Evaluation of an Electric Barrier as a Seal Deterrent on the Puntledge River

Prepared For

Pacific Salmon Commission
Southern Boundary Restoration & Enhancement Fund Committee
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February 2009

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EXECUTIVE SUMMARY

The Department of Fisheries and Oceans, the Pacific Salmon Commission and Smith-Root Inc. conducted a series of short-term trials in 2007 to assess how seals respond to very low electric fields and determine whether this technology could be used to deter seal predation on salmonids. Results from initial trials at Vancouver Aquarium indicated that at very low levels of electricity (voltage gradient < 0.32 volts/cm at surface, pulse width 0.4 msec, frequency 2.25 Hz, water conductivity 275µS at 15˚C) seals displayed an avoidance reaction to an underwater electric field. In situ testing followed a month later on the Puntledge River in Courtenay, B.C., where a temporary electric array appeared to deter seals from migrating to their preferred feeding areas in the lower river.

A more comprehensive evaluation was carried out in the Puntledge River in 2008 in order to examine the longer term effectiveness of an electrical array as a seal migration barrier as well as its effects on the migratory behaviour of salmonid fish in the river. The overarching goal of the study was to test and further refine a non-lethal marine mammal deterrent system having potential to assist in protecting threatened or endangered stocks of fish in this and other watersheds in the Pacific Northwest.

Three different configurations of electrodes (i.e. arrays) were tested in the lower Puntledge River between April 27 and June 5, 2008: a "3-cable perpendicular" array, a "17-element parallel" array and a "4-cable perpendicular" array, similar to that used in the 2007 trials. The configurations differed in their orientation of the electrodes relative to the direction of river flow. Each of the arrays was installed just upstream of the 5th Street Bridge in the lower Puntledge River. This location had been identified in previous assessments as a preferred foraging area for seals because they are able to utilize the light cast from the bridge lighting to silhouette and capture outmigrating salmon fry and smolts.

Baseline observations of seal foraging behaviour at the 5th Street Bridge prior to the start of the electric deterrent trials in 2008 were compared to observations collected in previous years. Results indicate that the shielding of bridge lights completed in the fall of 2007 appears to have reduced the number of seals feeding under the 5th Street Bridge. The average number of seals observed in 2008 was 0.7 compared to 5.2 in 2006 and 3.7 in 2007. The use of similar light shielding treatments should be further explored for other well lit sections of the river where seals have been observed congregating and foraging.

Tests of the "3-cable perpendicular" array, followed by the "17-element parallel" array were conducted between April 27 and May 3, 2008. Tests using the "4-cable perpendicular" array were conducted between May 14 and May 22, 2008. Two DIDSON acoustic cameras were used to record behaviour of seals and fish in the area of the active electrical array, and observers

were stationed at the site throughout the test period. For each configuration, tests commenced at the lowest pulse width setting (1 msec) and ramped up by 1 msec increments to a maximum of 5 msec (17-element array only). At the lower pulse width settings (1-2 msec), seals that successfully passed through the array were not harmed or exposed to excessive stress. At pulse width settings in the mid range (3 msec), seals displayed more distinctive behavioural responses (avoidance of short-term discomfort or pain) while at the highest pulse width settings (4-5 msec) seals exhibited more physiological responses (involuntary muscle contractions). This latter observation resulted in a recommendation for an upper threshold of 3 msec pulse width setting for future trials in the Puntledge River. The fact that seals continued to challenge the array at the higher field strengths was likely a product of the study design. By gradually increasing the power settings, seals may have become trained to tolerate the electrical stimulus, and charge through the array at levels that may cause harm. This phenomenon has been observed when using electric fences on terrestrial animals.

The first two array configurations tested were plagued with inconsistencies and voltage gaps in the electric field, possibly due to metal in the river bed or operator error, and may have facilitated the upstream movement of seals. The 4-cable perpendicular array seemed to be the most effective at deterring seals from moving upstream. Based on DIDSON sonar imagery, the 4-cable array, operated at the 3 msec pulse width setting, was effective in blocking 79% of the seals that approached the array from downstream.

