RECLAMATION
Managing Water in the West

Facility Vulnerability Assessment for Lower Granite Lock & Dam

Invasive Quagga and Zebra Mussels

U.S. Army Corps of Engineers
Walla Walla District

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Prepared for U.S. Army Corps of Engineers Walla Walla District and Lower Granite Lock & Dam Project Office

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Cover Photo: Photo of Lower Granite Dam.

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Executive Summary

The purpose of this assessment is to provide U.S. Army Corps of Engineers (USACE) management and project staff with information regarding the vulnerability of facility features to invasive mussel impacts. This report is not intended to be a risk assessment or prediction of the potential for a future mussel infestation. Instead it is intended to assist project management and staff in anticipating and planning for impacts should a future infestation occur.

Findings

Lower Granite Lock and Dam facilities are relatively complex and a heavy invasive mussel infestation would likely significantly impact facility operations and maintenance. Impacts would generally be expected to include fouling of trashracks, grates, gates, screens, bar racks, cooling water systems piping, valves, and associated equipment and instrumentation. However, some proactive steps have been taken through the retrofit of strainers with filtration for the units cooling water systems. Nevertheless, heavy shell debris loads can still overwhelm strainers and filters. Fish passage, handling, and transport facilities also appear highly susceptible to impacts which could include mussel fouling on submerged surfaces, diffusers, separators, instrumentation and equipment along with clogging of piping and associated systems from shell debris.

The variability of calcium levels from limited available water quality data would suggest that conditions at Lower Granite Dam may only be suitable for supporting moderate levels of infestation. If calcium levels are persistently on the low end, minor mussel-related impacts would be expected. Conversely, if calcium levels are typically on the high end (above 30 mg/L) and pH typically near 8.5, then moderate to heavy infestations may occur with more pronounced impacts. As such, there is an apparent need for additional analyses of water quality data to further ascertain the potential for mussel survival and establishment at Lower Granite. Doing so would also help to further prioritize response planning, both locally and regionally.

Recommendations

The following recommendations are provided for consideration:

- In conjunction with this assessment, consideration should be given to development of site-specific response actions that build upon the Columbia River Basin response plan to address a future infestation as soon as possible (if not already in place). While there is no accurate way to predict whether Lower Granite will become infested, planning ahead will allow time for budgeting and implementation of response actions if needed. Management options have been included in Appendix B along with links to other response plans and response planning guidelines developed by the National Parks Service.

- It is recommended that seasonal (spring-fall) monthly monitoring for mussel larvae via plankton net sampling be continued for the earliest possible detection. Although substrate monitoring can detect the presence of adult mussels, it is not considered an effective early detection method. An infestation is typically already in the advanced stages by the time settlement on substrates is observed, thereby substantially reducing the available time before mussels begin impacting facilities. The primary advantage of early detection is to allow lead time for planning, budgeting, and implementation of response actions.

- It is also recommended that future water quality sampling and analyses be conducted to further ascertain the potential for mussel survival and establishment at Lower Granite.

Introduction

Purpose and Objectives

The purpose of this assessment is to provide U.S. Army Corps of Engineers (USACE) management and project staff with information regarding the vulnerability of facility features to invasive mussel impacts. This report is not intended to be a risk assessment or prediction of the potential for future mussel infestation. Instead, it is intended to assist project management and staff in anticipating and planning for impacts should a future infestation occur.

Brief Project Description

Lower Granite Lock and Dam consist of a navigation lock, a concrete dam with an earthfill embankment at the right abutment, a spillway section, a powerhouse, and fish passage facilities. The project provides hydroelectric generation, navigation, recreation and incidental irrigation. The dam, lock, and powerplant are owned, operated, and maintained by the U.S. Army Corps of Engineers while the fish facilities are operated by various agencies involved with fish passage and protection.

The lock is located between the concrete gravity and the earthfill embankment sections and is 86-ft wide by 674-ft long with a total lift of approximately 100 ft. The downstream end of the lock is equipped with a miter gate which opens laterally while the upstream end is equipped with a submersible tainter gate that is raised and lowered accordingly. Separate waterways, controlled by culvert tainter valves, are used to fill and drain the lock.

The concrete gravity section contains a 512-ft-long radial gated spillway with eight 50- by 60.5-ft radial gates. The left-most gate bay is equipped with a removable spillway weir to provide improved downstream juvenile fish passage. The weir is operated seasonally between April and August for downstream passage of smolts and kelts.   The weir was designed to be "removable" by controlled descent to the bottom of the dam forebay returning the spillway to original flow capacity during major flood events. It is not able to be submerged at this time.

The powerplant is adjacent to the spillway and consists of six 135-MW kaplan turbine and generator units with a combined rated capacity of 810 MW. The powerplant operates year round with varying number of operating units as needed to meet demand. The fish facilities include an upstream passage ladder, powerplant extended submersible bar screens (ESBS) and downstream juvenile bypass, an adult trap facility, and a juvenile collection and transport facility.

Background on Potential Invasive Mussel Impacts

Quagga and zebra mussels (adult lengths typically average about 1 in) are unique in that they can firmly attach to the underwater surfaces using byssal threads. They begin spawning by emitting eggs and sperm into the water column when water temperatures reach about 10ºC (50ºF); though spawning has been observed at slightly lower temperatures in some cases. On a population-wide basis, egg production occurs in astronomical levels (on the order of 30,000 eggs/female/reproductive cycle). Depending on temperature and environmental suitability, multiple reproductive cycles may occur in a single year. Fertilized eggs develop into freely swimming larvae or veligers (ranging in sizes from 60 to 250 micron) which may be transported by water currents for many miles. Within a few weeks and if water conditions are suitable, the veligers will settle (i.e., attach to hard surfaces) and continue growth to adulthood.

Successful settlement is mediated by a number of environmental conditions inherent in the natural water system. These include calcium, alkalinity/hardness, pH, nutrients, dissolved oxygen, temperature and conductivity. It should be noted that some of these parameters are indirect measures of others. For example, alkalinity/hardness is presumptive for calcium and magnesium. It is generally accepted that highly successful mussel colonization occurs when calcium levels exceed about 24 mg/L. Successful establishment is more in question when calcium values fall below about 10 mg/L. With the possible exception of nutrients (implied indicators of food supply) in high mountain lakes, the remainder of listed parameters seems fairly well represented as having adequate levels in most Western waters where data are available. Table 1 provides water quality parameters suitability criteria for invasive mussels. It should be noted that this information may not be entirely applicable to all water bodies in the Western U.S. Nevertheless it provides an approximate indication of suitability requirements.

Table 1. Presumptive infestation-level suitability criteria for invasive mussels.

Parameter	Low Probability of Survival	**Infestation Levels**		
		Low	Moderate	High
Calcium (mg/L)	<10 (QM) <8 (ZM)	10-12 (QM) 8-15 (ZM)	12-30 (QM) 15-30 (ZM)	>30
Alkalinity/Total Hardness (mg $CaCO_3$/L)	<35 (QM) <30 (ZM)	35-42 (QM) 30-55 (ZM)	42-100 (QM) 55-100 (ZM)	>100
pH	<7.0 >9.5	7.0-7.8 9.0-9.5	7.8-8.2 8.8-9.0	8.2-8.8
Dissolved Oxygen (mg/L)	<3	5-7	7-8	>8
Dissolved Oxygen (% saturation)	<25%	25-50%	50-75%	>75%
Mean Summer Temperature (^{o}F)	<64 >86	64-68 83-86	68-72 77-83	72-75
Conductivity (µS/cm)	<30	30-60	60-110	>110
Salinity (g/L)	>10	8-10	5-8	<5
Secchi depth (m)	<0.1 >8	0.1-0.2 2.5-8	0.2-0.4	0.4-2.5
Chlorophyll a (µg/L)	<2.0 >25	2.0-2.5 20-25	8-20	2.5-8
Total phosphorous (µg/L)	<5 >50	5-10 35-50	10-25	25-35

It is also important to note that mean summer temperature does not imply temperature thresholds. Adult mussels have been observed to survive at temperatures near freezing. The low-temperature threshold for mussel growth is thought to be around 45 ºF. This would imply that mussels are more likely to colonize systems with raw water temperatures greater than about 45 ºF, with a lower probability of colonization for sustained temperatures below this threshold. On the upper end, temperatures greater than about 84-86 ºF for extended periods are not generally expected to support mussel survival. For additional information see Mackie G. & R. Claudi, Monitoring and Control of Macrofouling Mollusks, 2nd Ed., CRC Press, 2010.

Environmental and operational conditions of the structures themselves may also influence veliger settlement and subsequent colonization. Within a facility, veliger settlement is prohibited or greatly reduced in pipes where water velocities continuously exceed 6 feet per second (ft/s). However, intermittent operations or lower velocities may lead to successful settlement. Once attached, mussels can sustain that attachment even when flow velocities are well above 6 ft/s. Ideal areas for mussel colonization are those areas with continuous flows of moderate velocities (<6 ft/s) and ample supplies of food and oxygen. Piped systems which are seldom utilized or idle for prolonged periods and which have depleted oxygen are not generally supportive of successful colonization. A major exception is a situation where leaking valves allow constant flows and replenishment to such seldom used systems.

