Risk Assessment For Adult and Juvenile Fish Passage Facilities on the Mainstem Lower Snake and Lower Columbia Rivers Relative to a Potential Zebra Mussel Infestation

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1. Background: Zebra mussels (*Dreissena polymorpha*) were first discovered in Lake St. Clair, Michigan in 1988. Based on shell size, it was believed that they were introduced into the lake sometime in 1986 (O'Neill and MacNeill 1991). They have spread rapidly throughout the Great Lakes and Mississippi River drainage and are expected to reach across the United States and into the Pacific Northwest. A single specimen was recently found in the Missouri River near Sioux City, Iowa (near the head of navigation in April, 1999). The Washington Department of Fish and Wildlife has predicted a high probability that zebra mussels will become established in Washington state within the next 5 to 15 years and that they should adapt well to Pacific Northwest habitat conditions (Zook 1995). These mussels are biofouling organisms capable of colonizing all facilities connected to raw water systems. Furthermore, the potential for considerable impacts on water quality is high for areas susceptible to invasion and establishment of dense infestations. Impacts could include degradation of dissolved oxygen resources, increased nutrient cycling, increased water clarity, increases in macrophyte communities, changes in benthic communities, and reductions and changes in phytoplankton communities (Ashby and Effler 1998).

The presence of zebra mussels is already causing hundreds of million dollars in damage and increased operating expenses in the eastern U. S. and Canada. The western states, Federal agencies, Canadian provinces, and other concerned parties have been involved in meetings, workshops, and regional panels to discuss the threat of zebra mussel infestation in the northwest and ways to prevent introduction and spread into the western states.

More than a billion dollars have been spent on anadromous fish passage facilities in the Columbia River basin and several hundred million dollars more are likely to be spent in the foreseeable future. All of the existing and future facilities are at risk of zebra mussel infestation and none have included design considerations specific for reducing risks from such infestations. The Corps has been monitoring for zebra mussels at the eight lower Snake and Columbia River projects since 1994 (and more recently in the Willamette Valley). The U.S. Fish and Wildlife Service has been monitoring Lake Washington sites near Seattle.

2. Purpose: The purpose of this risk assessment is to identify the adult and juvenile fish passage facilities at the eight mainstem Snake and Columbia River dams that are vulnerable to zebra mussel colonization, describe the extent of risk, and make recommendations for reducing the risk.

3. Species Description and Habitat Requirements: Zebra mussels are small bivalves (up to a few cm long) with alternating light and dark bands on their shells. They attach to almost any hard surface (steel, concrete, aluminum, fiberglass, plastic, wood, glass, rubber, aquatic plants, etc.) by means of tough elastic fibers called byssal threads. The mussels prefer moving water at velocities up to 1 m/sec (O'Neill 1996) but can be found in higher velocity areas that have irregular surfaces or small eddy areas (up to 2 m/sec). Densities of 100,000 per m^2 are commonly described in facilities in the eastern United States. The mussels will attach to one another creating thick mats capable of clogging larger diameter pipes (>0.5 m) and openings. Clumps of mussels (called druses) may break off and clog openings up to several centimeters in diameter.

Sexual maturity is typically reached at age two (8 to 10 mm) but may occur in the first year at a size of 3 to 5 mm (O'Neill and MacNeill 1991) with mature females capable of producing up to 1,000,000 eggs per season (Miller, Payne, and McMahon 1992). The eggs hatch into a free-swimming veliger larva that can be carried long distances by water currents to colonize new areas. They settle within about two weeks and, during their first year of life, young mussels are capable of crawling along the substrate at speeds up to several cm/hr. They are also capable of detaching to relocate to a more desirable habitat (O'Neill 1996). Older mussels become more firmly attached although they are still capable of limited movement. Growth rate in fast-growing populations can be up to 1.6 cm/yr (Miller, Payne, and McMahon 1992).

The mussels are generally found within 2 to 7 meters of the water surface but may colonize much deeper depending on light intensity, food availability, and water temperature. They tend to be more successful in larger water bodies and large, low gradient streams (O'Neill and MacNeill 1991). They are not likely to colonize rivers prone to extensive flooding or lakes with large annual fluctuations in water level (Doll 1997).

Dispersal mechanisms include larval drift to areas downstream of an infected site, exchanges of water from an infected area to an uninfected area, such as from ballast, pumping bilge water, bait buckets, or other raw water transfer. Larval mussels can also be attached to boats and associated equipment, even though they may not be visible. Adult zebra mussels are visible but may be attached to boats in areas that are not readily observed such as engine cooling water intakes. Naturally occurring vectors, such as waterfowl (feet and feathers) and fish (opercular plates), are possible but it is unlikely that sufficient zebra mussel larvae could be introduced by these dispersal mechanisms to establish a viable population at a new site.

