RNT CONSULTING INC

Assessment of the Potential Impact of Quagga Mussels on Hoover Dam and Recommendations for Monitoring and Control

Prepared for: The U.S. Bureau of Reclamation – Lower Colorado Dams Region

Prepared by:

Renata Claudi MSc & Tom Prescott MSc, PEng.

RNT Consulting Inc.

Date: December 27, 2007

Order Number: 07PG308098

Table of Contents

Executive Summary

In response to the recent arrival of the Quagga Mussel in Lake Mead, the USBR initiated an assessment of the potential impact of mussels on Hoover, Davis and Parker dams on the Lower Colorado River.

Hoover Dam was inspected on November 13th, 2007. This report presents the findings from that inspection and sets out recommendations for quagga mussel control.

Inspections of de-watered external structures and of the penstock confirmed the presence of quagga mussels. Settlement decreases in the intake structure with increasing depth. There appears to be no settlement at 200 feet below lake level on the walls of the intake tower.

Inspections of various components during routine maintenance operations disclosed the presence of mussels within the plant equipment. The rate of individual mussel growth and the rate of mussel population increase are unclear at this point. For that reason, a comprehensive monitoring program is recommended and the details are given in this report. Initial observations indicate that the behaviour of the mussels in this region will be somewhat different than in other parts of North America and Europe. Therefore the data gathered from the monitoring program is expected to be useful in establishing the unique mussel population dynamics in this region. This knowledge will in turn aid in predicting the need for maintenance of various systems in the plant, such as the required frequency of cleaning trash racks. The data will also help determine if selected mitigation tactics should be modified.

Intra-dam coordination is recommended to maximize knowledge and experience gained. A data sharing initiative with other Lower Colorado stakeholders has already commenced, led by USBR and this will further add to the accumulated knowledge.

As settlement appears to stop at 200 feet below lake level we suggest that Hoover dam draws water only from the lowest intake tower gate rather than blending water from the upper tower gate for each penstock. This strategy would minimize the amount of mussel settlement within the penstock and within the plant. Minimizing the settlement would allow Hoover dam the necessary time to review different mitigation strategies and to implement them in an orderly manner rather than in a firefighting mode. It is also possible that by drawing only from the deepest level, the fouling of the internal structures will continue to be minimal; Of course this will need to be verified by rigorous inspections and monitoring. A mitigation plan is still required, but it may not be necessary to implement it.

Available mitigation responses are proposed on a system basis. The mitigation methods proposed are primarily mechanical and thermal techniques, in use by utilities in other areas. However, the method chosen for each system needs to be engineered, procured, installed and commissioned. The time required for this effort may exceed the maximum allowable accumulation of mussel settlement and growth. Therefore a rapid response plan using chemical treatment is suggested as an interim measure should the mussel problem suddenly reach a stage where it interferes with the plant operation. Chemical treatments require the approval of the State environmental regulator and discussions with the regulator should be initiated as soon as practical.

Hoover dam has 17 units plus water for central services. The selected mitigation response will therefore be repeated 18 times. The unit cooling water supply can be isolated via the common cooling water header sectionalizing valve. It may be beneficial to install the selected mitigation equipment first in a single unit to evaluate the efficacy and determine any adjustments needed to make the system work effectively before committing to the larger complete installation.

1.0 Introduction

Dreissenid mussels are aggressive biofoulers. When present in the source of the cooling water, they become a serious problem for industrial facilities using this water unless defensive steps are taken. There are two main types of fouling, acute and chronic.

Chronic fouling occurs when juvenile quagga mussels attach themselves to external and internal structures. The juvenile mussels grow in place and reduce or even cut off the water flow.

Acute fouling occurs when a large build up of adult mussel shells, alive or dead, becomes detached from upstream locations and is carried by the water flow into piping systems. The large quantities of mussel shells quickly plug small diameter pipes, fixed strainers, filters and heat-exchangers. Such events can occur at unexpected times and, if not anticipated, can have rapid and significant consequences. It is essential that any facility experiencing mussel fouling is prepared to deal with both types of fouling.

The three hydro-electric facilities we inspected for the U.S. Bureau of Reclamation, Hoover Dam, Davis Dam and Parker Dam, are located on the Colorado River. In January 2007, the Bureau was advised that Dreissenid mussels have been found upstream of the Hoover Dam in Lake Mead. In response to this imminent threat, the Bureau initiated a fact finding effort on how to deal with quagga mussel fouling. As part of this process, RNT Consulting was contracted to review the three dams and present a summary report on: areas of the dams at risk from mussel fouling, best management practices for coping with invasion and control options for raw water systems. It is important to note that this report contains what we believe are practical options for quagga mussel mitigation at the Hoover dam, but this report is not intended to represent an engineering evaluation of these options.

2.0 Assessment Process and Method

In September 2007, the Bureau of Reclamation provided RNT Consulting with flow diagrams of the Hoover dam, monthly water temperatures and water quality information. The team from RNT Consulting Inc. studied the documents and drawings prior to commencing the site visit.

On Tuesday November 13th, 2007, RNT Consulting team conducted a site visit of Hoover dam. The team was accompanied by Mr.Leonard Willett and led by Terry Warner, Planner for Maintenance Group at Hoover. As well as being able to physically trace all cooling systems identified on the drawings, we were able to inspect a de-watered penstock, a de-watered intake tower as well as various components of the cooling systems which were out of service. In addition, we were able to inspect some substrates exposed in the tail bay of the dam.

On Wednesday November 14th, the RNT Consulting team presented a summary of findings to the staff at Hoover dam and staff from other Bureau of Reclamation Offices. Present at this meeting were representatives from Central Arizona Project, Metropolitan Water District and representatives from the Imperial Dam.

During this presentation, RNT Consulting reviewed the need for monitoring, reviewed available control options and presented several possible control scenarios appropriate for the Hoover dam.

A suggested path forward, based on our experience at other sites, was also presented.

