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Assessment of the Potential Impact of Invasive Mussels to Water and Power System Facilities and Structures and Recommendations for Control - Willow Creek Reservoir, Granby Reservoir, Shadow Mountain Reservoir, Grand Lake, and Lake Estes, Colorado-Big Thompson Project

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EXECUTIVE SUMMARY

The Bureau of Reclamation's (Reclamation) Colorado-Big Thompson (C-BT) Project harnesses the Western Slope headwaters of the Colorado River. On a long-term average the project collects and delivers approximately 215,000 acre-feet of water annually. The focus of this report is on the water and power system structures at five reservoirs of the C-BT Project: Willow Creek Reservoir, Granby Reservoir, Shadow Mountain Reservoir, Grand Lake, and Lake Estes. The remainder of the C-BT facilities will be assessed at a later time.

During 2008, dreissenid veligers were found in Willow Creek, Granby and Shadow Reservoirs and Grand Lake, which are the headwaters of the C-BT Project. The veligers were found by microscopic examination of the plankton collected and later verified as veligers through genetic fingerprinting technique. No adults have been found in any part of the Project up to this point and no veligers have been found in Lake Estes.

In November 2008, RNT Consulting Inc. (RNT) was asked by the Eastern Colorado Area Office, Reclamation to examine the principle storage features at the head of the system as well as the structures associated with them, provide an assessment of the vulnerability of these structures, and make recommendations on possible control and management strategies.

As part of the evaluation, RNT briefly examined the environmental parameters in each body of water involved. Although examination of environmental suitability for mussel survival was not part of the contract requirement, some idea of environmental suitability is helpful when assessing the magnitude of risk to facilities and structures. This effort by no means replaces a full scale assessment of environmental suitability.

Because few studies have been completed on, and there is not a good understanding of, marginal habitats in the west, this evaluation was based on the experience in the Great Lakes, the eastern portion of North America and in

Europe. Data available indicate that the calcium levels in Grand Lake, Granby and Shadow Mountain Reservoirs are below those likely to support veliger survival and possibly even long term survival of adults. Given the importance of calcium to mussel development and survival, further monitoring of calcium in C-BT waters may be warranted to determine if there are any previously unknown micro-zones with higher calcium levels. The presence of concrete is unlikely to create calcium enriched zones except in water bodies with pH below 7.0. Dreissenids are not known to survive at pH below 7.0

Notwithstanding that mussels will not thrive and probably not survive in the calcium-poor waters of the C-BT Project, the facilities were evaluated assuming that mussels could survive in the C-BT waters. The parts of the facilities examined that would be subject to risk of fouling should the mussels survive in sustainable numbers were identified.

Gauging stations are an important component of managing the C-BT water resources and the stations would have some risk of reduced performance if mussel settlement occurs. Additional cleaning of the stations may be required. An advantage of these stations is that there is a regular program of inspecting the stations. This inspection program could allow the stations to function as monitoring locations for mussel arrival.

Intake structures such as trash racks, screens, grates and intake towers are ideal mussel settlement areas and increased inspection frequency as well as increased cleaning effort may be required among other control or mitigation actions.

Water conveyance structures such as piping, siphons, and parts of canals would likely require some increased inspection frequency and cleaning.

Some minor risks for pumping plant and power plant systems that use raw water were identified. It is likely that chemical treatment methods to protect the plant systems will not be acceptable due to the reliance of the area on sport fishing. Small-pore self-cleaning filters or UV systems are possible alternative protection methods should they become necessary and if they are suitable for specific systems.

Overall, it is recommended that Reclamation and its partners implement and maintain a monitoring program to verify continued presence of dreissenid veligers and to find adult mussel colonies which produce these veligers. Verifying presence of surviving adults in this environment would greatly change the risk assessment for other bodies of water in the west.

1.0 INTRODUCTION

The C-BT Project stores, regulates, and diverts water from the headwaters of the Colorado River. On average the project collects and delivers approximately 215,000 acre-feet of water annually. The water is transported from the western slope of the Continental Divide to the eastern slope through the 13.1-mile Alva B. Adams (Adams) Tunnel. The entire project contains more than 100 major structures. The focus of this report is on the water and power system structures at five reservoirs of the C-BT Project: Willow Creek Reservoir, Granby Reservoir, Shadow Mountain Reservoir, Grand Lake, and Lake Estes. The remainder of the C-BT facilities will be assessed at a later time.

The principal storage facilities in the western slope part of the system are Willow Creek Reservoir, Granby Reservoir, Shadow Mountain Reservoir and Grand Lake.

Water from Willow Creek Reservoir is pumped to Granby Reservoir. Granby Pumping Plant lifts the water up to 125 ft from Granby Reservoir to Granby Pump Canal. The canal conveys the water 1.8 miles to Shadow Mountain Reservoir which also intercepts North Fork flows of the Colorado River. Shadow Mountain Reservoir connects with Grand Lake to make a single body of water from which diversions flow to the Adams Tunnel to begin the journey to the eastern slope.

Emerging from Adams Tunnel into the East Portal Reservoir, the water flows across Aspen Creek Valley in a siphon and then under Rams Horn Mountain through a tunnel. At this point, it enters a steel penstock and falls 205 ft to Marys Lake Power Plant. This power plant is located on the west shore of Marys Lake, which provides afterbay and forebay capacity for reregulating the flow. These facilities and structures were not evaluated as part of this effort. Between Marys Lake and Estes Power Plant, on the shore of Lake Estes, the water is conveyed by Prospect Mountain Conduit and Tunnel and Estes Power Plant penstocks.

Lake Estes, below Estes Power Plant, is formed by Olympus Dam constructed across the Big Thompson River. The afterbay storage in Lake Estes and the forebay storage in Marys Lake enable the Estes Power Plant to meet daily variations in energy demand.

During 2008, dreissenid mussel veligers were found in all four west slope headwaters of the C-BT Project on several sampling dates by multiple agencies. The veligers were found using cross-polarized light microscopy. Their presence was verified with DNA detection in plankton samples using PCR-based analyses, currently at the cutting edge of early dreissenid detection. The polymerase chain reaction (PCR) is a technique widely used in molecular biology. It derives its name from one of its key components, a DNA polymerase used to amplify a piece of DNA by *in vitro* enzymatic replication. As PCR progresses, the DNA generated is used as a template for replication. This sets in motion a chain reaction in which the DNA template is exponentially amplified. With PCR it is possible to amplify a single or few copies of a piece of DNA across several orders of magnitude, generating millions or more copies of the DNA piece. This allows for genetic fingerprinting of the biological material under examination. In this case it allows for verification of suspected veligers found by microscopy. At this time the PCR technique is not foolproof, occasionally yielding results in direct contradiction to those obtained by microscopy.

No adults have been found in Project waters to date and no veligers have been found in Lake Estes.

Quagga mussels are members of the dreissenid family of bi-valves. Together with their sister species, the zebra mussel, these non-native, invasive mussels are an environmental and economic nuisance to North America.