The effectiveness of the electric field deteriorated as river depth increased (during high river discharge or flood tides) due to a weakening in the electric field strength at the water surface over the array. Seals staging downstream of the array were often observed passing through the array during high tides. A means to adjust the electrical power of the barrier with varying water depths should be further investigated so that the strength of the electric field provides a continuous effective barrier within the limits approved by the Animal Care Committee.

For all of the array configurations at settings up to 3 msec, there appeared to be no adverse effect on outmigrating juveniles passing through the array. Conversely, upstream migrating adults appeared to have been obstructed during operation of the 4-cable array at the 3 msec pulse width setting. Given the imperilled status of Puntledge summer chinook salmon, this observation resulted in an immediate suspension of further testing of the electric deterrent during the adult salmon migration period. The utility of the current technology may therefore be limited to reducing seal predation on juvenile salmon smolts and fry in localized foraging areas in the Puntledge River.

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ACKNOWLEDGEMENTS

We are very grateful to the Pacific Salmon Commission Southern Boundary Restoration & Enhancement Fund for their financial support for this study. Thank you to the following individuals and organizations for their support and various contributions towards the planning and execution of the project: Komoks First Nation, John Allen (Parks Foreman, City of Courtenay), Jim Coles (B.C. Hydro, Vancouver Island Generation Area Manager), Brian Scott (The Cona Hostel), Puntledge River Restoration Committee, and Puntledge River Hatchery staff. We also extend our gratitude to the Project Observers Ted Defeo, Tony Lowe and Dan Bernard for their vigilant monitoring during the project, and review of DIDSON image files; Kerry Smith (Smith-Root Inc.) for technical support, array fabrication and installation, and residents of the Comox Valley for their patience throughout the study.

1. INTRODUCTION

In 2007 Smith-Root Inc. (SRI), in partnership with the Pacific Salmon Commission (PSC) and the Department of Fisheries and Oceans (DFO) Puntledge River Hatchery, conducted a series of tests to assess how seals respond to very low electric fields and determine whether this technology could be used to deter seal predation on salmonids. Results from the three short-term trials in 2007, one conducted at the Vancouver Aquarium, the second in the Puntledge (Courtenay)[1] River in Courtenay, BC (Figure 1), and the third in the lower Fraser River, indicated that seals avoided the electrified zone (Cave et al. 2008). The low levels of electricity used in these trials (voltage gradient < 0.32 volts/cm at surface, maximum pulse width of 1 msec, frequency of 2.25 Hz) were considerably below levels capable of causing injury to fish (NMFS 2000). During three nights of testing on the Puntledge River, a fixed electric array appeared to deter seals from migrating to their preferred feeding areas in the lower river. Preliminary results from studies conducted in the Fraser River suggested that this technology had the potential for deterring marine mammal predation without affecting fish migration, thus contributing to the overall protection and conservation of both fish and marine mammal species (Cave et al. 2008).

In response to the encouraging results obtained in 2007, a more comprehensive evaluation was carried out in the Puntledge River in 2008. The primary goal of the 2008 project was to test and further refine a non-lethal marine mammal deterrent technology that would not adversely affect the migrational behaviour of salmonid fishes.

The objectives of this project were to assess and determine:

i. whether a very low electric field is an effective long-term deterrent in displacing seals from localized foraging areas (such as along the light shadow at the 5th Street Bridge), and as a barrier in blocking seal movements upstream of the array;

ii. whether electric field strength sufficient to deter seals affects the migratory behaviour of juvenile and adult salmon; and

iii. whether there is a difference in the efficacy of the two types of arrays tested in this study (perpendicular or parallel arrangement) in preventing upstream seal passage, while allowing unobstructed salmon migration.

