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

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

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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. Davis and Parker dams were inspected between November 5 and 7, 2007. This report presents the findings and recommendations for the Davis and Parker dams.

Sampling plates to detect mussel settlement had been placed in the fore bay of both dams in the summer of 2007. These plates confirmed that mussels were present at both sites. In addition, inspections of various components during routine maintenance operations disclosed the presence of mussels within the plant equipment.

Both dams will experience mussel settlement and growth on internal components and external structures. However, the quantity of settled mussels and their apparent rate of growth are much greater at Parker dam than at Davis dam making the risk to Parker dam acute.

A comprehensive monitoring program is recommended and outlined 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 and mitigation tactics can be modified as more is learned about the mussel.

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.

Suggested mitigation responses are proposed on a system basis. The mitigation methods proposed are primarily mechanical and thermal techniques. The methods proposed have been proven in utilities in other areas. However, the method chosen for each system needs to be engineered, procured, installed and commissioned which requires an elapsed time that 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.

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 on 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 each facility, but this report is not intended to represent an engineering evaluation of these options.

2.0 Assessment Process and Method

The Bureau of Reclamation provided RNT Consulting with flow diagrams and, in some cases, piping layout drawings of raw water piping systems at each of the dams in September 2007. The team from RNT Consulting Inc. studied the drawings prior to commencing the site visit on November 6th, 2007. The first visit was to Davis Dam. The team was accompanied by Mr. Leonard Willett from Hoover Dam and on site representative of Davis Dam, Mr. Robert Dillon. Together, we inspected all accessible areas of the dam from penstock to discharge, identifying various components and cooling systems previously highlighted on the drawings. We were also able to inspect sampling plates that had been exposed on the upstream face of the dam since August 2007 as well as the interior of a duplex strainer on the domestic water supply line. During this inspection, the team was able to identify the potential threats to the systems and to individual components.

This process was repeated the next day at Parker Dam. We were accompanied by the plant manager, John Steffen, plant supervisor Glenn Tuerschmann and Mr. Willett. On the day of the inspection, it was not possible to open duplex strainer on the domestic water supply. This was done subsequent to our site visit by Mr. Tuerschmann. Mr. Tuerschmann photographed the interior of the strainer and provided copies of the photographs to RNT Consulting.

On Friday November 9th, 2007, RNT Consulting presented a summary of findings from the two dams to dam personnel. Also present at the meetings were representatives from Central Arizona Project, Metropolitan Water District and representatives from the Imperial Dam. During this presentation, RNT Consulting also touched on the need for monitoring, reviewed control options and highlighted those most appropriate for the two sites.

3.0 Results of the Assessment at Davis and Parker Dams

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.

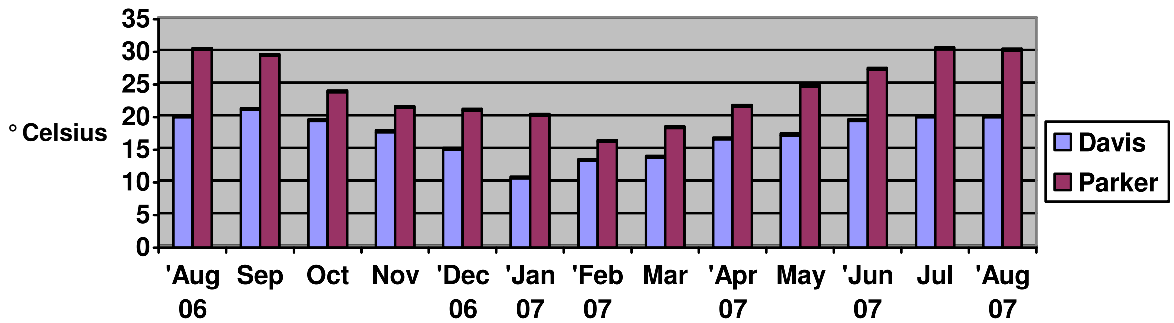
The incoming water at Parker Dam appears to be adequately warm to support quagga mussel reproduction year around. In fact, the maximum summer temperature of the water may exceed the upper lethal temperature for the quagga mussel veligers (Fig.1). Temperatures between 28°C and 30°C (82°F to 86°F), are generally regarded as lethal to veligers. These high temperatures may also limit the growth and survival of adult quagga mussels during the peak summer months and possibly result in vertical shifts in settlement to deeper levels in the water column.