Water quality and temperature are important to successful establishment of zebra mussels. The following information is from the Zebra Mussel Information System (ZMIS) CD (WES 1996). The temperature range for survival is from -2 ^{o}C to >40 ^{o}C while the threshold for growth is > 8 ^{o}C and for reproduction is 10 to 12 ^{o}C. Adequate dissolved oxygen (DO) is necessary for zebra mussels to grow and reproduce. Although they can survive in anaerobic conditions for short periods of time (up to two weeks) if the water temperature is low, they do best at DO levels near saturation. Zebra mussel survival is low at either extreme of the pH scale with the ideal range being 7 to <9. Calcium is an essential element in the composition of the zebra mussel shells. Optimum calcium levels are in excess of 20 to 50 mg/l.

A risk assessment calculator model (WES 1996) was used to evaluate the water quality conditions in the lower Snake and lower Columbia Rivers. Table 1 shows a summary of the assessment which concludes that both river reaches have a high potential for successful invasion by zebra mussels.

Table 1. Summary of risk assessment for potential zebra mussel infestation based on selected water quality parameters in the lower Snake and lower Columbia Rivers (water quality data from U. S. Army Corps of Engineers et al. 1995).

Parameter	Lower Snake River[1]		Lower Columbia River[2]	
	Range	Risk	Range	Risk
pH	7.1 —8.5	High	7.6 — 8.2	High
Calcium mg/l	34 - 100		44 - 94	
Dissolved Oxygen mg/l	7.5 — 13.5		8.2 — 13.3	
Temperature ^{o}C	2.5 — 25.5		4 — 22.1	
Months > 12 ^{o}C	5 - 6		5 - 6	

[1] Samples taken at Burbank, Washington.
[2] Samples taken at Warrendale, Oregon.

4. Potential Impacts of Colonization on Concrete, Metal, or Other Surfaces: In a study to determine if zebra mussels have a preference for different construction materials, Kilgour and Mackie (1993) found the highest preference for stainless steel plates followed by asbestos, polypropylene, pine, black steel, pressure treated wood, vinyl, Teflon, PVS, acrylic, aluminum, galvanized iron, and copper. For tubes they found the highest preference for 4.0-cm i.d. PVC followed by ABS, 5.0-cm i.d. PVC, polyethylene, black steel, acrylic, aluminum, galvanized iron, brass, and copper. They also noted that tubes with a horizontal orientation were preferred by zebra mussels over vertical orientations and inside versus outside surfaces. However, Eckroat et al. (1993) found that mussels had no preference for vertical or horizontal surfaces.

a. Clogging Screens, Trashracks, and Porosity Plates: Water velocities commonly associated with most screen systems are ideal (less than 1 m/sec) for zebra mussel colonization.

Zebra mussels attached to dewatering screens and porosity plates, would affect the open area and reduce the water volume passing through. These systems are specifically designed to provide particular flow characteristics and fish guidance efficiency (FGE) could be reduced if less flow passed through submersible traveling screens (STS) or extended-length submersible screens (ESBS) and was instead diverted around the lower end. More flow would be directed up into the gatewell slot by plugged or partially plugged screens and this would create adverse hydraulic conditions for juvenile fish. This could be further aggravated if the vertical barrier screens (VBS) and porosity plates were also partially blocked. Major colonization by zebra mussels on trash racks and other screens would increase the weight of these structures.

b. Clogging Pipes, Conduits, and Valves: The presence of zebra mussels in pipes and conduits increases friction and turbulence and disrupts laminar flow even before there are enough mussels to reduce the effective diameter of the pipes or conduits. A single 1- to 2-mm layer of mussels throughout a pipeline may decrease its water carrying efficiency by up to 5 to 10 percent as a result of increased friction along its walls (O'Neill 1996). Zebra mussel fouling in pipes could increase loads on pumps and cause poor valve operation. The mussels could also cause increased erosion and abrasion of components.

c. Accumulation on Concrete Surfaces: Zebra mussels can colonize concrete and other surfaces in layers up to 0.3 m thick with densities greater than 400,000 individuals/m^2. As an example, a car submerged for 8 months in Lake Erie was 90 percent covered with mussels at an average density of 45,000 individuals/ m^2 (Miller et al. 1992). Most often mussel accumulations have to be physically removed. This is both labor intensive and problematical for disposal of large quantities of putrefying mussels (they can have a very unpleasant odor). Access to infested areas may be difficult, particularly if unwatering capability is limited or time-constrained.