Three observational phases were incorporated in the study design: Phase I - baseline observations; Phase II - operation of electric barrier during juvenile salmon outmigration; and

[1] The 2007 and 2008 electric barrier trials were conducted in the Courtenay River which is the official gazetted name of the lower river downstream of the confluence of the Puntledge and Tsolum rivers, to the estuary. This section is also commonly referred to the Puntledge River in the context of seal predation since much of the predation is on salmonid production from the larger Puntledge watershed and the Puntledge River Hatchery (Olesiuk et al. 1996).

Phase III - operation of electric barrier during adult salmon migration. The electric barrier will be considered an effective deterrent if it prevents seals from migrating upstream to preferred salmonid foraging locations in the Puntledge River at power levels that do not adversely affect the migratory behaviour of salmon. If successful, this technology will assist to resolve predation issues on stocks of concern without lethal removal of the marine mammal predators, and may be applied to other watersheds in the Pacific Northwest.

2. BACKGROUND

The Puntledge River Summer chinook population is one of only a few summer-returning populations on Vancouver Island. DNA analysis has confirmed that this population is genetically distinct from the Puntledge fall-run population and from other Georgia Basin chinook populations, and its status is one of ongoing concern under the Pacific Salmon Treaty. It is the only escapement and exploitation indicator (PSC Chinook Technical Committee) for Georgia Strait Summer Chinook stocks. This genetically unique population, recently identified by DFO as its own Conservation Unit under the Wild Salmon Policy, is considered to be at risk. Key issues affecting the re-building of this stock have been identified as low freshwater productivity of naturally spawned fry, poor marine survival, excessive fishery exploitation and marine mammal predation during freshwater migration.

Seal predation has been identified as a significant contributor to juvenile and adult salmonid mortality within the Puntledge River. Detailed assessments conducted in 1990 and 1995 estimated that seals consumed 24% of the returning summer chinook adults and 15% of the out-migrating juvenile salmonids[2] respectively in the river (Olesiuk et al. 1995 and 1996). One of the key findings during these assessments was that a significant proportion of the total consumption of fry and smolts was performed by a small number of seals from the larger population that inhabit the Puntledge River estuary during April-May. These animals had developed a specialized foraging behaviour at the 5th Street Bridge, and to a lesser extent, the 17th Street Bridge, utilizing the light cast from the bridge lighting to silhouette and capture outmigrating salmon fry and smolts (Olesiuk et al. 1995).

In response to the declining summer chinook escapement, a number of conservation measures were taken in the late 1990's including a captive broodstock program, habitat improvements, and a lethal cull, which removed 52 habituated seals from the river in 1997-1998. An increasing trend in Summer chinook returns was realized until recently. Abundance of seals predating in-river has increased, reaching pre-cull numbers by 2007, potentially impacting the summer chinook population.

A successful seal deterrent technology may provide the opportunity to assist in protecting threatened or endangered stocks as part of a restoration / recovery plan for these fisheries without the

[2] The study estimated predation rates on outmigrating chum fry and coho smolts, and noted that seals continued to prey on outmigrating chinook smolts but did not estimate its magnitude.

need to reinstate a lethal cull of seals in the Puntledge River.