Invasive mussels pose serious threats to water resources infrastructure and operations. Of major importance to facilities is the ability of mussels to rapidly colonize hard surfaces at densities of tens of thousands per square meter. Heavy accumulation can lead to costly operations and maintenance problems. Flow restriction is the foremost concern because mussels can clog water intake structures, such as trashracks, pipes and screens, thereby threatening water delivery to critical systems at hydropower plants and reducing pumping and conveyance capacities of water distribution systems.

Assessment Findings

Potential Infestation Levels

Water Quality

Of importance for estimating potential infestation levels are those parameters necessary for establishment and growth of mussel populations discussed above (namely calcium, pH, dissolved oxygen, temperature, and nutrients). Though it should not be construed as anything close to a complete water quality analysis or prediction of future conditions, based on limited recent water quality data that was provided, calcium levels appear to vary widely from 9 – 34 mg/L. These levels span the range of what would be considered conducive to supporting low to high levels of infestation. Similarly, pH appears to range from about 7.4 – 9.4 which is also considered conducive for low to high levels of infestation. This variability, without information regarding frequency and duration, makes it difficult to assess potential infestation levels and point to a need to further define suitability for mussel survival and establishment.

Vulnerability of Features

Lock

The lock at Lower Granite Dam appears susceptible to mussel related impacts with perhaps some mitigating effects due to operating conditions. Clearly the fluctuating water levels during lockages, which can occur several times per day, would be expected to significantly reduce (and likely prevent) mussel settlement on surfaces that do not remain submerged. Conversely, mussel settlement and fouling of surfaces that remain submerged for extend periods of time would be expected; the degree to which would depend on levels of infestation.

The waterways and gates for filling and draining the lock may be exposed to greater impacts. Mussel fouling on the top-seal tainter gates has the potential to degrade seals over time. But, frequent operation may considerably reduce mussel settlement along sealing surfaces. The most significant impacts may result from mussel shell debris which can be drawn into the gate sections during operations and may affect seating of the gates upon closure.

Bulkhead slots for servicing the gates are also generally susceptible to long term mussel fouling which can lead to seal damage during installation and affect the ability to fully seat bulkheads. If deployed for extended periods of time, mussel fouling on the bulkheads themselves may occur, affecting drain ports (if so equipped) and making removal difficult. Furthermore, bypass or fill piping may be susceptible to complete clogging with the potential for inoperability which would also make bulkhead removal problematic.

Other submerged mechanical components for the gates may be exposed to increased wear due to mussel fouling and associated shell debris. However, regularly scheduled shutdowns with unwatering for inspection and maintenance are expected to reduce long term accumulation of mussels.

Figure 1. Submersible tainter gate at upstream end of lock

Figure 2. Miter gate at downstream end of lock

Figure 3. Unwatering pump cone screen

Dam & Spillway

Although it is currently uncertain (i.e., hypothetical), the structural drainage systems for Lower Granite Dam (under drains, formed drains, and toe drains), may also be impacted by mussels depending on the design of the systems, size of seepage passages, and potential for backflooding of outlets. Typically flow passages to drain systems are extremely small, but if they are sufficiently large for larval mussels (> 60μm) to enter and the water chemistry is suitable for survival, then mussel colonization and clogging of portions of the drainage systems may be possible.

Spillway Gates & Stoplogs

The spillway radial gates remain partially submerged more or less continuously. Impacts can range from increased friction along sealing surfaces and degraded seal performance to accelerated corrosion on submerged metallic surfaces (e.g., the gates themselves and embedded seal plates). Depending on the seats design, it may also be possible for shell debris to accumulate in recesses which could make fully seating the gates difficult.

Stoplogs are available for installation upstream of the radial gates to provide access for inspection and maintenance (one set is available to service a single gate bay at a time). While direct impacts to the stoplogs would not be expected since they are stored in the dry, the guides, seats, and sealing surfaces would likely be susceptible to fouling which could result in seal damage or incomplete seating during installation. If deployed for extended periods of time (i.e., months) direct fouling of the stoplogs may occur. Impacts can include clogging of bypass fill passages which could complicate stoplogs removal.

Figure 4. Spillway bay stoplogs

Removable Spillway Weir

The removable spillway weir (RSW) provides improved downstream passage for juvenile fish species. The RSW, located on spillway bay #1, can be raised (floated) into position and lowered (sunk) below the spillway crest when not in use. It is typically operated annually during the months of April through August. It is not able to be submerged at this time.

The RSW generally appears susceptible to mussel related impacts which may include fouling of fill and blow-off valves, associated water passages, mechanical linkages and components, or the entire structure. Long term fouling of the structure would increase weight which, depending on design, could make deployment more difficult. The RSW is removed by controlled descent to the bottom of the river during major flood events. While direct impacts to the fill and blow-off valves would not be expected since they are above the water surface except when the RSW is in the removed or stowed operations when they would be susceptible to fouling which under extreme circumstances might affect the ability to raise the structure into position. Fouling along flow boundaries of the weir could also impact fish passage performance by roughening flow surfaces that could potentially expose fish to injury during passage.

Figure 5. Air chamber and top deck of removable spillway weir (RSW)

Powerplant

Intake Trashracks

The powerplant intakes are equipped with trashracks which appear highly susceptible to mussel related impacts owing primarily to intermittent operations. Experience at Reclamation facilities that are heavily infested with quagga mussels suggests that portions of powerplant intake trashracks can become heavily fouled with significant reductions in open area resulting in increased headlosses. Depending on trashrack design and existing condition there may also be a remote potential for trashrack failure. The trashracks are equipped with raking systems which can reduce mussel fouling along leading edges of trashrack bars, but if rake head penetration is not sufficient, mussel fouling between bars can persist. The trashracks are removable (though they remain in place continuously) and the slots appear susceptible to long term mussel fouling which could make future removal difficult. Furthermore, long term fouling on submerged metal work can accelerate corrosion if not adequately protected.

Figure 6. Powerplant intake trashrack slot

Extended Length Submersible Bar Screens (ESBS)

The intakes extended length bar screens also appear somewhat susceptible to mussel fouling. The screen design and locally higher velocities may mitigate impacts to some degree, but intermittent operation of units would likely allow mussel fouling on the screens which would reduce open area and alter velocity distributions with the potential for increased fish impingement and injury potential. However, considerable mitigation is expected by the annual removal of the screens which allows opportunities for cleaning to reduce long term fouling and associated impacts.

Vertical Barrier Screens

The vertical barrier screens appear quite susceptible to mussel fouling which has further potential for adverse impacts to downstream passage. Increased impingement and injury potential from mussel settlement on the screens would be the primary concern, but heavy fouling of the screens could also make removal for cleaning difficult.

Figure 7. Wedgewire vertical barrier screen

Intake Gates & Bulkheads

The gates for each of the powerplant intakes appear generally susceptible to mussel fouling since they remain submerged. Mussel fouling has the potential to damage seals and sealing surfaces leading to degraded seal performance. Although not likely to render the gates inoperable, mussel fouling of the mechanical components may cause abrasion damage to bearing surfaces with some potential for incomplete seating on closure depending on design, infestation levels and operating conditions.

The single bulkhead for the powerplant intakes does not appear directly susceptible to mussel fouling since it is stored in the dry. However, the bulkhead slots are likely susceptible to varying degrees of mussel fouling which can indirectly impact rubber seals during installation. Like the intake gates, mussel fouling along the slots can damage seals and sealing surfaces with the possibility for incomplete seating during installation. If the bulkhead remains installed for extended periods of time (e.g., several months) then direct fouling may occur which can impact lifting equipment if drain holes in structural members become clogged. Fouling of bypass fill lines may also occur which could further complicate removal unless other means of pressure balancing are available.

Cooling Water Systems

The cooling water systems at Lower Granite Powerplant supply the bearing oil coolers, generator air coolers, compressor aftercoolers, station service transformers and HVAC system with raw water. Packing water is supplied from raw river water via the Hydac Strainer. Potable water is only used during maintenance of the Hydac Strainer. The well system would not be considered susceptible to mussel related impacts unless it is intertied in some way with the raw water systems for auxiliary purposes. The intakes for the cooling water are located in the gate slots and are guarded with fixed grates (bar racks on approximately 2-in centers). Cooling water systems with intakes, associated piping, and equipment of this type are some of the most susceptible features to mussel related impacts due mainly to the small size of piping and flow passages. Although these systems appear to have some measure of protection afforded by strainers, which were retrofit with fine mesh filtration, the inlets grating can still become clogged and excessive shell debris drawn into the system can still overwhelm strainers and filters if not adequately maintained. Strainers alone will not exclude mussel larvae (veligers) which can pass and settle in downstream portions of the system. Live mussels and dead mussel shell debris have the potential to clog supply lines and small flow passages (i.e., heat exchangers) reducing or cutting off water flow at multiple points in the system. Clogging can cause increased operating temperatures and has the obvious potential for costly outages until cooling water flows can be restored.

