RNT CONSULTING INC

Atlantium Technologies Medium Pressure UV Dose Required for Minimizing Downstream Settlement of Quagga 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 waterways, rivers, and lakes on the Eastern portion of the continent. These mussels are extremely prolific and can result in costly problems to industry by attaching to and clogging virtually all types of underwater infrastructure such as water intakes, trashracks, pipes, fire control systems, cooling water systems and fish screens.

Since 2007, quagga mussels have been present in the lower Colorado River. The mussel populations have exploded 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, dreissenid mussels are present in Texas, Kansas, Nebraska, and Oklahoma and have been detected in New Mexico, and Utah. Flow restrictions due to mussel infestation are the foremost concern because they threaten 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 in industrial cooling water systems.

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 in the Great Lakes Basin 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 would inhibit downstream settlement of dreissenids veligers if the veligers were exposed to a radiation dose of approximately 100 mW-s/cm².

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/cm². 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 an Aquafine medium pressure UV system (2 lamps X 12.5kW each) in late 2010 to protect a relatively small cooling water circuit (880gpm) 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 (total of 4 lamps X 12.5kW each, for treating 880gpm). Monitoring of the system performance carried out from May to November 14, 2012 confirmed that no settlement occurred downstream of the

UV system which was delivering a dose of approximately 100 mW-s/cm² (Claudi and Prescott 2013).

In parallel with the work at Hoover Dam, an experiment carried out by the authors on the Lower Colorado River 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.

Management teams in many facilities feel that absolute settlement prevention is not necessary and therefore finding a UV dose that would result in settlement reduction by 90%, 85% and 70% was considered desirable. If a lower than 100 mW-s/cm² UV dose would adequately protect the cooling water, lower capital costs and lower operating costs would be achieved.

Davis Dam had installed a full sized medium pressure UV system from Atlantium Technologies to protect all of the cooling water (total flow of total flow of 3550gpm) on power generating Unit 3. Part of the purpose for the installation was to finding the minimum UV dose required for the above mentioned settlement reduction. Davis Dam management agreed to allow the UV system to be adjusted so as to deliver various levels of UV irradiation. This in turn allowed for evaluation of downstream quagga veliger settlement after exposure to various UV doses. Results of this study are described in the following report.

2.0 Methodology

2.1 Experimental Set-up

A full sized Atlantium HOD (Hydro-Optic Disinfection system was installed in the cooling water piping of Unit 3 at Davis Dam (Fig.1). The installed unit contained six medium pressure UV lamps with maximum power of 4.2kW each. The unit was capable of automatic modulation of the lamp output (25%-100% of lamp power) to deliver the desired dose.

Fig.1 Atlantium HOD Installation at Davis Dam

Two bioboxes were installed on the cooling water system. Biobox 1 received raw water from upstream of the UV unit, biobox 2 received water that had passed through the UV unit. Biobox 3 (previously installed) received water from the cooling water system after it had passed Unit 3 cooling water for oil cooler in the turbine ring, approximately five minutes after it was irradiated. Each biobox was equipped with 3 large settling plates placed perpendicular to the flow (approx.14 x 11.25 inches) and 4 small settling plates placed parallel to the flow (approx. 6x6 inches) as shown in Fig.2. All the bioboxes were covered with black plastic to eliminate ambient light during the study.

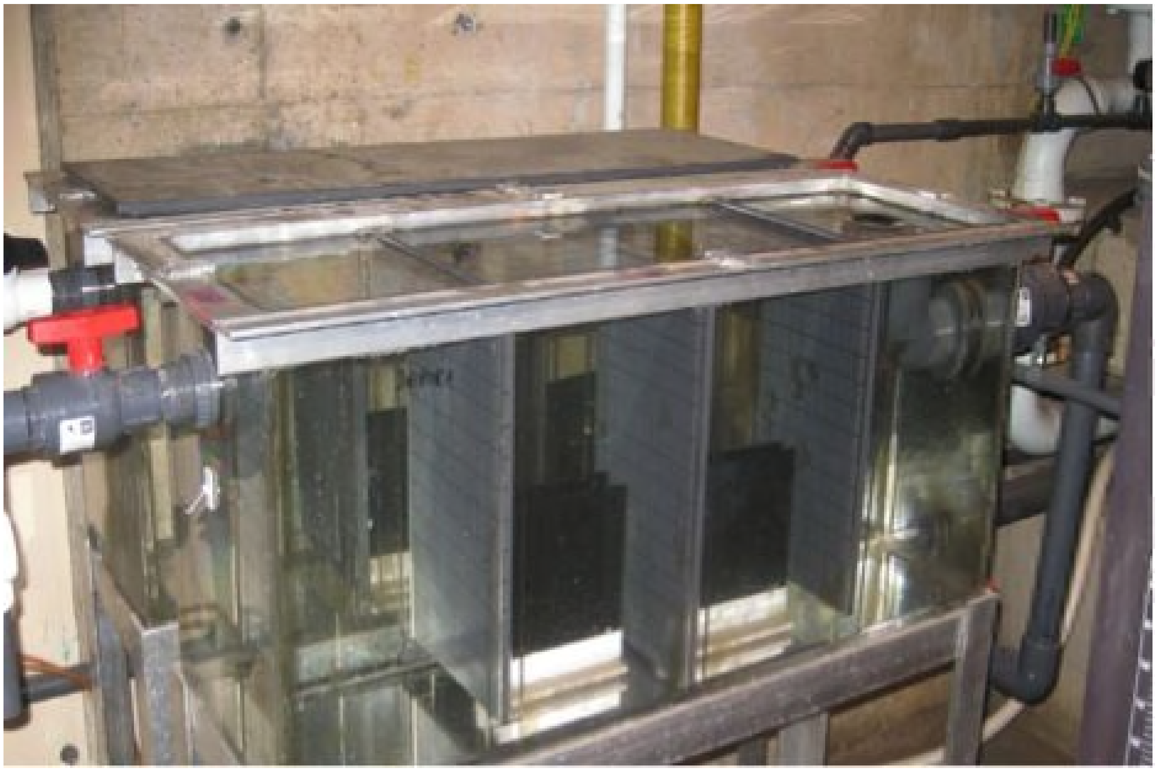


Fig.2 Monitoring bioboxes 1 and 2 with settlement plates

The water flow into Biobox 1 and 2 was monitored with flow totalizers to determine the flow into each biobox and the total volume of water that flowed through each biobox in-between monitoring events.

The UV system and the associated bioboxes were observed during five sequential experimental cycles (Table 1).

Table 1 The start and finish dates of each experimental cycle and dose delivered

Cycle	Start Date	End Date	UV Dose mW-s/cm²	Time (# of days)
1	6 June 2013	10 July 2013	50	35
2	11 July 2013	12 Aug 2013	40	33
3	13 Aug 2013	17 Sept 2013	20	36
4	18 Sept 2013	28 Oct 2013	40	41
5	29 Oct 2013	19 Nov 2013	40	21

2.2 Monitoring of Veliger Presence in Biobox 1 and Biobox 2

Plankton sample of 80 litres (approx. 21 US gallons) was collected from the outflow of biobox 1 and another from biobox 2 each week. The method of sample collection was slightly different during Cycle 1 than during the other four cycles. During Cycle 1 the plankton samples were collected through the outlet piping which drains water from the top portion of the biobox. After

Cycle 1, plankton samples were collected from a port located almost at the bottom of each biobox through permanently attached rubber hoses. Each hose was placed in the dedicated plankton net suspended over a drain. Both hoses were turned on at the same time and kept flowing for predetermined time period based on flow to collect 80 litres of raw water through a dedicated 63 micron plankton net. The resulting samples were collected into pre-labeled sample jars. Each sample was preserved with buffered grain alcohol (EverClear). In the laboratory, each sample was poured and rinsed into an Imhoff settling cone. The sample was given 24 hours to settle and the bottom 15 mL was retained in a 15 mL conical tube. Four 1mL replicate samples were examined using a Sedgwick-Rafter cell. Each subsample was examined using an American Optical compound scope equipped with a polarizer using 25x magnification. All veligers present were counted in each subsample.

2.3 Monitoring of Environmental Variables

Each week the flow into each biobox was equalized so that approximately the same volume of water passed through each biobox. At that time the water temperature was checked in each biobox as was pH, dissolved oxygen and conductivity.

UVT reading was taken using water from biobox 1 containing untreated water. The UVT readings were taken using Real Tech handheld UVT meter. The UVT meter was calibrated prior to each use using distilled water. The UVT reading from the Atlantium control panel was recorded at the same time.