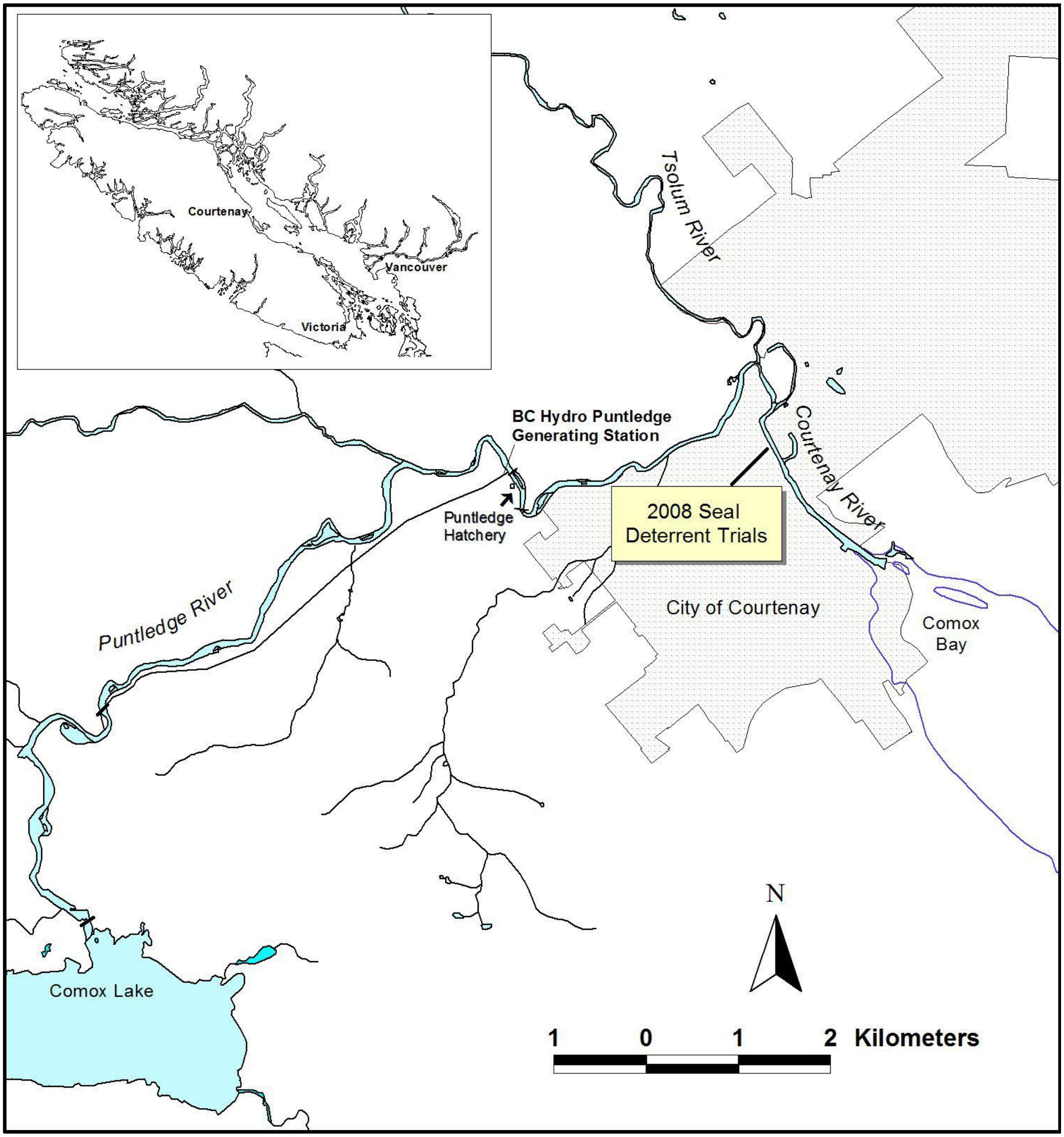

Figure 1. Location map of the 2008 Puntledge (Courtenay) River seal deterrent trials.

3. METHODS

The experimental marine mammal deterrent system (MMDS) tested in the Puntledge River was composed of two primary components: the on-shore power supply/control system, and arrays of electrodes positioned within the river. The on-shore system converted incoming electrical energy to quantities and types appropriate for interacting with aquatic organisms. The electrode arrays provide the interface between the on-shore electric system and water within the river. Essentially, the on-shore electrical system generates a difference in electric potential between electrodes, thereby causing an electric current to flow between electrodes through the water column. As electric current flows from the surface of the electrodes, a waterborne electric field is created, shaped by the contours of the electrodes, the electromagnetic forces of attraction and repulsion, and the distance between the electrodes. The electric field is most intense in the region of the electrodes and directly between electrodes, decreasing dramatically as distance from the electrodes increases. Thus, electric fields generated by electrodes positioned on the substrate are weakest at the water surface.

