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Fish Passage Operations and Maintenance Coordination Team (FPOM)

RE: foul-release coatings to mitigate zebra and quagga mussel fouling at FCRPS facilities

To whom it may concern:

Portland State University (PSU) is developing a cost estimate for applying a foul-release type anti-fouling paint to a FCRPS hydroelectric facility as part of an effort funded by Bonneville Power Administration (BPA) to explore control options for zebra and quagga mussels (*Dreissena polymorpha* and *D. rostriformis bugensis*) (ZQM). The ideal candidate components for foul-release coatings are associated with fish passage, and the objective of this document is to involve FPOM in the early planning stages.

Foul-release coatings may be part of an integrated control effort for ZQM. ZQM are invasive mussels that attach to hard surfaces and cause bio-fouling in freshwater habitats. ZQM have not been found in the Columbia River Basin (CRB), but are causing operational issues elsewhere, e.g., Parker and Davis Dams (US Bureau of Reclamation/ USBR) in the lower Colorado River.

The foul-release coatings being considered for use at FCRPS facilities include SherRelease or Duplex (Sherwin Williams/ FujiFilm) and Intersleek 970 (International). These coatings provide fouling protection through the physical properties of the topcoat that minimizes the strength of attachment between the organism's adhesive surface interface and the adhesive water interface (Chamber et al. 2006). These coatings may develop fouling, but the strength of bond is weak and can be broken by the force of flowing water or by light cleaning. These coatings employ multiple layers including 1) a water resistant anticorrosive layer used to protect the substrate, e.g., epoxy; 2) a tie coat used to bond the tough bottom layer to the hydrophobic topcoat; and 3) a topcoat that is silicone-based (Sher Release/ Duplex) or fluropolymer-based (Intersleek). Wells and Sytsma (2009) provide more details regarding the use of coatings to mitigate impacts of ZQM.

The foul-release coatings are considered environmentally friendly, but more work is needed to explore potential impacts on salmonid behavior before use in the CRB. The topcoat contains a silicone resin matrix primarily composed of polydimethylsiloxane or PDMS (Lawson 1986). The PDMS materials bound within the coating matrix are biologically inert, insoluble, show no toxic effects, do not react with body fluids, and are not released to environment under normal conditions (Lawson 1986; Nendza 2007). Mechanical damage to the coating matrix can release bound PDMS materials to the environment, but these silicones become particulate litter (Nendza 2007). The toxicity concerns for PDMS involve the PDMS oils that are not bound within the coating matrix. The free PDMS fluid migrates to the coating surface and exudes into the environment. These free-flowing PDMS oils, hereafter referred to as PDMS, have been

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evaluated through toxicity testing because of their release to the environment. Although no risk to the environment under conventional toxicity testing has been reported (Fendinger et al. 1997; Jarvie 1986; Nendza 2007; Stevens et al. 2001), adverse impacts on fish from PDMS cannot be overruled and more work is warranted prior to use in the CRB. A brief summary of toxicity testing and concerns with PDMS is in Appendix A.

This project builds upon prior (Wells and Sytsma 2009) and ongoing (Sytsma 2010) TI-funded projects, as well as research being conducted by USBR and Metropolitan Water District (MWD). USBR is currently conducting steel panel and grate experiments to assess the feasibility of using coatings on its facilities on the lower Colorado River because they are having problems with macrofouling on external structures such as trash racks and screens (Willett 2012). This coating research is led by Dr. Allen Skaja, and is currently focused on non-toxic coatings because of the concern over drinking water and endangered species. The foul-release coatings that have been evaluated by USBR and have been effective for a period over 36 months include Sher Release and Intersleek 900 systems (Skaja 2012). MWD is also currently involved with steel panel and grate experiments in the lower Colorado River using Intersleek 900 and Sher Release (Drooks 2009; De Leon 2009). PSU is currently evaluating the effective service life of the three most promising foul-release coatings coming out of the MWD and USBR research under Columbia River field conditions on both steel and concrete panels and comparing to protective coatings used by the US Army Corps of Engineers (USACE) to protect submerged steel and concrete as well as bare concrete. The PSU test panels are deployed in the Columbia River from the breakwater at the Port of Camas-Washougal as well as a moored buoy structure in San Justo Reservoir, CA, which is infested with zebra mussels. This project also builds upon older coating technology research and the experiences of other North American facilities. Foul-release coatings were evaluated in panel and trial applications by USACE (Beitelman 2009; Kelly 1998; Miller and Freitag 1992; Race 1992; Race 1992b; Race and Miller 1992; Race and Kelly 1994; Race and Miller 1994), Ontario Hydro (Leitch et al. 1992; Poulton 2009), Pacific Gas and Electric (Innis 2009), The Electric Power Research Institute (EPRI 1989; EPRI 1992), The Long Island Lighting Company (Gross 1997), and Consolidated Edison Company (Kovalak et al. 1993). These findings have historical relevance, but it is important to note that coating manufacturers have changed coating formulations, and to the authors' knowledge, foul-release coatings have never been evaluated in the Columbia River.