There is some concern about deterioration of concrete due to high ammonia levels in dense colonies (Neilson 1992). Also, zebra mussels colonize along discontinuities, such as construction joints, monolith joints, and cracks in monoliths. These areas tend to contain deteriorated concrete caused by normal weathering and this may be dislodged during zebra mussel removal (Wong 1992).

d. Increased Metal Corrosion: It has been generally agreed that macrofouling will facilitate corrosion of metallic surfaces due to anaerobic bacterial growth around the byssal attachments. The rate of metal corrosion beneath zebra mussels is significantly higher than would normally be expected (Race 1998).

e. Physical Injury to Fish: Migrating anadromous fish, particularly smolts, are susceptible to descaling and abrasion during transit through bypass facilities. Loss of the protective slime layer and scales can lead to fungal and other pathological infections and ionic imbalance in the vascular system. Even if these problems are not immediately lethal, they can result in diminished resistance to secondary infections, poor physiological performance, increased susceptibility to predation, and reduced spawning. Descaling is monitored continuously in juvenile fish sampling facilities as an indicator for general health and potential performance problems within the bypass facilities. Since zebra mussel shells have sharp edges, their presence in any pipes, conduits, trashracks, screens, or other facility components that fish would pass through could result in high descaling. Many fish are observed passing through these facilities close to the edges or bottom and that would make the even more susceptible to injury.

5. Project Fish Passage Facilities at Risk:

a. Adult Facilities:

1) Auxiliary water supply systems (pumps; conduits; trash racks; diffuser chambers, valves, and gratings; and water level and velocity monitoring equipment): Adequate volume and proper flow balance are essential to proper function of the auxiliary water supply systems. As mentioned above, the presence of mussels could diminish the water carrying efficiency of these systems by 5-10 percent. If valves are not operated on a regular basis, the valve plates, seals, and guide channels could become colonized and not function properly. Diffuser gratings would be particularly susceptible to fouling that could further aggravate the current problems encountered at some facilities with fine woody debris and other materials that clog the gratings. Even if zebra mussels did not colonize the diffuser gratings sufficiently to plug them (such as if they were removed and cleaned periodically), they could still be clogged by druses (clumps of zebra mussels up to several cm diameter) that break off from colonies inside the diffusion system conduits. Water level and velocity monitoring equipment could be affected by zebra mussel colonies that render the automatic control systems ineffective. Access to much of the auxiliary water supply systems is limited and, where possible, requires that the entire ladder system be unwatered. If zebra mussel colonization could not be controlled, then they would have to be physically removed. This is time consuming, and unpleasant when dealing with large quantities of odorous decaying debris and may be limited by current regulations regarding work in confined spaces. Disposal of the zebra mussels could also pose a challenge.

2) Ladders (weirs, bulkheads, guide slots, picketed leads, counting station crowders, entrance gates): All concrete surfaces in the ladders and collection systems could become colonized. If the zebra mussels cannot be controlled, they would have to be physically removed. Depending on the growth rate, this could be required at least annually and maybe more often. This would require unwatering the facilities. Picketed lead fouling would be similar to that described above for diffuser gratings. If counting station crowders were not operated on a regular basis, a buildup of zebra mussels could cause them to malfunction. Zebra mussels would likely accumulate in guide slots for bulkheads and other gates. If the gates are heavy enough, they would likely crush the zebra mussels and not be hindered, however, there could be problems with lighter structures (such as vertical barrier screens).

3) Monitoring/sampling facilities: It is not known at this time how zebra mussels might affect PIT tag detectors and other sensors (metal detectors at the Lower Granite adult trap). In general, however, the monitoring facilities would likely be affected to a lesser degree than other structures because they would usually be operated on a frequent basis and personnel would be present to keep them clear of any zebra mussel accumulations. The submerged, inaccessible parts, such as at the Bonneville adult evaluation facility and the Lower Granite adult trap would be susceptible to the same problems as in other facilities with piping, gratings, concrete and metal surfaces, and moveable structures. The presence of zebra mussels in fish sampling facilities where the fish are often crowded or otherwise confined could cause descaling problems mentioned above.