Dreissenid mussels are aggressive bio-foulers. When present in the source of raw cooling water, they become a serious problem for industrial facilities using this water unless control actions 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 accumulate and grow in place resulting in reduced water flow rates and in some cases can 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, heat exchangers, and other system components.. 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 C-BT Project has been monitored for the presence of dreissenid mussel since 2007. When veligers were found in 2008, Reclamation decided to take proactive steps and evaluate the susceptibility of various structures and facilities on the headwater reservoirs to mussel fouling. RNT was engaged to lead the process and to make the evaluation methodology available to Reclamation for use on other facilities.

This report is a summary of the findings on:

- Preliminary, calcium-based assessment of environmental suitability of the C-BT system for mussel invasion
- Areas of the various facilities 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 RNT believes are practical options for dreissenid 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

Reclamation provided RNT with flow diagrams and, in some cases, general arrangement drawings of raw water piping systems at each of the facilities. RNT studied the drawings prior to commencing the site visit in November 2008. The site visit team consisted of staff from RNT, Reclamation, and the Northern Colorado Water Conservancy District (Northern Water). At each facility, the team inspected all accessible areas from trash racks to discharge, identifying various components and cooling systems previously highlighted on the drawings. During these inspections, the team was able to identify the potential threats and impacts to the systems and to individual components.

In addition, available environmental data available was examined for each water body and each body of water was visited by the team.

3.0 RESULTS of the ASSESSMENT

3.1.: GENERAL ENVIRONMENT REQUIREMENTS MUSSEL INFESTATION

Koutnik and Padilla (1994) used a geographical information system (GIS) to test for associations between predicted lake population density classes and three landscape-scale characteristics (surficial deposits, bedrock type, ecoregions) to predict (i) absence or presence, (ii) categorical population density, and (iii) numerical abundance of zebra mussels for inland Wisconsin lakes. Although the models used differed in their predictions of specific lakes that would support Dreissena, they found a significant association between each landscape-scale characteristic and Dreissena density classes. Numerous researchers (see Table 3) have used available lake monitoring data to predict Dreissena density for inland lakes. It is clear that the more information available, the less uncertainty in the predictions.

Some parameters have better correlation with mussel survival and density than others. The most common parameters used (and listed in order of their predictive value from most predictive to less predictive) are:

- calcium content
- alkalinity, total hardness
- pH
- nutrients (total phosphorous, total nitrogen, chlorophyll *a* levels)
- Secchi depth
- dissolved oxygen content
- mean annual temperature
- conductivity (and/or salinity, total dissolved solids)

Although mean annual values of each of the parameters can be used, temporal (e.g. seasonal) and spatial (e.g. depth, horizontal) variations lend more certainty to the predictions of mussel survival and potential densities.

Calcium, alkalinity, pH, and total hardness are considered “chalk” parameters as they are generally related to the water mineral content. Of the chalk parameters, the calcium level is by far the most used and most reliable. The alkalinity informs us of the availability of the calcium. The total hardness consists of temporary hardness (i.e. amount of calcium and magnesium) in carbonate form and is similar to alkalinity values and permanent hardness (i.e. the amount of calcium and magnesium in non-carbonate form that is largely unavailable to mussels). The pH governs the form of carbonates, pH values below 8.2 having all the calcium in bicarbonate form and values above 8.2 having the calcium in monocarbonate form. Removal of carbon dioxide (e.g. by photosynthesis of plants and algae) results in precipitation of calcium carbonate, making it unavailable to mussels. Hence, while calcium is the key variable, knowledge of the values of the other chalk variables are also important in predicting densities of dreissenids.

The nutrient parameters (e.g. total phosphorous and nitrogen), chlorophyll *“a”* levels, Secchi depth, and dissolved oxygen content are known as “trophic indicators” and are all related. The higher the values of the nutrient variables, the greater the biomasses of algae and hence chlorophyll *“a”* and dissolved oxygen (at the surface), and the lower the Secchi depth values (i.e. water is more turbid). Since mussels feed on algae, the values of the trophic indicators are also important criteria for predicting dreissenid densities. Total phosphorous should be used when phosphorous is the limiting nutrient; whereas, total nitrogen should be used when nitrogen is limiting.

Dissolved oxygen in deeper waters of lakes and reservoirs may become a limiting factor during portions of the year. Seasonal oxygen profiles should be verified in all bodies of water examined.

Conductivity and mean annual surface water temperature are the only physical criteria used. Temperature becomes critical when the body of water in question is close to either the upper or lower thermal limit for veliger survival. Conductivity is rarely an issue, but it should be verified in all cases.

Studies using various parameters to assess risk potential of dreissenid invasion and densities are listed in a table in Appendix 1.

The following table was derived from the values reported by various authors and gives the ranges of values for each of the parameters and the potential risk of invasion. The key parameter is calcium content and its availability. Its availability becomes a question only if the pH is high. Ideally, seasonal risk potential should be assessed on monthly data collected over several years.

Criteria used in determining levels of infestation in temperate zone of eastern portion of North America and Europe

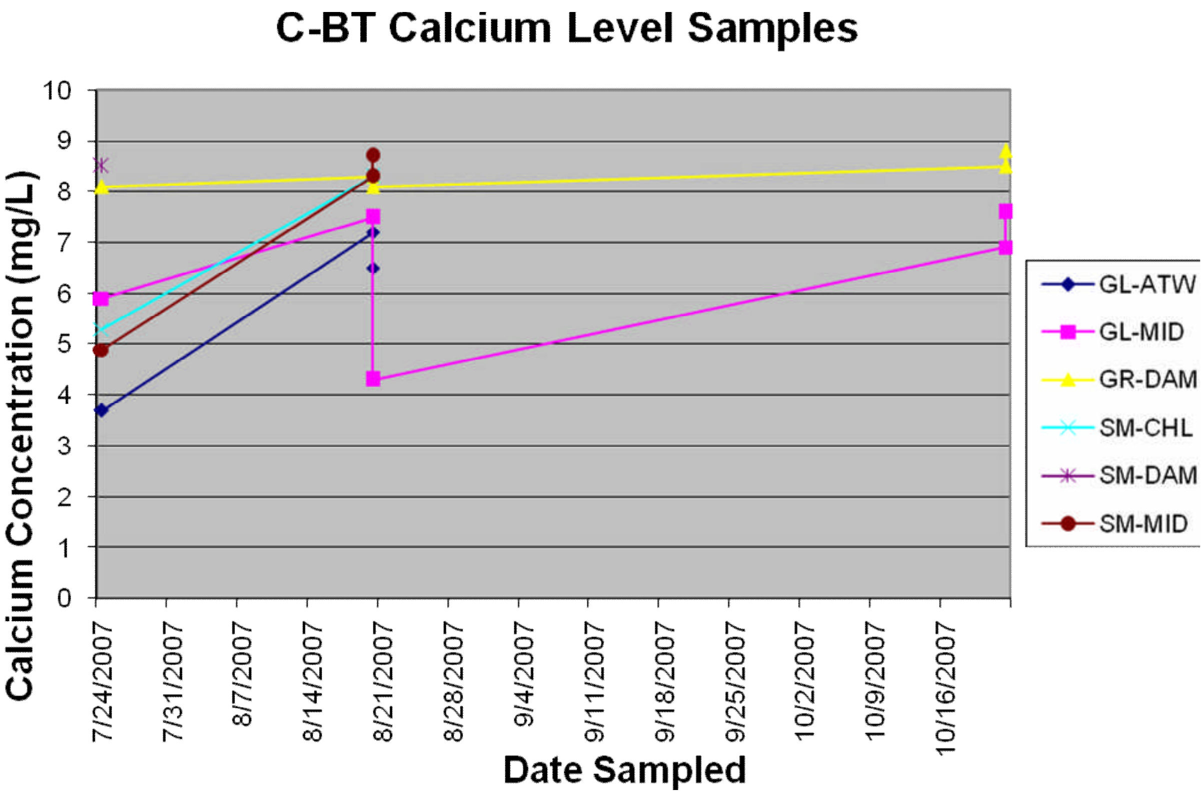
Parameter	None	Little	Moderate	High
Calcium mg/L	<10	<16	16-24	≥24
Alkalinity mg $CaCO_3$/L	<35	35-45	45-89	>90
Total Hardness mg $CaCO_3$/L	<40	40-44	45-90	≥90
pH	<7.2	7.2-7.5	7.5-8.0 or 8.7-9.0	8.0-8.6
Mean Summer Temperature ^oF	<64	64-68 or >83	68-72 or 77-83	72-75
Dissolved Oxygen mg/L (% saturation)	<6 (25%)	6-7 (25-50%)	7-8 (50-75%)	≥8 (>75%)
Conductivity µS/cm	<30	<30-37	37-84	≥85
Salinity mg/L (ppt)	>10	8-10 (<0.01)	5-10 (0.005-0.01)	<5 (<0.005)
Secchi depth m	<0.1	0.1-0.2 or >2.5	0.2-0.4	0.4-2.5
Chlorophyll a µ/L	<2.5 or >25	2.0-2.5 or 20-25	8-20	2.5-8
Total phosphorous µg/L	<5 or >35	5-10 or 30-35	15-30	10-15
Total Nitrogen µg/L	<200	200-250	250-300	300-500