These coatings are effective, but soft and expensive, and candidate components for foul-release coatings are limited to those structures that 1) are at high- to medium risk for fouling by ZQM; 2) if fouled by ZQM, would pose a serious problem to fish passage and/ or operations; 3) have limited other ZQM control options available such as mechanical and chemical cleaning; 4) can be dried and cleaned for paint application; 5) are accessible for paint application via conventional spray or airless; 6) and are protected from gouging from large woody debris, rocks, etc. A general list of candidate components for foul-release coatings at FCRPS hydroelectric facility includes screens, drains, diffuser gratings, trash racks, diffuser plates and fish passage facilities.

The auxiliary water system (AWS) diffusers are ideal candidates for foul-release coatings. AWS diffusers are susceptible to ZQM infestation and an infestation could affect fish passage and operations (Athearn and Darland 2007; Kovalchuk 2007). AWS diffusers are a part of upstream adult fish passage systems and are used to divert water from the project forebay or tailrace into the adult fish ladder to meet specified attraction flows in the fishway, the entrance pool, in areas between fishway weirs, and to provide additional flows to transition pools, trap pools, exit control sections and counting station pools (NMFS 2011). Water typically flows through an intake screen or fine trash rack, through a control gate and then through the diffusers before entering the fishway (NMFS 2011). The diffusers function as an energy dissipation zone, and consist of either vertically-oriented or horizontally-oriented non-corrosive flat bar stock with a maximum 1-inch clear spacing (NMFS 2011) (Figure 1). AWS diffusers are submerged and in-use for most of the year, except the period between December and February, during which, the gratings can be removed for cleaning and maintenance (Cordie 2013; NMFS 2011).

Figure 1: Horizontally-oriented AWS diffuser grating. [Photo credit: Robert Cordie, U.S. Army Corps of Engineers].

The maximum water velocity through a horizontally-oriented AWS diffuser is less than 0.5 ft/s (based on total diffuser panel area), and water velocities are nearly uniform (NMFS 2011). ZQM colonization is most abundant at water velocities between 0.3 – and 1.6 ft/ s (Jenner et al. 1998). Thus the AWS diffusers, especially on the underside of the gratings, would provide excellent habitat for the mussels regarding water flow, substrate type, protection from predators and surface area available for colonization (Wells 2013). ZQM colonization during the period of diffuser operation (i.e. March – November) could clog gratings and cause problems; ZQM settled and grew to a maximum of 21-mm in the five month period between April and September on coating test panels in San Justo Reservoir, CA (Wells 2013; Appendix B). The adult fish ladder and Bonneville Powerhouse 2 were shutdown in 2010 because the diffuser gratings were dislodged after plugged with debris (Athearn and Darland 2007).

PSU is in the process of completing a cost estimate to apply SherRelease/ Duplex to the 1,300 diffuser gratings located at The Dalles Dam Project. This cost estimate includes a work plan to remove, transport, paint and re-install the gratings within the periods of December to mid-January and mid-January to February. The cost estimate is intended to aid the cost/ benefit analyses to determine if foul-release coatings are a feasible control option should ZQM become established in the CRB and cause fish passage and operational problems. We encourage your comments and suggestions.

Many thanks for your time.

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Appendix A

PDMS pose no risk to the environment under conventional toxicity testing. PDMS are essentially inert, virtually insoluble in water, chemically and thermally stable, non-biodegradable (even in waste treatment), do not accumulate on surface waters or in the water column, rapidly adsorb to suspended particulate matter, and are only broken down chemically under special conditions (Fendinger et al. 1997; Jarvie 1986; Nendza 2007; Stevens et al. 2001). PDMS exhibit high molecular weights and therefore cannot pass through bilipid layer of cell membranes and do not bioconcentrate or bioaccumulate (Jarvie 1986; Nendza 2007; Stevens et al. 2001). PDMS derivatives have been shown to be virtually nontoxic, and it is unlikely that significant concentrations of toxic PDMS derivatives will form through reactions such as transalkylation (Jarvie 1986). Environmental loading of PDMS occurs primarily from down-the-drain consumer and industrial product disposal (Fendinger et al. 1997). Sorption removes 97% of PDMS from wastewater with the remaining 3% being discharged with liquid effluent into rivers and other bodies of water where the PDMS are rapidly deposited into sediments (Fendinger et al. 1997; Powell et al. 1999).

