Appendix G

Interstate 90/Homer Hadley Bridge, Light Rail Transit Stray Current—Assessment of Potential Effects on Fish Memorandum

Herrera Environmental Consultants, Inc.

Memorandum

To	Marti Louther, James Irish, Sue Comis – Sound Transit
cc	Ed Wetzel - Universal Technical Resource Services, Inc
From	José Carrasquero, Eric Doyle - Herrera Environmental Consultants
Date	June 13, 2008
Subject	Interstate 90/Homer Hadley Bridge, light rail transit (LRT) stray current - Assessment of potential effects on fish

Sound Transit retained Herrera Environmental Consultants (Herrera) to conduct a preliminary investigation into the potential effects of changes in the stray electrical current field associated with the Interstate 90 Homer Hadley Bridge over Lake Washington (referred to hereafter as the I-90 bridge). Specifically, Sound Transit is proposing to build the East Link light rail transit (LRT) line on the I-90 bridge. Operation of the LRT system could discharge stray electrical current into Lake Washington. This weak direct (DC) current would leak into the environment through various conductive pathways along the bridge alignment, creating one or more small electrical current fields around the span. Possible current leakage pathways include the bridge's existing cathodic corrosion protection system, and the stray current mitigation system planned as part of LRT expansion. The intent of this assessment is to investigate if the change in stray electrical current conditions is of sufficient magnitude to pose potential adverse effects on aquatic species.

The findings of this assessment are summarized as follows:

1. The proposed LRT system will produce stray electrical current fields that are essentially negligible relative to existing conditions.

2. Expected field intensity produced by leakage from the LRT is difficult to calculate with precision, but will be very low in intensity, ranging from tenths to hundredths of a microvolt per centimeter direct current (µV/cm DC) (Wetzel 2008).

3. These values are one to two orders of magnitude below established physiological detection and behavioral response thresholds for even the most sensitive species of potential concern.

On this basis, it appears reasonable to conclude that any change in stray DC electrical current emissions resulting from LRT operation would be unlikely to result in adverse effects on fish species of potential concern in the Lake Washington system.

The assessment approach and the findings are described in the following sections.

Assessment Approach

The screening level assessment of potential stray current effects consisted of the following steps:

1. Confirm that fish species of potential concern may be present in the study area. (These include but are not limited to species listed under the Endangered Species Act [ESA]; species listed at the state level as species of concern; and game fish.)

2. Identify known biological response thresholds for these or sufficiently similar species in the available scientific literature.

3. Identify the strength, dimension, and configuration of the stray current field under existing and proposed conditions.

4. Compare the existing and proposed electrical field conditions to these known response thresholds and determine the likelihood of potential effects.

Fish Presence in the I-90 Bridge Vicinity

For the purpose of this assessment, fish species of potential concern include the following: resident and anadromous salmonids native to the Lake Washington basin (including ESA listed species); Pacific and river lamprey; longfin smelt; forage fish species; and other native and introduced game fish species. These species are referred to hereafter as Lake Washington species.

The potential presence of these species in the general vicinity was determined by consulting with two experts on Lake Washington fisheries investigations: Kurt Fresh, a research scientist with the NOAA Fisheries Northwest Fisheries Science Center; and Roger Tabor, a research scientist with the U.S. Fish and Wildlife Service. While both agreed that specific studies of fish habitat utilization in the immediate vicinity of the I-90 bridge are lacking, they confirmed that several Lake Washington species either utilize habitats in the vicinity of the bridge, or must pass under the structure when migrating between spawning and rearing habitats. As such, it is apparent that a number of Lake Washington species could occur within the area of potential effects.