The HVAC system which utilizes raw water from the discharge side of the cooling water system during winter months also appears susceptible to impacts similar to the units cooling water system. Raw water for the existing heat pumps could clog heat exchangers adversely affecting HVAC system heat transfer performance. However, project staff indicated that the system has been retrofit to provide closed loop cooling during summer months. Furthermore, the new piping appears to be constructed of copper which can reduce mussel settlement. Both the closed-loop configuration and copper materials of construction afford a measure of protection, but impacts form heavy shell debris loads, if not adequately excluded upstream, can still become problematic.

Figure 8. Cooling water strainers retrofit for filtration

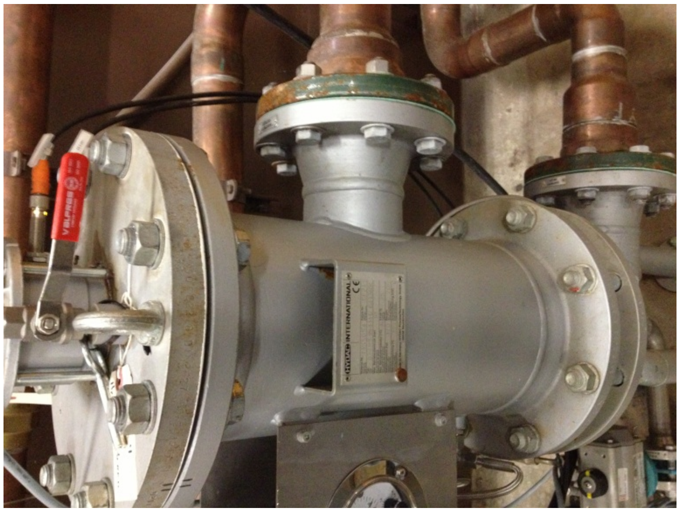

Figure 9. One HYDAC filtration unit on a cooling water system

Figure 10. Emergency Diesel Generator Piping

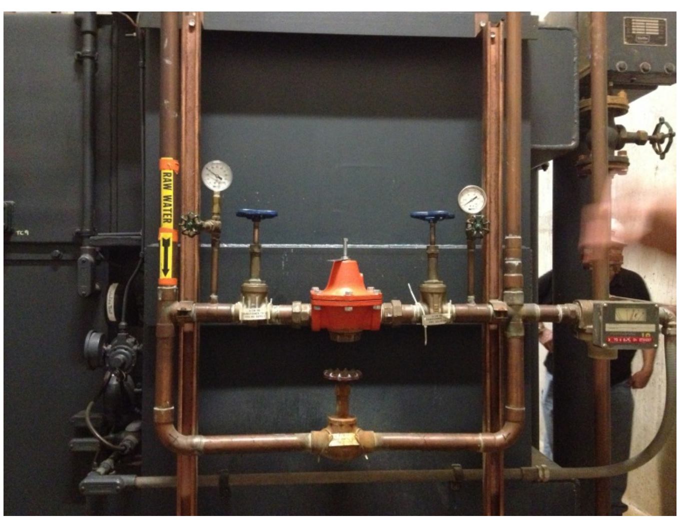

Figure 11. Station Service transformer cooling water piping

Figure 12. Typical strainer basket

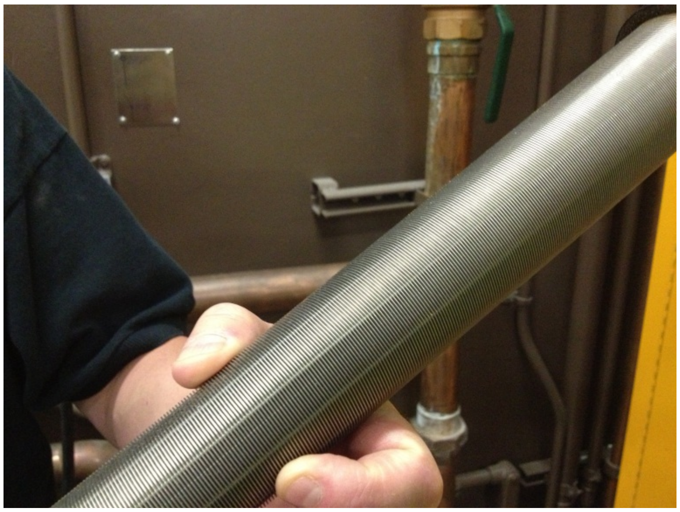

Figure 13. Filter media

Waterways & Draft Tubes

The internal surfaces of the intakes, casings, and draft tubes are not generally susceptible to mussel fouling due mainly to high velocities and perhaps high turbulence intensities which has been hypothesized to be prohibitive for mussel settlement. However, mussel fouling has been observed on portions of the draft tubes (with excessive fouling on recesses in access hatches) at powerplants which are exposed to heavy quagga mussel infestations. Such limited settlement is not expected to significantly impact operation of the units. Conversely, draft tube drain lines and valves would be susceptible to clogging from live mussels or mussel shell debris. Furthermore, draining to the powerplant unwatering sump would be a source of live mussels and shell debris contamination which would adversely affect sump operations.

Draft Tube Bulkheads

Draft tube bulkheads are typically stored in the dry above the tailrace water surface elevation and used when needed to dewater for inspection and maintenance. As such they will generally not be directly susceptible to mussel fouling. However, the guides and seats are likely to experience some degree of mussel fouling or shell debris accumulation which could lead to difficulty during installation, seal damage, and/or incomplete seating during installation. Like other bulkheads, if installed for extended periods of time, mussel fouling of drain holes in structural members can also adversely affect hoisting and operability of bypass fill valves which could further complicate removal.

Drainage & Unwatering Sumps & Pumps

The powerplant sump system collects drainage and unwatering flows from appurtenant systems. Leakage from or draining of the powerplant waterways to the sump would expose the system to colonization by live mussels and contamination from dead mussel shell debris. Impacts will likely include mussel attachment on submerged surfaces and equipment (including floats) which could affect sump pump performance and operability. Fouling of pumps intake screens (if so equipped) would reduce capacity and may even lead to inoperability of the pumps under extreme conditions. Entrainment of mussel shell debris could also increase mechanical wear for pump components. Furthermore, fouling of the float switch/level alarm arrangements could render the automated system inoperable. Bubbler systems would be similarly impacted with the potential of inoperability from mussel fouling or heavy shell debris accumulation.

Figure 14. Station unwatering sump pumps

Air Vents

Air vents can be impacted by mussel fouling at connections resulting in blockage which would reduce vent capacities. Air vents typically serve multiple purposes including air release during filling, air admission during draining, prevention of negative pressures downstream of the gate to ensure smooth operation, or in certain cases to prevent downstream pipe collapse during an unbalanced gate closure. In some cases, venting is also required to prevent cavitation damage. Impacts will vary depending on operating conditions and levels of infestation, but are likely to be more prevalent for smaller diameter vent lines.

Figure 15. Air vents on adult fish trap supply lines

Service & Domestic Water Systems

Due to the relatively small diameters, raw service water piping and hose taps (e.g., gate and deck wash supply header and taps) are generally susceptible to clogging from live mussel settlement and/or mussel shell debris with the potential for inoperability depending on levels of infestation and associated shell debris loads.

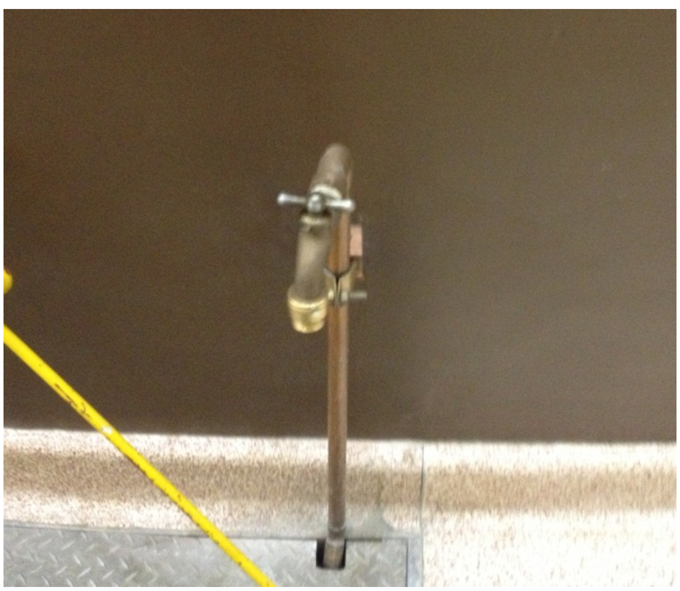

Figure 16. Service water tap

Fish Facilities

Fish Ladder

Adult fish passage at Lower Granite Dam is accomplished by means of a conventional fish ladder system. Multiple entrances are available at various locations along the downstream side of the dam. The north shore entrances are equipped with weir gates, the powerhouse entrances have separate bulkheads and weir gates, and the south shore entrances have combination bulkheads and weir gates. The north shore and powerhouse entrances are connected to a fish transport channel that leads underneath the spillway and across the tailrace below the tailrace deck to a junction pool and the fish ladder on the left abutment. The south shore entrances are connected to the same junction pool. Water is supplied from the auxiliary water systems (AWS) to the transport channel through diffusers along the power house collection channel. The AWS is driven by three pumps with an intake structure pulling water from the tailrace, through trashracks along the south side. Fish travel from the transport channel to the bottom of the ladder and ascend the lower reach of the ladder past a fish counting station. An adult fish trap is located at the switchback where fish can be trapped when needed. Auxiliary water for the adult trap is gravity fed via pipeline from a takeoff at the upstream reach of the ladder. The trap is operated using a swing gate that is essentially comprised of vertical bars similar to a trashrack. When the trap is not operated, fish can continue up the chute and pool ladder to the vertical slot reach leading to the exit at the upstream face of the dam. Three emergency pumps are located near the exit channel to provide water to the fish ladder when needed for temperature control purposes.