4) Drain systems: Zebra mussels could colonize water drain lines as easily as supply lines provided there are not times that the lines are not used when the temperature could become too hot or the DO could drop. A diminished drain capacity could result in water overflowing from parts of the facilities. If this occurred in facilities containing fish, they could escape and become stranded and die. This would be even more serious at the elevated facilities found at many projects. Most of these lines are not easily accessible for cleaning zebra mussels. Lines that are not normally full of water could still be at risk if they discharge to the river and the discharge end is submerged. Zebra mussels could colonize in the submerged portion and their presence could go undetected without special inspections or until the pipes clogged to the point that they did not function properly. Lines that fish are released through would be of particular concern as fish injury might go undetected.

b. Juvenile Facilities:

1) Bypass systems (STSs, ESBSs, VBSs, drain and dewatering screens, gatewell orifices, powerhouse collection channels, dewatering systems, bypass conduits, separators,

holding/sampling facilities, fish monitoring facilities, smolt monitoring detectors, water supply pipes and valves): All of the facilities would be at risk of colonization by zebra mussels however, many parts of the juvenile bypass system are accessible and could be more easily monitored and cleaned. The long, elevated corrugated metal bypass conduits at many of the projects would be more difficult to access but they are at low risk of colonization because of the high water velocity (3 m/sec). The water velocity through gatewell orifices is also too high for zebra mussel attachment, although the valves could be at some risk where there are recesses out of the high velocity area. Once zebra mussels become established and grow in a small eddy area, they create a bigger eddy and that provides areas for more zebra mussels to attach. Any of the facilities that can be unwatered and left dry and exposed to heat or freezing are at low risk of colonization. Thus, much of the juvenile bypass facilities at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, and John Day, would be at less risk than Bonneville which has most components watered up throughout the year and has submerged release lines. It would be important to assure that the facilities were entirely unwatered as zebra mussels could persist through the winter in pools so long as they didn't freeze. Although the STSs and ESBSs are pulled and dogged off at deck level during the winter, part of them remains submerged and at risk.

2) Collection/Transportation systems (raceways, crowders, screens, barge and truck loading facilities): The collection and holding facilities would all be at risk of zebra mussel colonization, however, the risk to many components would be low because they could be left unwatered except when in use (loading lines, raceways without fish, crowders). Any areas where zebra mussels did accumulate would be particularly problematical because of the potential for fish injury mentioned previously.

3) Water drainage systems (pipes, valves, and screens): Some of the emergency bypass lines and drain lines have submerged exits. These would be at risk as described previously. Dewatering screens with fine mesh could be at risk even though they would be unwatered for part of the year. There could be sufficient time for zebra mussels to establish and grow large enough to affect flow through the screens. Even if they didn't cause enough blockage to seriously hinder the operation, their presence might cause the screens to have a rougher surface that could be more susceptible to debris buildup. The cleaning brushes should keep this risk low on those surfaces that are brushed regularly.

c. Other Facilities Affecting Fish Passage or Affected by Fish Passage Criteria:

1) Turbine intake trashracks: As mentioned earlier, the trashracks are at high risk of zebra mussel fouling that could affect fish and, if the fouling was severe enough, affect turbine efficiency. During trashrack cleaning, either by removal or raking, the unit must be shut off. If this occurs during a high river flow period, it could result in increased spill. That spill could be sufficient to cause elevated levels of total dissolved gas that could be harmful to fish and other aquatic organisms.

2) Turbine operation: If some components of the fish bypass systems are not functional, such as the STSs and ESBSs, then generally fish passage criteria do not allow turbine operation in affected units. Problems resulting from zebra mussel colonization could cause this to occur. Even more of a concern might be that severe zebra mussel fouling could require extensive maintenance and removal from within the turbine intake, scroll case, and draft tube. The schedule for this could impact normal fish operations if it exceeded the 2-3 month winter maintenance period currently allowed. Even if it could be done quickly, it would add to other fish facility maintenance activities occurring at the same time.

3) Fish transport trucks and barges (hulls, sea chests, piping systems, degassing columns, drain screens, tanker water circulation systems): The fish barges would be at high risk of zebra mussel fouling. Further, if there were colonies attached to the hulls, they could spread more zebra mussels throughout their transit between Lower Granite to below Bonneville dams. The presence of zebra mussels on the hulls would add weight and drag to the barges which could affect their travel time to and from the release site and fuel efficiency (contract cost) for the towboats. The sea chests and gratings could become fouled and water supply to the fish holding tanks reduced. If the water flow into the sea chests is severely reduced, there could be damage to the fish pumps and motors. Zebra mussel shells could plug the water spray line ports, again potentially damaging the pumps and motors, as well as cutting off the water supply to fish in the holding tanks. Although not a Corps facility problem, the towboats could have similar fouling problems. A common site for zebra mussel settling is in the engine cooling water intake lines. If these plug and the engines overheat and fail, then the barges could be left stranded and full of fish, forcing premature release in undesirable areas.

Truck transport equipment is at much less risk. The tankers are only full of water during transport operations and they are disinfected with chlorine which is fairly toxic to zebra mussels.