Fish Response to Electrical Field Exposure: A General Review

To aid in interpreting the findings of this assessment, it is desirable to provide a general review how fish interact with and respond to electrical fields. Weak electrical fields are common in nature, and many organisms have evolved specialized means of detecting and orienting to these fields. Organisms with this specialized capability are referred to as electroreceptive, meaning they have the ability to detect, orient to, or even produce and navigate by an electrical field. Not all fish species are electroreceptive, and for most species that are this ability is limited to short-range sensory awareness used to locate prey species or detect objects at close range. However, certain fish species, including the sharks, lampreys, and other specialized higher fish, have specialized electroreceptive organ systems that greatly increase sensitivity to weak electrical fields (Hopkins 1983, New 1999, Smith 1991, Gibbs 2004, Von Der Emde 2007, Alves-Gomes 2001).

Electroreceptivity confers a number of useful abilities. For example, electroreceptive predators like sharks and rays are able to detect the weak electrical signals produced by muscle activity in their prey (Kalmjin 1982). Some fish species, such as eels, are able to detect and orient to the weak electrical fields generated by ocean currents, using these fields as a means of navigation (McCleave and Power 1978). Certain fish species that live in highly turbid water environments where eyesight is useless have evolved the ability to produce weak electrical fields that are used like sonar systems to communicate, navigate, and detect predators and prey (Knudsen 1974). Species like lamprey have evolved specialized electroreceptive organ systems to detect prey organisms (Bodznick and Preston 1983). Because of their specialized ability to detect weak electrical fields, electroreceptive fish species are by nature more susceptible to weak electrical fields, like those produced by stray current from LRT systems. Weak fields can stimulate or confuse their sensory systems, potentially altering behavior and physiology in ways that are difficult to observe and detect.

Most of the fish species common to Lake Washington, such as the trout, salmon, perch, and bass, lack specialized electroreceptive organ systems. As such they are unable to detect very weak electrical fields and are thereby relatively insensitive to weak field exposure.

Electroreceptivity should not be confused with behavioral and physiological responses that all fish exhibit in the presence of strong electrical fields. All organisms are susceptible to the effects of electrical shocks, which essentially “short-circuit” physiological systems. Responses to strong electrical field exposure can range from attraction or avoidance, to altered feeding behavior, or even unconsciousness. A sufficiently large electrical exposure can cause seizure, injury, and even direct mortality. Responses to strong electrical field exposure can vary widely, based on the species and size of the fish exposed, site specific conditions, and the nature of the electrical field (Snyder 2003).

For example, the orientation of a fish’s body relative to an electrical field is a determining factor in amount of voltage exposure a fish will receive. A fish swimming parallel to an electrical field (i.e., directly towards or away from the source) will experience a larger exposure than one swimming perpendicular to the field. This is because the longest body axis is oriented to the increasing field strength, creating the greatest electrical gradient from end to end and thereby a large voltage potential. The fish oriented perpendicular to field strength presents a minimal aspect to the field, creating much smaller electrical potential from one side of the body to the other, minimal voltage exposure, and little or no effect. Larger fish are inherently more sensitive to strong electrical fields because a bigger body has inherently greater potential voltage gradient.

Literature Review Methods

Available information on the relevant biological response thresholds of Lake Washington fish species or similar organisms was derived from available scientific literature. Literature sources were identified using the Google Scholar online search engine. The studies relied upon in this assessment express electrical field strength in units of Volts per meter (V/M), volts per centimeter (V/cm), or microvolts per centimeter (µV/cm). These metrics are commonly used to characterize the response of biological organisms to electrical field exposure.

The types of threshold responses reported in this assessment range from physiological detection of the electrical field (e.g., measured changes in cardiac response), to behavioral detection (e.g., attraction, avoidance, twitching), to marked physiological responses including paralysis and injury. When considering this information, it is important to note that electrical fields capable of causing paralysis or injury are many orders of magnitude stronger than what is expected from the I-90 stray current field. The intent of providing this information is to present a basis of comparison to the expected strength of the I-90 stray current field.