2.4 Power Consumption of the UV System at Various Dose Levels

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 during each treatment cycle.

2.5 Monitoring of Settlement

At the end of each experimental cycle, the settlement in bioboxes 1, 2 and 3 was visually evaluated. The settlement plates were removed and any individual mussel greater than 500 microns was counted. Note was made of any individuals larger than 6mm. These individuals were considered translocators from upstream locations. This was based on maximum potential growth rate of the individuals being 1mm/week. This growth rate is higher than that reported by Wong et.al 2011 for Lake Mead is therefore considered very conservative. Given this growth rate, 6mm and greater individuals could not have reached their size by settling as pediveligers in the biobox during the 5 week cycle. The total settlement surface monitored was:

a) four 6 x 6 inch plates counted on both sides = 288 square inches (2 ft^2)
b) three 14 x 11.25 plates monitored on both sides = 944 square inches (6.56 ft^2)

The edges of the settling plates were not counted.

3.0 Results

3.1 Dose Delivered

The Atlantium HOD system is engineered to deliver the desired UV dose regardless of changes in the water transmissibility (UVT) or decline in performance of the UV lamps. This ability rests on the presence of two separate UV intensity sensors present in the reaction vessel. These sensors automatically adjust the output of the UV lamps to compensate for increased or decreased transmissibility and for decreased lamp performance due to age. The system tracks UVT values continuously and displays and stores the data.

Between June and November 2013 UVT was measured weekly with a handheld UVT meter and recorded. The UVT value displayed by the Atlantium unit was recorded at the same time (Fig.3). The hand recorded transmissibility fluctuated between 88.5 and 90.4.

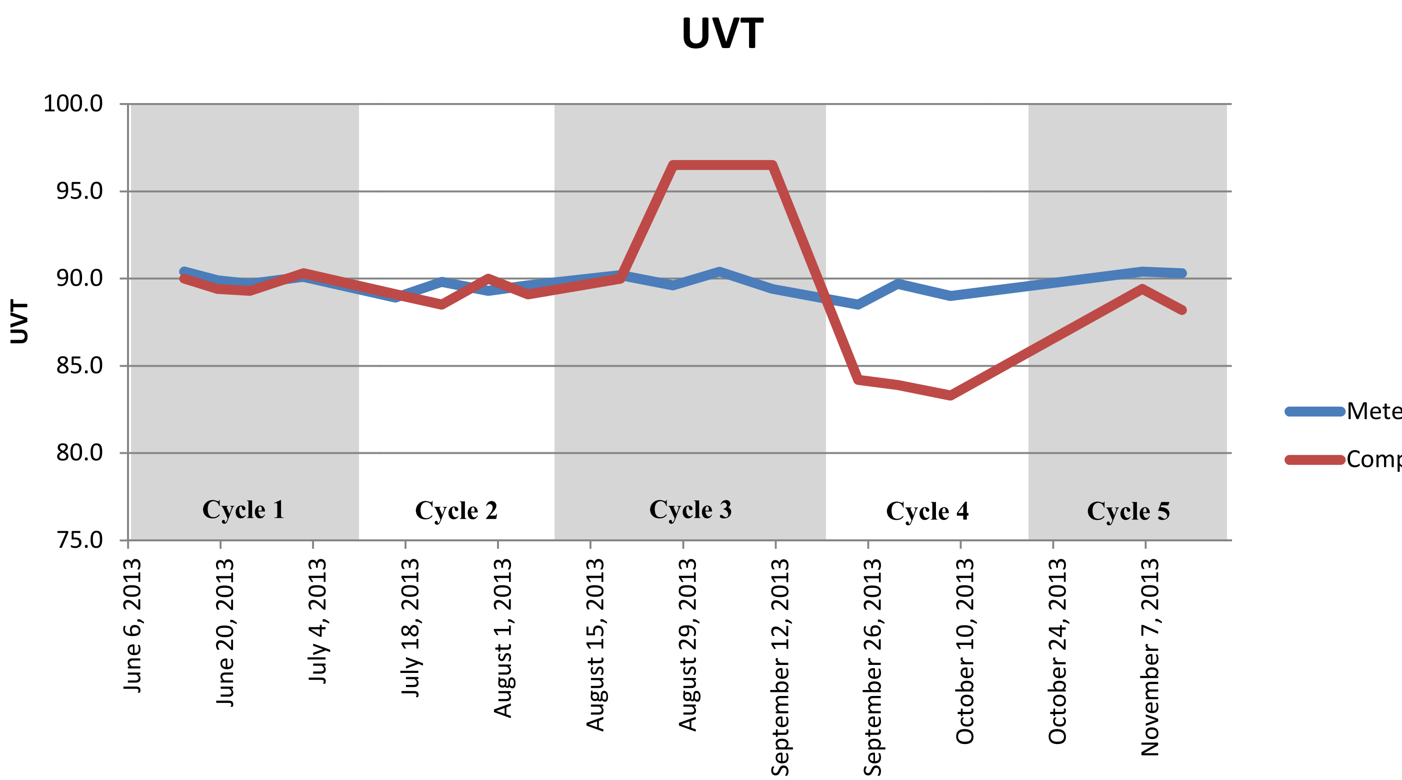


Fig.3 UV transmissibility between June and November

During Cycle 3, a technician performing maintenance on the system inadvertently calibrated the Atlantium system with an incorrect UVT reading of 96.5. Normally this would have resulted in a dose lower than desired, however, since the minimum power modulation of the Atlantium unit is 25% of the lamp power, the actual delivered dose to the water was as planned for cycle 3 (20 mW-s/cm²). This was verified by calculating the actual delivered dose from the data stored by the system. During Cycle 4 and 5, the sensor which corrects the dose delivered within the Atlantium system must have become fouled and the system perceived lower UV transmissibility than was measured by the hand instrument. This has resulted in higher dose being delivered by the system than desired. This increase in dose is reflected in increased electrical power consumption.

3.2 Power Consumption

The power recording meter was installed on July 30, 2013 and therefore was not available for Cycle 1 and part of Cycle 2. The energy consumption was recorded during the one cycle at 20 mW-s/cm² and the three cycles at 40 mW-s/cm². The energy and flow data are reported in Table 2 below.

Table 2 Power consumption during various dose levels

Cycle	Start Date	End Date	UV Dose mJ	Time Days	Total Flow*** 100 m^3	Cumulative Energy Use kWh	Energy used in interval kWh	Energy used per 100 m^3 kWh	Energy 100,000 kWh
1	6/6/2013	7/10/2013	50	35	6678				
2*	7/11/2013	8/12/2013	40	14.75	2814	5127	5127	1.82	6.90
3	8/13/2013	9/17/2013	20	36	6869	12770	7643	1.11	4.21
4	9/17/2013	10/30/2013	40	43.5	8300	33454	20684	2.49	9.43
5**	10/30/2013	11/6/2013	40	7.2	1374	36063	2609	1.90	7.19
5	11/7/2013	11/12/2013	40	5.8	1107	38405	2342	2.12	8.01

* Power Meter was turned on July 30th, recorded Aug 14th
** Unit continued to run until Nov 19
*** Based on a flow rate of 13250 L/min

At the 20 mW-s/cm² dose level the energy use translates to 1.11 kWh/100m^3 (4.21 kWh/100,000 gallons). Conservatively, a unit UV system at Davis would need to run for a maximum of 11 months of the year allowing for a one month annual outage. The UV unit may run for a shorter period if there are very few veligers present in the raw water; possibly January and February. Based on the electrical consumption value the total projected electricity use for eleven months would be approximately 65,000 kWh. Using a generating cost for electricity of 3 cents per kWh, the annual operating cost for power for a UV system protecting the cooling water of one Davis Dam unit would be approximately $1,950.

At the 40 mW-s/cm² dose level, energy readings were taken during three separate cycles. It was observed that the energy use readings varied and this appeared to be related to the on board UVT instrument reading water transmissibility low as compared to the independent instrument grab samples. The effect of this was that the UV unit was dosing higher than necessary during some periods of its operation thereby using more energy. More frequent cleaning of the onboard UVT sensor would alleviate the sensor drift that results in overdosing.

The energy use at 40 mW-s/cm² is reported as a maximum and minimum, where the minimum coincides with the UVT sensor recording transmissibility readings that match the independent grab sample measurements. The energy use translates to a range of 1.82 to 2.49 kWh/100m^3 (6.90 to 9.43 kWh/100,000 gallons). Using the same annual operating base as for the 20 mW-s/cm² dose, the total projected electricity use for eleven months of UV operation at 40 mW-s/cm² would be in the range of approximately 106,000 to 145,000 kWh. This electricity use to protect the cooling water of one Davis Dam unit would have an annual cost of $3,150 to $4,350.