Between April 27 and June 5, 2008 three different configurations of electrodes (i.e. arrays) were tested in the lower Puntledge River: a "**3-cable perpendicular"** array, a "**17-element parallel**" array and a "**4-cable perpendicular**" array. Each of the electrode arrays were installed just upstream of the 5th Street Bridge in an approximately 24 metre stretch of river between the upstream edge of the bridge and a metal retaining wall located on the west side of the river (Figure 2). Each array was securely anchored to both shorelines as well as in several locations in the river bottom. Anchors were also placed upstream with securing lines extending to the arrays to hold their position throughout the test period (Appendix A).

The electrodes of the "**3-cable perpendicular**" array consisted of three copper cables, 12.7 mm (½-inch) in diameter, strung across the river perpendicular to the stream flow. The electrodes were spaced 3 meters apart by securing the cables to PVC pipes each 6 meters long (Figure 3). The "**17-element parallel"** array consisted of 17 copper pipes, 19 mm (¾-inch) in diameter and 6 metres long, laid parallel to the stream flow every 3 meters across the 49 m (160 ft) of river. Although this configuration was originally designed with seventeen copper electrodes, four electrodes were eventually disconnected (see Section 4.2). Insulated cable connected the ends of the copper electrodes to the power source and served to maintain the 3-meter spacing forming a ladder like structure (Figure 3). The orientation of the electrodes parallel to the stream flow was expected to be less likely to affect adult fish upstream migration behaviour as it creates an electric flow across the width of the fish (side to side) rather than along the length of the fish (head to tail) as would occur with perpendicular orientations of the electrodes The "**4-cable perpendicular**" array was an exact duplication of the array used in 2007, consisting of four copper cables, 12.7 mm (½-inch) in diameter, strung across the river perpendicular to the stream flow, held at even spacing 2 meters apart by securing the cables to PVC pipes each 6 meters long (Figure 4).