Physiological and Behavioral Response Thresholds for Electrical Field Exposure

The literature review identified several exposure response thresholds that are relevant to Lake Washington species. This information is summarized in Table 1. The range of response thresholds shown varies from the smallest observed physiological and behavioral detection limits, to electrical field strength sufficient to cause injury and incapacitation. The intent of providing this broad range of threshold values is to provide a broader context for interpreting the potential effects of the I-90 stray current field.

Stray Current Field Strength and Dimensions Under Existing and Proposed Conditions

The strength and dimensions of the stray current field under existing and proposed conditions was characterized for Sound Transit by Mr. Ed Wetzel of Universal Technical Resource Services, Inc (UTRS) (Wetzel 2008). Per request from Herrera staff, these values were provided in the same units commonly used to characterize biological effects (µV/cm). The maximum strength of the I-90 stray current field under existing and potential future conditions is shown in Table 2. These estimates represent the worst-case stray electrical current field strength and size expected to occur under each condition.

While the LRT system will produce a stray current field, the proposed system design and additional shielding mechanisms will limit the intensity of this field to very low levels. The cathodic protection system is expected to be the dominant source of electrical current emanating from the I-90 bridge. The positioning and orientation of the cathodic protection system and the intensity of the field it produces are not expected to vary measurably under proposed conditions with LRT operation.

Table 1. Electrical field strength associated with observed responses in various fish species.

Response Type	Species Type	Environment Type Where the Response was Observed	Electrical Field or Source Strength Associated with Observed Response	Source
Attraction/avoidance (attraction to the anode, avoidance or repulsion from the cathode)	Lamprey	Marine	1–10 µV/cm	Bodznick and Preston 1983
Twitch response to field exposure	Lamprey	Marine	10-60 µV/cm @ 0.05-0.5 Hz	Muraveiko 1984
Observed physiological detection limit (measurable change in heart rate or the electrical pattern of the heartbeat)	Atlantic salmon, American eel	Freshwater	7-70 µV/cm @ 60-75 Hz	McCleave et al. 1974
Theoretical limit above which chronic electrical field exposure could alter cellular biochemical systems.	n/a	General	90 µV/cm	Weaver et al. 1998
Attraction (anodic taxis)	Rainbow trout (21 to 50 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.13-0.19 V/cm pulsed DC @ 15 Hz 0.05-0.09 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
	Colorado pike minnow (30 to 39 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.16-0.21 V/cm pulsed DC @ 15 Hz 0.09-0.20 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
Twitch response to field exposure	Rainbow trout (31 to 48 cm fork length)	Freshwater (conductivity 103 µS/cm @ 11ºC)	0.19-0.43 V/cm pulsed DC @ 20 Hz 0.15-0.71 V/cm pulsed DC @ 30 Hz 0.11-0.97 V/cm pulsed DC @ 60 Hz	Taube 1992 (as cited in Snyder 2003)
	Rainbow trout (21 to 50 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.06-0.10 V/cm pulsed DC @ 15 Hz 0.03-0.05 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
	Colorado pike minnow (30 to 39 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.08-0.13 V/cm pulsed DC @ 15 Hz 0.02-0.10 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
Altered migratory behavior (changed orientation relative to electrical field)	American eel elvers (juveniles)	Marine	1 µA/cm^2 to 100 µA/cm^2	McCleave and Power 1978
Observed avoidance responses (electrofishing voltage used to direct fish out of an in-water work area)	Salmonids (adult and juvenile), other resident fish species	Freshwater (riverine ~1-6 ft. depth)	500 to 1,000 V pulsed DC @ 7.5 Hz	Johnson and Hoffman 2000
Observed avoidance responses (electrical fish barrier used to prevent access to an in-water work area)	Salmonids (adult and juvenile)	Freshwater (riverine ~1-6 ft. depth)	~0.5 to 100 V/M pulsed DC @ 2 Hz	Johnson and Hoffman 2000

Table 1 (continued). Electrical field strength associated with observed responses in various fish species.