3.3 Environmental Parameters in Bioboxes

All the raw data collected on Temperature, pH, DO, conductivity and flow are available in Appendices 7.1 & 7.2. Dissolved oxygen (Fig. 4) and conductivity (Fig. 5) did not vary among the bioboxes. The temperature (Fig. 6) and pH (Fig. 7) in the bioboxes varied seasonally, but all bioboxes experienced the same regime. Although the flow through the bioboxes was adjusted weekly, biobox 3 appears to have been receiving larger volume of flow throughout most of the study (Fig. 8).

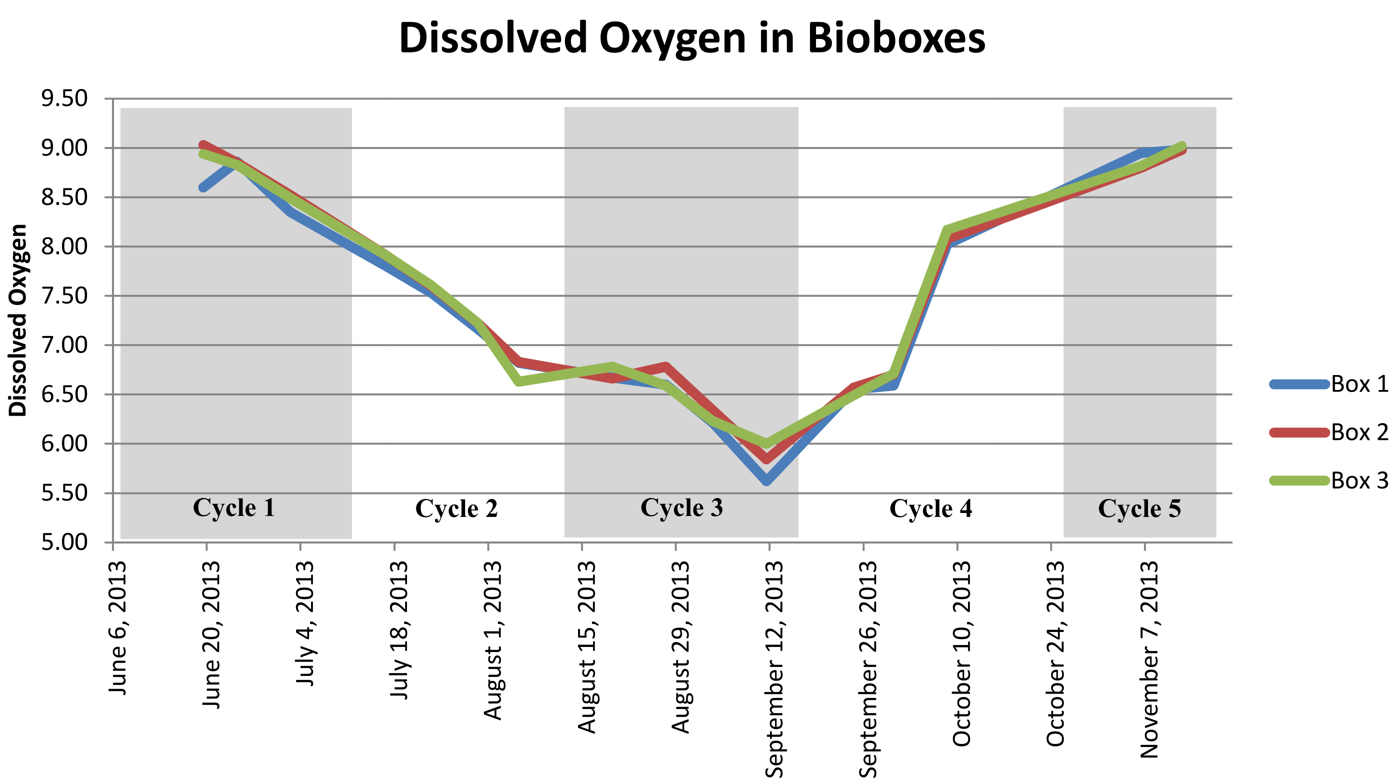


Fig.4 Dissolved Oxygen in Bioboxes

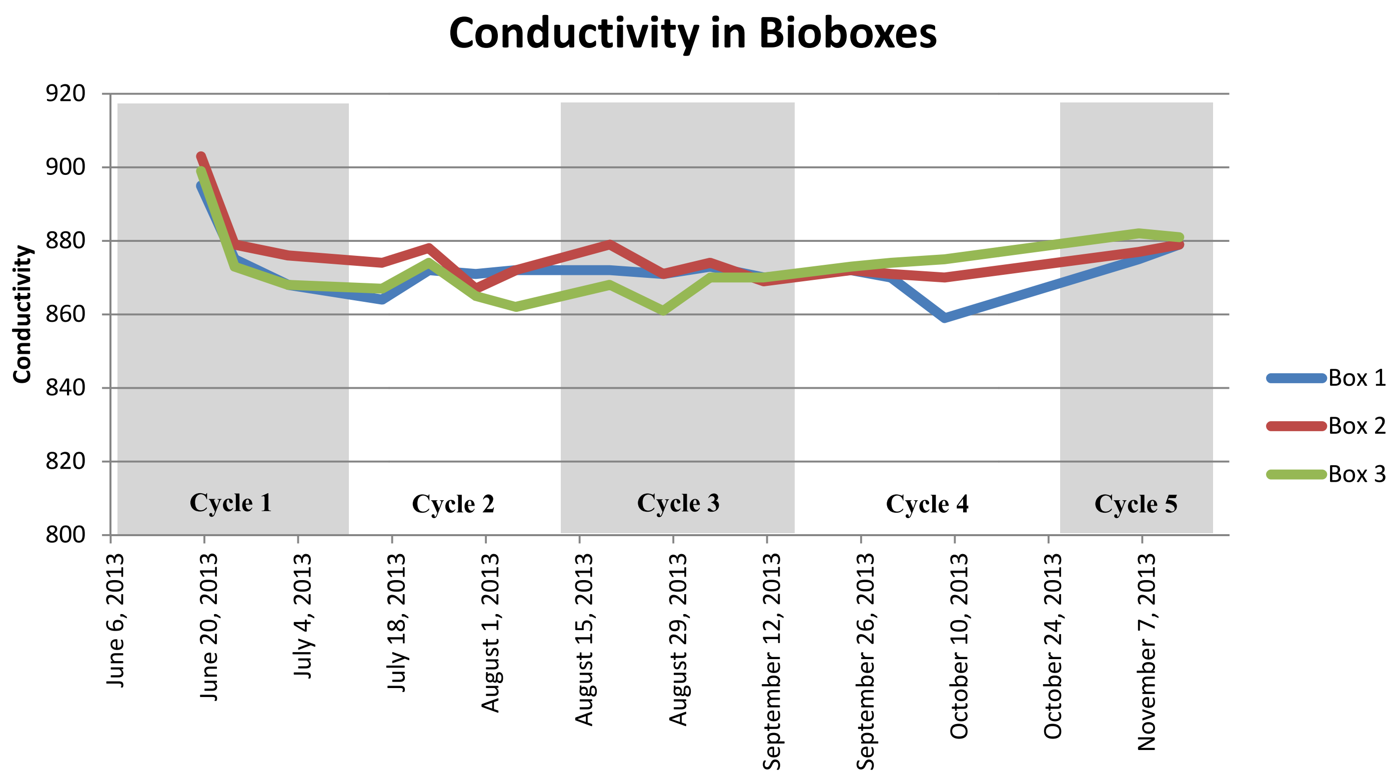


Fig. 5 Conductivity in Bioboxes

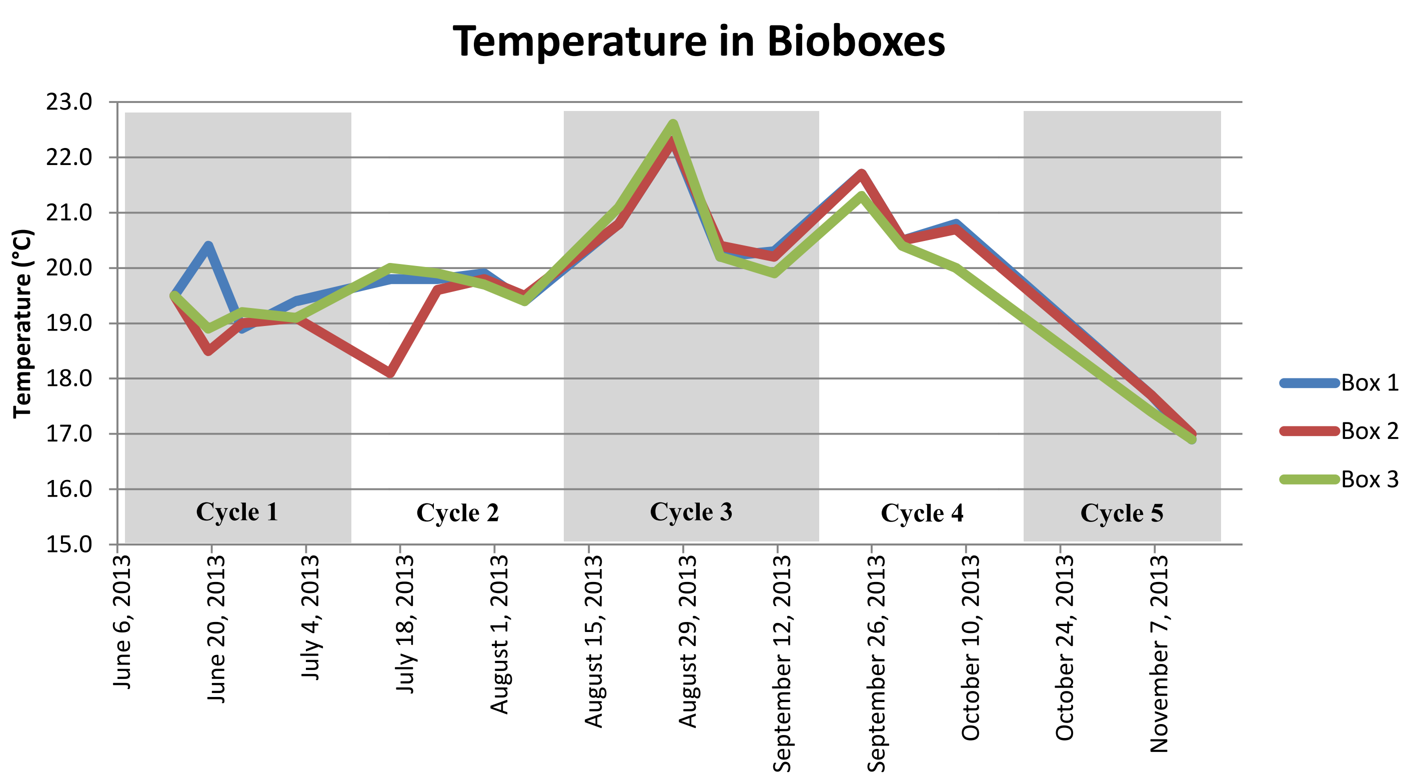


Fig.6 Temperature in Bioboxes

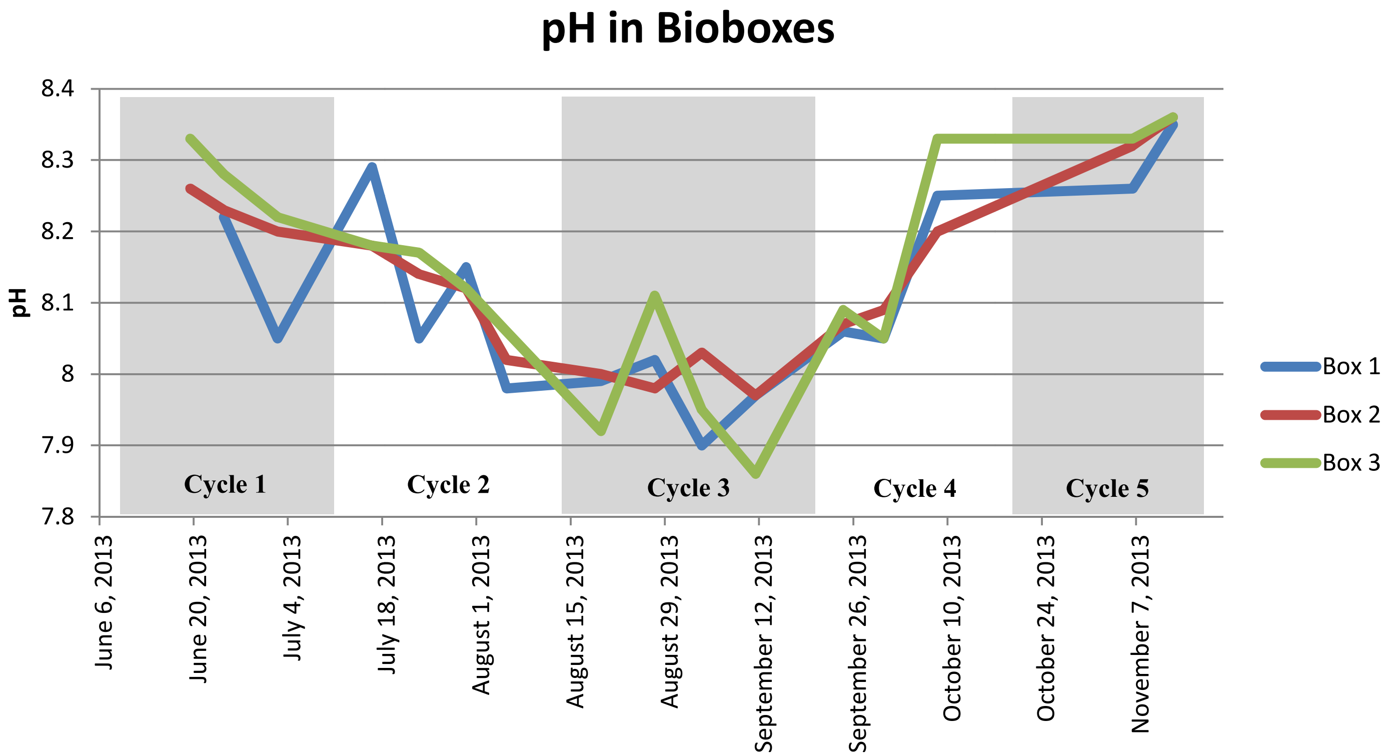


Fig.7 pH in Bioboxes

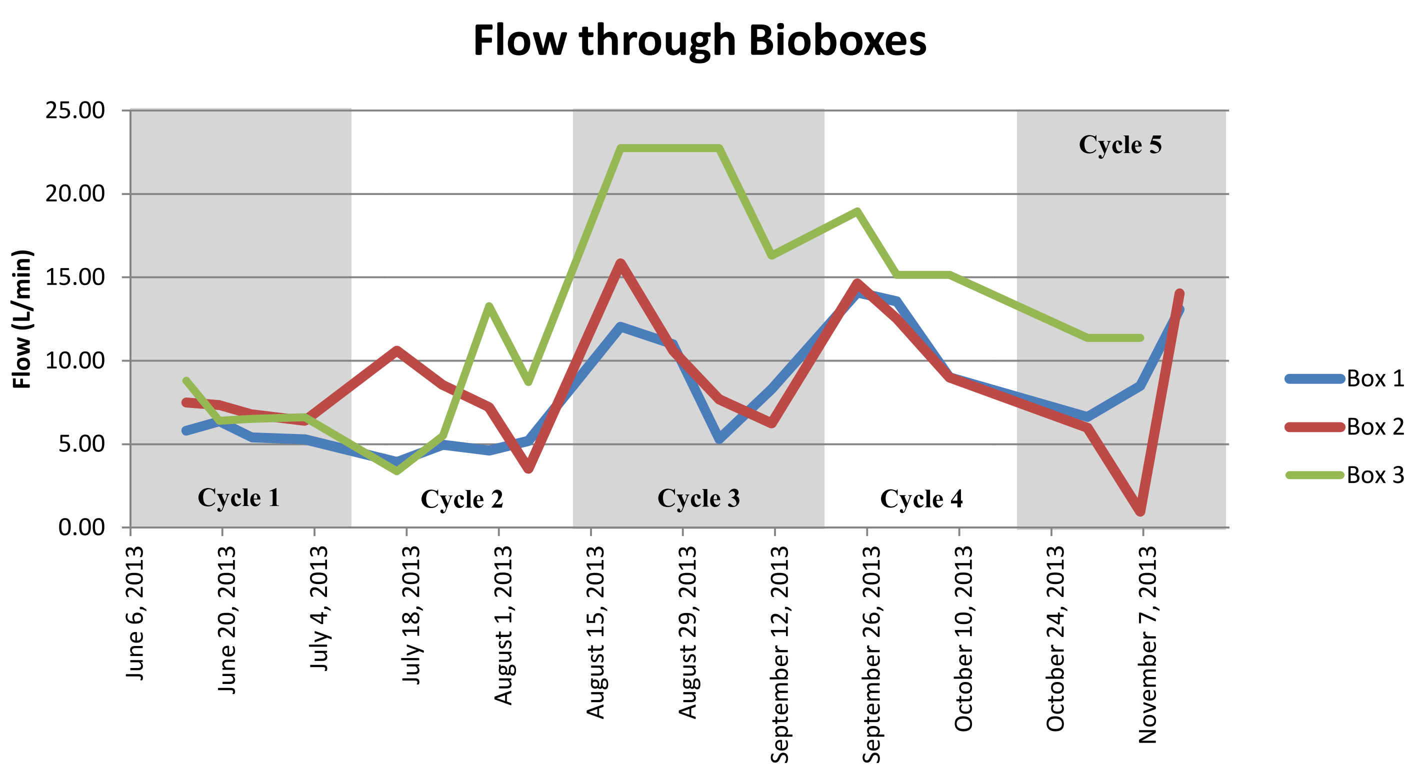


Fig. 8 Flow through Bioboxes

3.4 Plankton Samples Analysis