The temperature regime at Davis Dam (Fig.1) is very different from that at Parker Dam. While the ambient water is warm enough to support reproduction for 11 month of the year, the summer temperatures at the dam do not reach the upper thermal limit for veliger survival observed at Parker Dam. The growth of individual shells at the Davis Dam may be slower then at Parker Dam due to lower ambient temperature, however control of settlement due to very warm temperature is not likely.

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 Davis Dam and Areas of Concern

3.2.1: Intake Stuctures

The fore bay entrance to the dam is bounded by a floating boat barrier. The dam structure is generally "L"-shaped with the water intakes on the stem of the "L" and the spillway structure at the foot of the "L". The spillway structure has 3 gates.

The plant water intake has 5 trash racks, one covering each of the 5 penstocks. The unit trash rack structure is of concrete and metal construction, semi-cylindrical in shape and fixed in place on the upstream face of the dam. The rack assemblies are approximately 120 ft tall and are in segments that appear to be resting in vertical slots.

3.2.2: Unit Cooling Water

Cooling water for each generator and the turbine thrust bearing is taken from the turbine casing. This water passes through a duplex strainer and then on to the generator coolers via an 8" line and to the turbine thrust bearing via a 3" line and booster pump. The screen openings on the strainers are approximately 3/8". An 1100 gpm pump exists in parallel to the generator cooling line presumably to provide additional capacity in low head conditions.

The generator cooler tubes are 5/8" diameter and would be at risk of tube plugging from shells originating from settlement and growth in the piping after the discharge of the Duplex strainers.

The cooling water system for each of the generator/turbine units is identical. The unit cooling water systems are interconnected by a common header.

3.2.3: Domestic Water

There are two domestic water supply intakes on the face of the dam in the fore bay. One is located inside the #1 trash rack (most northerly trash rack) and the other is adjacent to the first but outside the boundary of the trash rack. The intakes are covered by a metal grille. The intakes are approximately 80 ft below the top of the trash racks. The fixed intake grilles will be at risk of mussel settlement and growth.

From these intakes, two 10” supply pipes proceed to the transformer gallery. The entire length of the 10” supply lines would be at risk of mussel settlement and growth.

Prior to entering the transformer gallery, a 4” line branches from each of the 10” supply lines and enters the former chlorinator room where they each terminate at a strainer. One of the lines is now used to provide cooling water via a 1-1/2 inch line to a local air cooler that provides air-conditioning to the electrical room. This line is protected from large shells by the strainer but is not protected from mussel settlement, subsequent growth and production of shells downstream of the strainer. This line is suggested as a location for a monitoring bio-box.

When the two domestic water lines enter the plant in the transformer gallery, the water in each line passes through a Duplex strainer and then enters a common header. The water then is directed to a water treatment plant where it is filtered and chlorinated.

The filtration and chlorination process will remove veligers and any mussel shells that pass through the Duplex strainers. All piping and components downstream of the of the water treatment plant are protected from mussel settlement and shell accumulation.

3.2.4: Fire Protection Water

The fire protection water is provided to fire hydrants and to the exterior of the transformers. The fire protection water is drawn directly from the domestic water system after the water has been filtered and chlorinated. The fire protection water is, therefore, not at risk of mussel settlement or shell accumulation.

The drawings provided for our review indicate that there is an automatic sprinkler system in the oil tank room and oil purifier room. We were advised that this system is no longer used and that the fire protection in these rooms is provided by CO_2 gas cylinders. However, in the event that the sprinkler system should ever be reactivated, the existing piping indicates that the water supply to the sprinkler system is taken from the filtered and chlorinated domestic water. The sprinkler system would not be at risk of mussel fouling.