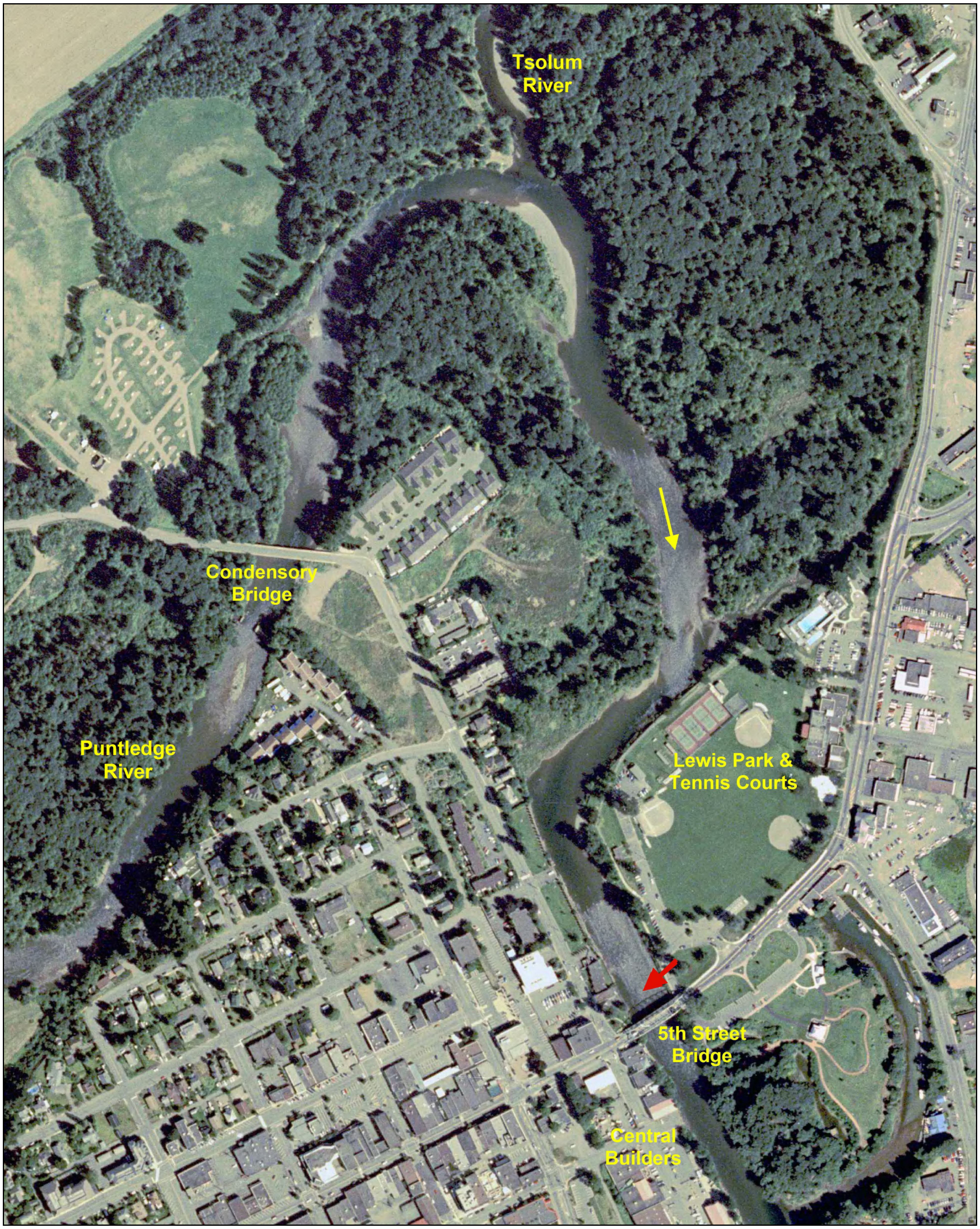

Figure 2. Location of the 2008 Electric Seal Deterrent Trials (red arrow) in the lower Puntledge (Courtenay) River, and other key features associated with the study. The 17th Street Bridge (not shown) is located ~1km downstream of the 5th Street Bridge.