3.2.: SUITABILITY of C-BT WATERS for DREISSENID MUSSEL INFESTATION

This assessment was done based on the limited data available, provided by Northern Water, for the various bodies of water contained in this portion of the C-BT Project. As the most important parameter to consider is calcium, we examined available calcium values first. This dataset did not include calcium values for Willow Creek Reservoir or Lake Estes, therefore they were not evaluated. Calcium data for the aforementioned two water bodies should be obtained and evaluated.

Calcium	Maximum –mg/L	Minimum – mg/L
Grand Lake	7.6	3.7
Granby	8.8	8.1
Shadow Mountain	8.7	4.9

The following graph shows calcium level data collected from Grand Lake at the west portal (ATW) and mid-lake (MID), Granby Reservoir at the dam and Shadow Mountain Reservoir at the dam (DAM), mid-lake (MID) and channel (CHL). This data indicates that at none of the sampling sites in Grand, Granby or Shadow Mountain did calcium exceed 9 mg/L.



The pH levels in the available data were highly variable in all three lakes. The pH generally decreased with depth and hovered around 7.0 near the bottom. The pH of the surface waters was as high as 9.5 at SM-MID station in June 2005, and as low of 6.89 in July 2005 at the same sampling site. There were several such anomalies in the pH data. For example on November 6, 2006 the pH at Granby Dam site was between 6.2 and 6.5 throughout the water column, while data for October 2006 was recorded as high of 7.76 at the surface and 7.28 on the bottom. Comparison of the data available to a historical database is outside the scope of this report.

Experience from Lake George in New York State suggests what the borderline conditions for calcium and pH may be for zebra mussels. Hansen et .al 1998 document that calcium of 10.68 mg/L +/-1.17 mg/L and pH of 7.56 +/- 0.18, both 10 year averages, have supported a very low level of zebra mussel presence in Lake George for the last 10 years. A confounding factor in Lake

George is the presence of scattered limestone deposits which may be creating microzones for dreissenid survival. This could mean that without these microzones both the calcium and the pH might not be adequate for long term survival.

Studies by Nierzwicki-Bauer et al. in 2000 documented that adult mussels are able to survive in Lake George water (Ca=12 mg/L, pH=7.15) but veligers fail unless both calcium and pH levels are raised. The study placed healthy veligers, up to two weeks of age in Lake George water. There was 100% mortality of the veligers within one week.

Hincks and Mackie (1997) tested adult survival, juvenile growth rates and veliger production against different concentrations of calcium, alkalinity, total hardness, chlorophyll and pH, by rearing adults and newly settled juveniles collected from Lake St. Clair in water from 16 Ontario Lakes. Six of these lakes had mean calcium levels below 8.5 mg/L and mean pH of 8.4 or less. In these low calcium waters all adults died within 35 days, juvenile growth rates were near zero or negative, and no veligers were produced. The other ten lakes all had mean calcium levels of 20-48 mg/L and mean pH of 8.2-9.3. In these waters adult survival was 52-100%, juvenile growth rates ranged from 3 to29 µm/day (low compared to rates measured in the field in Lake St. Clair of up to 125 µm/day), and very small numbers of veligers were produced, from 0 to 7 veligers from an initial population of 21adults.

Cohen and Weinstein (2001) in their extensive review of calcium requirements of the zebra mussel concluded that “Experimental data suggest that populations cannot be sustained where calcium levels are below 15 mg/L, although there are few reports of zebra mussel veligers from inland lakes with calcium measurements in this range, and adults in Lake George in a small area with possibly higher calcium than the levels usually reported for the lake.”

The recorded lack of calcium in the headwaters of the C-BT Project is supported by the following observations:

- Perceived lack of native or introduced bivalves. No Asian clams have been reported by any pumping station on this portion of the system. (Fingernail clams were collected further down the C-BT below the Olympus Dam of Lake Estes and Asian clams have been reported in the Rams Horn Tunnel between E.Portal and Marys Lake as reported by Reclamation)
- No record of snails by any pumping plant on this portion of the system
- No calcium deposits in 50+ year old system piping

The requirement for calcium by the quagga mussels, although not precisely established, is assumed to be in the same range as for zebra mussels.

In summary, the calcium levels in Grand Lake, Granby and Shadow Mountain Reservoirs are below those likely to support veliger survival and possibly even long term survival of adults. It is possible that scattered limestone deposits may exist in the area, and these may be creating micro-zones for dreissenid survival similar to that which is occurring in Lake George, NY. A review of the geology of the lakes is needed to confirm or reject this possibility.

