,724	149	87.8	96	17.7	16.9
12/09/12	1,015	14,772.4	2,748	149	89.0	104	18.3	18.6
13/09/12	1,017	14,895.9	2,740	149	88.7	102	18.2	18.2
15/09/12	997	15,130.4	2,724	151	88.6	101	17.3	16.8
17/09/12	998	15,384.7	2,724	151	88.3	99	16.8	16.3
18/09/12	996	15,508.7	2,732	152	87.9	97	17.8	17.6
19/09/12	996	15,631.2	2,716	151	88.8	102	17.4	16.9
20/09/12	997	15,751.4	2,708	150	88.6	101	17.3	16.7
21/09/12	1,030	15,888.6	2,732	147	89.3	106	18.5	18.3
25/09/12	974	16,373.6	2,708	154	88.6	101	17.3	17.5
26/09/12	1,001	16,494.6	2,708	149	88.0	97	17.5	17.5
27/09/12	989	16,614.0	2,708	151	88.9	103	18.6	18.6
01/10/12	997	17,111.0	2,587	143	89.5	108	18.1	17.5
02/10/12	985	17,228.8	2,603	146	88.7	102	16.0	16.5
03/10/12	990	17,350.1	2,635	148	88.4	100	18.2	17.5
04/10/12	962	17,472.2	2,619	150	88.6	101	17.7	16.6
05/10/12	966	17,596.6	2,635	151	88.2	98	17.0	17.1
10/10/12	959	18,211.4	2,627	151	87.5	95	16.3	15.9
11/10/12	955	18,344.8	2,635	152	88.2	98	17.1	16.8
12/10/12	949	18,437.3	2,635	153	88.9	114	15.9	15.5

Date	Flow	UV System kW/hrs	Intensity	Dose	UVT	Corrected Dose	Box A - Post UV Temp A	Box B - Pre UV Temp B
15/10/12	946	18,826.5	2,635	154	89.1	116	16.3	15.8
16/10/12	934	18,949.8	2,635	156	88.0	108	15.7	15.6
17/10/12	952	19,074.9	2,651	154	88.5	100	15.9	16.0
18.10/12	940	19,194.0	2,643	155	89.0	115	15.9	16.1
19/10/12	931	19,305.1	2,635	156	87.5	105	16.2	16.2
22/10/12	974	19,687.2	2,627	149	88.1	98	17.2	17.1
24/10/12	983	19,935.8	2,651	149	88.5	100	16.5	16.8
25/10/12	967	20,055.8	2,651	152	89.1	104	16.6	16.4
26/10/12	988	20,179.8	2,643	148	88.8	102	16.8	17.1
29/10/12	968	20,550.0	2,627	150	88.7	102	16.4	15.9
30/10/12	961	20,671.6	2,627	151	88.4	100	16.1	15.8
31/10/12	960	20,793.9	2,635	152	87.9	97	16.1	15.6
01/11/12	971	20,905.9	2,659	151	89.0	104	18.0	18.2
Average Flow	**963**							