The relative complexity of waterways, equipment, and operations for the adult fish passage facilities will likely be problematic in a number of ways should an infestation occur at Lower Granite Lock and Dam. Although the fish ladder itself is relatively shallow, which may mitigate some impacts by potentially reducing settlement, mussel fouling of picket barriers, along the ladder invert, portions of the weirs, orifices, diffusers and vertical slots could increase fish injury potential. These impacts would likely also affect the fish transport channel. Increased roughness due to mussel fouling and/or shell debris accumulation would be expected to reduce fish ladder capacity to some degree and in extreme cases of excessive fouling could adversely alter fish ladder hydraulics and associated performance. Water level sensors or automated systems exposed to raw water would be equally susceptible which could result in misoperation, inability to meet passage criteria, or inoperability. The fish ladder is dewatered annually for inspection and maintenance during the winter which allows opportunities for cleaning to reduce long term fouling and associated impacts within the fish ladder system.

Mussel fouling on the AWS pump intake trashracks would likely also be problematic which could affect discharge capacity and transport channel hydraulics. If the pumps are equipped with cooling or seal water systems, mussel related clogging could lead to inoperability of bearing coolers and degraded seal performance. Mussel fouling on diffuser screens and bar racks could further reduce capacity and alter function of diffusers with a remote potential for failure if excessive fouling occurs. While the equipment arrangements for the ladder entrances are not entirely clear, any mechanical components that remain submerged would also likely be impacted which can include increased wear on seal elements and/or operational difficulties with adjustable floating weirs or orifices, particularly those that are automated. Like other bulkheads and stoplogs, the ladder entrance bulkhead slots may be susceptible to long term fouling which can make bulkhead installation difficult with the possibility for incomplete seating.

The fishway emergency pumps located in the reservoir appear most susceptible to mussel related impacts primarily due to depth of the intakes and intermittency of operation. Mussel fouling on the intakes and internal surfaces of the bowls and columns, impellers, and shafts could significantly reduce pump capacity with the potential for increased mechanical wear. If the intakes are equipped with screens or strainers, heavy mussel fouling may lead to inoperability of the pumps.


Figure 17. Adult fish ladder auxiliary flow diffuser screens


Figure 18. Lower reach of fish ladder


Figure 19. Fish guidance barrier to fish counting station

Figure 20. Fishway emergency pumps

Adult Fish Trap Facility

The adult fish trap facility, including the dewatering screens, piping, and associated equipment appears susceptible to mussel-related impacts in varying degrees. Although mussel settlement will likely occur in various places, impacts from shell debris may be most problematic. The auxiliary water supply piping, air vent, manifold and distribution system for the fish trap facility also appears quite susceptible to impacts from both mussel settlement and shell debris. Although the facility shuts down annually, which will help to reduce or eliminate impacts from long term fouling, any mussel fouling on surfaces that may come into contact with fish would represent increase fish injury potential. Furthermore, clogging of supply piping could affect operation of the entire facility.

Figure 21. Adult fish trap diversion bar rack

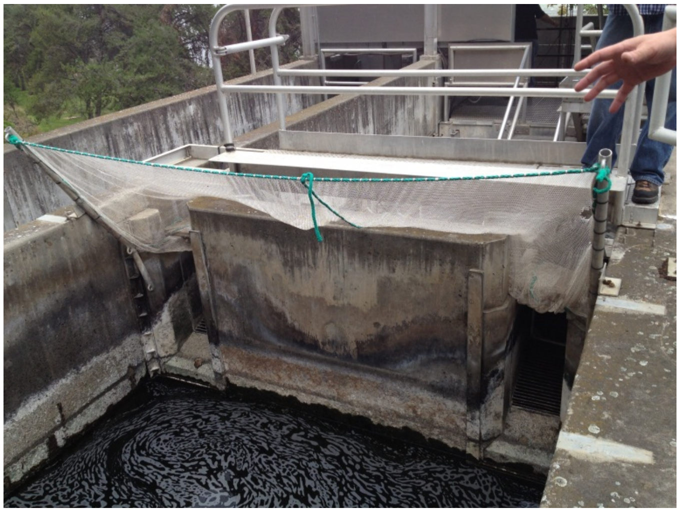

Figure 22. Fish trap facility entrance bay

Figure 23. Adult fish trap facility auxiliary water supply piping and air vent

Juvenile Collection Channel & Bypass Conduit

The juvenile fish bypass facilities are operated annually late March-October. Fish excluded at the powerplant intakes are diverted with a small amount of water to a collection channel and then transported to the juvenile fish facility via the bypass conduit. The outfall valves from the gate well orifices could be impacted depending on operating conditions. The system is equipped with makeup water inlets, valves and a float controller all of which appear susceptible to mussel fouling which would be expected to reduce channel capacities with the potential for clogging of the inlet grates and, under extreme fouling, could lead to misoperation of float control equipment.

Mussel settlement in the collection channel and transport conduit would be expected to increase fish injury potential and alter flow capacity of the conduit if fouling becomes excessive. Furthermore, mussel fouling in the upstream portion of the system would become a source of dead mussel shell debris that can adversely impact the downstream juvenile fish facility. However, the annual shutdowns with provisions for unwatering will likely mitigate impacts and preclude long term accumulation of mussels as well as afford opportunities to clean waterways and associated systems.

Figure 24. Orifice at juvenile fish collection channel

Juvenile Fish Facility

Similar to the adult trap facility the juvenile fish facility and transport operations appear highly susceptible to mussel related impacts due primarily to complexity and the relatively small sizes of piping, screens, equipment and related systems. Shell debris from upstream may be most problematic to deal with from operations, removal and handling standpoints. Any small diameter piping (less than about 6-in) would be susceptible to complete clogging depending on levels of infestation, shell debris loads, and operating conditions. Bar racks, separator screens (wedgewire or perforated plate), and crowders all have the potential to become fouled to some degree during the operating season. The most significant affects would be fouling of separator screens which would be expected to increase fish injury potential. Excessive accumulation of mussels could also impact valves, instrumentation, and related equipment. Though not part of this assessment, the juvenile transport barge system would clearly also be susceptible to mussel related impacts.

Figure 25. Juvenile fish separator rack

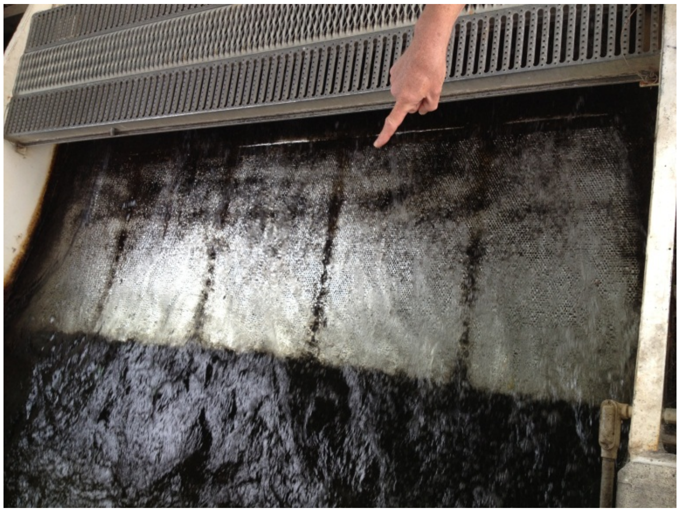

Figure 26. Juvenile fish separator screen

Figure 27. Juvenile fish holding raceway

Figure 28. Juvenile fish transport piping and barge dock

Instrumentation

Pressure, temperature, flow and level measurement instrumentation (including forebay and tailrace Hydrosonde equipment and perhaps even pit tag detectors) in contact with raw water are susceptible to errors or inoperability due to mussel fouling. This also includes stilling wells, floats, piezometer rings, pressure transducers, pressure and temperature gauges and switches, and acoustic flowmeters.

Crane & Hoist Certification

If water weight bags are used for crane or hoist testing, the contract statement of work must include language for preventing the spread of invasive species from one site to another. Information about decontamination procedures can be found in Appendix B with a link to Reclamation's Equipment Inspection and Cleaning Manual.