Toxicity tests with PDMS have demonstrated no significant risk to fish. PDMS in general have very low toxicity to fish (Fendinger et al. 1997). Mann et al. (1977) as cited in Fendinger et al. (1997), fed rainbow trout (*Oncorhynchus mykiss*) food containing approximately 10 mg PDMS/ d for 28 d, which corresponded to 10,000 mg PDMS/ kg body weight, and observed no mortality, no growth effects, and no abnormalities observed during histopathological examination of skin, muscle, liver, bile, adrenal gland, stomach and gut. The 4 d TL_{50} for fish exposed to a PDMS emulsion was greater than 10,000 μg/ g (Jarvie 1986). Opperhuizen et al. (1987) exposed one year old guppies (*Poecilia reticulate*) and two year old goldfish (*Carassius auratus*) to PDMS at feeding rates of 25 mg PDMS/ g* day^{-1} and found no significant retention or accumulation of PDMS in tissue. LT_{50} values for scorpionfish exposed to PDMS emulsions of 35% at 1,000 mg/

L, 2,000 mg/ L, and 10,000 mg/ L were 120 hrs, 50 hrs, and 4 hrs, respectively (Fendinger et al. 1997). LC_{50} values from acute testing are generally greater than 1,000 mg PDMS/ L, which is a concentration many times greater than found in natural waters (Fendinger et al. 1997). Stevens et al. (2001) reported no observed effects upon mature fish. PDMS with molecular weights greater than 600 MW were not absorbed by bullhead catfish (*Ictalurus melas*) (Annelin and Frye 1989). Hill et al. (1984) as cited in Craig and Caunter (1990) and Fendinger et al. (1997) did observe significant deleterious effects upon hatchability of sheepshead minnow larvae (*Cyprinodon variegates*) at 67 mg PDMS/ L. A comparison between the blanks and the emulsion control, however, indicated that the emulsion itself caused problems with larval weight and length.

PDMS have shown essentially no toxic effect on zooplankton and benthic organisms. PDMS in the aquatic environment are found in the sediment, and are large molecules that cannot pass through biological membranes. PDMS concentrations measured in marine and freshwater sediments representing the worst-case situations for the U.S. ranged from 0.2 µg/ g to 309 µg/ g (Powell et al. 1999). PDMS that are small enough to pass through the bilipid layer of membranes volatize to the atmosphere (Jarvie 1986). PDMS have a very low bioavailability for sediment dwelling organisms because the very high binding affinity for sediments means that the PDMS do not readily desorb from ingested particles and are passed in feces (Stevens et al. 2001). Additionally, the PDMS concentration in the pore water is very low, thus reducing uptake via respiration processes (Stevens et al. 2001). Acute studies exposing mussels to saturated solutions of PDMS showed no evidence of mortality (Stevens et al. 2001). Henry et al. (2001) found that PDMS added to sediments at concentrations greater than 1,000 mg PDMS/ kg did not reduce the survival, growth, emergence and reproduction for the amphipod, *Hyalella azteca*, and midge larvae, *Chironomus tentans* after 10 d and whole-life exposures. No effect upon survivorship or weight was observed during a 28 d study with *Nereis diversicolor* (Craig and Caunter 1990). Craig and Caunter (1990) observed, however, that the burrowing activity was slowed in PDMS treated soils compared to controls. No acute toxic effects were observed on *Balanus amphitrite* larvae exposed to a variety of PDMS elastomers with exuding PDMS oils (Watermann et al. 2005).

There is evidence suggesting that PDMS may cause physical-mechanical effects on some organisms. Although Watermann et al. (2005) observed no toxic effects of PDMS, significant differences in mortality in *B. amphitrite* were observed in the PDMS treatments compared to controls, *B. amphitrite* larvae becoming immobilized in PDMS films. Fendinger et al. (1997) and Stevens et al. (2001) also noted that *Daphnia magna* and *B. amphitrite* larvae become trapped, immobilized, and died in PDMS films or droplets. Craig and Caunter (1990) reported that the burrowing behavior of a polychaete worm was reduced in sediment treated with PDMS. Aubert et al. (1985) reported PDMS dispersions at concentrations greater than 2,000 mg/ L caused significant mortality in *Mytilus edulis* mussels by clogging the respiratory passages. These findings suggest that physical-mechanical effects are possible with the accumulation of PDMS layers in the sediments.