3.0 Results of the Assessment at Hoover Dam

3.1: Characteristics of the incoming raw water from the Colorado River

The Colorado River has favourable pH and calcium content for quagga mussel growth. This conclusion is supported by a significant presence of adult quagga mussels through out the system as well as the presence of Asian clams (*Corbicula*) at all sites.

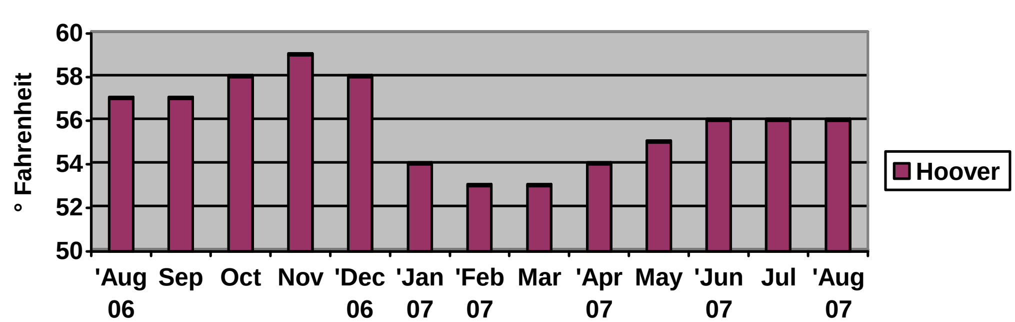
The temperature of the incoming water at Hoover Dam (Fig.1) is relatively low, ranging from 53°F to 59°F (11.7°C to 15.0°C) year around. While the ambient water temperature is warm enough to support reproduction for most of the year, the summer temperatures of the dam cooling water will **not** reach the upper thermal limit for veliger survival.

However, temperatures high enough to cause mortality of veligers and possibly even of adult quagga mussels may be reached in various parts of Lake Mead where the water is more shallow. Such mortality may greatly influence the incoming numbers of veligers at different times of the year.

A rigorous monitoring program should be implemented immediately to help answer the uncertainties of quagga mussel reproductive behavior and growth in the Colorado River system. The suggested monitoring program is outlined below in Section 4.1.

It is important to note that Asian clams are not very numerous at any of the dam locations at this time. However, when Asian clams first invaded the Colorado River system, they were much more numerous and, at least at Parker Dam, they were considered a problem. It is not clear at this time if the quagga mussels will follow a similar pattern of rapid population increase followed by a steep population decline ultimately reaching a stable population level.

Fig 1: Generator Cooling Water Supply Temperature



3.2: Physical Characteristics of the Hoover Dam and Areas of Concern

3.2.1: Intake Structures

The water enters Hoover dam through four separate penstocks. Each penstock has its own cylindrical intake tower, a segmented intake opening at each of two different water depths with gates for each segment opening, and trash racks set on 3” centers.

The trash racks of the intake tower are likely to be an area of heavy fouling and should be inspected, possibly every three months to make sure that the gap between the individual trash racks is not closing.

One of the intake towers was dewatered at the time of our visit. The inside surfaces of the tower were inspected by Mr.Willett and Mr. Warner. Almost the entire internal concrete surface of the intake tower was colonized by mussels. There was a gradient of settlement density, with most settlement observed in the upper 60-90ft of the tower. Settlement tapered off with increasing depth, but it was only at 200ft below lake level that we saw no further settlement on the tower walls.

The significant mussel population settling on the internal concrete surfaces of these towers is not likely to interfere with the function of the tower itself, but it may become the source of large volume of shell debris as individuals or clumps of mussels become detached from the walls of the towers and are swept into the penstocks and possibly into the plant piping systems.

The internal surface of each penstock is painted with a corrosion protection coating. During our inspection of the dewatered penstock, we observed that the mussel settlement occurred primarily in areas where the coating had cracks or crevices. However, some mussels did attach to the coating itself. The coating is removed and replaced at 6 year intervals as part of a routine maintenance program. The settlement in the penstock demonstrated that the mussels are capable of settling and growing at depths where the pressure is in the order of 200 psi.

3.2.2: Unit Cooling Water

Each main penstock has 4 branches, one branch penstock for each unit. Adjacent penstock branches are connected with a cross tie header. This header provides high pressure cooling water (HPW) to a common header known as the HPW Eductor Header.

The HPW is raw water. It has no strainers or other devices to remove foreign objects from the water stream. The HPW has 3 main functions. It provides raw cooling water for the transformer coolers and turbine seal rings. It also provides the raw water for the fire protection system. Finally, it provides pressurized water for the eductors which creates suction to pull tail bay water to mix and blend with the HPW. The discharge from the eductors is low pressure cooling water.

The water drawn in from the tail bay passes through duplex strainers prior to reaching the eductors.

The low pressure cooling water provides water for the turbine packing box, the thrust bearing and guide bearing oil coolers and for the generator air coolers.

We observed a refurbished turbine oil cooler. The cooling tubes on this cooler are fabricated from stainless steel. We were advised that the original tubes were of copper material.

We also observed a generator air cooler that had its inlet plenum opened. We were able to view the tube face on the interior of the plenum and noted that the tubes were approximately ¾" diameter. The tubing was of copper material.

3.2.3: Station Service Water

The raw water for Station Service Water is taken from a 42" penstock that runs between the Units 1 and 2 penstocks. A "T" in this line directs water through a 30" line referred to as the station service penstock. This penstock then proceeds to the central services area.

The Station Service Water penstock provides water for a Pelton wheel generator, for the water filtration plant to produce treated domestic water and for cooling water for central station services.

3.2.4: Fire Protection Water

The raw water supply for the fire protection system is taken from the unit 8 cross tie header HPW and from the station service penstock HPW. The take offs are protected by strainers

4.0 Action Plan/Recommendations for Hoover Dam

4.1: Monitoring at Hoover Dam

The monitoring recommendation given for Hoover dam is identical to that given for Davis and Parker Dams.