The weekly plankton samples collected from the outlet of biobox 1 and 2 were examined for veliger presence to verify that veligers were in fact coming into each biobox in adequate numbers to settle (Fig.9). Raw data is available in Appendix 7.3.

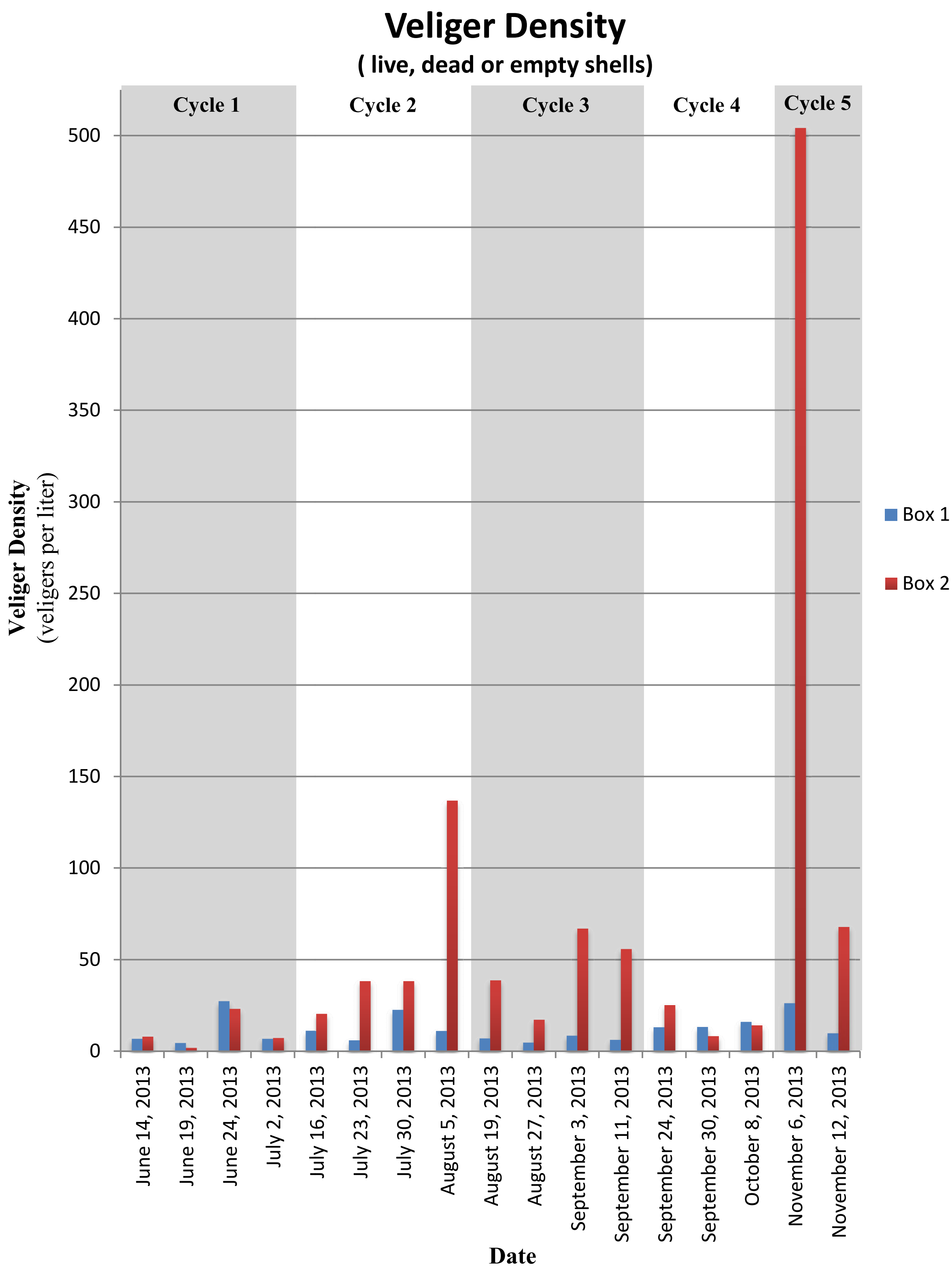


Fig.9 Veligers per liter

In almost all instances, the number of veligers found in the plankton sample taken at the outlet of the treated biobox, biobox 2, was greater than the number of veligers found in the equivalent sample taken at the outlet of biobox 1 which was the untreated control. There were two exceptions to this observation. First was in samples collected during Cycle 1 which, as described in Section 2.2, employed a slightly different collection method. The second exception was during Cycle 4. During this period, the authors observed that a large proportion of the incoming veligers were in fact dead while the overall veliger numbers were low.

A paired t-test was used to test the null hypothesis of zero difference between before and after UV veliger densities (Whitlock et al. 2009). We found that there was a significant effect of treatment on veliger densities per liter since $p < 0.01$ (R 2012). The mean effect of treatment was an increase of 25 veligers per liter, with a 95% confidence interval from 9 to 40 veligers per liter.

In order to conduct the paired t-test, we excluded the results from Cycle 1 due to different sampling methodology. In order to achieve normality, we also removed two outliers which had extremely high veliger counts (August 5th and November 6th), leaving $n = 11$ and a Shapiro-Wilk normality test with $p = 0.201$, therefore normally distributed data (Crawley 2007).

We can only speculate that the reason for the greater number of veligers in the outlet of the treated biobox is related to the instantaneous mortality of some of the veligers passing though the UV system. The instantaneous death phenomena while passing through UV lights was observed by the authors in a related study. It is possible that dead veligers/empty shells were sinking to the bottom of the treated biobox where they accumulated in-between plankton sampling events.