Conclusions

Lower Granite Lock and Dam facilities are relatively complex and a heavy invasive mussel infestation would likely significantly impact facility operations and maintenance. Impacts would generally be expected to include fouling of trashracks, grates, gates, screens, bar racks, cooling water systems piping, valves, and associated equipment and instrumentation. However, some proactive steps have been taken through the retrofit of strainers with filtration for the units cooling water systems. Nevertheless, heavy shell debris loads can still overwhelm strainers and filters. Fish passage, handling, and transport facilities also appear highly susceptible to impacts which could include mussel fouling on submerged surfaces, diffusers, separators, instrumentation and equipment along with clogging of piping and associated systems from shell debris.

The variability of calcium levels from limited available water quality data would suggest that conditions at Lower Granite Dam may only be suitable for supporting moderate levels of infestation. If calcium levels are persistently on the low end, minor mussel-related impacts would be expected. Conversely, if calcium levels are typically on the high end (above 30 mg/L) and pH typically near 8.5, then moderate to heavy infestations may occur with more pronounced impacts. As such, there is an apparent need for additional analyses of water quality data to further ascertain the potential for mussel survival and establishment at Lower Granite. Doing so would also help to further prioritize response planning, both locally and regionally.

Although not part of this assessment, if Lower Granite Reservoir becomes infested in the future, downstream water delivery and power generation facilities would also eventually become exposed to infestation and mussel-related impacts in varying degrees depending on operating conditions and infestation levels.

Recommendations

Monitoring and Detection

To date mussels have not been detected in the Snake River system. However, it is recommended that seasonal (spring-fall) monthly sampling and analyses for larval detection (plankton tow sampling) be continued for the earliest possible detection of mussels. Larval detection potentially allows for 2-3 years of lead time to enable planning, budgeting, and implementation of response actions for facilities protection should mussels be detected. If invasive mussels are detected in the future and suitability appears adequate for survival and establishment, emphasis should transition to monitoring for settlement using substrates. This post-introduction monitoring provides information on the evolution of the infestation. Typically settlement on intake structures will be observed first followed by impacts to internal piping and related systems and equipment. Continued monitoring can also be used to refine maintenance schedules, further inform facility protection strategies, or anticipate future changes in population dynamics as well as ecological impacts attributable to mussels, as needed.

Response Planning

It is recommended that this report be used in conjunction with the Columbia River Basin Response Plan to develop site-specific actions for the possibility of a future mussel infestation at Lower Granite Lock and Dam facilities. One specific response action worth considering would be the inclusion of mussel impacts and associated requirements into the SOP and O&M schedules where possible. Appendix B provides some management options for response planning, including links to various response planning guidelines and online examples.

Facility Protection Options

While a variety of solutions may be possible (or new technologies may become available), not all solutions are applicable to all situations or all facility components. Some options may be as straightforward as routine cleaning while submerged or inaccessible structures and systems may require unique measures, including redesign or retrofit, to deal effectively with invasive mussels. The options provided below are suggestions on where to begin should a future infestation occur, but they do not substitute for thorough planning and engineering.

Lock, Dam & Spillway

The regularly scheduled annual shutdowns for unwatering and inspection of the lock afford the opportunity to access waterways and equipment for inspection and removal of mussels and shell debris as needed. Servicing of gates involves bulkhead installation which will likely require a means for cleaning of bulkhead slots and seats prior to installation to achieve adequate sealing.

Depending on levels of infestation, the unwatering pumps may become difficult to operate if live mussel fouling or shell debris accumulation around pump intake strainers occurs. Options for reducing settlement on the strainers could include the use of foul release coatings, but the system would still be susceptible to clogging from shell debris if accumulations around the intakes become excessive. For pump cooling and seal water systems, where so equipped, installation of self-cleaning filtration may provide adequate protection by excluding live mussels and dead mussel shell debris that could otherwise clog supply lines.

Mussel fouling on submerged surfaces of the dam would not be expected to require corrective actions. However, long term settlement would become a source of mussel shell debris which could be drawn into downstream systems depending on location. If an invasive mussel infestation occurs at Lower Granite, more frequent monitoring and inspection of structural drainage systems would be warranted. If mussel fouling or changes in drainage system flows are observed, more frequent inspections and cleanout of accessible portions of the systems may be required.

Few options are available to proactively protect the spillway gates and long term fouling is likely to occur without more frequent servicing of gate seals. Like bulkheads, provisions for cleaning stoplog slots and seats prior to installation may be required to achieve adequate seating and seal performance. Foul release coatings may also be an option to reduce mussel settlement on upstream surfaces of the gates if needed.

The RSW will also be difficult to proactively protect. The use of foul release coatings to minimize fouling may be an option worth considering. If the entire structure cannot be coated and mussel fouling on uncoated portions would not affect the ability to deploy the RSW, coatings could at least be considered to reduce fouling along flow boundaries for which fish may come in contact. But, the size of the structure would undoubtedly make coatings an expensive alternative and removal for coatings application is likely impractical

Powerplant

Trashracks

One option for trashracks throughout the facilities includes removal and replacement with backup sets followed by manual cleaning where possible. However, depending on the level of infestation, frequent cleaning could become expensive. Foul-release coatings could also be considered as a proactive strategy to reduce the maintenance frequency and facilitate cleaning. Various coatings for metallic structures are currently being tested at Reclamation’s Parker Dam which is heavily infested with quagga mussels. Results to date are promising, but limitations in durability have been identified and so applications where raking occurs would not likely be viable. Nevertheless, suitably durable coatings systems may become available in the near future which could provide solutions for reducing fouling in many cases.

Other options where raking is in place could involve retrofit of the rake heads with high pressure water jetting to remove mussels between bars during raking operations. In such cases, a mussel free water supply would be needed to eliminate impacts to water delivery piping and nozzles for the water jetting system.

Extended Length Bar Screens

Lodged shell debris could become problematic and may require more frequent removal and manual cleaning. Foul release coatings would afford some measure of proactive protection to reduce fouling, but potential problems with lodged mussel shell debris in the screen would likely remain.

Vertical Barrier Screens

Options for the vertical barrier screens could include removal and replacement with back up sets for cleaning at regular intervals. Foul release coatings may also be worth consideration to reduce or minimize fouling and lengthen the period of time between removal and cleaning cycles. Owing to the design and performance requirements, any mussel fouling on the screens may be unacceptable

Intake Gates & Bulkheads

Available options for proactively protecting the intake gates are generally limited to removal and manual cleaning at regular intervals. Regularly exercising the gates can reduce mussel attachment along the guides, stems and seals, but doing so can also increase wear on seal elements and mechanical components. A means for cleaning bulkhead slots and seats prior to installation may be required for adequate sealing. Consideration could also be given to alternative materials of construction for guides and sealing surfaces to prevent or reduce mussel fouling where possible.

Cooling Water Systems

The units cooling water systems appear somewhat protected. The supply strainers for the generator air coolers, bearing oil coolers and other portions of the cooling water system have been retrofit which appears sufficient to exclude a significant percentage of mussels. In addition to filtration, ultraviolet (UV) light treatment systems may also be viable, if needed. UV equipment with sufficient dose capability could be installed just downstream of the existing filters to kill any remaining veligers that make it past the filters. An environmentally acceptable option involving the use of a promising bacterial-based product that appears selectively lethal to mussels has also recently become available as another option for mussel control in the cooling water systems. It should be noted that portions of the cooling water supply piping upstream of the strainers to the inlets at the gate slots (including grates) would remain susceptible to mussel fouling which will likely require frequent manual cleanout, depending on levels of infestation.

Proposed conversion of the HVAC system to closed loop is another proactive step that has apparently already been taken is planned and would be expected to reduce or mussel-related impacts to that system. Although makeup water will be periodically needed, there are substantially more treatment options available for closed loop cooling systems as compared to single-pass or once-through systems.

Draft Tube Bulkheads

As with other bulkheads, options are limited to manual cleaning of guides and seats prior to installation of the bulkheads in order to prevent seal damage and ensure adequate seating. Storage of bulkheads in the dry is recommended when and where possible. Alternative materials may also be considered for the guides to reduce mussel fouling and facilitate cleaning.

Drainage & Unwatering Sump

The sump will likely require regular manual cleanout when possible to manage mussel fouling on continuously submerged surfaces and remove accumulated mussel shell debris. Increased inspection and maintenance frequencies for the float switch arrangements and pump intake screens (where so equipped) will also likely be required to ensure reliable operation of the system. Consideration could also be given to replacing float switch arrangements with a noncontact level sensor/switching arrangements (e.g., downlooking acoustic water level sensor), if possible, to ensure reliable operation of pumps and sump system.

Air Vents

Periodic inspection and cleaning of all air vents throughout the facility will likely be required at more frequent intervals and should be a high priority if an infestation occurs. While there are few options available for ensuring that air vents operate reliably for the intended purpose, more frequent inspections will provide information on the extent of the problem. If significant blockage is observed, retrofit of the vent systems, perhaps using copper-based materials of construction to reduce mussel fouling, could be considered.

