RECLAMATION
Managing Water in the West

Facility Assessment for Little Goose 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 Little Goose Lock & Dam Project Office

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Cover Photo: Photo of Little Goose 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

The facilities at Little Goose Lock and Dam 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, and associated equipment and instrumentation as well as impacts from heavy shell debris loads which can overwhelm strainers and filters. Fish passage, handling, and transport facilities also appear susceptible to impacts which could include mussel fouling on submerged surfaces, screens, diffusers, separators, instrumentation and equipment along with clogging of piping and associated systems from shell debris. However, the annual shutdown and unwatering of the fish facilities will likely reduce or eliminate long-term settlement. Shell debris would likely be the most significant impact for the fish facilities during operation.

The variability of calcium levels from limited available water quality data would suggest that conditions at Little Goose 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.

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 an infestation will occur at Little Goose, 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) 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 seasonal water quality sampling and analyses be conducted to further ascertain the potential for mussel survival and establishment near Little Goose.

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

Little Goose facilities consist of a dam, navigation lock, power plant, adult fishway, juvenile fish facilities and appurtenances. The project provides navigation, hydroelectric power generation, recreation and incidental irrigation. The dam is 2,655 feet long with an effective height of about 100 feet. It is located on the Snake River near Starbuck, Wash. It is a concrete gravity dam with an earthfill embankment. 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 concrete gravity section of the dam contains a 512-ft-long radial gated spillway with eight 50- by 60-ft radial gates. The right-most gate bay is equipped with a temporary spillway weir that is essentially a modified bulkhead to spill surface water and provide improved downstream juvenile fish passage. The weir is operated seasonally between April and August and was designed to be "adjustable" to raise and lower the crest to two positions (high and low).

The lock is located adjacent to the powerplant on the left abutment. The downstream end of the lock is equipped with miter gates which open laterally while the upstream end is equipped with a submerged tainter gate that is raised and lowered accordingly. Separate waterways, controlled by tainter valves, are used to fill and drain the lock.

The powerplant is adjacent to the spillway and consists of six 135-MW Kaplan turbine and generator units. The powerplant operates year round with varying number of operating units as needed to meet demand. The fish facilities include an upstream passage ladder, intake fish screens, downstream juvenile bypass system, and a juvenile collection and transport facilities.

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 water quality data that was provided for Lower Granite Dam, 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. Additional water quality information proximate to Little Goose Dam would be helpful to further assess potential infestation levels which can provide valuable direction for anticipating infestation levels and prioritizing accordingly.

Vulnerability of Features

Lock

The lock at Little Goose generally 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 multiple 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 on 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 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, bulkhead bypass or fill piping (if so equipped) may be susceptible to complete clogging with the potential for inoperability which would also make bulkhead removal problematic.

Figure 1. Downstream end of lock

Dam & Spillway

Although it is currently uncertain (i.e., hypothetical), the structural drainage systems (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. Little Goose staff indicated that clam shell debris is frequently seen in drainage galleries which would suggest it may be possible for invasive mussel larvae to enter drainage systems.

Spillway Gates & Stoplogs

The spillway radial gates remain partially submerged more or less continuously. Impacts from mussel fouling can range from increased friction along sealing surfaces with 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 in some cases.

Stoplogs are available for installation upstream of the radial gates to provide access for inspection and maintenance. 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.

Temporary Spillway Weir

The temporary spillway weir (TSW) can be raised or lowered to two different positions (high and low) via gantry crane. It is typically operated annually during the months of April through August. The TSW would likely be susceptible to mussel related impacts which may include general fouling of the structure, mechanical linkages and components. Long term fouling of the structure could make adjustment or removal difficult. Fouling along flow boundaries of the weir could also impact fish passage performance by roughening flow surfaces that could potentially expose fish to injury.

Powerplant

Intake Trashracks

The powerplant intakes are equipped with trashracks which would be susceptible to mussel related impacts owing primarily to intermittent operation of the units. Experience at Reclamation facilities that are heavily infested with quagga mussels suggests that portions of the 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 under heavy fouling. 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 potentially accelerate corrosion.

Extended Submersible Bar Screens (ESBS)

The intakes ESBS system also appears 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 screens that remain deployed which would reduce open area and alter velocity distributions with the potential for increased fish impingement and injury. The screens are equipped with brush cleaners, which can reduce mussel fouling. However, the back sides of the screens would remain susceptible. Nevertheless, considerable mitigation is afforded by the annual removal (mid-December to mid-March) of the screens which allows opportunities for cleaning to reduce long term fouling and associated impacts.