3.3: Physical Characteristics of the Parker Dam and Areas of Concern

3.3.1: Intake Structures

The plant has a floating boat barrier upstream of the spillway and trash rack structures. The trash racks are metal frames with vertical trash bars. The frames cannot be practically removed for mechanical cleaning.

The penstock gates are located downstream of the trash racks by a considerable distance estimated to be 200 yards. Each penstock gate is a fabricated structure with reinforcing webs and flanges. The horizontal webs have holes drilled to allow water to drain as the gates are raised. We observed that some of the holes were plugged or partially plugged by mussels. Plugged holes would trap water in the reinforcing webs and flanges, increasing the weight of the gate as it emerges from the water during lifting. The gate lifting crane capacity will need to be verified to ensure that the gates can be removed if all drain holes are plugged with mussel shells.

There are floating vortex breakers at the face of the dam above the penstocks. These rafts had significant mussel settlement.

Spillway gates have seals that were recently replaced. It is possible that the seal joint could become encrusted with mussels making it difficult to open the spillway gates. The spillway gates are 50ftx50ft structures that weigh 250 tons each. An encrustation of mussels 1 inch thick would add approximately 6-1/2 tons to each gate increasing the load required to be lifted by the gate crane.

3.3.2: Service Water

Service water enters the plant via an 8" supply pipe originating at the dam fore bay face. The inlet at the dam face is covered with a metal grille which will be at risk of mussel settlement. Inside the plant the 8" line forms a supply header which supplies water for the fire protection system and plant service water. The header is connected to each of the unit cooling water lines via branch lines isolated by normally closed valves.

The service water is sent to a treatment plant where it is filtered and chlorinated. After treatment, the service water will not have any mussels present.

The 8" header including the portion embedded in the dam is at risk of mussel settlement. A 6 "line branches from the header and supplies water to the oil sump, oil storage and purifier sprinklers. This line is also at risk of mussel settlement. Sprinklers in the oil room would be at risk of plugging from mussel shells.

3.3.3: Fire Protection Water

The fire protection system takes raw water from the 8" service water header and pumps that water via a 6" header to hydrants, hose racks and transformer sprinklers. We understand that the piping system is leak tight and that fire protection water is not used for any other purposes. The water in the fire protection lines will therefore be stagnant for long periods of time.

3.3.4: Unit Cooling Water

Cooling water for each generator and turbine is taken from the turbine casing. We observed attached adult mussels on the access hatch to one of the turbine casings indicating that mussels can settle and grow in the turbine casing environment. The unit cooling water passes through a Duplex strainer and then into a 10" line where it is distributed to generator air coolers (8 in total per unit), to the turbine thrust bearing cooler, turbine upper and lower seal rings and to the turbine shaft seal packing.

The screen openings on the Duplex strainers are approximately 3/8". The plant is progressively replacing the Duplex strainers with Hayward self cleaning strainers. Based on the model number of the Hayward strainers, we understand that the strainer baskets have screens with 1/8" openings.

Unit cooling water is at risk of mussel settlement. Growth of mussels could reduce flows to any of the heat load areas supplied with cooling water. Shedding of mussel shells could precipitate rapid plugging of cooler piping. We were advised that mussel shells have been found in a turbine shaft seal packing box. This would indicate that the risk of equipment problems is now present.

4.0 Action Plan/Recommendations for Davis and Parker Dams

4.1: Monitoring at Davis and Parker

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

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

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.

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. 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.

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 Common to Davis and Parker

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, Buoys

Inspect boat barriers and manually clean as necessary. If cleaning buoys would damage the buoy material it may be necessary to add or replace buoys to make sure the barrier stays floating even if it experiences heavy mussel settlement.