Service & Domestic Water Systems

For domestic water systems, options for proactively protecting supply and distribution piping beyond the use of strainers, filtration, and UV would include moving treatment processes as far upstream as possible. If the domestic intake is separate from other raw water systems, provision may still be required to protect the intake(s) from clogging.   Station service water lines, equipment, and taps utilizing raw water will likely require frequent disassembly and cleaning to maintain operability.

Fire Protection Systems

The best available proactive strategy for maintaining reliable operation of water-based fire protection systems is conversion to a treated or mussel-free water supply where possible, or use of alternative suppression technology that does not rely on raw water. Any fire system solution utilizing infested water should be considered highly susceptible to acute impacts from heavy mussel shell debris loads which can, even for dry deluge systems, overwhelm strainers upon activation. In this case, the generators are protected by CO_2 suppression systems while the oil storage room and station service transformers are protected by fine mist spray systems that utilize the potable water supply.

Fish Facilities

Juvenile Bypass

Aside from manual cleanout at frequent intervals, there seems to be few options for preventing mussel settlement in the juvenile collection channel except for the use of foul release coatings if and where possible. Use of foul release coatings or installation of foul release liners for the juvenile bypass pipe may also be an option worth consideration to reduce mussel fouling. Additionally, pigging equipment may provide opportunities for cleanout with minimal interruptions to operation. Operating criteria are not entirely clear, but if possible, increasing mean velocities in the bypass pipe to greater than 6 ft/s would likely reduce or maybe even prevent mussel settlement. While, annual shutdowns afford opportunities for mussel removal and reduce long term fouling, it is not likely that any mussel settlement can be tolerated in fish transport piping and related systems owing to the likelihood of increased injury potential. Thus, provisions for ensuring the juvenile bypass pipe does not become fouled during the operating season would appear to be a high priority.

Adult Fish Ladder

Options for reducing settlement on bar racks, pickets, and diffusers is likely limited to foul release coatings. Where possible (and if not already the case), retrofit of structures to facilitate removal and cleaning or replacement with back up sets would be worthwhile should an infestation occur. The auxiliary and emergency water supplies pumped systems may be difficult to proactively protect. Any cooling or seal water supply systems for the auxiliary water supply pumps could potentially be protected by self-cleaning filtration systems, but intake screens will likely require frequent removal and cleaning to maintain systems discharge capacity and reliable operation.

The ladder itself will be difficult to proactively protect. Some mitigation may inherently occur due to relatively shallow flow depths and annual shutdowns to reduce long term fouling, but fouling would still be expected for portions of submerged surfaces. Like the juvenile collection channel, foul release coatings may be worth consideration, but frequent cleanout may still be required to minimize fish injury potential and maintain adequate hydraulic operation of the fish way. Ladder entrances and associated equipment will also likely require frequent inspection and cleaning to minimize fouling.

Adult Fish Trap & Juvenile Fish Facility

Although impacts from long term mussel accumulations are not expected due to annual shutdowns of the fish facilities, as with other fish passage systems, foul release coatings may the best proactive means of reducing settlement during operations. This would include use on separator racks and screens as well as within transport piping and raceways. Regardless of proactive settlement prevention, provision for shell debris removal and handling will likely be required. Other equipment including valves, pumps, and piping would be expected to require frequent disassembly and cleaning.

Instrumentation

The forebay and tailrace monitoring systems (Hydrosonde equipment) will likely require frequent inspection and cleaning. Other instrumentation including pressure taps, gages, temperature sensors, pressure and temperature switches, and flow measurement devices will likely also require frequent inspection and disassembly for cleaning to maintain accurate and reliable operation. In the event of an infestation, all critical instrumentation for safe systems operation should be inventoried and priority schedules developed to inspect and test frequently to ensure reliable operation.

Appendix A

Facility Vulnerability Checklist

Project Name: **Lower Granite Lock & Dam, USACE**

Prepared by: Kubitschek & Willett **Date of Preparation:** 7/31/2013

2. Preparation (Step 1)

Item No.	*Item*	Status [1]	Comments / Plan to Resolve
1	**Planning**		
1.1	Has the project scope – including definition and objectives – been prepared?	Y	
1.2	Has the *Project Scope Statement* been approved?	Y	
1.3	Is there a *Project Plan* against which to measure progress?	Y	Project Management Plan (PMP)
1.4	Does the *Project Plan* address the following areas:		
1.4.1	• Project Scope and Deliverables	Y	
1.4.2	• Project Schedule	Y	
1.4.3	• Project Budget	Y	
1.4.4	• Project Organization and Resources	Y	
1.5	Were key project stakeholders brought into the *Project Plan*?	Y	
1.6	Were potential customers involved early in the planning process?	N/A	
1.7	If there are vendors, have they signed off on the *Project Plan*?	N/A	
1.8	If there is an independent oversight contractor, have they signed off on the *Project Plan*?	N/A	
1.9	Is the Project Sponsor function identified and defined?	Y	
1.10	Are there alternate persons if key members of the project are not available or become reassigned?	Y	
1.11	Other organization items (*please list*):	N/A	
2	**Tracking & Monitoring**		
2.1	Are the various types of reports, their contents, frequency, and audience defined and communicated to the Project Team?	Y	
2.2	Are the input requirements from Project Team members clearly documented and communicated?	Y	
3	**Meetings and Input Data**		
3.1	Have the various meetings, purpose, context, frequency, and participants been defined and communicated?	Y	
3.2	Have the drawings and documents from the facility sites been requested?	Y	

[1] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **Y** (Yes), **N** (No); **NA** (Not Applicable)

2. Preparation (Step 1)

Item No.	*Item*	Status [1]	Comments / Plan to Resolve
4	**Project Assumptions and Constraints**		
4.1	Are there any key assumptions upon which the assessment is based and have these assumptions been documented?	Y	
4.2	Does the Project have any Constraints such as:		
4.2.1	• Facility shutdown schedules?	Y	Facilities operating at time of site visit
4.2.2	• Facility access limitations and ventilation requirements?	Y	Access limited to structures, systems, and equipment without requiring shutdown
4.2.3	• Monitoring issues such as availability of reports from sampling plates set out in previous seasons?	N	
4.2.4	• Any training needed for key project staff?	N	
4.2.5	• Any pre-project procurement needed for portable field equipment?	N	

3. In-house Review and Preparation for Field Visits (Step 2)

Item No.	*Item*	Status [2]	Comments / Plan to Resolve
1	**Reviewing**		
1.1	Have drawings and documents from the facility site been reviewed?	Y	Review of available dwgs
1.2	Have questions arising from the document review been communicated to and discussed with the site experts?	Y	Generally during site visit
1.3	Did the document review identify any pre-site-visit activities that should be done such as video inspections requiring divers or shutdown of equipment that needs to be scheduled?	N	
1.4	Are all pre-site-visit tasks needed to be done at site completed?	Y	
1.5	Has the deliverables list been updated based on the information from the site documents?	Y	
1.6	Have all system checklist sheets been prepared?	Y	

[2] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **Y** (Yes), **N** (No); **NA** (Not Applicable)

4. Site Visits, Follow-up and Reporting (Step 3)

The general approach should be to follow the path of the water through the site facility. The water path will become more complicated each time the water branches into a specific system. Follow each system in turn and you will have covered the complete flow of water through the facility.

Item No.	*Item*	Status	*Comments / Plan to Resolve*
1	**Field Walkthroughs**		
1.1	Has the pre-meeting at site been completed?	Y	Presentation on mussels given to project staff and brief discussions with project personnel on purpose/intent of the assessment
1.2	Were all necessary site staff available?	Y	
1.3	Have follow-up discussions with staff not available during the site visit been scheduled and completed?	N/A	
1.4	Have all the system walkthrough checklists been completed?	Y	
1.5	Have all actions arising from the site meeting and system walkthroughs been documented and communicated to the person responsible for the action?	Y	
1.6	Has the draft project report been reviewed by all contributors?	N/A	Will be completed following site visit
1.7	Has the final report been approved for issue?	N/A	Will be completed following site visit
1.10	Has the final report been distributed?	N/A	Will be completed following site visit

5. Mussel Vulnerability Evaluation - Project Team Contact List

Project Name: Lower Granite Lock & Dam, USACE

Project Lead: Kubitschek & Willett

Some suggestions for the roles of the various team members and the skills or knowledge that would be helpful for each team member are contained in Appendix A.