4) Fish release sites: The Bradford Island juvenile fish release site is at high risk because it has a submerged discharge that would likely be colonized by zebra mussels. The tanker flushing water line is supplied by raw water and could also become fouled. Even though it is only operated during a short time of the year, it could still become fouled at the inlet and, if the valves had any leaks, it would be possible for even a trickle of water to sustain zebra mussel growth inside.

5) Ice and trash sluiceways (gates, guide channels, seals, sluice conduit): Those parts of the ice and trash sluiceways that are watered up for the entire year are at high risk of zebra mussel colonization. Even if the channels are not used throughout the year, there is enough leakage to keep some water in them. The gates, guide channels, and seals would be susceptible to fouling. The gates are heavy enough that this should not pose a serious problem although they are not used frequently and some fairly extensive zebra mussel buildup could occur.

6) Spillways and associated equipment (gates, guide channels, seals): The gates, guide channels, and seals that are submerged would be at high risk of zebra mussel colonization. Severe fouling could add considerable weight to the gates. On some facilities, the added weight has been reported at up to 20-30 lbs/m^2 (O'Neill and MacNeill 1991).

7) Dissolved gas monitoring equipment (sensor probes and submerged housing): The dissolved gas monitoring program is important for providing information used to manage controlled spill at the dams within levels that are considered safe for fish (from a dissolved gas production standpoint). The monitoring probes are submerged for at least 6 months during the spring/summer with some stations being kept operational through the winter. The probes are checked about every two weeks and so any zebra mussel fouling could be detected and removed. The housings that the probes are placed in for protection are fixed and could become fouled. This could result in some difficulty placing the monitoring probes at the proper depths.

6. Recommendations for Reducing Risks:

a. Monitoring: The existing monitoring program at the mainstem Snake and Columbia river projects and Willamette Valley should be continued. Consideration should be given to developing a veliger monitoring program for at least one site on the lower Columbia River. Whenever a part of any fish passage or other project facilities are unwatered, project personnel should visually inspect for zebra mussel presence.

b. Information and Education: A zebra mussel warning placard has been developed and is available from The Dalles Project (POC Jim Griffith). These should be placed throughout the Northwest at all high-risk water bodies (any lake with recreational boating and/or near metropolitan development). This effort should be coordinated with the states of Washington, Oregon, Idaho, and Montana, as well as with the U. S. Fish and Wildlife Service, to assure that we have a coordinated, common message to provide to the public when there are inquiries (the sign has phone numbers to contact). The Corps representatives for zebra mussel coordination should continue to maintain contact with regional and national interest groups to share info and to participate in public information programs. This should include continuing the ad hoc coordination committee activities to bring together key resource agencies and other interest groups to share information and coordinate zebra mussel activities in the Columbia River Basin and to promote public awareness of the potential zebra mussel threat. According to Kraft (1993), educated observers are likely to provide first reports of mussels in a given area.

c. Develop Project/Regional Response Plan: Project personnel should prepare project response/action plans that describe available control measures for each potential impact area described in this document. The plans would recommend the most appropriate control measures and how they could be applied considering all of the existing fisheries and other environmental sensitivities in this region. The CENWD-NP POC (Jim Athearn) can provide some assistance.

d. Design Considerations: No new fish passage facilities should be built that do not take into consideration potential infestation by zebra mussels. This means that all parts of the facilities that are in contact with raw water should be accessible for removing zebra mussels or some other control measure should be available for that component. Further, if there are areas that are inaccessible or that could not be accessed except during certain times of the year, then the facility components most susceptible to problems resulting from zebra mussel infestation should be removable so that they can be cleaned or exchanged or some alternate zebra mussel control method should be developed prior to construction. Existing facilities at highest risk because of inaccessibility or lack of spare components should be evaluated for possible structural modifications.

e. Lake Washington Ship Canal: Although this risk assessment focuses on the Columbia River Basin, the fish passage facilities at the Ballard Locks are likely in the highest risk location in CENWD and the above information is pertinent there. The risk comes from being located in the middle of a large city with a major recreational boating industry. In the early 1990's, an environmental research facility, located adjacent to Lake Washington, imported live zebra mussels to conduct experiments. If any of the mussels had escaped, they would have found an excellent habitat in the lake for colonization. More recently, activities of yacht brokers in the area have come under scrutiny because they have been bringing large boats from the depressed boating market in the Lake Michigan area to resell in Seattle. These are the type of vessels that California border check stations have found live zebra mussels aboard entering that state. Biologists from the National Marine Fisheries Service have conducted several dives in the lake and, so far, have not discovered any zebra mussel colonies.

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