Inspect spill gates, trash racks and penstock gates at regular intervals. If spill gates are required for safety reasons to be opened within a certain period of time, the inspection and cleaning frequency of the spill gates may need to be adjusted accordingly. Depending on the amount of infestation, these components are usually cleaned using divers or removed from service and allowed to air dry before using pressurized water to clean off the mussels. If 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. 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.

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 one possible area of concern are the penstock drains (if present). 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 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 unless there is a strainer at the beginning of each cooling water line at the junction with the penstock or branch line.

4.2.3: Domestic / Service Water Intake Line and Grille

Both Davis and Parker dams have intake pipes for domestic / service water that originate at the dam fore bay face. This water enters the plant via duplex strainers. These 8” or 10” pipes experience variable flow and are likely to see significant settlement of mussels. These lines may have to be mechanically cleaned at relatively frequent intervals. Until there is better understanding of the quagga population dynamics in this area, inspect and clean if necessary every 3 to 6 months.

Three possible cleaning alternatives should be evaluated immediately for these pipes; pigging, hot water flush and cleaning with expanding air bubbles. This evaluation is required so that a mitigation plan is in place if flow through the intake pipe becomes restricted.

The grilles covering the intakes are most practically cleaned by scraping. A hydraulic vacuum can be used while scraping to collect the debris and prevent it from entering the plant. If the grilles can be readily removed, then coating the grilles with anti-fouling paint would be a good investment.

4.3: Mitigation Recommendations for Domestic/Service Water Systems

4.3.1: Domestic Water System – Davis Dam

Establish a frequent inspection period for any duplex strainers already on this system.

At Davis dam, the domestic water is filtered and chlorinated very soon after entering the plant. Prior to the filtration and chlorination point, a 1-1/2 inch pipe takes raw water to the local air cooler that provides air conditioning for the electrical shop. This pipe and cooler may be first to develop problems due to macrofouling. Frequent inspections of this area are recommended. This pipe and equipment in this area may have to be manually cleaned. A typical method of cleaning small diameter, short runs of piping is isolate the system and have the water in the pipe heated to 90°F for 48 hours or 105°F for one hour. The heat treatment should be followed by flushing of the system to collect shell debris.

The rest of the domestic water system at Davis dam is well protected from macrofouling by mussels.

4.3.2: Service Water System - Parker Dam

Establish a frequent inspection period for any duplex strainers already on this system.

At Parker dam, the service water system is not treated until the service water header exits the dam building into the water treatment plant. The duplex strainer on the service water was inspected in November /07 and significant number of mussels was found colonizing the top of the basket and the body of the strainer.

We suggest that an engineering evaluation be done to determine if the existing baskets in the duplex strainers could be replaced with baskets with smaller holes without compromising the flows in the system. A basket with smaller holes would aid in removal of incoming shell debris.

Alternately, consider replacing the Duplex strainers with self-cleaning strainers capable of removing particles down to 1/8 inch as is being progressively done on the Unit Cooing Water System.

Following the strainer discussed above, installation of a self-cleaning, 40 micron absolute filter should be evaluated immediately on this system. An installation just past the duplex strainer or self cleaning strainer would protect the remainder of the domestic water system from both primary settlement and migrating shell material. Existing shells in the system would slough off over the next 2 to 3 years and exit the system. Typically small pore filters are accompanied by a parallel by-pass line to provide continued operation in the event of a filter outage. In addition to verifying adequate flow with a small pore filter, space requirements will have to be evaluated to accommodate the filter, by-pass piping and valves, and back-wash drain plumbing.

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.

Chlorine injection just prior to the duplex strainer could also be considered. There are numerous ways to configure the chlorination system and this should be done during an engineering analysis.

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.

A secondary risk is that during system testing, shells may be transported into the fire protection system and obstruct flow.

4.4.2: Fire Protection System – Davis Dam

At Davis dam, the fire protection system used to protect the transformers, draws water from the filtered and chlorinated portion of the domestic water. No further action is required on this system. The rest of the fire protection system uses CO_2 and is therefore not at risk.