Name	***Title***	***Location***	***Office Phone & E-mail***
Joe Kubitschek	Hydraulic Engineer	Reclamation, TSC – Hydraulic Investigations and Laboratory Services, Denver, CO	(303) 445-2148 jkubitschek@usbr.gov
Leonard Willett	LC Region Mussel Task Force Coordinator	Reclamation, LC Region, LC Dams Office, Boulder City, NV	(702) 494-2216 lwillett@usbr.gov
Greg Moody	Fisheries Biologist	USACE – Walla Walla District	(509) 527-7124 gregory.p.moody@usace.army.mil
Ben Feider	Chief of Tech	USACE – Lower Granite Lock & Dam	(509) 843 -1493x258

5. Mussel Vulnerability Evaluation - Project Team Contact List

Charles Weatherspoon	Mechanical Engineer	USACE – Lower Granite Lock & Dam	(509) 843 -1493x260 Charles.H.Weatherspoon@usace.army.mil
Mike Halter	Fisheries Biologist	USACE – Lower Granite Lock & Dam	(509) 843 -1493x263 Mike.J.Halter@usace.army.mil
Damian Walter	Wildlife Biologist	USACE – Walla Walla District	(509) 527-7136 Damian.J.Walter@usace.army.mil
Ann Setter	Fisheries Biologist (Lead)	USACE – Walla Walla District	(509) 527–7125 Ann.L.Setter@usace.army.mil

6. Mussel Vulnerability Evaluation – Sample Facility Deliverables List

Facility Name: Lower Granite Lock & Dam, USACE

The deliverables are internal document packages prepared for each system or major structure. Once all deliverables are completed, they are then used to prepare the overall assessment report which would be the only external deliverable. It will be helpful when preparing this list to refer to Appendix D for additional detail about typical systems and components at risk that should be considered.

Major Structure or System	***Reference drawings Used***	***Deliverables***
Dam & Appurtenances	Avail dwgs provided by USACE	
eg2: pump station unit cooling water system	N/A – No pumping plant	
eg3: powerplant & fire water system	Avail dwgs provided by USACE	
Continue with systems or structures until all areas in contact with raw water are covered.		

System Walkthrough Checklist

System or Structure Name: **Lower Granite Lock & Dam, USACE**

Prepared by: Kubitschek & Willett **Date of Preparation:** 7/31/2013

1. Instructions for Using this Document

- Prepare one of these sheets for each system or major structure identified in the Deliverables list.
- For each *Item No.* below, complete all blank fields (see footnotes for *Status* and *At Risk of Mussels* columns).
- For some of the components such as valves and strainers there may be several in one system. If more than one component needs to be considered add an extra sheet for that particular component group.
- Refer to Appendix C for additional information and suggestions about various systems and components.
- Add additional rows as required where you identify items that need to be considered and are not covered elsewhere in the list.

2. Walkthrough Checklist

Item No.	*Item*	*Status* [3]	*At Risk (yes/no)*	*Comments*
1	**General for Dams, Reservoirs, Aqueducts**			
1.1	Are there any membranes, control joints, permeable construction media, drains, etc. that will let raw water pass?	Y	Y	No specific structural drainage systems were identified/pointed out during the walk thru, but there is a spillway under drain system and formed drains for the concrete section. Potential for mussel related impacts to drainage systems currently unknown
1.2	Are there any air vents?	Y	Y	Various throughout the facility
1.3	Check if the spillway and appurtenances are always wet or dry and record duration of dry period.			Spillway operates seasonally and radial gates typically submerged
1.4	How much does the water level (i.e. reservoir water surface elevation) fluctuate?			Varies slightly, typically about 5 ft. Min pool to max pool is 22.5 ft
1.5	Are all potential water seepage paths inspected on a regular basis?	Y		
2	**Water Intake Structures**			
2.1	Types of intake structures present (more than one may be present):			
2.1.1	• Open Canal Direct into Facility (concrete)	N		
2.1.2	• Open Canal Direct into Facility (other material-specify)	N		
2.1.3	• Forebay (specify lining material)	N		
2.1.4	• Tower (specify construction material)	N		
2.1.5	• Submerged Tunnel or pipe intake (specify construction material)	N		
2.1.6	• Penstock intakes (specify construction material)	Y	Y	Separate power plant intakes
2.1.7	• Fish Barriers	Y	Y	Power plant intakes ESBS and vertical barrier screens
2.2	Is the floor of any intake structures likely to be covered with silt or sediment?	N		

[3] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **A** (Absent); **Y** (Yes), **N** (No); **NA** (Not Applicable)

2. Walkthrough Checklist

Item No.	Item	Status [3]	At Risk (yes/no)	Comments
2.3	Are any structures duplicated to provide a backup?	N		
2.4	What is the flow velocity range in the structure?			Velocities will likely range from 0-5 ft/s at the intakes and exceed 20 ft/s depending on operating conditions.
2.5	Is the structure accessible for inspection?	N		Intakes submerged and operating at time of site visit
2.6	Are there any shutdowns to provide easy access and what is their frequency?	Y		For regularly scheduled inspection and maintenance cycles.
2.7	Are there scheduled maintenance cycles and what are their frequencies?	Y		Varies depending on the system/equip, but typically annual.
3	**Trash Racks, Grates, Screens**			
3.1	Record spacing, size and material of trash rack bars.		Y	Unavailable at time of site visit but intake trashracks bar spacing likely between 6-8 in
3.2	Are trash racks fixed or easily removable for maintenance?		Y	Powerplant intake trashracks removable, but typically remain in place
3.3	Is there a planned maintenance frequency for the trash racks? If so what is interval?	N	Y	
3.4	Is there a trash rake or other style of cleaning system?	Y	Y	Powerplant intake trashracks raking system
3.5	Are the rake fingers sufficiently large to remove mussels from sides of trash rack bars?	N	Y	
3.6	Record location, material, size and grid spacing of any small intake grates.		Y	Makeup water intakes for juvenile collection channel, cooling water intake grates (1/2-in bars on 2-in centers)
3.7	Are grates fixed or removable for easy maintenance?		Y	Fixed
3.8	Check if grates at bottom of pipes or channels get covered with silt or sediment.	N	Y	
3.9	Record location, material, size and grid spacing of any screens.		Y	ESBS and vertical barrier screens appear to be wedgewire
3.10	Are screens fixed or removable for easy maintenance?		Y	Traveling and vertical barrier screen removable
4	**Wells and Sumps**			
4.1	Location and material of constructions of wells.	N/A		
4.2	Identify level fluctuations in pump wells.	N/A		
4.3	Distance of pump suction from bottom of wells. Will pump ingest shells that are transported along the floor into the well?	N/A		
4.4	Location and material of constructions of sumps.		Y	Powerplant drainage and unwatering sump - concrete
4.5	Is there a float or other instrumentation in sump that could become covered with mussels?	Y	Y	Float switches
4.6	Frequency of sump inspection by plant staff.		Y	Monthly (assumed)
5	**Pumps and Turbines**			
5.1	Is pump motor or turbine generator water or air cooled? Water cooled motors are at risk.		Y	Generator air coolers, bearing oil coolers, station transformers, and HVAC systems utilize raw water
5.2	Can mussel shells get into wear ring gaps?	Y	Y	Assumed possible
5.3	Does pump have a mechanical seal?	N		Sump pumps do not use seal water
5.4	How is the seal flushed during start-up?	N/A		
5.5	How is the seal flushed during normal running?	N/A		

2. Walkthrough Checklist

Item No.	Item	Status [3]	At Risk (yes/no)	Comments
5.6	Does the turbine have a stuffing box?	Y	N	Turbine packing does not use raw water
5.7	Is there a stuffing box lantern ring or other cavity for cooling and flushing water?	N/A		
5.8	How is the ring flushed during start-up?	N/A		
5.9	How is the ring flushed during normal running?	N/A		
5.10	Check if the turbine bearings have water cooled lubrication?	Y	Y	Bearing oil coolers for all units use raw water
5.11	Check if the pump has water cooled bearings?	N		
5.12	Can mussel shells get into the water lubricated bearing passages?	N/A		
5.13	Do seal or stuffing box cavities have a means of monitoring or inspection?	N/A		
5.14	Can seals or stuffing box be cleaned without removing generator?	N/A		
6	**Piping**			
6.1	Identify materials of construction for piping.		Y	Steel, copper
6.2	What is flow velocity range in piping?		Y	Varies depending on system & operating conditions
6.3	How much time is velocity above 6 ft/sec?		Y	Varies depending on system
6.4	How much time is velocity below 6 ft/sec?		Y	Varies depending on system
6.5	Are there any offsets or changes in pipe diameter?	Y	Y	Offsets, bends, fittings, etc... throughout the facility
7	**Instrument Tubing and Instruments**			
7.1	Identify any small diameter lines (2” diameter or less) including material of construction such as:		Y	Service water taps, bearing oil coolers supply and return lines, fish facilities piping, etc…
7.1.1	• Flow measurement taps	N		
7.1.2	• Piezometer taps	N		
7.1.3	• Pressure taps	Y	Y	Pressure taps/gages/switches throughout the facility
7.1.4	• Sample lines	N		
7.1.5	• Pressure balance lines	N		
7.1.6	• Other – Outlet works flowmeter	N		
	• Other – Reservoir El. gauge	Y	Y	
8	**Heat Exchangers**			
8.1	Identify material of construction of plenum.		Y	Generator air cooler tubes and bearing oil coolers heat exchangers
8.2	Identify material of construction of tubing.		Y	Assumed copper
8.3	What is diameter of tubing?		Y	Smallest diameters ~¾-in tubing
8.4	What is flow velocity range in tubing?		Y	Depends on operating conditions, but likely less than 6 ft/s
9	**Valves**			
9.1	Identify all normally open (NO) valves.		Y	Juvenile collection channel outfall, cooling water supply, various throughout the facility
9.2	Can NO valves fail to seal properly if valve seat or valve face becomes mussel coated?	Y	Y	Possible, particularly for butterfly valves