Gatewells & Vertical Barrier Screens

Surfaces in the gate wells and 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 gatewell surfaces and screens would be a primary concern.

Intake Gates & Bulkheads

The operating 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 depending on design, infestation levels and operating conditions.

Bulkhead slots are also likely susceptible to varying degrees of mussel fouling which can indirectly impact bulkhead seals during installation. Mussel fouling along the slots can damage seals and sealing surfaces with the potential for incomplete seating during installation. If bulkheads 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.

Cooling Water Systems

The powerplant cooling water systems supply the bearing oil coolers, generator air coolers with raw water from the spiral case. The packing glands are supplied using potable water and would not be impacted except indirectly via the raw supply to the water treatment facility. The transformers are air cooled and are not equipped with a fire protection system. 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, they can still become clogged with excessive shell debris drawn into the system which 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 small flow passages reducing or cutting off water flow at multiple points in the system. Clogging can cause increased operating temperatures and has the obvious potential in extreme cases for costly outages until cooling water flows can be restored.

Waterways & Draft Tubes

The internal surfaces of the waterways, casings, and draft tubes are not generally susceptible to mussel fouling during operation due mainly to high velocities and perhaps high turbulence intensities which are considered prohibitive for mussel settlement. However, mussel fouling has been observed 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. However, intermittent operation of units would allow for mussel settlement. Draft tube drain lines and valves would also be susceptible to clogging from live mussels or mussel shell debris.

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 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 which could affect sump pump 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 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.

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 gates 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.

Service & Domestic Water Systems

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 operating conditions, levels of infestation, and associated shell debris loads.

Fish Facilities

Adult Fishway

Adult fish passage at Little Goose Dam is accomplished by means of a conventional fish ladder system. Multiple entrances are available at the downstream side of the dam and powerplant (north shore, north powerhouse, and south shore entrances). The entrances are equipped with weir gates and bulkheads. The north shore and powerhouse entrances are connected to a fish transport channel that leads underneath the spillway and across the tailrace below the powerplant 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 by gravity from upstream of the dam and from the auxiliary water systems (AWS) to provide attraction flows at the entrances. 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.

The waterways, equipment, and operations for the adult fish passage facilities may be problematic in a number of ways should an infestation occur at Little Goose Lock and Dam. Although the fish ladder itself is relatively shallow, which may mitigate some impacts by potentially reducing settlement, any mussel fouling of pickets, along the ladder invert, portions of the weirs, orifices, diffusers and vertical slots could increase fish injury potential. Water level sensors or automated systems exposed to raw water would be equally susceptible which could result in misoperation or inoperability. However, the fish ladder is dewatered annually for inspection and maintenance during the winter which allows opportunities for cleaning and will reduce long-term fouling and associated impacts.

Mussel fouling on the AWS pump-turbine intake trashracks and piping would likely also be possible which could affect capacity. However, pump-turbine bearing cooling water (raw) and seal water (nonpotable) systems would likely be most problematic with susceptibility to mussel related clogging that could lead to inoperability of bearing coolers and degraded seal performance. Mussel fouling on diffusers could further reduce capacity and alter function of diffusers (velocity distributions). The equipment arrangements for the ladder entrances also appear susceptible and 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 exit bulkhead slots may be susceptible to long term fouling which can make bulkhead installation and seating difficult.

Juvenile Collection Orifices

Orifices in the gatewells allow fish to enter the collection channel. There are two 12-in orifices in each gatewell which are opened or closed by knife valves at the downstream sides. Fouling of internal surfaces is not likely during continuous operation due to relatively large velocities (> 10 ft/s), but may be possible for intermittent operation which could roughen internal surfaces and expose fish to potential injury.

Juvenile Collection Channel & Bypass System

The juvenile fish bypass facilities are operated annually late March-November. 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.

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.

Dewatering Systems & Corrugated Metal Flume (CMF)

The collection channel transports fish to a primary dewatering screen and then onto the juvenile fish facility. The primary dewatering is accomplished by means of a bar screen floor panel with make water diffuser used primarily for dewatering and waterup. The intake for the makeup water supply is likely susceptible to long-term mussel fouling which could potentially affect operation, particularly if the intake has a grating or bar rack.