Concrete structures contain calcium largely in the form of insoluble calcium silicates. Liquid water moving through concrete can cause a steady deterioration of these materials by leaching out the calcium from the calcium silicate bonding materials. Leaching of calcium from the concrete reduces the concrete strength and is undesirable. The calcium that is leached out is soluble in water and therefore available to mussels. This leaching action is most pronounced with soft or mildly acidic waters such as are found in reservoirs fed from swampy areas. The rate at which leaching occurs is a function of many variables including the pH of the water, and the presence of additives that improve the performance of concrete in water environments. Civil structures such as dams are typically designed to have a life of 100 years so the leaching process is bound to be very slow. Other structures such as boat launching ramps, retaining walls and canal linings would possibly have concrete compositions that may be less resistant to leaching than major civil structures but would still have slow leaching rates. The C-BT reservoirs have water with pH that does not promote leaching. Any leaching that would provide sufficient calcium to support mussel growth would likely be in quiescent areas that are not flushed continuously. Any such areas would be good candidates for monitoring stations to provide early indication of adult mussel presence. It is important to note that water conditions that promote leaching of concrete also promote leaching of the mussel shell requiring the mussel to have access to an ongoing supply of calcium to maintain its shell. Otherwise mussel mortality will occur. Therefore any mussels located in areas where calcium may be sufficient to support mussel growth would not necessarily place the main water bodies at risk.

Without sufficient calcium, all other parameters become insignificant criteria. Only if calcium was considered borderline, then other parameters such as pH, dissolved oxygen, chlorophyll *"a"* and temperature should be examined in detail.

3.3: REVIEW OF C-BT HEADWATERS AND LAKE ESTES FACILITIES

Notwithstanding the conclusions reached above that mussels are unlikely to be able to establish reproducing populations in the C-BT Project waters, a selected number of facilities and structures were evaluated for areas of risk **should mussels become established**. The observations and recommendations apply to both zebra and quagga mussels.

3.3.1: INSPECTING for MUSSEL ACCUMULATION

Presence of mussels requires vigilance to ensure timely response to clean structures to maintain performance. Inspection frequency of structures needs to be related to the rate at which the mussels accumulate and the tolerance of the particular structure to mussel growth. There is a significant diversity of structures and equipment within the C-BT system so it would be poor use of resources to give a single inspection interval. In addition, the number of breeding cycles and rate of growth of mussels in this particular environment has not been established by measurement.

There are existing programs of regular equipment, dam, and other structural inspections that occur at various timings. Where practical, mussel inspections should be combined with the regular inspections to make most effective use of labor resources. However, initially the inspections should be no less frequent than quarterly. It is suggested that once the presence of settling mussels is detected, that all structures be inspected to establish the baseline condition and that quarterly inspections continue until the accumulation pattern is established on each structure or component. Once a degree of comfort is reached that the rate of accumulation is known, inspection frequencies can be adjusted accordingly.

Cleaning cycles may be timed to coincide with other normal operations tasks such as cleaning trashracks when the water level is lowered and maintenance access is easier.

3.3.2: GAUGING STATIONS

Dispersed throughout the C-BT Project there are gauging stations used to track the water levels in the various water bodies and the movement of water between the water bodies. The gauging stations usually include a tap line, stilling well and float. The inlet pipe could become colonized with mussels and could impair the accuracy of the gauging station where there are frequent or sudden changes in flow and levels. For locations where flow rates and water levels change very slowly, there may not be a reduction in accuracy as a plugged pipe would still allow water to percolate to the stilling well. The floats could have sufficient mussels attached such that the level readings become unreliable. The gauging stations are inspected frequently and cleaned regularly. Cleaning of the tap line should be added to the regular cleaning procedure, especially if mussels are found in the stilling well or on the floats. The normal observation and maintenance program should be able to keep the stations free of mussels. In addition, the frequent inspection of the gauging stations means they could be used as natural mussel monitoring locations with only a little extra effort on the part of the operations and maintenance staff to check for mussel veligers or small adults on the floats.

Should the mussels become established and the cleaning of the gauging stations becomes an onerous task, the use of non-contact instrumentation such as ultra-sonic or infra-red level probes can be considered.

3.3.3: WILLOW CREEK RESERVOIR

The Willow Creek Reservoir is formed by the Willow Creek Dam. Water from the reservoir is transferred to Lake Granby via the Willow Creek Pumping Plant and canal system. The head works to the intake canal are protected by trash racks.

In part, the dam outlet structure provides water to the McQueary Ditch, which is subsequently used for agriculture. The intake to the outlet structure is a hexagonal tower with metal trash racks on each face of the tower. The tower discharges through a concrete pipe to a stilling basin and subsequently to the McQueary Ditch. However, a significant amount of the discharged water continues down Willow Creek.

The discharge delivery pipe from the outlet structure will be at risk of mussel settlement. If water flow in this pipe can be stopped for a 1-month period and the walls of the pipe are allowed to dry, the mussels will die from desiccation. Subsequent flow will flush out the dead mussels. If this pipe is normally kept flooded, then mussel build up will occur and over time the flow will be reduced. The pipe is too large to become totally blocked so it is unlikely that the flow will be stopped by mussel accumulation. If some flow reduction is acceptable then the pipe will probably not require manual cleaning.

Trash racks at the canal head works and the outlet structure tower will be at risk of mussel settlement. Trash racks are ideal settlement areas for mussels as the flow around trash racks is slow to allow easy settlement and provides a continuous source of fresh nutrients. Periodic inspection and manual cleaning as required is recommended for these structures. It is understood that the normal inspection and cleaning cycle of trash racks in the C-BT system is 5 years. If mussels become established in this area, then inspection frequency should be increased to a quarterly basis until experience is gained with the rate at which the mussels accumulate on trash rack structures. Should cleaning become frequent and constitute a maintenance nuisance then consideration could be given to removing the grates and painting them with an anti-fouling paint or foul release paint. Foul release paints have performed well even in areas of low flow such as quiescent portions of pump wells.

3.3.4: WILLOW CREEK PUMPING PLANT and CANAL

Willow Creek Pumping Plant takes water from the Willow Creek Reservoir via an intake canal and lifts this water to a delivery canal. The water flows in the delivery canal by gravity to Granby Reservoir. Willow Creek is a seasonal pumping plant, operating from May until November. During the winter season, the pumps and equipment are drained and winterized and any accumulated mussels would die by either freezing or desiccation.

During the summer pumping months, there would be time for mussels to settle and grow only to a small size. The limited time for settlement and small amount of growth that would occur means that there would be little to no effect on the main piping or flow capacity.

There is no requirement for pump cooling water as the pump motors are normally air cooled. There is an auxiliary ambient air cooler that is chilled by raw water. This cooler is drained and winterized each year and any mussels that managed to settle would die before the following pumping season. There may be some extra maintenance on the auxiliary air cooler to ensure it is cleaned of mussel debris before being put into service each year.

Domestic water is provided by a well that will be free of mussels.

There is no fire water system. Fire protection is provided by chemical extinguishers.

The discharge from the pumps travels through a pipe that delivers water to the delivery canal leading to Granby Reservoir. The discharge piping will be at risk of mussel settlement. The increased roughness of the piping caused by mussel settlement and growth will increase the pumping power required. When mussel accumulation is observed that could result in unacceptable increased pumping costs, the delivery piping should be cleaned of mussel debris during the winterization program when the discharge pipe is drained and before the pumping plant is put into service the following season.