Given the uncertainties regarding the physiology and biology of quagga mussels in the Lower Colorado region, we consider a monitoring program to be essential. The objectives of the monitoring program are to:

- Determine when veligers appear in the raw water in the spring
- Determine how fast the mussels grow once they have settled
- Determine how many adults will be present per square foot at the end of three a month period
- Determine if / when the veligers disappear from the raw water

The data collected will aid in predicting the need for maintenance of various systems in the plant, such as the required frequency of cleaning trash racks. The data will also help determine the frequency of mitigation, if periodic treatment strategy is selected.

To achieve these monitoring objectives, a combination of settling plates, plankton net sampling and in-plant monitoring is recommended.

4.1.1: Settlement Plates

Specifically we suggest that settling plates made of carbon steel or stainless steel be placed into the water immediately on the lakeside of each dam as well as in the tailrace. Plates which would provide 1square foot of sampling surface per side are recommended for ease of reporting sampling results. Such plates can be strung together at predetermined intervals (5 ft or 10 ft intervals) and suspended from a rope. The first plate should be at least 5 feet below the surface of the water. Additional plates can follow in predetermined intervals to within 5 feet from the lake bottom. An anchor should be placed at the very bottom to insure the sampling plates remain vertical in the water column.

Weekly visual observation of the plates will determine if any ready to settle veligers are coming into the plant and settling at this location. Once initial settlement has been detected, continue to use the settling plates to determine the density of settlement.

Determination of settlement density would best be done by having at least five identical strings of settlement plates deployed at the same time. One string deployed at the tailrace and four strings on the lakeside of the dam. The sampling frequency of the settling plates is flexible, provided all sites sample at the same frequency and they do so all year. The sampling can be weekly, bi-weekly or monthly. Whatever time period is chosen, scrape plates from the tailrace and two strings from the lakeside location. Using two strings on the lakeside will provide better average density of settlement at each depth. Each plate can be scraped onto a paper towel or filter papers and allowed to drain for 30 minutes (draining period is flexible as long as the same period is used by all sites for all samples). After draining, the samples are then weighed and density can be expressed as wet weight of mussels / ft^2. Alternatively, if the collected sample is relatively small, settled individuals can also be counted and density expressed as number of mussels / ft^2. As there is no direct way to relate wet weight to number of individuals, whichever method is chosen, should be the method used at all dams for the entire sampling period.

After collecting the wet weight or total number of individuals, we suggest measuring the size of shells in a sub sample removed from the plates. This will provide weekly growth rates of mussels at various depths at different times of the year. As the plates are scraped clean each sampling period, the largest shells found on the plates during the next sampling period will have been settled for the duration of the interval between sampling. If maximum growth is realized, 1mm mussels would be present after 1 week, 2 mm after two weeks and up to 4mm mussel shells after one month. An occasional large mussel outside of the expected size range could be found on the sampling plates. These mussels are usually called translocators and may have moved onto the plate from another location. They should not be included in the weekly growth calculations.

It would be very useful to measure and record ambient water temperature at each plate depth when collecting samples from the settlement plates. Having a record of the temperature at various depths could greatly help interpret settlement and growth data from the settling plates.

Average the data collected between the two strings of sampling plates deployed on the lakeside. We believe that settlement will be minimal in the tailrace and the one string at the tailrace is deployed to verify this assumption.

Leave the third and fourth string deployed lakeside un-scraped for a three to six month period. At the end of this time, scrape each plate into a separate vessel, allow the sample to drain for the same period of time as used previously for other samples and weigh the contents. Take the average between corresponding plates from the two strings. Measure the size of all settled mussels in a sub-sample taken from each scraped plate. This will give you maximum growth rate at each depth; the largest mussels have been settled for three or six months. It will also show the number of settling events that have occurred during this time period, individual size categories of mussel shells will correspond to individual settling events.

Increasing the number of sampling strings will increase the statistical robustness of the data. Ideally, three strings in the tailrace and lakeside for frequent sampling, three strings for quarterly/bi-annual sampling. The actual number of strings deployed will depend on the availability of site resources. To gather and analyze a useful number of samples it may be necessary to have external assistance for data analysis

Figure 2: Typical Chart for Data to be collected from settlement plates

Date of Collection	
# of weeks since last collection	
Sampling String #	
Depth of sampled plate	
Temperature at that depth	
Wet weight of mussels/ft2	
Number of mussel size classes present	
Estimated growth/week	

4.1.2: Plankton Sampling

Once settlement is seen on the settlement plates, we suggest collecting weekly veliger samples using a plankton net or a plankton pump to compare numbers of veligers collected to data collected from settling plates. Our experience is that the veliger sampling with a plankton net is less reliable then the settling plate method for detecting ready to settle veligers. However, plankton sampling does provide back up for settlement monitoring. In some instances, veligers have been detected in the plankton, but have failed to settle/grow on the plates. This could be a function of unfavorable water temperature or possibly lack of appropriate food.

We recommend a plankton net with a top diameter of approx. 20 inches and a 75 micron mesh size. The plankton net should have a removable bucket at the bottom to facilitate sample collection. Collection should be done weekly on the lakeside of the dam. Plankton net should be lowered as close to the bottom as possible without touching it. It is then raised slowly to the surface. The net is then taken out of the water. Collected plankton will be concentrated in the removable bucket at the end of the net. The sample is then removed into a pre-labeled sample jar (date, location, maximum depth of water sampled) and preserved with 70% ethanol. This procedure should be repeated two more times, collecting a total of three samples in one jar for microscopic analysis. Once the samples are preserved with ethanol, analysis can take place at any time in the future.

When analyzing the samples under a microscope, presence and absence of veligers is noted first.