4.4.3: Fire Protection System – Parker Dam

The fire protection supply comes from the service water supply header 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 checks of the oxygen content should be carried out to confirm that the water in the fire protection piping is too low in oxygen to support mussel growth.

It is likely that any shells approaching the service water piping will exist only in small quantities as some protection is afforded by the Duplex strainers.

Veliger settlement and growth can occur in the service water piping. Therefore to protect the fire water piping from plugging by shells originating the service water piping, the service water system must be kept free of mussel settlement and shells.

4.5: Mitigation Recommendations for Unit Cooling Water Systems

4.5.1 Cooling Water Systems - General

Establish a frequent inspection period for any duplex strainers already on these systems, at both sites.

4.5.2: Cooling Water System – Davis Dam

Currently the only barrier to entry of foreign material into the unit cooling water system is a single Duplex strainer for each unit. Mussel shells with a dimension of 3/8” or less will be able to enter the piping system where they can cause a flow impediment in the generator air coolers, turbine thrust bearing cooler, turbine shaft packing box and turbine upper and lower seal rings. In addition, mussel veligers can settle in the piping and grow causing flow impediments either through accumulated growth or by subsequent shell detachment and migration of detached shells to areas of small diameter.

Based on our inspection in November 2007, it appears that the mussels are present at Davis. It is difficult to judge how immediate or urgent the threat is. The sampling plates we examined and the lack of mussels in the duplex strainer we examined, suggest a low threat at this time. However, photographs taken of penstock gate removed and cleaned prior to our arrival suggest 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.

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. 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.

The rapid response plan could involve use of the Domestic Water System. Davis has the advantage that its Domestic Water System is chlorinated. It appeared from our inspection that it would be practical to connect the Domestic Water system to the Unit Cooling Water System header. By increasing the concentration of chlorine in the Domestic Water, each Unit Cooling Water System could sequentially be given a chlorine flush to dislodge settled mussels. Sequential chlorine injection (sometimes referred to as semi-continuous) has been found to be effective at power stations on the Great Lakes.

We discussed the possibility of connecting the domestic water to this common header and supplying super-chlorinated domestic water to the cooling water system as a rapid response temporary measure in the event there was a sudden and rapid increase in mussel presence. This appeared to be a feasible arrangement.

In the event that it is impractical to use the Domestic Water System as a temporary source of chlorinated water, portable chlorination skids are available as described in more detail in the next section on Parker Dam.

For the longer term, assuming the regulator is prepared to only grant temporary use of chemical treatment methods, mechanical filtration with small pore filter mesh (micro-filtration) should be considered. Also, self cleaning 1/8" strainers (such as the Hayward strainers already in use) to exclude shells combined with ultraviolet UV light to disable veligers from settling should be considered.

An 1100 gpm pump exists in parallel to the generator cooling line presumably to provide additional capacity in low head conditions. This pump may be of assistance if mechanical filtration is selected as a strategy to eliminate mussel settlement and/or to provide more complete shell removal in the line leading to the generator coolers.

4.5.3: Cooling Water System – Parker Dam

Based on our inspection in November and subsequent photos provided by Parker staff of the internals of a Duplex strainer, the mussels are present in significant numbers to be considered an immediate threat.

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.

Parker Dam is already replacing the Duplex strainers with self-cleaning strainers as equipment maintenance demands dictate. This process should be accelerated. In addition, if flow conditions will tolerate, the self-cleaning strainers should have slot size as small as practical. The current slot size at Parker according to the manufacturer's data label is 1/8". Most nuisance shells would be removed at this basket mesh size.

As indicated for Davis Dam, usually the quickest means to prevent mussel settlement or to cause already settled mussels to leave the piping is to create a hostile environment with chemical treatment. 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 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 for maintenance.