2. Walkthrough Checklist

Item No.	Item	Status [3]	At Risk (yes/no)	Comments
9.3	Identify all normally closed (NC) valves		Y	Various throughout the facility, particularly the fish facilities
9.4	Can NC valves fail to open if valve face becomes coated with mussels?	Y	Y	May be possible depending on size, operational frequency, and levels of infestation
9.5	What is throat diameter of valve? Is it small enough to become plugged by mussel shells?		Y	Various valves through facility
10	**Strainers and Filters**			
10.1	Identify the style of strainer, material of construction of strainer body and basket as well as the size of the basket pores. Typical styles are:			Various strainers on cooling water supply lines
10.1.1	• Fixed In-line strainer	N		
10.1.2	• Duplex strainer	Y	Y	Cooling water supply lines
10.1.3	• Self-cleaning strainer	N		
10.1.4	• Wye (Y) strainer	Y	Y	Cooling water supply lines
10.1.5	• Other type - specify			
10.2	Identify the style of filter, material of construction of body and filter element, as well as the size of the filter pores. Typical styles are:		Y	Fine mesh filter media used on cooling water supply. Strainers recently retrofit
10.2.1	• Self-cleaning filter	N/A		
10.2.2	• Replaceable cartridge filter	Y	Y	
10.2.3	• Other type - specify	N/A		

Appendix B

Management Options for Quagga & Zebra Mussel Infestations

Concurrent with Prevention & Public Outreach/Education Actions

Most water bodies in the western United States are now at risk of infestation by invasive quagga and zebra mussels. While the actions taken to prevent or respond to infestation must be tailored to each specific location, the following activities represent options for consideration as part of any readiness planning as well as options for dealing with mussels following detection. Information on preventing the spread of invasive mussels can be found at the 100th Meridian Initiative website http://100thmeridian.org/ and http://protectyourwaters.net.

Procedures have also been developed by Reclamation and are documented in Technical Memorandum No. 86-68220-07-05 *Inspection and Cleaning Manual for Equipment and Vehicles to Prevent the Spread of Invasive Species* which provides guidance for inspecting and cleaning vehicles and equipment to help prevent the spread of invasive species during Reclamation activities. The manual can be found at http://www.usbr.gov/mussels/prevention/docs/EquipmentInspectionandCleaningManual2012.pdf

Actions to consider prior to detection of mussels:

1. **Develop Coordinated Response Plan(s) -** This plan would detail policies, command and authority structure, strategies, communications, roles and responsibilities, and response actions to be implemented – Involves multiple federal, state, and local agencies and stakeholders. An example Response Plan for the Columbia River Basin may be found at the 100th Meridian website http://www.100thmeridian.org/Columbia_RBT.asp. The National Parks Service also has information and guidelines for prevention and response planning that can be found at http://www.nature.nps.gov/biology/Quagga/index.cfm.

2. **Perform Infestation Risk Assessment(s) –** This activity may be completed as standalone or as part of the Coordinated Response Plan. The purpose is to identify which water bodies are most at-risk of infestation within the geographic region of interest or management jurisdiction. The likelihood of infestation is typically based upon recreational usage, nearest known infestation, and the extent to which environmental conditions (including calcium, pH, dissolved oxygen, temperature, etc…) are likely to support mussel establishment. This information can be used to prioritize facility vulnerability assessments (below). A variety of examples for risk assessments are available on the web. Information specific to environmental suitability based risk assessments is available at the U.S. Army Corps of Engineers Zebra Mussel Information System (ZMIS) website http://el.erdc.usace.army.mil/zebra/zmis/zmishelp.htm.

3. **Perform Facility Vulnerability Assessment(s) –** This activity may be completed as standalone or following the infestation risk assessment(s) and consists of a detailed inventory of critical water related infrastructure at a water body and how each component is likely to be affected by mussels should infestation occur. The results can be used to prioritize facility protection needs and actions. A facility vulnerability assessment template can be found at www.usbr.gov/mussels/.

4. **Implement Monitoring Program(s) –** Monitoring programs should be considered for high priority water bodies where infestation is either most likely or would cause significant harm to water systems or other key resources. Monitoring programs, designed to provide early detection of mussel larvae (through water sampling and lab analysis), potentially provide 2-3 years of lead time for planning and implementing protective actions before the infestation impairs operations via adult settlement on hydraulic structures or within critical systems. Additional information on monitoring can be found at the U.S. Army Corps of Engineers Zebra Mussel Information System (ZMIS) website http://el.erdc.usace.army.mil/zebra/zmis/zmishelp.htm.

Actions to consider following detection of mussels:

1. **Execute Coordinated Response Plan –** Involves notification, information exchange, and implementation of containment and control actions (i.e., components of the response plan).

2. **Increase Monitoring –** Transition from monitoring for detection to monitoring with increased frequency to confirm detection, identify or locate the presence of adults, and track infestation levels. This activity may also include regular facilities inspections to determine when facilities are being impacted by adult colonization. This information can guide facilities protection actions and assists in anticipating ecological impacts for future mitigation planning.

3. **Identify and Implement Appropriate Facilities Protection Measures –** Identify which actions or technologies are best suited for maintaining water operations and reducing O&M costs or other expenses. Various conventional technologies have been used with reasonable success. The table below provides some conventional as well as experimental options, each of which has advantages and disadvantages. It should be noted that there are a number of commercial treatment products that have not been listed, but may be applicable in various situations.

Table 1 – Control and facilities protection options for various applications

Technology	**Example Applications**
Filtration to prevent mussel entry to piped systems – Self-cleaning 40-80 micron filters may be more than adequate depending on exclusion requirements. Exclusion avoids the need for treating infested systems.	Low volume systems - Facilities service water, unit or transformer cooling water, HVAC, pumped systems, and delivery pipelines
Ultraviolet (UV) Treatment of water in piped systems – In-line UV systems are being evaluated to prevent mussel settlement. UV has additional water treatment benefits and is not expected to require discharge permitting [†]	Low volume systems - Facilities service water, unit or transformer cooling water, HVAC, pumped systems, and delivery pipelines
Chemical Treatments – Injection or delivery of chemicals (oxidizing and nonoxidizing) to kill mussels or impair ability to attach to surfaces • Bromine • Chlorine • Chlorine dioxide	Low and medium volume systems - Facilities service water, unit or transformer cooling water, HVAC, pumped systems, and delivery pipelines. Permitting often required for chemical treatment methods

• Hydrogen peroxide • Ozone • Potassium salts • Potassium permanganate • Sodium Hypochlorite • Salinity	
Alternative Treatments – Alternatives to kill mussels or impair ability to attach • Thermal • Biological • Desiccation	Low and medium volume systems – Facilities service water, unit or transformer cooling water, HVAC, pumped systems and delivery pipelines. Desiccation requires capability to dewater system for extended durations
Coatings to protect exposed surfaces – Prevents mussel attachment or facilitates cleaning (anti-fouling & foul-release) †	Hydraulic Structures & Equipment - Gates, valves, penstocks, intake structures, trashracks, fish screens
Alternative Materials – To prevent mussel attachment or facilitate cleaning • Copper • Galvanizing (requires high zinc content)	Intake grating, piping/tubing, heat exchangers, HVAC systems
Mechanical Removal – For routine maintenance • Mechanical raking/scraping • Hydrojetting/water spraying • Pipeline pigging • Traveling intake screens (self-cleaning)	All structures, systems, equipment, and instrumentation where access is possible – Diversion structures, pipelines, trashracks, intakes, fish screens. For instrumentation, noncontact methods should be considered where possible
Redundant Systems – Multiple intakes or duplicate systems for switching during treatment or cleaning to provide uninterrupted service	All systems for which retrofit is possible/practical

† - Under development or being field tested.

Technologies selection for each application depends on a number of considerations including periodic or continuous mussel exclusion requirements, operations and maintenance requirements, permitting requirements, environmental impacts, and cost; to name a few. If conventional technologies are not applicable then alternatives should be developed and demonstrated as early as possible to meet unique facilities requirements. Operational strategies may also be available to reduce or eliminate mussel impacts. However, such strategies are often limited depending on the type of system and available flexibility. Additional information on control strategies and facilities protection methods may be found in The Practical Manual for Zebra Mussel Monitoring and Control, R. Claudi & G.L. Mackie, CRC Press, Inc. (2000) and at the U.S. Army Corps of Engineers Zebra Mussel Information System (ZMIS) website http://el.erdc.usace.army.mil/zebra/zmis/zmishelp.htm

Identify Ecological Impacts – Involves developing and initiating actions to measure and track ecological changes, develop mitigation plans, and implement long-term mitigation actions (considers endangered species, food webs, aquatic weeds, water quality, etc…)