If the veligers are present, it is possible to count veligers in the sample and extrapolate number of veligers per unit volume. It is also possible to distinguish between ready to settle veligers (referred to as the pediveliger stage) and more juvenile forms which are likely to pass through the dam without settling and note their relative proportions.

This type of information may be useful when comparing data from over several years. It also provides a back-up to the sampling plate data. For example, if large quantity of ready to settle veligers is found in the plankton samples, but no corresponding settlement is observed on the settling plates, environmental variables need to be examined for factors limiting settlement.

Figure 3: Typical chart for data collected from plankton samples

Date of Collection	
Size of Net Opening used & Mesh size	
Tow taken from which depth to surface	
Veligers present/absent	
Density of veligers volume of water (optional)	

4.1.3: In-plant Monitoring

To monitor the settlement of mussels in the power plant, install side-stream samplers which are aquarium-like devices commonly known as bio-boxes. We suggest a minimum of one location and, if possible, two locations. Suggested locations are; one bio-box at the beginning of the service water system and a second bio-box location near the end of the system where the service water returns to the river.

We suggest that each plant immediately proceeds to obtain bio-boxes. Given the skills available, in-house manufacture may be the fastest and most economical. A suggested design for a bio-box is provided in Appendix I.

If possible, the supply to the side-stream to be used by the bio-box should be taken from a valve located in the lower third of the diameter of the system pipe. Water from a location on the lower portion of the system pipe will be likely to contain more veligers than supply from the upper portion of a pipe. This is due to veligers settling under gravity after they have passed through a pump or a strainer basket. Such physical disturbance generally results in the veliger closing the valves of their shells. When closed, the veligers slowly sink.

The volume of flow into the bio-box is regulated by a valve on the incoming water line. The suggested flow through the bio-box is approximately 4L/min (1.5 gpm). This flow would give the bio-box shown in the Appendix a 20 minute retention time. This retention time was chosen as the maximum length of time water travels from the start of a system to the end of it. Any ready to settle veligers in the side-stream will have an opportunity to settle in the bio-box. The stand-pipe through which the out-flow exits guarantees the water level in the bio-box remains constant regardless of inflow.

Settlement in the bio-boxes can be monitored much like the settlement on plates deployed outside of the plant. Monitoring interval can be determined by each facility, monthly sampling is suggested.

If mussel control measures are deployed in the cooling systems, the absence of mussels in the bio-box at the discharge end of the piping system would verify that the control measures are working. Conversely, if settled, live mussels are found in the bio-boxes, the control measures are not working.

Figure 4: Typical chart for data collected from biobox sampling

Date of Sampling	
# of weeks since last sample	
Biobox ID	
# of mussels/ft2	
Wet weight of mussels/ft2	
Number of size classes present	
Estimated growth/week	
Observation Notes	

Table 1: Summary of Monitoring

Monitoring tool	Location	Frequency	Observation
Settlement plates Size: 1square foot Material: Carbon steel, stainless steel, PVC	Lakeside of the dam and Tailrace of the dam	Weekly, bi-weekly, monthly Quarterly/bi-annually	Start of settlement Growth rate Number of settlement events Total population/time period Note: Collect water temperatures at various depth during each sampling event
Plankton tows Plankton net, 20 inch mouth, 75micron mesh	Lakeside of the dam	weekly	Presence and density of veligers %of ready to settle life stage
Side-stream samplers/bio-box Sampling plates same as used for settlement plates above.	Service water system	Weekly/ monthly	Presence of mussels in the plant Efficacy of Control

4.2: Mitigation Recommendations

The following sections deal with the actions that can be taken to mitigate the consequences of quagga mussel presence at the station. The sections cover the various areas that, either need to be protected or maintained. The paragraphs provide recommendations and options for achieving the necessary level of mitigation. Depending on plant practices or plant QA requirements, the chosen methods may need to be rendered into a procedure and incorporated into plant operating manuals or periodic inspection flow charts. The paragraphs that follow are intended to provide enough information upon which to base the procedures for the particular methods chosen.

Included for convenience, in Appendix II is a sample table comparing various mussel treatment options. We have found such a table to be a useful guide to decision makers when evaluating options.

4.2.1: External Structures – Gates, Trash Racks

Inspect trash racks at regular intervals, if possible every three months until clear growth patterns are determined at which time the inspection frequency may be altered accordingly. Depending on the amount of infestation, trash racks and intake gates can be cleaned using divers. The divers may be required to manually scrape the infested surfaces. Use a vacuum pump at the same time as scraping to collect the mussel shells if there is danger that dislodged shells could be transported into the station cooling system.

If periodic manual cleaning is not feasible or economical, consider painting the surfaces in question with an anti-fouling paint during a penstock outage. Paints which have been found effective are either silicone based paints with low surface tension, or self polishing copper rich paints. The silicone based paints are non-toxic and generally do not require registration with EPA or regulatory approval for use. The self polishing copper paints generally require an EPA registration.

As settlement appears to stop at 200 feet below lake level we suggest that Hoover dam draws water only from the lowest possible depth of the lake rather than blending water from different depth for each penstock. This strategy would minimize the amount of mussel settlement within the penstock and within the plant. Minimizing the settlement would allow Hoover dam the necessary time to review different mitigation strategies and to implement them in orderly manner rather than in a firefighting mode. It is also possible that by drawing only from the deepest level, the fouling of the internal structures will continue to be minimal, (verified by rigorous inspections and monitoring) and although a mitigation plan has to be developed, it may not be necessary to implement it.

4.2.2: Penstocks

Due to high speed of flow in the penstocks and the large size of the penstock pipe, mussels are unlikely to cause problems in these areas. The penstock is inspected and re-painted every 6 years. This periodic program should be sufficient to deal with mussels as well as the original intended purpose of the inspection.

The one possible area of concern is the penstock drains. The drains are used to evacuate the last remaining water during dewatering of the penstock. These drains may become overgrown with attached mussels or they may become plugged with shell debris originating elsewhere. Either problem is likely to be best handled by manual cleaning. The penstock draining procedure flow chart should allow for the process of cleaning the drains so that the work crews can identify the needed work and plan accordingly.