The primary dewatering inclined screen also appears susceptible to mussel related impacts including short-term mussel fouling and shell debris accumulation. The system is equipped with brush and air burst cleaning systems which may reduce impacts to some degree. The secondary dewaterer perforated plate floor panels would also be susceptible to mussel related impacts including plugging from short-term settlement and mussel shell debris. It's unlikely that significant live mussel settlement will occur in the corrugated metal flume which transports fish from the collection channel to the JFF. Velocities in the flume are generally greater than 8 ft/s and the system is dewatered annually which would reduce long term mussel attachment. However, shell debris may be problematic as accumulation in the corrugations would expose fish to potential injury. Furthermore, shell debris accumulation on the porosity control system would also be problematic. In general, impacts to the collection system components will no doubt be significantly mitigated by the annual shutdowns and unwatering which will reduce or eliminate long-term fouling. Like most other systems, the main impacts are likely to result for shell debris drawn into the collection system during operation which would likely impact downstream interconnected systems (i.e., the JFF).

Figure 2. Juvenile bypass channel

Juvenile Fish Facility

The JFF and transport operations appear broadly 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 clogging depending on levels of infestation, shell debris loads, and operating conditions. Separator bar racks, separator screens (wedgewire or perforated plate), diffusers, piping and associated valves, distribution flumes, raceways and loading waterways all have the potential to become fouled to some degree during the operating season. The most significant affects would likely be fouling of separator screens which could increase fish injury potential. The juvenile transport trucking and barge systems would also be susceptible to mussel related impacts (namely shell debris). However, it should be noted that the annual shutdown and unwatering period for the JFF would be expected to significantly reduce or eliminate long-term mussel fouling and associated impacts and afford opportunities for manual cleaning.

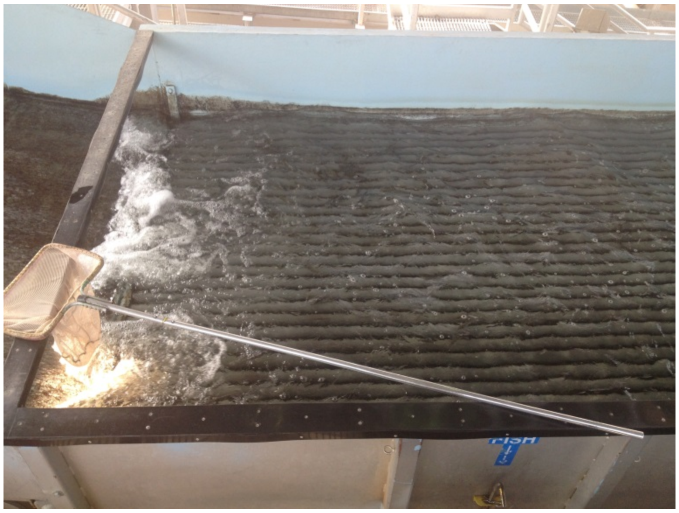

Figure 3. Juvenile fish separator bar rack

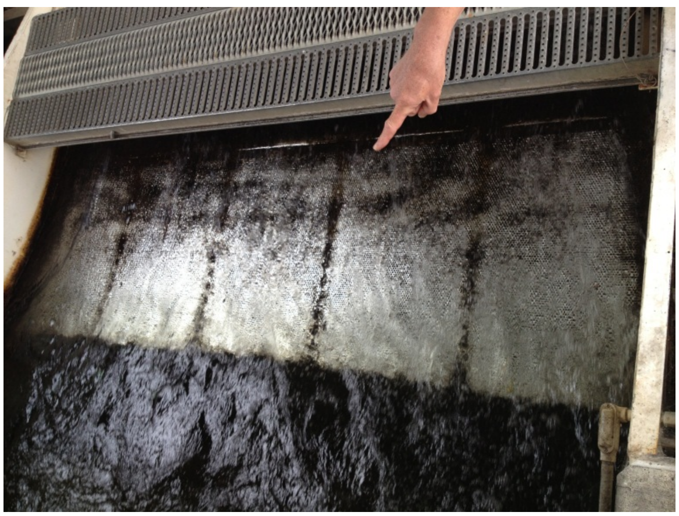

Figure 4. Juvenile fish separator screen


Figure 5. Juvenile fish holding raceways

Instrumentation

Pressure, temperature, flow and level measurement instrumentation (including forebay and tailrace equipment) 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.