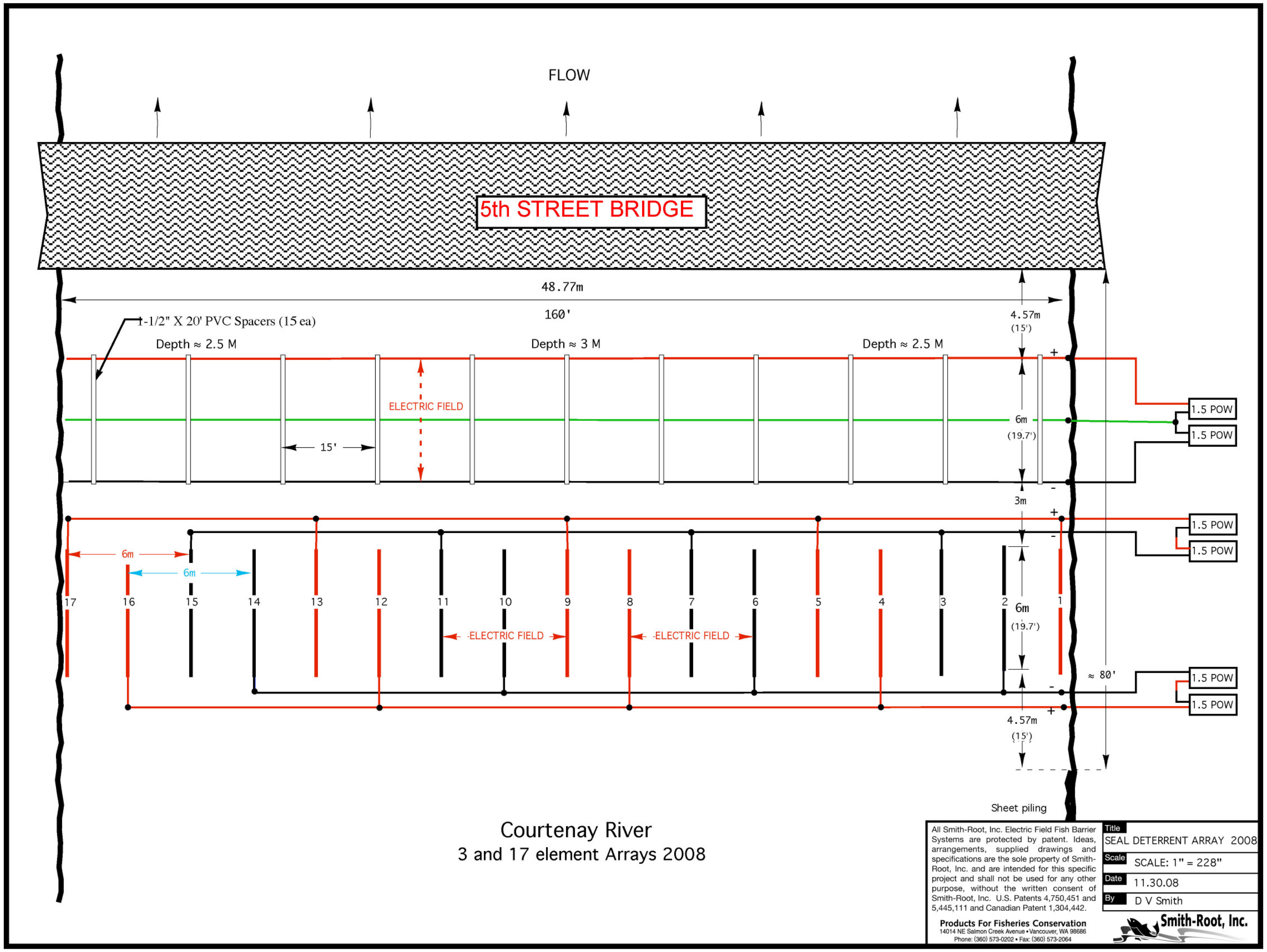

Figure 3. Schematic of the 3-cable and the 17-element arrays tested in the Puntledge (Courtenay) River upstream of the 5th Street Bridge between April 27 and May 3, 2008.