Extended periods of low flow or no flow in either the main penstock or its branches leading to the individual turbines, may result in mussel settlement and growth. This settlement may become source of shell debris inside the plant cooling systems as there are no strainers at the beginning of each cooling water line at the junction with the penstock or branch line.

4.3: Mitigation Recommendations for Domestic/ Central Services Water Systems

4.3.2: Service Water System

The service water that proceeds from the station service penstock to the water treatment and filtration plant will not be at risk of mussel shells or mussel settlement and growth after it has passed through the treatment process. The filtration and chlorination process for domestic water will remove both shells and veligers. Components such as sinks, toilets, showers, eye-wash stations will therefore not be at risk.

The service water that proceeds from the station service penstock to the Pelton wheel generator will likely have sufficient flow that settlement will not occur. It is expected that the Pelton wheel is sufficiently rugged construction that shells will not present a problem. However, if there are sensitive areas on this equipment such as water supplies to packing boxes or seals, then these areas should have their water supply provided from the domestic water if possible.

The service water that proceeds from the station service penstock to provide cooling water for central services is presently untreated and unfiltered. Local air coolers, air compressor coolers and seals for any small pumps will be at risk of settlement and from plugging by shells.

Installation of a self-cleaning, 40 micron absolute filter should be evaluated for the above portion of the service water system.

If an installation of a small pore, self cleaning system is found to be not practical, a combination of a self cleaning strainer (1/8 inch penetration) followed by an in-line UV system could be considered. The self cleaning strainer would remove shell material and the UV light would eliminate ready to settle veligers, provided the incoming water was low in suspended solids.

If the system becomes heavily fouled prior to the installation of the filter, temporary chlorination treatment or hot water flush may become necessary to restore integrity.

4.4: Mitigation Recommendations for Fire Protection Systems

4.4.1: Fire Protection System - General

Provided the fire systems are stagnant, the dissolved oxygen levels in the fire protection piping should be low. Less then 3mg/L of dissolved oxygen in the piping should protect the fire protection system from mussel fouling by primary settlement.

The fire protection supply comes from the high pressure cooling water supply and is therefore raw water. We were advised that the fire protection system is leak tight and not used for other purposes. It is likely that the piping will then have sufficiently low dissolved oxygen that mussels will not be able to settle and survive in the fire protection piping. Periodic checking of the dissolved oxygen content in the fire water piping would be prudent. A sampling location near to the fire protection take off is recommended.

A secondary risk is that during system testing, shells may be transported into the fire protection system and obstruct flow. The system schematic diagram indicates that there are strainers at the supply end of the fire water piping. These strainers should keep shells out of the fire protection piping during use of the fire protection system.

4.5: Mitigation Recommendations for Unit Cooling Water Systems

4.5.1 General

Establish a frequent inspection period for any duplex strainers already on these systems and an inspection of the sight glasses on the various pieces of equipment.

Small diameter liquid take offs such as flow measuring pipes and pressure gauges are at risk of fouling and thereby providing inaccurate readings. Where possible these instruments should be periodically verified for accuracy. For critical measurements, replacement with non contact gauges should be considered.

Currently there are no barriers to entry of foreign material into the unit cooling water system. As a minimum strainers will be required to remove shells from the incoming flow stream.

Based on our inspection in November 2007, the mussels are present at Hoover Dam. It is difficult to judge how immediate or urgent the threat is. The equipment we examined suggests a low threat at this time. However, the internal surface of the intake towers suggests fairly heavy infestation. As mentioned earlier, a monitoring program is essential to confirm our initial observations and to maintain vigilance about future increases in mussel numbers.

4.5.1 Short Term / Near Term Actions

To prepare for a possible mussel increase we suggest that a rapid response plan be prepared as a temporary measure while a longer term, permanent strategy is evaluated and implemented.

For Hoover dam, the possibility of minimizing mussel infestation by drawing from the deepest possible lake level is a very attractive and immediate option. If through monitoring it is proven that relatively few mussels are moving into the cooling system, Hoover dam will have time available to evaluate long term control strategies.

If limiting the intake of water to the deepest lake level is not considered a viable option, typically the quickest solution to put in place is chemical treatment with chlorine. In addition to the technical aspects of a chlorine system, permits will be required from the state environmental regulator. The permitting process can be time consuming and it would be prudent to approach the regulator as soon as practical to alert them to the problem and obtain their initial reactions and suggestions.

We understand that there are temperature monitors for air coolers, bearing coolers, packing boxes and turbine seals. If these monitors are located adjacent to the equipment, then we suggest increased inspection frequency is warranted. If the monitors are located in the control room, then normal station response to temperature alerts should be adequate.

Portable chlorination skids are available on short notice. Portable, skid-mounted systems can be obtained either by purchase or lease that are self-contained with storage tank, metering pump, plumbing and integral control system. It is sometimes more practical, if staff shortages exist, to sub-contract the overall chemical treatment program.

Chlorine injection is typically the lowest cost method to treat mussels. Non-oxidizing chemicals are also used by some sites for periodic chemical treatment. However, chemicals do have negative environmental impacts and may not be viewed favorably by the regulator. We would suggest that a chemical use permit for 2 years would provide the station with sufficient time to evaluate alternatives, issue purchase requisitions, install and commission the selected mussel control system equipment. It would also be prudent to have long term permission to occasionally use chemicals to kill any mussels that may enter during periods where the selected normal treatment such as filtration or UV is unavailable due to maintenance or equipment malfunction.

4.5.2 Long Term Mitigation Options – Filtration

Use of filters with small mesh size of no more than 40 microns has been shown to be effective at eliminating entry of veligers into piping systems. The small mesh size would also keep out any shell material. Filtration requires some pressure drop. The available hydraulic head at Hoover appears to be sufficient such that no additional pumps would be required. Filtration also requires piping changes to insert the filter, provide drainage for the backwash and usually a by-pass line to allow for continued operation in the event of a filter problem.