Thermal flushes are also an option provided the equipment did not exceed its operating limits. Based on the temperature profile for unit cooling water provided by plant staff, it appears that, for at least three month of the year, the incoming raw water temperature is likely to eliminate any new settlement and may in-fact be high enough to eliminate adult mussels. This assumption needs to be verified through monitoring. If this assumption proves correct, the use of self-cleaning strainers and raised cooling temperature to keep systems free of mussels should be evaluated.

It may be possible to use some of the heated discharge water from the generator air coolers as tempering water fed back to the duplex strainers thereby maintaining the cooling water at near 30°C (86°F) year round. This approach would require a pump, piping modifications, and associated control valves. The advantage of such an approach is that there is no chemical treatment required and existing waste water is used as the heat source for the tempering water. If the station piping layout is amenable to the above modifications, we suggest this option would be the most practical long term solution for Parker dam unit cooling water.

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.

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 (approx. 1 gpm). 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 manufacturers 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.

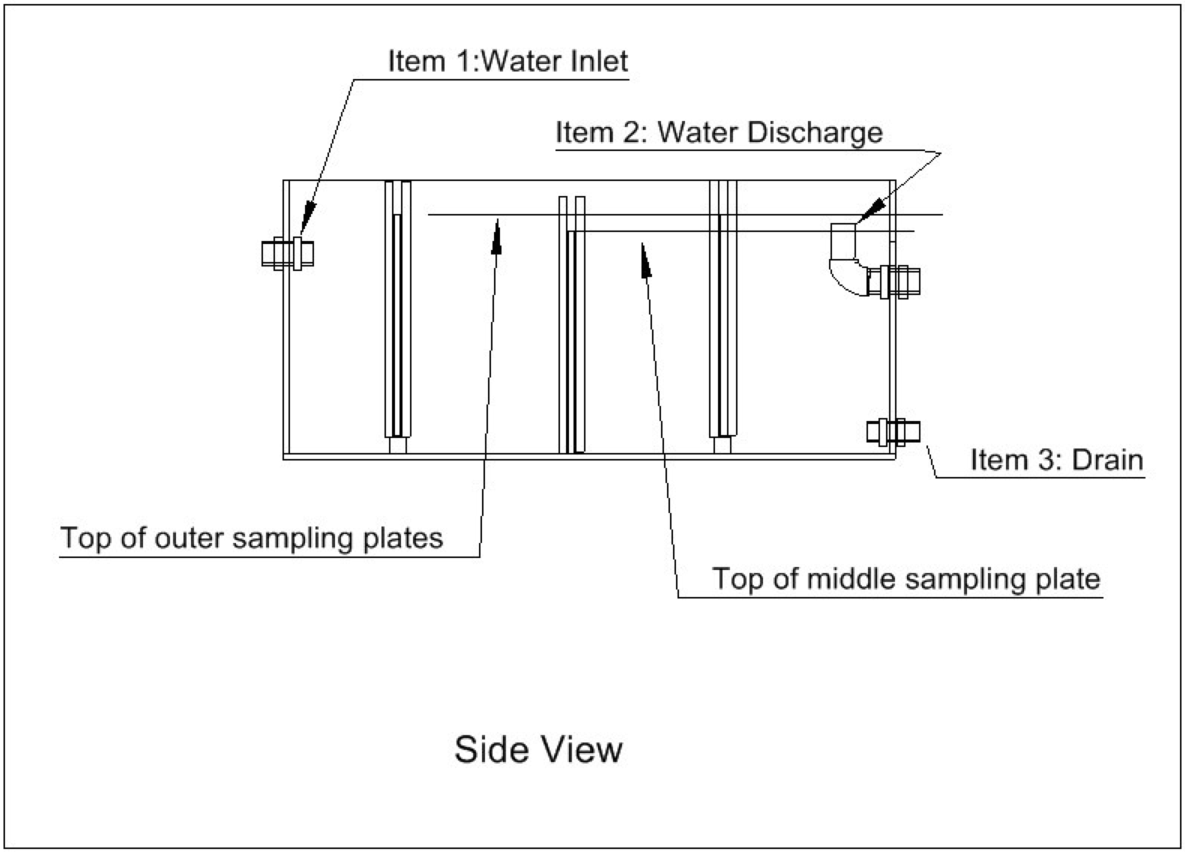
5. Exposed edges should be routered or filed with a bevel to remove the sharp edge.