3.5 Total Settlement

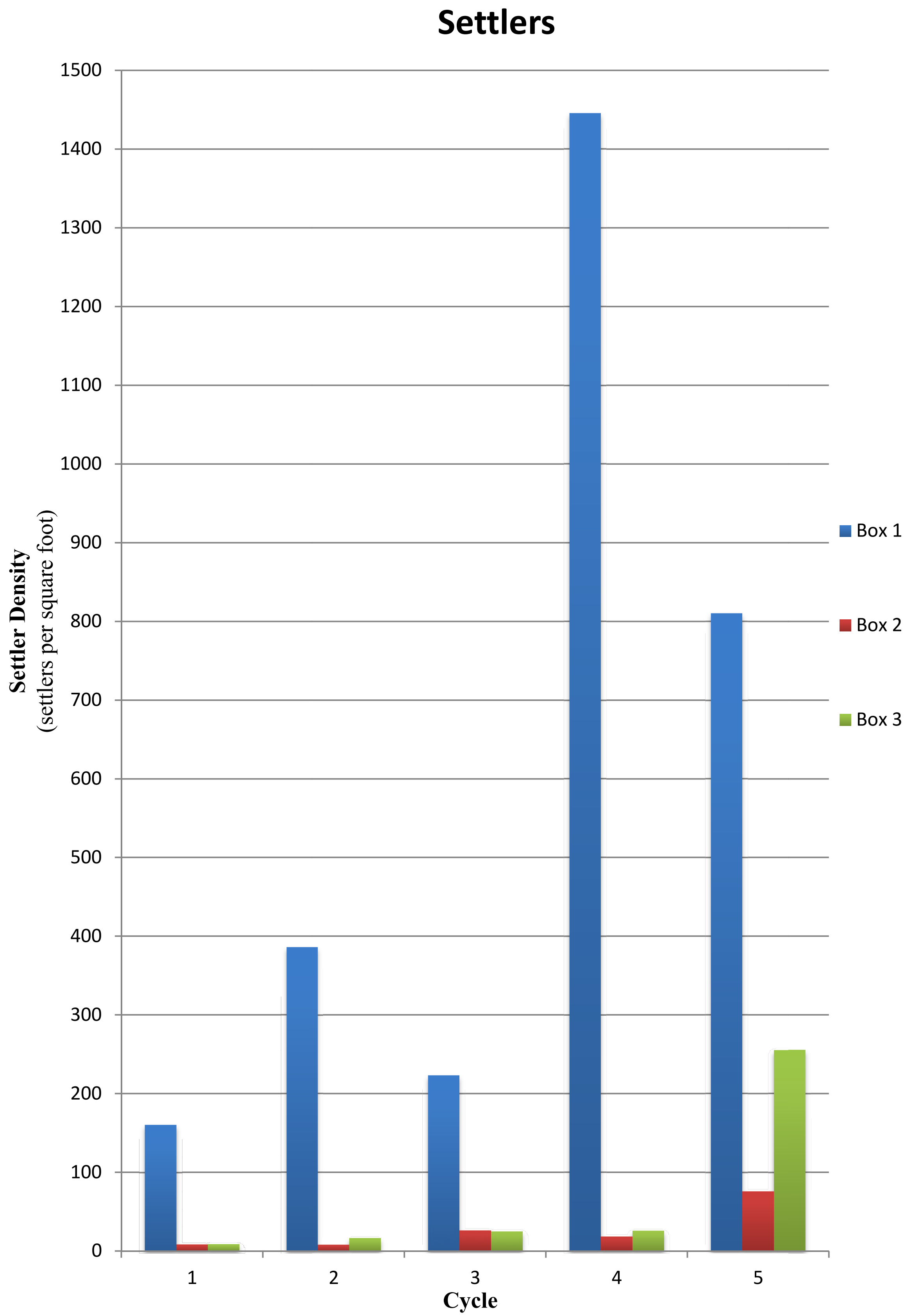
New mussel settlement was observed during each of the cycles. Mussel settlement numbers in the control were vastly different from those in the treated water bioboxes (Fig.10). The raw data is contained in Appendix 7.4.

There did not appear to be great differences in settlement reduction at the different UV dose levels (Table 3). Seasonally, the same dose level of 40 mW-s/cm² appeared to be less effective in November than in July and September.

Table 3 Total settlement of mussels per square foot, including percent reductions

Cycle	**UV**	**Settlers**			**% Reduction**		
		Box 1	Box 2	Box 3	Box 1 to 2	Box 1 to 3	Box 1 to Average of 2 and 3
1	50	160	8	9	95%	94%	95%
2	40	386	8	16	98%	96%	97%
3	20	223	26	25	88%	89%	89%
4	40	1445	18	26	99%	98%	98%
5	40	810	76	255	91%	68%	80%

Fig. 10 Mussel Settlement



3.6 Translocator Settlement

During the first cycle we noted few translocators in biobox 1, none in biobox 2 and two in biobox 3. We separated the translocators from the total settlement counts to get a sense of the effect a UV dose may have on translocating adults. Table 4 shows the actual number of translocators found in each biobox rather than densities, as the actual number of translocators tends to be very small.

Table 4 Translocators, including percent reductions

Cycle	**UV**	**Translocators**			**% Reduction**		
		Box 1	Box 2	Box 3	Box 1 to 2	Box 1 to 3	Box 1 to Average of 2 and 3
1	50	4	0	2	100%	50%	75%
2	40	30	0	3	100%	90%	95%
3	20	347	0	23	100%	93%	97%
4	40	190	10	36	95%	81%	88%
5	40	57	40	28	30%	51%	40%

4.0 Discussion

During Cycle 3, a technician performing maintenance on the system inadvertently calibrated the Atlantium system with an incorrect UVT reading of 96.5. Normally this would have resulted in a dose lower than desired, however, since the minimum power modulation of the Atlantium unit is 25% of the lamp power, the actual delivered dose to the water was as planned for cycle 3 which was 20 mW-s/cm². This was verified by calculating the actual delivered dose from the data stored by the system.

The Atlantium HOD Unit has the capability to automatically compensate for loss of performance in aging UV lamps and to compensate for changes in UV transmissibility. Unfortunately the sensor which tracks UV transmissibility can be fouled by the raw water as occurred in Cycle 4 (Fig. 3). The fouling of the sensor leads to the HOD unit increasing power to compensate for the perceived loss of transmissibility and therefore the delivery of higher UV dose than anticipated. This is not likely to cause any operational problems other than slight increase in power consumption by the UV unit. This is in fact reflected in the power consumption calculation in Section 3.2

By tracking the power consumption at the different UV dose levels we can estimate that at 40 mW-s/cm² UV dose electricity use to protect the cooling water of one Davis Dam unit would have an annual cost of $3,150 to $4,350. At a dose of 20 mW-s/cm² the annual operating cost for power for a UV system protecting the cooling water of one Davis Dam would be approximately $1,950. At either dose level the cost of power for preventative treatment of unit cooling water is very modest for the high degree of settlement control achieved.

None of the environmental variables tracked in the bioboxes are likely to interfere with the settlement of mussels.

As expected, the absolute number of incoming veligers varied widely throughout the various cycles. We did observe that although the absolute number of veligers in September was high, the number of live veligers in the raw water was about 20%. The rest were either dead individuals or empty shells. This observation was made by the authors during an unrelated study at Davis Dam. We hypothesize that this high veliger mortality was due to high ambient water temperature in the shallower parts of Lake Mohave. The excessively high temperatures were not reflected in the bioboxes as they were receiving cooling water from deeper depth and well mixed during intake.

Another observation of note was the consistently higher numbers of veligers collected from the outflow of the treated biobox 2 as compared to those collected from the biobox 1 (control). We counted the total numbers of veligers present and did not distinguish empty shells or dead individuals from the total count. Therefore we can only hypothesize that the sample collected from Biobox 2 contained greater number of dead veliger or empty shells which had sunken to the bottom, accumulated near the outlet of the biobox and were collected during the weekly sampling of the bioboxes. This hypothesis would also support the likelihood of increased immediate mortality of veligers when they are exposed to UV light.

Settlement was greatly inhibited at each of the dose levels tested. The lowest settlement inhibition was observed at the 20 mW-s/cm². There was an 88% reduction in settlement after the UV dose. This was an unexpected result given the generally accepted settlement prevention threshold of 100 mW-s/cm². Further, it would appear that translocators were also affected even at this dose, showing a 100% reduction in biobox 2 and a 93% reduction in biobox 3. Biobox 3 was downstream of piping that was already colonized by quagga mussel prior to the start-up of the UV system. It is difficult to determine if the translocators in biobox 3 originated in the piping between the UV unit and the biobox or if they came in from outside the dam. The absence of translocators in biobox 2 suggests that the former scenario is more likely.

The slightly less successful results for settlement prevention during Cycle 5 may have several reasons. The power Units was shut down for maintenance on November 19th. During the shutdown, the flow of cooling water may surge periodically dislodging individual mussels from upstream location. Also, biobox 1 and 2 were closed immediately after the UV system was shutdown, it is not certain when biobox 3 was closed down. Given these uncertainties, the results from Cycle 5 need to be interpreted with caution.

Following the restart of Unit 1 we were able to observe the amount of shell debris collected by strainer baskets downstream of the UV unit (Fig.11 & Fig.12). The amount of shell debris collected was modest despite the fact that the UV system was only started up on June 6, 2013. This meant that settlement of approximately four months (February to May) was already present in the cooling water pipes.

The mechanical maintenance personnel agreed that the amount of debris was far less than normally observed in the strainer baskets and provided Fig.13 for comparison. The picture was taken following a start up of another Davis power unit, one not protected by UV.

Fig.11 Strainer basket from upper turbine bearing cooling water supply on Unit 1 immediately following start up, with UV protection

Fig,12 Strainer basket from lower bearing cooling water supply on Unit 1 immediately following start up, with UV protection

Fig.13 Strainer basket from upper turbine bearing cooling water supply immediately following start up, without UV protection

5.0 Conclusions

The Atlantium HOD Unit was successful at preventing majority of primary quagga settlement at all levels tested. There also appeared to be an effect of the UV lights on secondary settlement, the translocators. Translocators appeared to be partially prevented from settling once they were exposed to the UV lights.