The delivery canal consists of various concrete structures including a flume, siphons and delivery chute. The walls of the delivery canal have steeply slopping sides. Mussel attachment is possible on the concrete structures and sides of the canal. The bottom of the canal is likely to have some sediment deposition. Mussels will not settle on soft sediment unless there are some firm pieces of substrate present (pop cans, rocks, dead shells and so on). The floor of concrete structures will tend to be scraped or brushed clean of mussels by debris if there is sufficient flow to move debris along the floor of structures. Mussels will therefore accumulate on the sides of structures because the floors of the structures will either have an inhospitable environment of sediment or regular scraping by small debris moving along the floor. Most mussel shells that slough off from the sides of these structures will join the sediment on the floor of the canal. There should be little mussel settlement on the floor of the canal only accumulation of shell debris.

The flow from the canal into Granby Reservoir can be isolated by a stop log structure. In the winter the delivery canal is isolated from Granby Reservoir and the canal is drained. During the drained period, accumulated mussels will die by either freezing or desiccation. The mussels that accumulate on the canal surfaces will be at most one season old. The dead shell debris would subsequently be carried into Granby Reservoir the following spring. The debris should be harmless to the reservoir.

3.3.5: GRANBY DAM

Granby Reservoir is formed by Granby Dam and four dike structures. The dam has a diversion and outlet tunnel. The entrance to the outlet works is a six sided tower, similar in concept to that at Willow Creek Reservoir. The tower trash racks would be at risk of mussel settlement and growth. The racks should be inspected and cleaned as necessary, similar to Willow Creek.

The outlet tunnel has a control valve chamber at approximately mid-length along the outlet tunnel. Upstream of the control valves, the tunnel is continuously flooded and significant mussel accumulation could occur in this portion of the tunnel. As the tunnel is 11.5'- ft diameter, it is unlikely that mussels could cause a tunnel blockage. However, there could be some flow reduction due to mussel accumulation. If the tunnel is required to pass a predetermined maximum flow for dam safety reasons, then the mussel accumulation that can be tolerated needs to be assessed and the tunnel cleaned as required. Any vent lines should be inspected and cleaned of mussels prior to draining any pipes or inter-valve chambers.

The downstream portion of the tunnel will not normally have its tunnel walls continuously wetted. Mussel accumulation will preferentially occur on the floor of the tunnel where there will likely be some continuous flow of water. Cleaning of this portion of the tunnel will likely be easier as the downstream section can be more easily isolated to allow access for cleaning crews.

The dam spillway is controlled by two 21 x 20-ft radial gates. Because the gate motors are sufficiently powered, some mussel accumulation in the seal areas will not likely cause opening problems. The gate side seals are rubber tubes that bear against metal side wall plates. There may be some slight abrasion from trapped shells at the seal / side plate interface as the gate is opened or closed. The lower gate seal is similarly a rubber tube bearing against a metal sole plate. The bottom seal should be flushed by fast flow as the gates close. When the gate is closed, it is possible some mussel shells could be trapped at the bottom seal or settle and grow at the bottom seal and some minor scoring of the rubber seal could occur when the gate is opened. Fouling of the gate face should not add sufficient weight to cause opening problems.

The attachment of mussel byssal threads to metal structures creates an anoxic area for pitting corrosion to occur. Some pitting corrosion may be acceptable to the dam engineers based on the material corrosion allowances of the original design and the presence of general corrosion protection such as impressed currents. However, if pitting corrosion cannot be tolerated, the gate face should be cleaned of mussels any time the water level drops below the level of the gates. If water levels do not expose the gates, inspection and cleaning by divers should be done annually, to reduce pitting corrosion.

3.3.6: FARR PUMPING PLANT

This plant is located on the north shore of Granby Reservoir and transfers water from Granby to Shadow Mountain Reservoir. The water is lifted to its maximum elevation via a pipe and discharged at the outlet of the pipe into an open channel where it flows by gravity to Shadow Mountain Reservoir. Reverse flow in the discharge conduit is possible via a siphon effect and a vacuum break valve is provided should it become necessary to break the siphon effect.

3.3.6.1: Intake

The intake structure is a 40-foot tall tower located 580 feet off shore into the lake. The tower comprises a massive wall with six vertical intake opening segments forming a semi-circular arc on one side of the wall and three 7.25-ft diameter intake pipes through the other side at the base of the wall proceeding to the pump plant.

The wall has slots to accommodate bulkhead isolation gates that allow the three intake pipes to be isolated individually. The six intake openings also have slots for stop logs to allow the intake tower to be isolated from the lake.

The intake structure and pipes leading to the plant are concrete, which would provide an ideal settlement substrate for mussels.

There are 6 sets of intake trash racks, one covering each of the 6 intake opening segments. The trash racks are likely to be heavily infested should mussels arrive in the area. The flow around trash racks is slow to allow easy settlement and provides a continuous source of fresh nutrients. Semi annual inspection is recommended initially. Inspection intervals can be increased once mussel accumulation patterns are established. Inspections will need to be done by divers or remotely operated cameras to determine when the racks will require cleaning. Cleaning will have to be done by divers. A scrape and vacuum method is highly recommended in order to minimize the shell debris coming into the plant.

Should cleaning become a serious operational burden, consideration could be given to painting the trash racks with proven anti-fouling paint or foul release paint as a possible longer term solution.

Past the trash racks, the entrance into each pump intake tube can be isolated by means of a bulkhead gate suspended above the intake opening. The lower portion and toe of the bulkhead gate appears to be immersed in lake water when the gate is in the stowed position. This lower area of the gates would be prone to mussel fouling and may result in a poor seal when the gate is lowered into the isolation position. Consideration could be given to raising the position of the gates when stowed if this is possible. Alternatively, the gates should be inspected and cleaned before being lowered into the isolation position

It is normal that an intake structure is oversized and can accommodate some fouling. The mussel population density and amount of fouling that can be tolerated will therefore govern the frequency of cleaning.

Fouling of the intake structure will also mean that the intake will become a source of adult mussels or dead mussel shells that can be transported into the plant service water systems.

3.3.6.2: Pumps

The three intake pipes connect individually to the three vertical pumps located in the pumping plant. Each pump is powered by a 6,000-HP electric motor. The motor windings, motor thrust and guide bearings, pump guide bearing and pump shaft seal all require cooling water.

Cooling water for each motor and pump is taken from the pump discharge. This water then passes through a duplex strainer before being delivered to the various cooling loads. The screens on the strainers have 0.25-in mesh openings.

The strainers are effective at preventing adult mussels or mussel shells large enough to cause plugging problems from entering into the piping system. However, veligers will readily pass by the strainers and could settle in areas of the piping that are not made of copper or copper alloy.

The unit cooling water serves the main pump guide bearing, the motor guide and thrust bearings, and the motor air coolers. The inlet plenum and outlet plenum of coolers is typically at risk of veliger settlement unless these portions of the components are made from copper or copper alloy. In addition, the inlet plenum of a cooler is typically a catchment area for any shells that manage to find their way along the upstream piping and shell material can gradually accumulate in the plenum ultimately blocking tubes and causing poor performance of the coolers. If poor cooler performance is detected, the maintenance personnel should be advised that mussel shell accumulation is a possible cause. Follow the manufacturer's recommendations or existing operating procedures to isolate the cause of the poor performance, inspect the heat exchanger for mussel fouling and clean the heat exchanger. Incorporate mussel fouling as a possible cause in any plant troubleshooting guides. Note if mussels in heat exchangers (or other fouled equipment for that matter) are alive and attached or if the fouling is dead shells only. Fouling that is dead shells only indicates there is a source of dead mussels upstream of the heat exchanger and a coarse filter could be considered to protect the heat exchanger. Live attached mussels indicate that veligers have settled in the equipment. Preventing veligers from settling in equipment requires more complicated barriers such as fine pore filtration, UV or chemical treatments.