Response Type	Species Type	Environment Type Where the Response was Observed	Electrical Field or Source Strength Associated with Observed Response	Source
Recommended voltage settings for electrofishing equipment to avoid fish injury (voltage requirements dependent on conductivity)	Salmonids (juvenile)	Freshwater	100 to 800 V pulsed DC @ ≤30Hz	WSDOT 2006
Electrofishing injury (electrofishing voltage settings associated with spinal and tissue injury)	Rainbow trout (juvenile)	Freshwater	300 V pulsed DC @ 30 Hz	McMichael et al. 1998
			1-9 V/cm within 100 cm of anode (produced by electrofishing at a setting of 350-400 V @ 60 Hz)	Dalbey et al. 1996
Stunning or unconsciousness	Rainbow trout (31 to 48 cm fork length)	Freshwater (conductivity 103 µS/cm @ 11ºC)	0.53-10.4 V/cm pulsed DC @ 20 Hz 0.92-6.5 V/cm pulsed DC @ 30 Hz 0.61-6.4 V/cm pulsed DC @ 60 Hz	Taube 1992 (as cited in Snyder 2003)
	Rainbow trout (21 to 50 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.54-0.70 V/cm pulsed DC @ 15 Hz 0.14-0.20 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
Stunning or unconsciousness (continued)	Colorado pike minnow (30 to 39 cm fork length)	Freshwater (conductivity 530 µS/cm @ 18ºC)	0.25-0.36 V/cm pulsed DC @ 15 Hz 0.18-0.27 V/cm pulsed DC @ 60 Hz	Meismer 1999 (as cited in Snyder 2003)
	Atlantic salmon (adult)	Marine	15-250 V/M @ 50 Hz AC (depending on duration of exposure)	Roth et al. 2003

µV/cm = microvolts per centimeter
V/cm = volts per centimeter
V/M = volts per meter
µS/cm = microsiemens per centimeter (measure of electrical conductivity)
DC = direct current
Hz = Hertz
V = volts
ºC = degrees Celcius
Fork length = the length of a fish from the tip of the nose to the indent, or fork, in the middle of the tail fin

Table 2. Stray electrical current field strength under the I-90 bridge, under existing and proposed conditions

Source	Parameter	Existing Conditions	Proposed LRT Conditions	Notes
Existing cathodic corrosion protection system	Electrical field intensity	Maximum: 26.2 µV/cm DC Typical: 13.1 µV/cm DC	Similar to existing conditions.	LRT operation will have little impact on the potential strength of the stray current field. Maximum rectifier output is the limit of the rectifier specifications. Most units are operating about half the rated output. Planned upgrades in rectifier and anode design will maintain current conditions, or possibly reduce field intensity.
	Maximum electrical field size around each cathode/anode	30 meters (horizontal) 21 meters (vertical)	30 meters (horizontal) 21 meters (vertical)	The electric field will be concentrated between the cathode (anchor cable) and the anode, which are spaced approximately 30 meters apart. Each anode is suspended 10 to 11 meters below the surface and is between 10 to 21 meters in length.
	Minimum horizontal distance between each field	10 meters (horizontal) Pontoons A & R; 5 meters pontoon J; 100 meters remaining pontoons.	10 meters (horizontal) Pontoons A & R; 5 meters pontoon J; 100 meters remaining pontoons.	
Stray electrical current from LRT system	Maximum electrical field intensity	n/a	Uncertain but will most likely range from 10^{-1} to 10^{-2} µV/cm DC	The proposed LRT system will produce a stray DC current field, but the design and additional shielding mechanisms will limit the intensity of this field to very low levels (essentially negligible in comparison to the existing cathodic corrosion protection system). The size and orientation of the potential stray DC current field is difficult to determine. Stray current could leak to the aquatic system through a number of pathways on the structure, including drainpipes, power lines, the cathodic protection system, and even the concrete structure itself when wet with rain. It is not practical to analyze each of these potential pathways for the purpose of this analysis. Given the limited intensity of the field however, its size and orientation would appear to be irrelevant with regards to potential effects.
	Field size and orientation	n/a	Unknown	