Since the unit water a Hoover has two entry points for each unit; one from the HPW and one from the tail bay suction to provide blended cooling water, the use of filtration would need to have filters at both entry points. This would increase capital costs.

We observed that space is at a premium for locating filters and layout will need to be considered to ensure that a practical and economic path is available for the modifications needed to accommodate a filtration system.

4.5.3 Long Term Mitigation Options – Ultra Violet

Ultra Violet (UV) radiation can also provide effective prevention of mussel settlement. It will not prevent entry of shell material and would need to be combined with a strainer on the HPW to keep out shell material.

As with filtration, because there are two entry points for cooling water, the UV units would have to be duplicated at each unit. However, there are already strainers on the low pressure cooling water supply at the tail bay.

UV systems typically require large current draw so attention would need to be given to availability of suitable power in the installed areas. UV equipment tends to have reduced effectiveness during periods of increased water turbidity. We understand that the water in Lake Mead generally has low turbidity and should therefore be suitable for continuous UV.

UV equipment lay out will be subject to the same space restrictions as filtration above.

4.5.4 Long Term Mitigation Options – Thermal

Thermal treatment is also a possibility. The objective would be to increase water temperature in the cooling water lines to 30°C by recirculation of existing cooling water, and blending in only enough tail bay water to maintain the cooling water at 30°C. A recirculation / tail bay pump would be needed and the HPW would be used only for the turbine seals.

If the equipment can accommodate elevated temperatures or can be conveniently modified to accommodate elevated temperatures, then the cooling water could be maintained at near 30°C year round.

If recirculation can raise the water temperature to 30°C but the station equipment is **not** designed to accommodate this temperature level on a continuous basis, then periodic heat flush could be used to kill any settled veligers before they grow to a size that could plug equipment. The heat source for this periodic treatment could come from recirculation of existing cooling water thereby using waste heat or by an auxiliary boiler, whichever approach is most suitable for the station.

It may also be prudent to replace the existing duplex strainer on the tail bay suction with a self cleaning unit that has a screen opening size of 1/8" as this would keep out any shells that may enter through the tail bay suction. The heat would then kill any veligers.

4.5.4 Long Term Mitigation Options – Separate Closed Systems

One feature of the Hoover design that increases the capital cost of mitigation options is that there are two entry points for raw water to provide the unit cooling water. One entry point is at the penstock take off for high pressure water (HPW). The HPW is used to provide cooling water for the turbine seals and the transformer oil coolers. Some HPW is also directed to eductors where the HPW is used to create suction and draw in tail bay water and blend with the HPW. The blended water is at lower pressure and higher volume than the HPW. The tail bay water is the second entry point of raw water into the unit cooling water system.

The transformer coolers are located outside the main building structure at Hoover. These coolers could be converted to a closed loop system which would then reduce the flow demand on the remaining unit cooling water. If this demand reduction were sufficient to eliminate the need for the water pumped from the tail bay, then the tail bay entry point for unit cooling water could be eliminated. The eductors could then be eliminated but a pressure reducing valve would be required in place of the eductors to regulate the low pressure cooling water supply pressure.

The capital savings of eliminating the need to treat two entry points would have to be compared to the capital costs of separating the transformer coolers into an independent cooling system.

5.0 Summary and Recommended Path Forward

In the body of this report we have made numerous suggestions as to monitoring, preventative maintenance and long-term mitigation strategies for quagga mussels. We believe that it is very important to begin the implementation process immediately.

An effective immediate step would be to draw water from the intake tower lower gate at each penstock. Considering the minimal settlement in this area, the risk of veligers present at this depth is much reduced and consequently the risk of veligers being transported into the station is reduced. The economic penalty of operating with only one gate open would need to be evaluated.

From an administrative perspective, we have found that a dedicated staff person (mussel champion) is necessary to usher the mussel response program through to implementation and turnover to operations staff. In addition, there are still uncertainties about the specific behaviour of the mussels in the Colorado River system. There is a benefit from exchanging information, experience and ideas between all involved dams. There is also a benefit from a consistent approach to the regulator.

We suggest that a single coordinator of quagga mussel issues be appointed. The coordinator would then head an inter-dam group responsible for negotiating uniform monitoring strategy for all Bureau of Reclamation dams. Once in place, the coordinator could source monitoring equipment in bulk and ensure that sampling plates and bio-boxes are installed as soon as possible, working through the contacts of the inter-dam group. The inter-dam group would also allow for quick information sharing on quagga mussel issues, a valuable resource at this point of infestation.

The coordinator of the group would also interact with other agencies working on quagga mussel issues and bring information back to the Bureau and disseminate it to all sites.

At individual dams, the mitigation strategy chosen will be based on engineering assessment of the individual mitigation strategies available. The coordinator would play a valuable role in addressing the requirements of various stake-holders during this process. The coordinator would have to make sure that risks vs. economics vs. individual preference of the stakeholders are properly balanced.

Appendix I: Typical Bio-box Fabrication and Assembly

1. Bio-boxes may be constructed according to the following general instructions. The size of the bio-box in these instructions will provide a retention time of approximately 20 minutes at a flow rate of 4 litres per minute. The retention time should be adjusted to simulate the maximum time that the service water is resident in the plant from the time the water enters the plant piping until the water is discharged to the receiving water.

2. The bio-box components and assembly are shown in Figure 2. The component description is in the accompanying bill of material table. All bio-box material of construction is clear Cast Acrylic Plexiglas unless otherwise noted in the bill of material.