As a general guideline, if temperatures in the cooling water are below 90° F, water flow is less than 6 ft/sec and the tubes are non-copper, then the tubes could become settlement areas for mussels.

The pump shaft seal water system is supplied with filtered water only during pump start up. During normal running, the seal cavity may be exposed to small shell fragments and some increased wear may be experienced. The seal cavity may become a settlement area for mussels and will need to be inspected and cleaned per manufacturer instructions if seal cavity temperatures rise above permitted levels.

Any instrument using raw water could attract mussel settlement. If the lines have no flow, such as pressure sensing lines, then the settlement is likely to occur near the tap end of the line where oxygen and nutrients are available for the mussels. RNT suggests that the lines be monitored for any irregular readings if mussels are present at the plant. The lines can be cleaned by flushing with a weak organic acid. Hot water or compressed air are alternative methods of cleaning.

A 30” diameter float well pipe is located at the pump plant to monitor the surface elevation of Granby Reservoir. The pipe walls as well as the float will be at risk of mussel settlement. Mussel accumulation on the float will cause unreliable level detection. The floats should be inspected at regular intervals. It may be helpful to add non-contact level measuring equipment as a cross check for float devices.

3.3.6.3: Domestic and Service Water System

Domestic and service water is taken from the raw water supply and is then filtered and chlorinated. A portion of the service water is utilized to flush each main unit pump’s mechanical seals for a short duration of time during start up and shutdown periods. The service water should not be subjected to veliger settlement or problems from mussel shells because of the chlorine treatment and filtering. Sections of the system upstream of the treatment point may be impacted.

3.3.6.4: Fire Protection Water and Discharge Line Fill System

The fire protection water is drawn from the raw water supply past the duplex strainers by a fire water pump.

The main pump motors have a CO_2 fire suppression system. The fire water system protects the remainder of the plant. The fire water pump is tested monthly. However, for the remainder of the time, the fire water system is stagnant, providing little opportunity for mussel infestation due to low dissolved oxygen levels. The decay rate of the dissolved oxygen level in the fire water piping should be measured approximately 10 ft along the fire water piping from the fire water branch take-off. If the dissolved oxygen is reduced to 3 mg/L within the fire protection system shortly after test, than mussel veligers that may have entered and settled during the monthly fire water test will not survive.

Of some concern is shell debris which may develop on the downstream side of the duplex strainers and in the piping between the strainers and fire water system branch take-off. It is likely that periodic inspections of the strainer will keep the strainer itself in good operating order. If strainer inspections indicate that mussels are settling in the raw water piping, the portion of the piping leading the fire water system should be cleaned annually. To minimize any possibility of shell transport during fire system testing, the strainer should be inspected and cleaned as necessary before commencement of any fire system test. Mussel shells can be excluded from the fire water system during testing by installing a by-pass line with a filter to remove shells. The same technique can be used to exclude veligers if the dissolved oxygen does not decay sufficiently quickly. The mesh of the filter needs to be a 40 micron size and therefore the filter body will be larger than a filter sized to exclude shells only.

3.3.6.5: Compressed Air and HVAC Systems
Station air compressors are air cooled and require no cooling water.

There is no raw water required for any in plant HVAC system.

3.3.6.6: Un-watering System and Sump
Provision for un-watering any piping and the station sump is done by two vertical pumps. The sump pump motors are air cooled. The pump impellers are suspended from shafts concentric with a discharge tube. The sump level is

controlled via float switches. The sump discharge is returned to Granby Reservoir.

Accumulation of mussels on the sump floats could cause unreliable level detection. The floats and sump should be inspected at regular intervals. Mussels typically settle on the external portions of submerged pump casings and on the walls of the sump at levels below the level shut off switch.

3.3.6.7: Discharge Pipe and Canal

The discharge from each pump is combined into a common pipeline that delivers water to the interconnecting canal leading to Shadow Mountain Reservoir. The discharge piping is at risk of mussel settlement. The increased roughness of the piping caused by mussel settlement and growth will increase the pumping power required. Therefore even light mussel accumulation will result in an economic penalty for increased electricity costs. An analysis will need to be done to evaluate the increased pumping costs versus the increased maintenance costs to remove mussel accumulation.

The walls of the canal are earthen consisting of soil, gravel and rocks with sloping sides. Mussel attachment is possible on the sides of the canal and any concrete structures along the canal. The bottom of the canal is likely to have some sediment cover which should inhibit mussel settlement as explained for the Willow Creek delivery canal.

As a safety precaution against back-flow in the canal, radial gates are present on the canal near the Shadow Mountain Reservoir gates. The bottom seal for the gates is typically formed from an elastomeric material. If the flow through the bottom seal is not sufficiently fast to flush the seal area, some shell material could become trapped and cause the sealing material to become scored. This scoring would decrease the lifespan of the bottom seals. Depending on the frequency of gate use, a reduced seal life span may require seals to be replaced more frequently than anticipated.

3.3.7: GRAND LAKE and SHADOW MOUNTAIN RESERVOIR

Shadow Mountain Reservoir is formed by Shadow Mountain Dam at the south shore of the reservoir. At the north end of the reservoir a connecting channel directs flow into Grand Lake for subsequent delivery to the Adams Tunnel.

Shadow Mountain Dam is much smaller than Granby Dam. The spillway flow is managed by radial gates and all comments for the gates at Granby would be applicable to Shadow Mountain. The gates at Shadow Mountain also incorporate a bubbler system to prevent ice formation from impairing the operation of the gates in the winter period. There is a submerged 3 inch diameter intake for the float well at the dam. The intake and its connecting pipe to the float well would be at risk of mussel settlement. The grate would need to be cleaned manually by divers. From the drawings, the pipe appears to be about 100 ft long. Use of a remotely operated pipe cleaner (either mechanical or high pressure water powered) is the normal way to clean pipes of this diameter and length.

There is a 30 inch square concrete conduit that runs under the spillway floor and it serves as a bypass for the dam. The by pass originates in the concrete bull nose that separates the two radial gates at the spillway entrance. There is a 4ft square water inlet opening on each side of the bull nose for the bypass. The inlet openings and the conduit would be at risk of mussel settlement. If the conduit can be drained annually and allowed to dry or freeze, then any mussels that manage to inhabit during that year will die. The conduit has a 4 inch vertical vent just aft of the inlet opening. The wetted portion of the vent is must be confirmed to be clear prior to draining the conduit.

The spillway downstream of the radial gates contains a number of drains beneath the concrete. If the drainage water can come from reservoir seepage, then there is a remote chance that the drains could be settled with mussels. Mussel problems at Shadow Mountain Dam are expected to cause only minor increases in maintenance and no dam performance problems.

It is noted that Shadow Mountain Reservoir is shallow (7 m max depth) and is nutrient rich in the summer. If inspection programs need to be targeted to optimize resources, then the shallow areas along the shoreline, boat ramps and islands of this reservoir would facilitate inspections.