Adverse impacts on fish from PDMS cannot be overruled. There have been no long-term sediment toxicity tests to evaluate the sublethal effects of PDMS on benthic communities (Nendza 2007). Although PDMS have shown no toxic effect on zooplankton, benthic organisms and fish, the abundance and distribution of benthic zooplankton may change because of PDMS accumulation in sediments (Nendza 2007). PDMS accumulations in sediment could potentially impact fish by clogging fish gills and egg pores (Nenzda 2007). Organosilicon compounds such as PDMS can transfer alkyl or other groups to metal derivatives, i.e. heavy metals, through transalkylation reactions (Jarvie 1986). These transalkylation reactions would make heavy metals more available to organisms such as fish.

Caution should be taken interpreting conventional toxicity tests regarding PDMS. Conventional aquatic toxicity tests use water to deliver the test material to the organism, and the test material must have a measureable aqueous solubility in order to measure the uptake into the organism (Stevens and Annelin 1997). PDMS exhibit extremely low aqueous solubility, i.e. ppb to ppt, and it is difficult to analyze PDMS at such low concentrations (Nendza 2007; Stevens and Annelin 1997). Due to the low aqueous solubility, different methods are used to prepare the test medium, e.g. solvents and surfactants, but many carrier solvents are not effective with PDMS and many surfactants exhibit toxicity themselves (Stevens and Annelin1997).

Appendix B

Test panels are deployed in San Justo Reservoir, CA as part of the PSU field experiment to evaluate the service life of foul-release coatings. San Justo Reservoir is infested with zebra mussels, and test panels are deployed in the reservoir to determine the shear force to remove attached mussels, i.e. evaluate changes in efficacy of the coatings over immersion time. A subset of panels was removed from San Justo in September of 2013 after being deployed in the reservoir for approximately five months. Two age classes of mussels had settled on the test panels, and the oldest age class ranged in size from 12 to 21-mm in shell length (Figure 2). Mussels are reproductive at shell lengths of 5 to 10-mm.

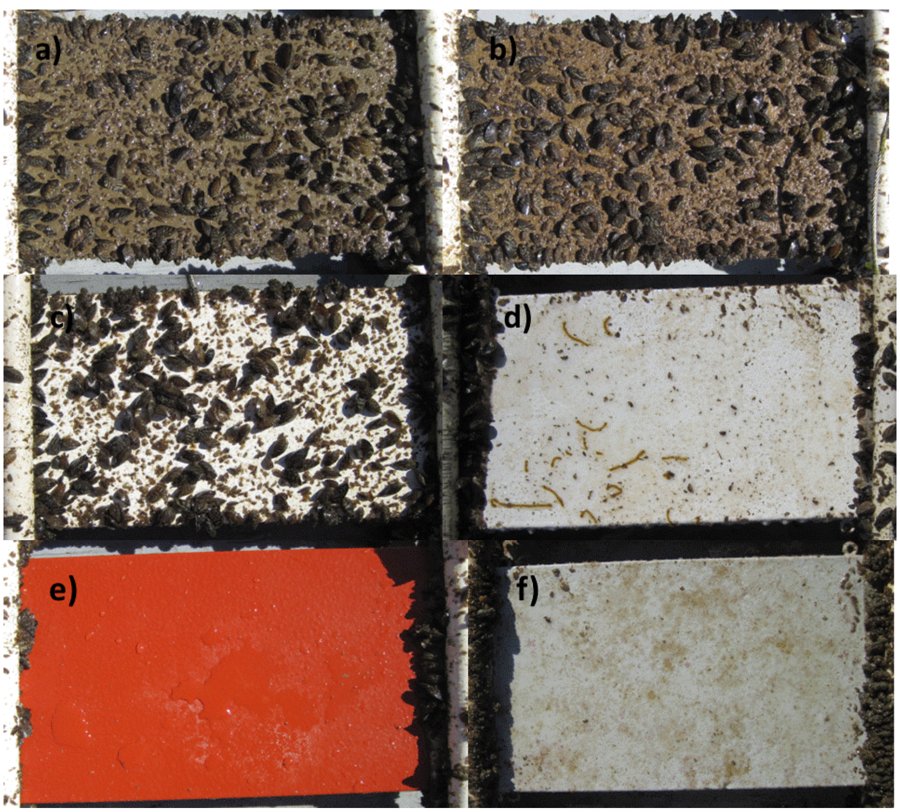

Figure 2: PSU test panels with zebra mussel colonization after five months immersion in San Justo Reservoir including a) bare concrete, b) CrystalSEAL, c) Corps V-766E vinyl paint, d) SherRelease/ Duplex*, e) HempasilX3*, and f) Intersleek 970*. Foul-release coatings are indicated by the asterisk.