3. Use a waterproof acrylic cement such as Weld-On#4 or equivalent. Follow the manufacturer's instructions for cement use. Allow at least 48 hours after joining panels with cement before filling the completed bio-box with water

4. All cemented edges should be routered smooth with a straight edge fence to ensure a water tight joint.

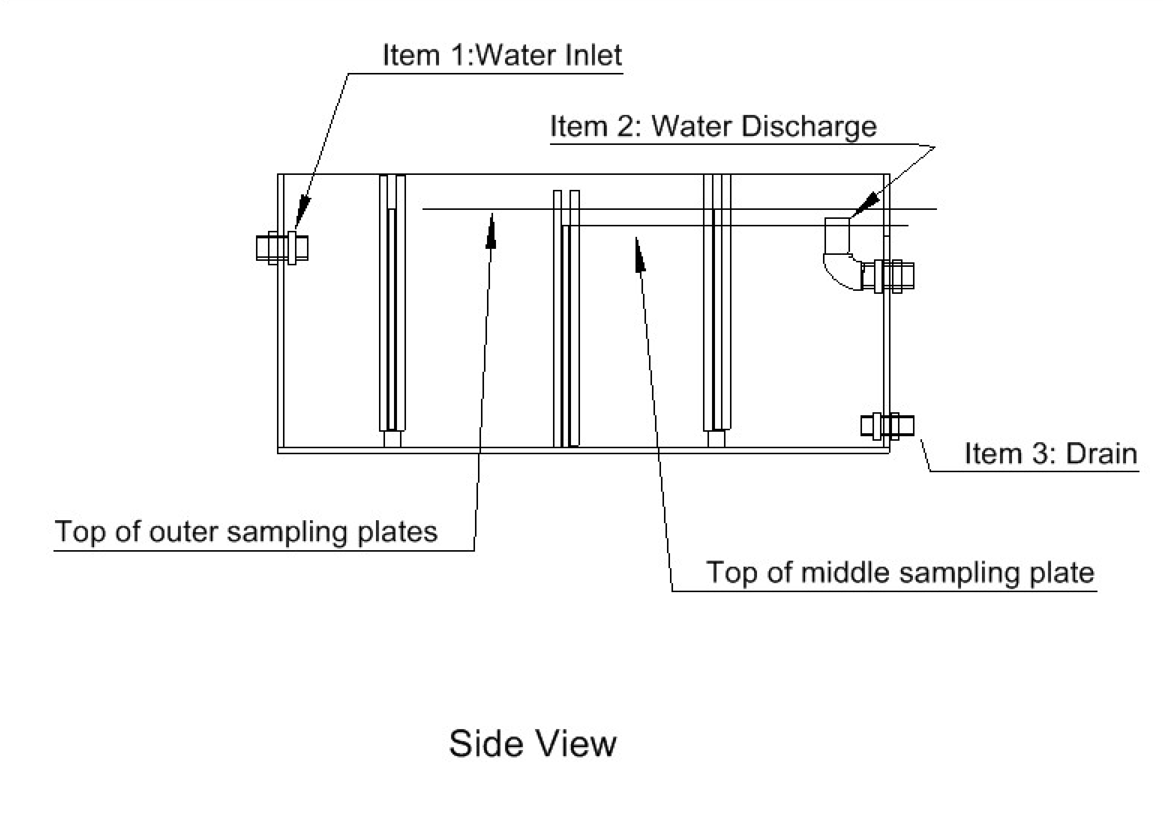
5. Exposed edges should be routered or filed with a bevel to remove the sharp edge.

6. A cover is not shown in these instructions but can be made from acrylic, plywood or other suitable material and may be either hinged or constructed with a lip to fit loosely over the bio-box.

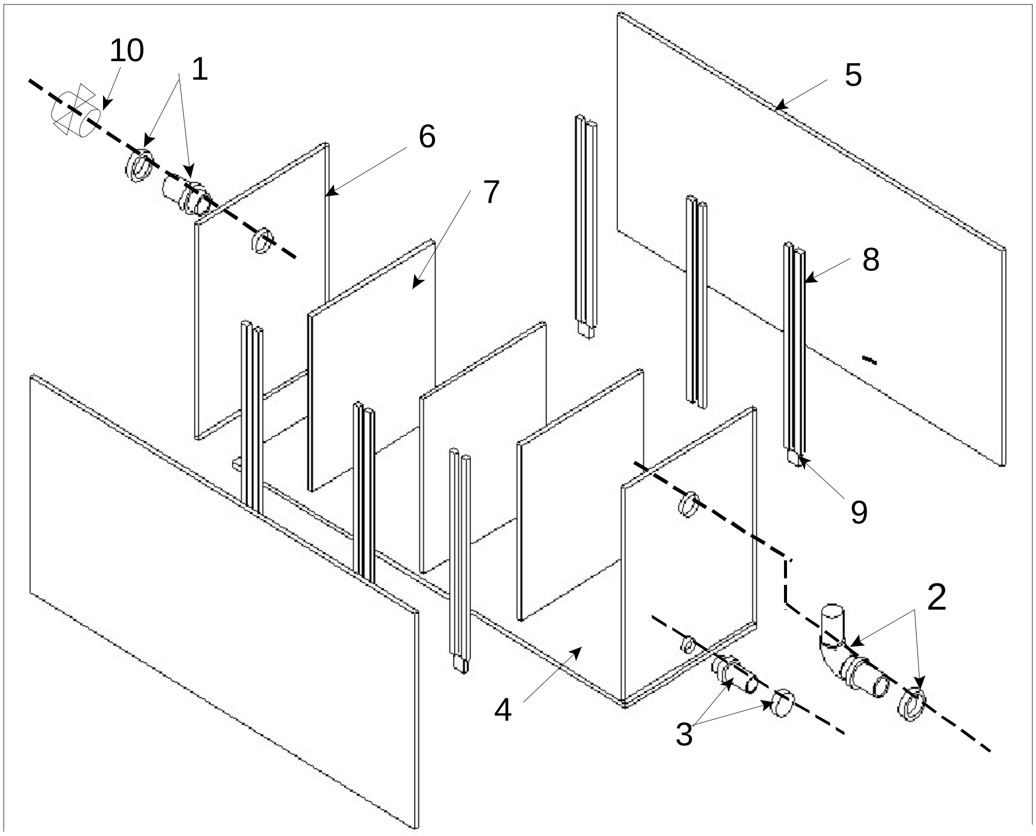
7. The bio-box cavity is divided into four equal chambers by three sampling plates. The sampling plates are removable and slide into slots formed by acrylic guides cemented to the walls of the bio-box. The outer two sampling plates rest on 1" spacers also cemented to the walls of the bio-box thereby creating a gap between the bottom of the tank and the lower edge of the sampling plate.