Mussel accumulation along the interconnecting canal between Shadow Mountain Reservoir and Grand Lake is likely to be limited by the earthen canal structure. Mussels would accumulate on rocks but large accumulations on gravel and soil would not be stable and would break away, settling onto the canal floor.

3.3.8: ALVA B. ADAMS TUNNEL

The Adams Tunnel transfers water from Grand Lake to East Portal Reservoir, which then releases water through a series of conduits and tunnel to Marys Lake. The Adams Tunnel inlet has a metal rack system with 7.5 ft tall trash racks arranged in a semi-circular arc approximately 240 ft long. The water enters the tunnel gate house and flows by gravity through the two control gates then into the tunnel.

The trash rack system will accumulate mussels and will require manual cleaning, probably using divers. The racks may be candidates for foul release or anti-fouling coatings to increase the time between manual cleaning cycles. The large size of the trash rack system suggests that there is a substantial size margin such that significant mussel accumulation can be tolerated. However, the amount of fouling that can be tolerated needs to be evaluated.

The tunnel itself is drained and inspected annually. Any mussel accumulation can be monitored and removed at a normal planned tunnel outage. The inspection should include the air vents and weep holes along the tunnel length. Any mussels located should be removed as part of the annual inspection. A mechanical scraper, steam lance or high pressure water jet are suitable methods to remove attached mussels. Accumulation of mussels will likely present only an economic cost for cleaning mussel accumulation from the tunnel walls. There appears to be no components of the tunnel that are at risk of causing performance or water delivery problems of a sudden nature that would result in an unplanned tunnel outage.

Water discharges from Adams Tunnel into East Portal Reservoir then to Marys Lake (neither of which have been included in this assessment) and finally to Lake Estes.

3.3.9: ESTES POWER PLANT and OLYMPUS DAM

Estes Power Plant takes diversion water delivered from Marys Lake and produces up to 45 MW of electric power. The plant has 3 generating units.

Lake Estes, below Estes Power Plant is formed by Olympus Dam constructed across the Big Thompson River. Lake Estes forms the after bay for the power plant and holds diversion water for subsequent downstream deliveries.

The afterbay storage in Lake Estes and the forebay storage in Marys Lake enable the Estes Power Plant to meet daily variations in energy demand while the lakes allow variations in water demand to be managed.

3.3.9.1: Intake Structures

The inlet to the power plant is via three penstocks, one leading to each of the plant turbines. The inlet flow is controlled by butterfly valves. The flow in the penstocks is likely to be too high (greater than 6 ft/sec) for mussels to settle during normal operation. The penstocks are always flooded. Should it become necessary to drain a penstock, any air vents should be checked for proper operation in the event mussels have managed to settle in the wetted portions of the vent line. It is possible that mussels could attach to the penstock walls when a turbine unit is shut down and no flow is passing through the penstock. During periods of extreme cold, mussels on the walls of penstock can act as nucleation points for frazil ice formation on the internal walls of the penstocks when they are not in-service. If the plant has ever experienced frazil ice problems, then presence of mussels could increase the frequency of ice formation problems. It may be necessary to maintain some flow in the penstocks at all times during winter months to prevent ice formation.

3.3.9.2: Raw Service Water

Raw water for station services is taken from the turbine discharge tail race area by a pump. This water passes through a fixed strainer and is pumped to the various water demands. The water is used for generator bearings and winding cooling, fire protection and general services.

The strainers are cleaned two times per week. The strainer body will therefore be a good device to observe for the presence of mussel shells transported from upstream and of mussel veligers settling on the interior walls of the strainer.

The strainers are effective at preventing entrance of adult mussels or mussel shells into the piping system. However, veligers will readily pass by the strainers and could settle and grow in areas of piping, sprinkler nozzles, valves, instrument lines and equipment coolers. The veligers that grow into adults will then provide a source of shells to impair system performance.

Use of chlorine to treat the service water and prevent mussel settlement is not permitted due to fish sensitivity in Lake Estes. The addition of small pore self cleaning filters past the strainers would be of assistance if mussel infestation occurs. The filters would remove any veligers and small shell material. RNT understands that the service water delivery pressure is likely to be insufficient to support the addition of filters without the addition of a booster pump.

Alternately, there is an emergency service water back up system available via a takeoff from the penstock piping. This is a source of high pressure raw water. By switching to this source of water as the primary water source, filters could be added to the system and protect all equipment and piping from mussel settlement and shell accumulation.

3.3.9.3: Domestic Water

Domestic water is provided by a connection to the city water. This water is filtered and chlorinated and will not have any risk of mussel transport. The domestic water system will not be at any risk of mussel problems.

Water for air compressor coolers is provided by the domestic water system.

3.3.9.4 Un-watering System

Each unit draft tube incorporates an un-watering system at the lowest level in the tube. The inlet to the un-watering piping is covered by a metal grate which would form an ideal settlement structure for mussels. Extensive growth on the metal grate could slow the draining process. Should this occur, consideration should be given to replacing the drain grate with a bronze or brass material to limit mussel fouling.

The drain piping will remain stagnant for long periods of time since draining is an infrequent event. The water in the drain piping will have oxygen levels too low to support mussel growth and the piping will not be at risk of mussel settlement.

General drainage is directed to the plant sump. The float switches in the main sump should be monitored for mussel attachment as the mussels could weigh down the floats and cause level errors.

3.3.9.5 Discharge area

Water that exits from the turbines passes through the draft tube and then into Lake Estes. This area has fast and turbulent flow and is unlikely to experience any mussel settlement or problems associated with mussel shell debris.

3.3.9.6 Olympus Dam Structure

Olympus Dam is a composite concrete and earth fill structure. The concrete section is at the south end of the earth fill embankment. The spillway section is within the concrete portion and discharges directly into the Big Thompson River.

The spillway has 5 radial gates that allow flow into the Big Thompson River. As discussed earlier in section 3.3.3 for the Granby Dam, radial gates are not likely to experience any mussel problems. Some minor decrease in the service life of the elastomeric bottom seals may occur.

Water from the lake can also be discharged directly into the river via an 18" river outlet pipe in the dam concrete structure. The entrance to the pipe is covered by a fixed trash rack. This trash rack will be at risk of mussel settlement and would require regular inspection and manual cleaning.

There is little piping within the dam structure that is exposed to raw water. Service water is not available. The fire protection system is provided by means of chemical extinguishers. Instrumentation is typically only for pressure measurement. These instrumentation lines would have no flow and would not be likely settlement areas for mussels due to low oxygen and lack of nutrients. Level gauges that are float based should have the floats inspected and cleaned periodically.

The dam wall incorporates 5-in diameter formed drain tubes oriented vertically in the dam wall. The drains terminate in the inspection gallery where water is then directed via floor gutters to the sump area. The drain will collect dam water that manages to seep through the concrete wall structure. Mussel veligers may be able to travel with the normal dam leakage into the drain tube where they could settle and grow. The occurrence of such attachment is likely to be rare but has been documented at other facilities.