At the lowest dose tested, 20 mW-s/cm² , we had exceeded the minimum requested control level of 75% settlement inhibition. Due to the current configuration of the UV system we could not decrease the UV dose any further. Given the successful control achieved at 20 mW-s/cm², it would be desirable to repeat this dose level for several cycles to verify the results.

Although the Atlantium HOD system was extremely successful at settlement prevention even at very low UV doses, it is not possible to conclude that similar success would be achieved using traditional medium pressure UV systems without testing them under similar circumstances.

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7.0 Appendices

7.1 Environmental Data

Date	Cycle	Box	Temp	pH	DO	Conductivity	Flow (L/min)
June 14, 2013	1	1	19.5	NA	NA	NA	5.80
June 14, 2013	1	2	19.5	NA	NA	NA	7.50
June 14, 2013	1	3	19.5	NA	NA	NA	8.80
June 19, 2013	1	1	20.4	7.73	8.60	895	6.37
June 19, 2013	1	2	18.5	8.26	9.03	903	7.35
June 19, 2013	1	3	18.9	8.33	8.94	899	6.40
June 24, 2013	1	1	18.9	8.22	8.86	875	5.40
June 24, 2013	1	2	19.0	8.23	8.85	879	6.79
June 24, 2013	1	3	19.2	8.28	8.83	873	6.51
July 2, 2013	1	1	19.4	8.05	8.35	868	5.30
July 2, 2013	1	2	19.1	8.20	8.52	876	6.41
July 2, 2013	1	3	19.1	8.22	8.49	868	6.62
July 16, 2013	2	1	19.8	8.29	7.81	864	3.92
July 16, 2013	2	2	18.1	8.18	7.92	874	10.60
July 16, 2013	2	3	20.0	8.18	7.92	867	3.37
July 23, 2013	2	1	19.8	8.05	7.53	872	4.96
July 23, 2013	2	2	19.6	8.14	7.60	878	8.53
July 23, 2013	2	3	19.9	8.17	7.61	874	5.50
July 30, 2013	2	1	19.9	8.15	7.16	871	4.62
July 30, 2013	2	2	19.8	8.12	7.22	867	7.20
July 30, 2013	2	3	19.7	8.12	7.22	865	13.27
August 5, 2013	2	1	19.4	7.98	6.82	872	5.19
August 5, 2013	2	2	19.5	8.02	6.83	872	3.52
August 5, 2013	2	3	19.4	8.06	6.63	862	8.72
August 19, 2013	3	1	20.8	7.99	6.67	872	12.05
August 19, 2013	3	2	20.8	8.00	6.66	879	15.84
August 19, 2013	3	3	21.1	7.92	6.78	868	22.74
August 27, 2013	3	1	22.3	8.02	6.60	871	10.99
August 27, 2013	3	2	22.3	7.98	6.78	871	10.61
August 27, 2013	3	3	22.6	8.11	6.59	861	22.74
September 3, 2013	3	1	20.2	7.90	6.21	873	5.31
September 3, 2013	3	2	20.4	8.03	6.34	874	7.69
September 3, 2013	3	3	20.2	7.95	6.23	870	22.74
September 11, 2013	3	1	20.3	7.97	5.62	870	8.30
September 11, 2013	3	2	20.2	7.97	5.84	869	6.25
September 11, 2013	3	3	19.9	7.86	6.00	870	16.30
September 24, 2013	4	1	21.7	8.06	6.55	872	14.10
September 24, 2013	4	2	21.7	8.07	6.57	872	14.63
September 24, 2013	4	3	21.3	8.09	6.49	873	18.95
September 30, 2013	4	1	20.5	8.05	6.59	870	13.56
September 30, 2013	4	2	20.5	8.09	6.70	871	12.51

September 30, 2013	4	3	20.4	8.05	6.71	874	15.16
October 8, 2013	4	1	20.8	8.25	8.02	859	9.01
October 8, 2013	4	2	20.7	8.20	8.08	870	8.99
October 8, 2013	4	3	20.0	8.33	8.17	875	15.16
October 29, 2013	5	1					6.63
October 29, 2013	5	2					5.99
November 6, 2013	5	1	17.7	8.26	8.95	875	8.49
November 6, 2013	5	2	17.7	8.32	8.80	877	0.96
November 6, 2013	5	3	17.4	8.33	8.82	882	11.37
November 12, 2013	5	1	16.9	8.35	8.98	879	13.08
November 12, 2013	5	2	17.0	8.36	8.98	879	14.04
November 12, 2013	5	3	16.9	8.36	9.02	881	11.37

7.2 UVT and Flow rates for each cycle

Date	Cycle	Meter UVT	Computer UVT	Flow (gpm)
June 14, 2013	1	90.4	90.0	3495
June 19, 2013	1	89.9	89.4	3492
June 24, 2013	1	89.7	89.3	3495
July 2, 2013	1	90.1	90.3	3539
July 16, 2013	2	88.9	89.1	3539
July 23, 2013	2	89.8	88.5	3536
July 30, 2013	2	89.3	90.0	3538
August 5, 2013	2	89.6	89.1	3535
August 19, 2013	3	90.2	90.0	3509
August 27, 2013	3	89.6	96.5	3544
September 3, 2013	3	90.4	96.5	3556
September 11, 2013	3	89.4	96.5	3512
September 24, 2013	4	88.5	84.2	3454
September 30, 2013	4	89.7	83.9	3430
October 8, 2013	4	89.0	83.3	3209
November 6, 2013	5	90.4	89.4	3372
November 12, 2013	5	90.3	88.2	3340

7.3 Veliger Count Data and Average Veliger Density per Liter

Date	Box 1					Box 2				
	Slide 1	Slide 2	Slide 3	Slide 4	Average Density per L	Slide 1	Slide 2	Slide 3	Slide 4	Average Density per L
13-06-14	28	41	37	43	7	34	56	55	28	8
13-06-19	23	24	16	35	5	9	14	8	12	2
13-06-24	111	136	171	166	27	136	120	84	152	23
13-07-02	31	46	39	34	7	37	38	42	39	7
13-07-16	32	50	73	83	11	106	119	106	109	21
13-07-23	24	27	28	48	6	161	199	257	200	38
13-07-30	154	134	106	90	23	154	246	238	180	38
13-08-05	81	63	42	54	11	860	655	670	735	137
13-08-19	32	28	48	44	7	176	222	206	224	39
13-08-27	25	25	34	18	5	68	91	85	125	17
13-09-03	35	47	51	52	9	305	351	439	335	67
13-09-11	31	25	39	41	6	230	259	318	382	56
13-09-24	64	68	78	67	13	110	85	267	74	25
13-09-30	51	52	61	116	13	74	46	29	25	8
13-10-08	77	70	61	136	16	78	68	87	70	14
13-11-06	142	153	143	124	26	2410	2690	2950	2710	504
13-11-12	49	61	60	40	10	554	268	354	275	68

7.4 Raw Settlement and Translocation Data

Cycle	UV	Box	Plate	Type	Side	Settlers	Translocators
1	50	1	1	Big	Inlet	332	1
1	50	1	1	Big	Outlet	127	0
1	50	1	2	Big	Inlet	80	0
1	50	1	2	Big	Outlet	60	0
1	50	1	3	Big	Inlet	133	0
1	50	1	3	Big	Outlet	74	1
1	50	1	1	Small	Smooth	66	0
1	50	1	1	Small	Rough	46	0
1	50	1	2	Small	Smooth	97	0
1	50	1	2	Small	Rough	124	1
1	50	1	3	Small	Smooth	64	0
1	50	1	3	Small	Rough	75	0
1	50	1	4	Small	Smooth	46	0
1	50	1	4	Small	Rough	48	1
1	50	2	1	Big	Inlet	2	0
1	50	2	1	Big	Outlet	8	0
1	50	2	2	Big	Inlet	8	0
1	50	2	2	Big	Outlet	9	0
1	50	2	3	Big	Inlet	3	0
1	50	2	3	Big	Outlet	4	0
1	50	2	1	Small	Smooth	16	0
1	50	2	1	Small	Rough	3	0
1	50	2	2	Small	Smooth	3	0
1	50	2	2	Small	Rough	1	0
1	50	2	3	Small	Smooth	2	0
1	50	2	3	Small	Rough	1	0
1	50	2	4	Small	Smooth	8	0
1	50	2	4	Small	Rough	3	0
1	50	3	1	Big	Inlet	29	0
1	50	3	1	Big	Outlet	5	0
1	50	3	2	Big	Inlet	4	2
1	50	3	2	Big	Outlet	1	0
1	50	3	3	Big	Inlet	0	0
1	50	3	3	Big	Outlet	0	0
1	50	3	1	Small	Smooth	18	0
1	50	3	1	Small	Rough	8	0
1	50	3	2	Small	Smooth	7	0
1	50	3	2	Small	Rough	2	0
1	50	3	3	Small	Smooth	1	0
1	50	3	3	Small	Rough	0	0
1	50	3	4	Small	Smooth	0	0
1	50	3	4	Small	Rough	1	0
2	40	1	1	Big	Inlet	225	1