Source: Wetzel 2008.
AC = alternating current
DC = direct current
LRT = light rail transit

As shown in Table 2, operation of the LRT system on the I-90 bridge will not change the output of the cathodic corrosion protection system in any significant way, meaning that the existing electrical field intensity and orientation associated with this feature will remain unchanged under proposed conditions (Wetzel 2008).

The LRT system is expected to produce a stray electrical current field in and around the I-90 bridge. Because this current can discharge along any conduction pathway, the location and extent of this field is difficult to predict. However, much of the discharge is likely to occur from the stray current mitigation system. The intensity of this stray current field is expected to be on the order of 10^{-1} to 10^{-2} µV/cm DC (Wetzel 2008).

Comparison of Stray Current Field Intensity to Established Response Thresholds

Retrofitting of the I-90 bridge to support the LRT system could conceivably alter the electrical field associated with the structure through two pathways: 1) modification of the cathodic corrosion protection system; and 2) creation of a stray electrical current field leaking from the DC electrical system used to power the trains. As shown in Table 2, the size and intensity of the electrical field produced by the existing cathodic protection system is not expected to change under the proposed conditions. As there is no related change in stressor exposure for fish Lake Washington species, there is no further need to consider this particular issue.

The stray current field produced by the LRT system will result in a change in potential electrical exposure from the existing conditions. However, the range of electrical field intensity likely to occur from stray current leakage appears to be lower than levels necessary for sensory detection or physiological effects in Lake Washington species. The intensity of the stray current field will range between 10^{-1} to 10^{-2} µV/cm DC. These levels are one to three orders of magnitude lower than observed physiological response limits in Atlantic salmon and American eel (7-70 µV/cm DC) (McCleave et al. 1974). These species are representative of the likely sensitivity of the majority of Lake Washington species exposed to stray electrical current.

Lamprey are the most electroreceptive, and thereby the most potentially sensitive of the Lake Washington fish species to stray current field exposure. At least one and possibly two species of lamprey (Pacific and river lamprey) are known to occur in the Lake Washington basin (a third species, western brook lamprey, may also be present). Even in the case of lamprey however, the anticipated stray current field appears to be at least one to as much as two orders of magnitude below known physiological and behavioral response thresholds (Bodznick and Preston 1983; Muraveiko 1984).

In recent years, concerns have emerged regarding the potential health effects of long-term exposure to low intensity electro-magnetic fields. Theoretically, long-term exposure even at levels below behavioral response thresholds could lead to adverse effects that would otherwise go undetected. Considerable research effort has been devoted to this concern. For example, Weaver et al. (1998) examined the biochemical response profile of various cellular systems to electromagnetic field exposure in order to evaluate the potential for human health effects. They developed a model to estimate the minimum threshold limits at which an electromagnetic field could potentially cause harmful changes in cellular level physiological systems. They determined that 90 µV/cm was the minimum field intensity necessary to alter physiological systems at the cellular level in species lacking specialized electroreceptive organ systems. Like the physiological and behavioral response thresholds discussed previously, the anticipated I-90 stray DC current field is well below this threshold.

Conclusions

The East Link project proposal to locate LRT on the I-90 bridge is likely to create a low intensity stray current field around the bridge structure. The size and intensity of this field cannot practically be determined with accuracy. However the best possible estimate indicates that stray current intensity will be one to three orders of magnitude below physiological or behavioral response thresholds for even the most sensitive Lake Washington fish species. Given these findings, the conclusion of this screening level assessment is that stray current from LRT operation is unlikely to lead to adverse effects on aquatic life, and there is no need to investigate the issue further.

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