In the unlikely event that sufficient mussels should accumulate to restrict the drain flow, the reduced drainage should be picked up during the frequent routine inspections by dam staff. An accumulation of mussels could be removed using a cable operated pipe cleaner.

In addition to the wall drains, the dam foundation incorporates several foundation drain pipes. These pipes are monitored frequently. Any changes from the norm are investigated further and the pipes cleaned as necessary. The normal vigilance of dam staff will identify any problems associated with mussels even though such problems are not expected.

All water seepage drains to a sump evacuated by a sump pump. The sump should be inspected periodically for presence of mussels. Mussels typically settle on the external portions of submerged pump casings and on the walls of the sump at levels below the level shut off switch.

4.0 RECOMMENDATIONS

Our review of the C-BT system indicates that there is a great diversity of structures, equipment and how the facilities are used. The recommendations below will therefore not be applicable to all facilities or components assessed. In addition, some of the recommendations are for immediate action (proactive steps) while others are suggested to be implemented only when the mussel infestation reaches a stage that reaction is necessary (reactive steps).

Recommendations for Immediate or Continued Action

Current dreissenid mussel monitoring effort should continue in the C-BT system to verify that there is no developing dreissenid population.

Continued monitoring of key environmental parameters, primarily calcium, dissolved oxygen, temperature and pH by depth, date and location, is recommended to detect any trends that may place the system at greater or lesser risk.

As calcium data for Willow Creek Reservoir and Lake Estes was not available at the time of our inspection to permit further comment, obtain, evaluate and continue monitoring of calcium in those two water bodies. This is particularly important for Lake Estes as Fingernail clams have been reported downstream of Olympus Dam.

Review the geology of the area to identify possible sources of micro-zones of calcium in the reservoirs including areas within the watershed where human activity may have exposed calcium bearing rock such as quarries, open pit mines, and clear cutting of forests accompanied by erosion

The review of facilities and structures in this report documents which areas might be at risk if a dreissenid population was able to develop. Having this assessment means that management is capable of a swift response should protection of facilities and structures become necessary. In particular, the following monitoring activities are proposed for areas that should be watched closely:

- Level and flow measuring gauges in direct contact with raw water. These gauges if infested with mussels would not operate properly. Non-contact instrumentation is advisable.
- Integrate observation of mussels into normal dam, plant, and component inspection cycles and routine walk arounds to minimize the operational burden of inspection. For example, components checked on a monthly basis need not be included in a dedicated quarterly mussel check as the inspection would be deemed to have occurred in the normal course of work.
- Provide staff training on mussel identification and likely locations inside the dam such as drain gutters and the sump.

Recommendations for Actions with Discretionary Timing

Although adult mussels have not been detected, in the unlikely event a significant infestation occurs, the intake and discharge piping will present a unique challenge. The achievable flow rate through the piping could be restricted by increased roughness or even reduced diameter of the piping by mussel accumulation. The consequences of a flow reduction may be unacceptable and should be analyzed

The C-BT Project's many canals provide ideal settlement environment for dreissenid mussels. While mussel settlement in this area will not cause plugging, the increased roughness could affect the rate of flow. If flow reductions cannot be tolerated and if mussels cannot be kept from the canal system, then cleaning options should be explored.

If a vigorous mussel population is established by detection of adult settlement, conduct an inspection of all facility components to establish a baseline condition. Facility components or structures that are part of a regular inspection program and have been inspected within the previous 3 months would be considered to have the baseline already established. Only structures not recently inspected need to form part of a baseline inspection. Repeat the inspections quarterly until mussel accumulation patterns are established. Extend inspection cycles as confidence in the growth patterns and tolerance of various components is established. As no control technology may be required immediately, waiting until mussels are established in the reservoir, time and resources may be targeted more appropriately.

Develop non-intrusive techniques to predict mussel accumulation such as matching flow to control valve position or ultrasonic inspection of piping. (Note: mussels are difficult to distinguish from corrosion products using ultrasonic so a baseline inspection is necessary).

Prepare and test operational procedures to clean critical areas of the dam such as the seepage collection pipes and vent pipes. Vent lines should be inspected prior to draining pipe lines.

For any trashracks that are approaching the end of their life cycle, consider application of a foul release or antifouling coating for the new racks to extend the time between cleaning cycles.

For any trashracks that are removable but normally submerged, consider removing and coating the racks with foul release or antifouling coating to extend the time between cleaning cycles.

For water uses that are occasional such as fire water systems or systems that have low water usage but are at risk due to mussels, consider connecting to municipal water systems or wells in the future.

Analyze the costs of mussel infestation versus the cost of cleaning out the mussels on energy intensive applications such as the pumping costs associated with infestation of Farr Pumping Plant discharge pipes.

Appendix 1

Parameters	References
Alkalinity	Claudi and Mackie 1994; Mackie 1994; Hincks & Mackie 1997; Ashby et al. 1998
Calcium	Mackie *et al*. 1989; Neary & Leach 1992; Baker *et al.* 1993; Murray *et al.* 1993; Claudi and Mackie 1994; Mackie 1994; Koutnik & Padilla 1994; Tammi *et al.* 1995a,b; Doll 1997; Hincks & Mackie 1997; Sorba & Williamson 1997; Hayward and Estevez 1997; Janik 1997; Cohen 2001; Cohen & Weinstein 1998, 2001
Chlorophyll *a*	Claudi and Mackie 1994; Mackie 1994; Hincks & Mackie 1997
Conductivity	Claudi and Mackie 1994; Mackie 1994; Sorba & Williamson 1997
Dissolved oxygen	Mackie 1994; McMahon 1996; Doll 1997; Sorba & Williamson 1997; Hayward and Estevez 1997; Ashby et al. 1998; Cohen 2001; Cohen & Weinstein 1998, 2001
Nitrogen, total	Mackie 1994; Koutnik & Padilla 1994; Claudi and Mackie 1994;
pH	Mackie *et al*. 1989; Neary & Leach 1992; Koutnik & Padilla 1994; Claudi and Mackie 1994; Mackie 1994; Doll 1997; Hincks & Mackie 1997; Sorba & Williamson 1997; Janik 1997; Hayward and Estevez 1997; Ashby et al. 1998; Cohen 2001; Cohen & Weinstein 1998, 2001
Phosphorous, total	Mackie *et al*. 1989; Mackie 1994; Koutnik & Padilla 1994; Claudi and Mackie 1994;
Salinity	Strayer & Smith 1993; Kilgour *et al.* 1995; Sorba & Williamson 1997; Doll 1997; Hayward and Estevez 1997; Cohen 2001; Cohen & Weinstein 1998, 2001
Secchi depth (or turbidity)	Claudi and Mackie 1994; Sorba & Williamson 1997; Hayward and Estevez 1997
Temperature, mean annual	Strayer 1991; Cohen 2001; Armistead 1995; McMahon 1996; Doll 1997; Janik 1997; Sorba & Williamson 1997; Hayward and Estevez 1997; Roe & MacIsaac 1997; Ashby et al. 1998; Cohen & Weinstein 1998, 2001
Total hardness	Baker *et al.* 1993; Claudi and Mackie 1994; Mackie 1994; Hincks & Mackie 1997; Sorba & Williamson 1997

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