8. Water enters the bio-box through an inlet fitting into the first chamber. The water passes under the first sampling plate into the second chamber, then over the second sampling plate into the third chamber. Finally, the water passes under the third sampling plate into the fourth chamber where the water exits through the overflow standpipe and out the discharge fitting.

9. The standpipe in the discharge fitting is adjusted to control water level. The standpipe level should be set so that the water level is maintained between the top of the outer sampling plates and the top of the middle sampling plate as shown in Figure 1 below.



Bio-box Bill of Materials		
Item	**Description**	**Qty**
1	Bulkhead fitting, 1" socket x NPT female, PVC with EPDM gasket	**1**
2	Bulkhead fitting, 1-1/4" socket x NPT female, PVC with EPDM gasket and solvent welded PVC elbow and PVC standpipe.	**1**
3	Bulkhead fitting, 1/2" socket x NPT female, PVC with EPDM gasket	**1**
4	Bottom plate, 36"x12", Plexiglas 3/8" thick	**1**
5	Side plate, 35-1/4"x15-5/8", Plexiglas 3/8"thick	**2**
6	End plate, 12"x15-5/8", Plexiglas 3/8"thick, drill or cut holes to suit bulkhead fittings.	**2**
7	Sampling plates, 11-1/8"x14", PVC plate 3/8"thick	**3**
8	Sampling plate guides, 14"x1/2", Plexiglas 3/8"thick	**12**
9	Sampling plate spacers, 1"x1", Plexiglas 3/8" thick	**4**
10	1/4-turn Ball Valve, NPT male x NPT male, PVC	**1**



Exploded View of Bio-box

Appendix II – Sample Decision Assistance Chart

Summary of Quagga Mussels Mitigation Options for in-plant Raw Water Systems

	Sodium hypochlorite /Chlorine dioxide		Non-oxidizing chemical	Thermal Treatment		Filters	UV – Radiation
Type of application	Continuous or semi-continuous	Once or twice/year	Once or twice/year	Once or twice/year	Continuous	Continuous	Continuous
Concentration	0.5ppm TRC	0.5pmm	2-5 ppm for 24 -48 hours	38°C (100°F) for 5hrs 40°C (104°F) for 1hr	30 -32°C (86-90°F)	40 micron absolute mesh	Radiation dose is 0,07 to 0.1 Watt-sec/cm^2
Expected Mortality	100%	100%	100%	100%	100%	100%	85 – 90%
Cost of treatment	Chemicals, staff, regulatory compliance			Energy intensive, system outage may be requ'd	Low if waste heat used	Very low	Energy intensive, lamp replacement
Cost of Installation	Function of # of injection points, low cost relative to filters and UV.			Portable heat source requ'd	Piping changes needed including valves and possibly a pump	Piping changes needed. Filter cost depends on flow and pore size	Piping changes needed. Strainers still needed for shells. UV cost depends on flow.
Time to design, mfr &install	<3months		<2months	<3months	3-4 months	>6mos for large flow, <3mos for small flow	3-4months
Regulatory Approval requ'd	Yes	Yes	Yes	No	N o	No	No
Risks	Health and safety for workers.	Health and safety for workers. Growth between treatments produces shells	Growth between treatments produces shells	Potential to exceed equipment temp limits	Potential to exceed equipment temp limits	Limited industrial experience for very large flow ultra-filtration	Low effectiveness in high turbidity
Reference Plant	many	many	many	few	unknown	Nanticoke TGS, Ship ballast applications	Bruce NGS and Ship ballast water

	Sodium hypochlorite /Chlorine dioxide		Non-oxidizing chemical	Thermal Treatment		Filters	UV – Radiation
Type of application	Continuous or semi-continuous	Once or twice/year	Once or twice/year	Once or twice/year	Continuous	Continuous	Continuous
Appropriate for total flow	No – too much chemical in discharge		No –impractical to de-toxify. Sediment remains toxic	No- not practical to heat that much water		No – Flow too large for fine pore filters.	No – Flow too large. UV is not effective during periods of turbidity.
Central Services cooling water	Yes, injection at take off for cooling water so treatment not applied to Pelton wheel		Possible.	Possible – piping modification for steam heaters	No –no source of waste heat	Yes- piping modifications, pre-straining by coarse (1/8 inch) strainer	Yes- piping modifications, pre-straining by coarse (1/8 inch) strainer. May lose performance during periods of high silt load
Unit Cooling Water	Yes	Yes – would have to done frequently enough to avoid large growth of shell material	Yes – discharge would probably have to be de-toxified with bentonite clay, particulate load to the river. Would have to done frequently enough to avoid large growth of shell material	Possible – piping mods required for heaters. Would have to done frequently enough to avoid large growth of shell mate	Yes - provided waste heat is used. Need to confirm if water can be raised to high enough temp and equipment temp limits not exceeded	Yes - piping modifications, pre-straining by coarse (1/8 inch) strainer	Yes- piping modifications, pre-straining by coarse (1/8 inch) strainer. May lose performance during periods of high silt load
Fire Protection	Yes, when water is flowing such as during testing. Shell material an issue			Unlikely to be practical	No – normal flow is stagnant	**Yes but a bypass is necessary**	No, primary issue may be shell material