8.2 Appendix B: UVT Dose Curves after 5000 hours of lamp operation



8.3 Appendix C: Plankton and Veliger Data

Sample ID	Collection Date	Volume filtered (Gallon)	Volume sample (ml)	AVG veligers (umbo and pedi only)	Veligers density (L)	Veliger density (1000 L)	Phyto-plankton present	Zooplankton present
1A	18-May-12	5,887.1	150	3.80	0.026	25.55	Yes	Yes
1B	18-May-12	8,712.7	150	2.90	0.013	13.17	Yes	Yes
2A	25-May-12	8,894.4	150	2.40	0.011	10.68	Yes	Yes
2B	25-May-12	9,185.6	150	1.40	0.006	6.03	Yes	Yes
3A	31-May-12	17,202.0	150	6.00	0.014	13.80	Yes	Yes
3B	31-May-12	17,500.0	150	3.80	0.009	8.59	Yes	Yes
4A	08-Jun-12	24,354.9	150	2.40	0.004	3.90	Yes	Yes
4B	08-Jun-12	23,897.3	150	3.60	0.006	5.96	Yes	Yes
5A	15-Jun-12	30,325.4	150	7.40	0.010	9.66	Yes	Yes
5B	15-Jun-12	30,515.6	150	4.60	0.006	5.97	Yes	Yes
6A	26-Jun-12	41,449.6	150	4.80	0.005	4.58	Yes	Yes
6B	26-Jun-12	42,828.5	150	113.67	0.105	105.04	Yes	Yes
7A	05-Jul-12	52,205.0	120	66.78	0.040	40.50	Yes	Yes
7B	05-Jul-12	54,370.6	120	55.11	0.032	32.09	Yes	Yes
8A	14-Jul-12	62,779.1	120	104.33	0.053	52.62	Yes	Yes
8B	14-Jul-12	67,142.9	120	93.00	0.044	43.86	Yes	Yes
9A	24-Jul-12	78,220.3	120	127.33	0.052	51.54	Yes	Yes
9B	24-Jul-12	76,600.4	120	23.33	0.010	9.64	Yes	Yes
10A	31-Jul-12	87,019.7	120	48.67	0.018	17.71	Yes	Yes
10B	31-Jul-12	82,045.2	120	28.33	0.011	10.93	Yes	Yes
11A	08-Aug-12	98,255.0	120	45.67	0.015	14.72	Yes	Yes
11B	08-Aug-12	88,625.8	120	5.75	0.002	2.05	Yes	Yes
12A	12-Aug-12	104,336.9	120	12.00	0.004	3.64	Yes	Yes
12B	12-Aug-12	92,267.2	120	1.50	0.001	0.51	Yes	Yes
13A	24-Aug-12	113,353.2	120	270.00	0.075	75.42	Yes	Yes
13B	24-Aug-12	99,915.2	120	483.00	0.153	153.06	Yes	Yes
14A	30-Aug-12	120,695.5	120	24.67	0.006	6.47	Yes	Yes
14B	30-Aug-12	105,508.2	120	57.67	0.017	17.31	Yes	Yes
15A	6-Sep-12	128,007.0	120	6.33	0.002	1.57	Yes	Yes
15B	6-Sep-12	112,369.0	120	18.33	0.005	5.17	Yes	Yes
16A	15-Sep-12	137,769.9	120	5.67	0.001	1.30	Yes	Yes
16B	15-Sep-12	120,025.3	120	7.00	0.002	1.85	Yes	Yes
17A	20-Sep-12	143,486.9	120	3.00	0.001	0.66	Yes	Yes
17B	20-Sep-12	124,629.6	120	4.00	0.001	1.02	Yes	Yes

Sample ID	Collection Date	Volume filtered (Gallon)	Volume sample (ml)	AVG veligers (umbo and pedi only)	Veligers density (L)	Veliger density (1000 L)	Phyto-plankton present	Zooplankton present
18A	27-Sep-12	151,377.4	120	63.33	0.013	13.25	Yes	Yes
18B	27-Sep-12	131,598.2	120	42.67	0.010	10.27	Yes	Yes
19A	05-Oct-12	161,242.8	120	26.00	0.005	5.11	Yes	Yes
19B	05-Oct-12	139,297.4	120	18.00	0.004091	4.09	Yes	Yes
20A	12-Oct-12	171,306.7	120	261.00	0.048240	48.24	Yes	Yes
20B	12-Oct-12	147,943.3	120	111.00	0.023756	23.76	Yes	Yes
21A	18-Oct-12	181,323.9	120	31.67	0.005530	5.53	Yes	Yes
21B	18-Oct-12	156,002.9	120	22.33	0.004533	4.53	Yes	Yes
22A	25-Oct-12	191,744.2	120	31.00	0.005119	5.12	Yes	Yes
22B	25-Oct-12	169,974.6	120	78.67	0.014654	14.65	Yes	Yes
23A	01-Nov-12	203,618.2	120	12.00	0.001866	1.87	Yes	Yes
23B	01-Nov-12	183,174.7	120	29.33	0.005070	5.07	Yes	Yes

Average Volume filtered:	**Gallons**
Sample ID 'A'	100,645.9
Sample ID 'B'	90,614.4