2	40	1	1	Big	Outlet	181	3
2	40	1	2	Big	Inlet	805	2
2	40	1	2	Big	Outlet	349	3
2	40	1	3	Big	Inlet	92	4
2	40	1	3	Big	Outlet	115	1
2	40	1	1	Small	Smooth	143	1
2	40	1	1	Small	Rough	322	2
2	40	1	2	Small	Smooth	294	6
2	40	1	2	Small	Rough	371	1
2	40	1	3	Small	Smooth	131	3
2	40	1	3	Small	Rough	73	2
2	40	1	4	Small	Smooth	132	0
2	40	1	4	Small	Rough	75	1
2	40	2	1	Big	Inlet	1	0
2	40	2	1	Big	Outlet	0	0
2	40	2	2	Big	Inlet	5	0
2	40	2	2	Big	Outlet	11	0
2	40	2	3	Big	Inlet	9	0
2	40	2	3	Big	Outlet	7	0
2	40	2	1	Small	Smooth	3	0
2	40	2	1	Small	Rough	6	0
2	40	2	2	Small	Smooth	4	0
2	40	2	2	Small	Rough	4	0
2	40	2	3	Small	Smooth	6	0
2	40	2	3	Small	Rough	2	0
2	40	2	4	Small	Smooth	3	0
2	40	2	4	Small	Rough	7	0
2	40	3	1	Big	Inlet	16	0
2	40	3	1	Big	Outlet	18	0
2	40	3	2	Big	Inlet	41	2
2	40	3	2	Big	Outlet	15	0
2	40	3	3	Big	Inlet	6	0
2	40	3	3	Big	Outlet	7	0
2	40	3	1	Small	Smooth	6	0
2	40	3	1	Small	Rough	4	0
2	40	3	2	Small	Smooth	8	0
2	40	3	2	Small	Rough	2	1
2	40	3	3	Small	Smooth	3	0
2	40	3	3	Small	Rough	6	0
2	40	3	4	Small	Smooth	5	0
2	40	3	4	Small	Rough	4	0
3	20	1	1	Big	Inlet	16	12
3	20	1	1	Big	Outlet	46	14
3	20	1	2	Big	Inlet	501	77
3	20	1	2	Big	Outlet	256	45
3	20	1	3	Big	Inlet	81	28

3	20	1	3	Big	Outlet	107	20
3	20	1	1	Small	Smooth	131	31
3	20	1	1	Small	Rough	195	25
3	20	1	2	Small	Smooth	132	22
3	20	1	2	Small	Rough	207	30
3	20	1	3	Small	Both	134	29
3	20	1	4	Small	Smooth	58	9
3	20	1	4	Small	Rough	46	5
3	20	2	1	Big	Inlet	4	0
3	20	2	1	Big	Outlet	3	0
3	20	2	2	Big	Inlet	53	0
3	20	2	2	Big	Outlet	46	0
3	20	2	3	Big	Inlet	7	0
3	20	2	3	Big	Outlet	10	0
3	20	2	1	Small	Smooth	31	0
3	20	2	1	Small	Rough	22	0
3	20	2	2	Small	Smooth	24	0
3	20	2	2	Small	Rough	12	0
3	20	2	3	Small	Both	2	0
3	20	2	4	Small	Smooth	5	0
3	20	2	4	Small	Rough	5	0
3	20	3	1	Big	Inlet	10	0
3	20	3	1	Big	Outlet	18	2
3	20	3	2	Big	Inlet	23	0
3	20	3	2	Big	Outlet	40	2
3	20	3	3	Big	Inlet	36	3
3	20	3	3	Big	Outlet	17	0
3	20	3	1	Small	Smooth	9	4
3	20	3	1	Small	Rough	5	9
3	20	3	2	Small	Smooth	7	2
3	20	3	2	Small	Rough	6	0
3	20	3	3	Small	Smooth	7	1
3	20	3	3	Small	Rough	13	0
3	20	3	4	Small	Smooth	6	0
3	20	3	4	Small	Rough	15	0
4	40	1	1	Big	Inlet	204	6
4	40	1	1	Big	Outlet	322	7
4	40	1	2	Big	Inlet	2309	39
4	40	1	2	Big	Outlet	1681	29
4	40	1	3	Big	Inlet	1126	9
4	40	1	3	Big	Outlet	1359	14
4	40	1	1	Small	Rough	806	14
4	40	1	1	Small	Smooth	749	8
4	40	1	2	Small	Rough	952	8
4	40	1	2	Small	Smooth	611	9
4	40	1	3	Small	Rough	800	13

4	40	1	3	Small	Smooth	445	2
4	40	1	4	Small	Rough	610	18
4	40	1	4	Small	Smooth	410	14
4	40	2	1	Big	Inlet	7	0
4	40	2	1	Big	Outlet	1	2
4	40	2	2	Big	Inlet	4	1
4	40	2	2	Big	Outlet	3	0
4	40	2	3	Big	Inlet	7	0
4	40	2	3	Big	Outlet	12	0
4	40	2	1	Small	Rough	3	3
4	40	2	1	Small	Smooth	12	1
4	40	2	2	Small	Rough	17	0
4	40	2	2	Small	Smooth	5	1
4	40	2	3	Small	Rough	23	0
4	40	2	3	Small	Smooth	42	0
4	40	2	4	Small	Rough	11	0
4	40	2	4	Small	Smooth	11	2
4	40	3	1	Big	Inlet	3	0
4	40	3	1	Big	Outlet	5	2
4	40	3	2	Big	Inlet	54	14
4	40	3	2	Big	Outlet	33	6
4	40	3	3	Big	Inlet	0	0
4	40	3	3	Big	Outlet	0	0
4	40	3	1	Small	Rough	20	1
4	40	3	1	Small	Smooth	18	1
4	40	3	2	Small	Rough	17	0
4	40	3	2	Small	Smooth	11	0
4	40	3	3	Small	Rough	29	2
4	40	3	3	Small	Smooth	11	7
4	40	3	4	Small	Rough	16	2
4	40	3	4	Small	Smooth	3	1
5	40	1	1	Big	Inlet	87	0
5	40	1	1	Big	Outlet	143	0
5	40	1	2	Big	Inlet	950	0
5	40	1	2	Big	Outlet	830	22
5	40	1	3	Big	Inlet	103	6
5	40	1	3	Big	Outlet	591	19
5	40	1	1	Small	Rough	628	0
5	40	1	1	Small	Smooth	759	0
5	40	1	2	Small	Rough	688	1
5	40	1	2	Small	Smooth	569	0
5	40	1	3	Small	Rough	530	2
5	40	1	3	Small	Smooth	423	2
5	40	1	4	Small	Rough	441	4
5	40	1	4	Small	Smooth	199	1
5	40	2	1	Big	Inlet	4	1

5	40	2	1	Big	Outlet	3	1
5	40	2	2	Big	Inlet	26	1
5	40	2	2	Big	Outlet	26	1
5	40	2	3	Big	Inlet	13	3
5	40	2	3	Big	Outlet	6	5
5	40	2	1	Small	Rough	112	0
5	40	2	1	Small	Smooth	79	1
5	40	2	2	Small	Rough	47	1
5	40	2	2	Small	Smooth	32	1
5	40	2	3	Small	Rough	91	5
5	40	2	3	Small	Smooth	37	0
5	40	2	4	Small	Rough	117	12
5	40	2	4	Small	Smooth	58	8
5	40	3	1	Big	Inlet	122	6
5	40	3	1	Big	Outlet	35	7
5	40	3	2	Big	Inlet	94	2
5	40	3	2	Big	Outlet	87	0
5	40	3	3	Big	Inlet	68	0
5	40	3	3	Big	Outlet	63	0
5	40	3	1	Small	Rough	312	0
5	40	3	1	Small	Smooth	190	0
5	40	3	2	Small	Rough	135	0
5	40	3	2	Small	Smooth	147	0
5	40	3	3	Small	Rough	252	2
5	40	3	3	Small	Smooth	218	2
5	40	3	4	Small	Rough	257	2
5	40	3	4	Small	Smooth	208	7