Conclusions

The facilities at Little Goose Lock and Dam 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, and associated equipment and instrumentation as well as impacts from heavy shell debris loads which can overwhelm strainers and filters. Fish passage, handling, and transport facilities also appear susceptible to impacts which could include mussel fouling on submerged surfaces, screens, diffusers, separators, instrumentation and equipment along with clogging of piping and associated systems from shell debris. However, the annual shutdown and unwatering of the fish facilities will likely reduce or eliminate long-term settlement. Shell debris would likely be the most significant impact for the fish facilities during operation.

The variability of calcium levels from limited available water quality data would suggest that conditions at Little Goose 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.

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. If invasive mussels are detected in the future and suitability appears adequate for survival and establishment, consideration should be given to monitoring for settlement. This post-introduction monitoring provides additional 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 Little Goose Lock and Dam facilities. One specific response action worth considering would be the inclusion of mussel impacts and associated requirements into SOPs 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 exist (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

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 and valves 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 system may become difficult to operate if live mussel fouling or shell debris accumulation. Options for reducing settlement could include the use of foul release coatings.

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 Little Goose, 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 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 with the possible need for more frequent servicing of gate seals. Provisions for cleaning bulkhead slots and seats prior to installation may be required to achieve adequate seating and seal performance

The TSW will also be difficult to proactively protect if it remains continuously submerged. 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 TSW, coatings could at least be considered to reduce fouling along flow boundaries for which fish may come be exposed. But, the size of the structure would undoubtedly make coatings an expensive alternative.

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 cumbersome and 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 have been 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. 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 itself.

Extended Submersible Bar Screens

Lodged shell debris could become problematic and may require more frequent removal and manual cleaning. Foul release coatings may 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.

Intake Gates & Bulkheads

Available options for 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

For cooling water systems, 1/8-in strainer media should be installed to capture as much shell debris as possible which will also increase the frequency of cleaning. Ultraviolet (UV) light treatment may be a viable option for cooling water systems protection. UV equipment with sufficient dose capability could be installed just downstream of the existing strainers to reduce or prevent mussel settlement in downstream portions of the system(s). It should be noted that upstream sections of the cooling water supply piping from the strainers to the inlets at the gate slots (including grates) would remain susceptible to mussel fouling which will likely require more frequent manual cleanout, depending on levels of infestation.

Conversion of HVAC systems to closed loop is a proactive option where possible to reduce or eliminate 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.

Drainage & Unwatering Sump

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

Air Vents

Periodic inspection and cleaning of air vents 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. Station service water lines, equipment, and taps utilizing raw water will likely require frequent disassembly and cleaning to maintain operability. If an infestation occurs, consideration should be given to conversion of critical water systems to well water if possible.

Fish Facilities

Juvenile Bypass

Aside from manual cleanout at frequent intervals, there seems to be few options for preventing short-term mussel settlement in the juvenile collection channel while the system is operating. Use of foul release coatings may be an option worth consideration to reduce mussel fouling. 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 systems owing to the likelihood of increased injury potential. 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, retrofit of structures to facilitate removal and cleaning or replacement with back up sets would be worthwhile should an infestation occur. The auxiliary water supply pump-turbine systems may be difficult to proactively protect. Any cooling or seal water supply systems could potentially be protected by self-cleaning filtration systems.

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 possible for continually 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. Ladder entrances and associated equipment will also likely require frequent inspection and cleaning to minimize fouling.

Juvenile Fish Facility

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

Instrumentation

Instrumentation including pressure taps, gages, temperature sensors, pressure and temperature switches, and flow measurement devices will likely require frequent inspection and manual cleaning to maintain accurate and reliable operation. In the event of an infestation, all critical instrumentation should be inventoried and prioritized for inspection, testing, and/or cleaning to ensure reliable operation. Replacement of water level sensors with noncontact designs would also be worth consideration.

Crane & Hoist Certification

If water weight bags are used for crane or hoist testing, the contract statement of work should 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.