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.

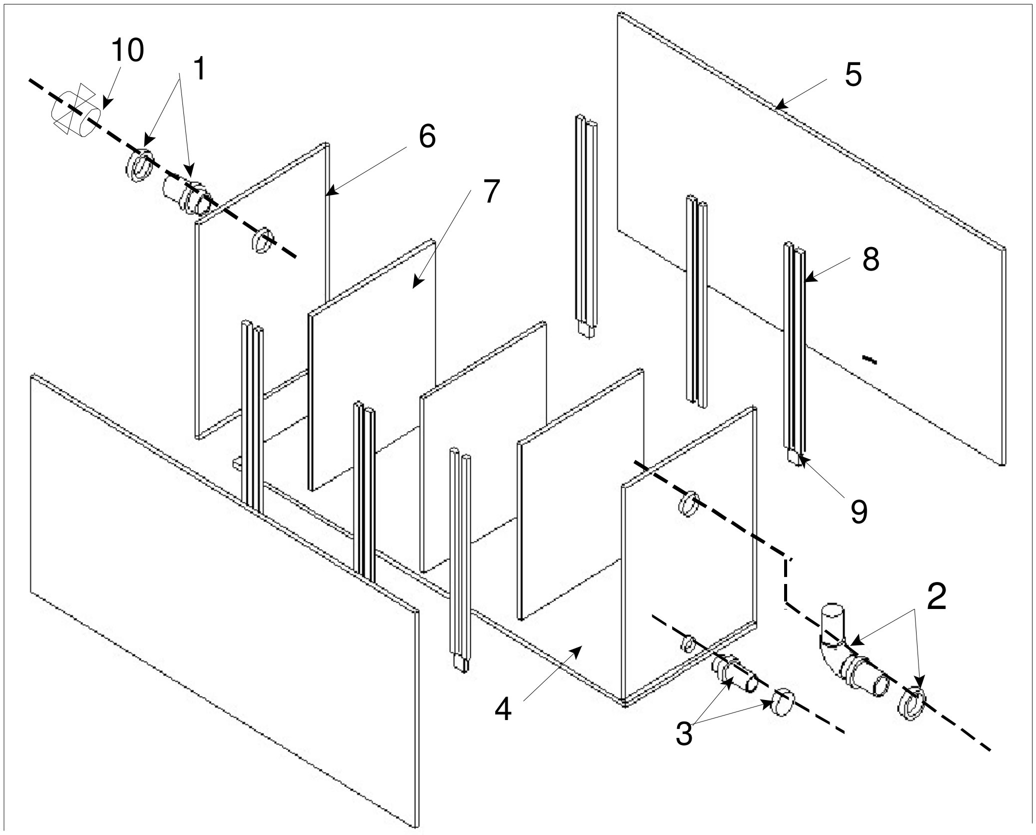
7. The bio-box cavity is divided into four equal chambers by three sampling plates. The sampling plates are removable and slide into slots formed by acrylic guides cemented to the walls of the bio-box. The outer two sampling plates rest on 1" spacers also cemented to the walls of the bio-box thereby 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", Plexiglass 3/8" thick	**1**
5	Side plate, 35-1/4"x15-5/8", Plexiglass 3/8"thick	**2**
6	End plate, 12"x15-5/8", Plexiglass 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", Plexiglass 3/8"thick	**12**
9	Sampling plate spacers, 1"x1", Plexiglass 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

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	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 station temperature limit if it exists	Potential to exceed Equipment 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.
Domestic water or Common Service water	Yes, injection at duplex strainer		Possible. Needs to be approved for drinking water	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 at Parker only, provided waste heat is used	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