Appendix A

Facility Assessment Checklist

Project Name: **Little Goose Lock & Dam, USACE**

Prepared by: Kubitschek & Willett **Date of Preparation:** 8/25/2015

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?	N	
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?	Y	Limited WQ data avail
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	Avail dwgs provided
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?	N	Limited avail ability of dam and powerplant personnel. Pertinent systems assumed similar to Lower Granite

[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 fisheries staff with brief discussions on purpose/intent of the assessment
1.2	Were all necessary site staff available?	N	Dam and powerplant staff unavailable at time of site visit. Systems assumed similar to Lower Granite
1.3	Have follow-up discussions with staff not available during the site visit been scheduled and completed?	N	
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	TBC following site visit
1.7	Has the final report been approved for issue?	N/A	TBC following site visit
1.10	Has the final report been distributed?	N/A	TBC following site visit

5. Mussel Vulnerability Evaluation - Project Team Contact List

Project Name: Little Goose 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	Fishery Biologist	USACE – Walla Walla District	(509) 527-7124 gregory.p.moody@usace.army.mil
Towns Burgess	Supervisory Fishery Biologist	USACE – Little Goose Lock & Dam Project	(509) 399-2233 Oliver.t.burgess@usace.army.mil

6. Mussel Vulnerability Evaluation – Sample Facility Deliverables List

Facility Name: Little Goose 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	Limited avail dwgs provided	
eg2: pump station unit cooling water system	N/A – No pumping plant	
eg3: powerplant & fire water system	Limited avail dwgs provided	
Continue with systems or structures until all areas in contact with raw water are covered.		

System Walkthrough Checklist

System or Structure Name:	**Little Goose Lock & Dam, USACE**
Prepared by:	Kubitschek & Willett
Date of Preparation:	8/25/2015

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 pointed out, but there is a spillway under drain system and formed drains for the concrete section. Clam shells observed in drainage galleries. 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.		Y	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 13.5 ft
1.5	Are all potential water seepage paths inspected on a regular basis?	Y	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	Power plant intakes, separate for each unit
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 not removed
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	Cooling water intake grates (size undetermined)
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		
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, 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		
5.6	Does the turbine have a stuffing box?	Y	Y	Turbine packing

2. Walkthrough Checklist

Item No.	Item	Status [3]	At Risk (yes/no)	Comments
5.7	Is there a stuffing box lantern ring or other cavity for cooling and flushing water?	Y	Y	Flushing water and turbine pit drains
5.8	How is the ring flushed during start-up?			Prior to startup
5.9	How is the ring flushed during normal running?			Continuously
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 (assumed steel)
8.2	Identify material of construction of tubing.		Y	Assumed copper
8.3	What is diameter of tubing?		Y	Smallest diameters assumed ¾-in tubing
8.4	What is flow velocity range in tubing?		Y	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 other 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
9.3	Identify all normally closed (NC) valves		Y	Various throughout the facility, particularly the fish facilities

2. Walkthrough Checklist

Item No.	*Item*	*Status* [3]	*At Risk (yes/no)*	*Comments*
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:			Strainers on cooling water supply
10.1.1	• Fixed In-line strainer	N		
10.1.2	• Duplex strainer	Y	Y	Cooling water supply
10.1.3	• Self-cleaning strainer	N		
10.1.4	• Wye (Y) strainer	N		
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:			
10.2.1	• Self-cleaning filter	N/A		
10.2.2	• Replaceable cartridge filter	N/A		
10.2.3	• Other type - specify	N/A		

Appendix B

Management Options for Quagga & Zebra Mussel Infestations

Concurrent with Prevention & Public Outreach/Education Activities

Most water bodies in the western United States are at risk of infestation by invasive quagga and zebra mussels. While 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.

Guidance has also been developed by Reclamation and is 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 information for inspecting and cleaning vehicles and equipment to help prevent the spread of invasive species. 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, the 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 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 likely or would cause significant impacts 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. The information obtained can guide facilities protection actions and assists in anticipating ecological impacts for future mitigation planning and budgeting.

3. **Identify and Implement Appropriate Facilities Protection Measures –** Identify which actions or technologies are best suited for maintaining 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	**Potential 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 piping
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 piping
Chemical Treatment – 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 required for chemical treatment methods

• Hydrogen peroxide • Ozone • Potassium salts • Potassium permanganate • Sodium Hypochlorite	
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 – Routine maintenance • Mechanical raking/scraping • Hydrojetting • Pipeline pigging • Traveling intake screens (self-cleaning)	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	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 Mackie & Claudi, Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems, 2010 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 track ecological changes, develop mitigation plans, and implement long-term mitigation actions (considers endangered species, food webs, aquatic weeds, water quality, etc…)