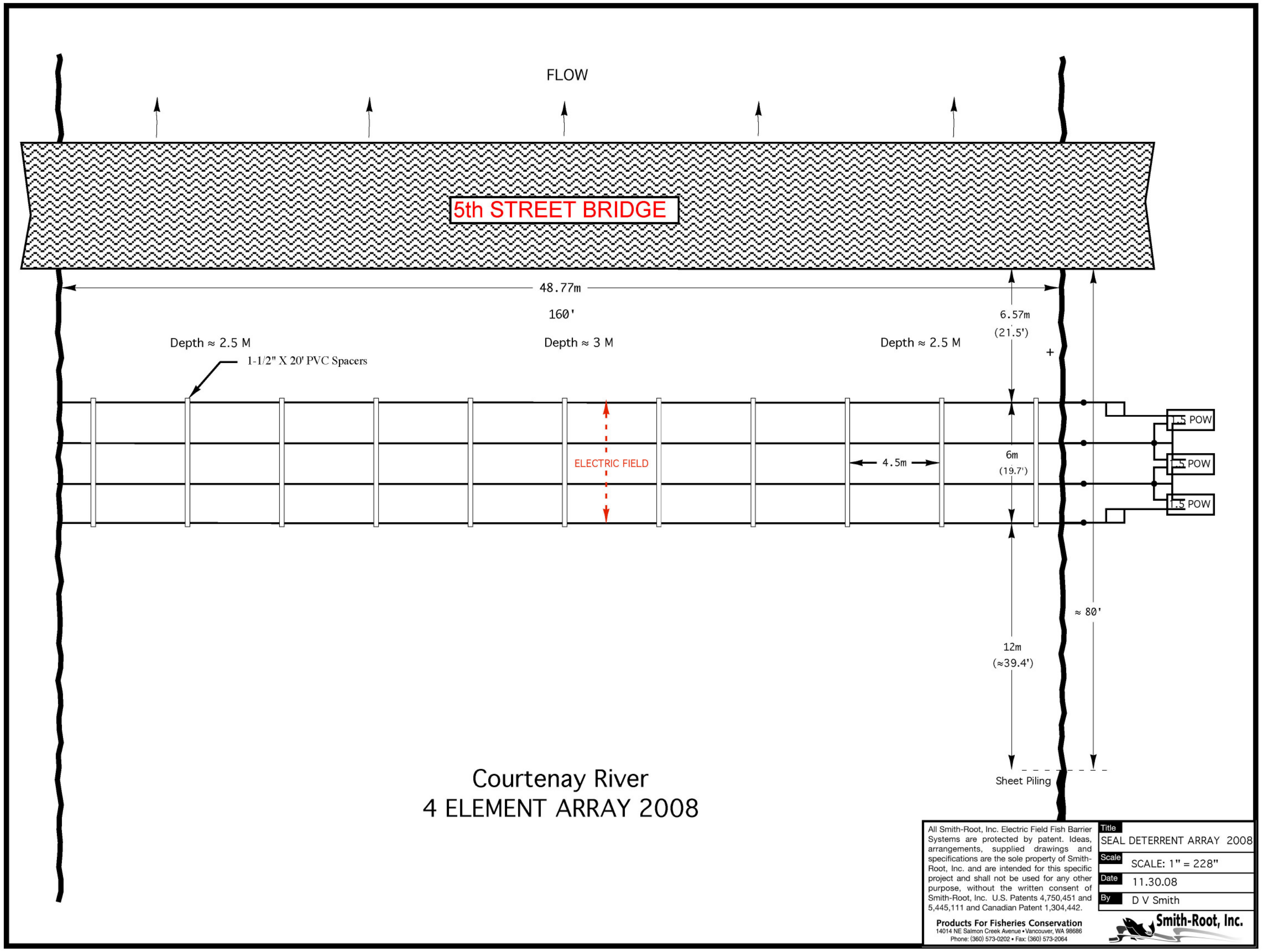

Figure 4. Schematic of the 4-cable array tested in the Puntledge (Courtenay) River upstream of the 5th Street Bridge between May 14 and June 5, 2008.

The "3-cable perpendicular" and "17-element parallel" arrays were fabricated and installed during the week of April 21 - April 26, 2008. The "3-cable perpendicular" array was situated approximately 4 meters upstream of the 5th St Bridge and the "17-element parallel" array was placed approximately 3 meters upstream of the upstream end of the "3-cable perpendicular" array. Both of these arrays were in the water and operational from April 27th – May 3rd. The "3-cable perpendicular" array was operated on April 27- 28 (2 evenings). The "17-element parallel" array was trialed from April 30 - May 2. During the period of May 5th – 9th the "17-element parallel" array was pulled out and the "3-cable perpendicular" was converted into the "4-cable perpendicular" array. This was done in-situ by adding an additional cable and repositioning two other cables so as to maintain even spacing of 2 meters between cables. The "4-cable perpendicular" array was operated from May 14 to May 22 and was removed from the river on June 5, 2008.

All electronic and computer equipment necessary for the project was housed on the west side of the river in a secure metal building provided by DFO (Appendix C - Photo 4). This included a series of customized 1.5 Programmable Output Waveform (POW) pulsators (SRI), computer components needed to produce and control electrical output to the arrays, and computers to record DIDSON (Dual-frequency IDentification SONar, Sound Metrics, Inc.) images. The 1.5 POW barrier pulsators converted incoming alternating current (commercial 220V, 30 Amp) from a neighbouring apartment building to pulsed direct current (PDC), and served as the power supply for the electrode arrays. Heavy gauge wires encased in conduit transmitted power to the array cables at the water's edge. The arrays laid flat on the river bottom and, when energized at a frequency of 2.25 Hz, created an electric field directly over the cables with a voltage gradient of 0.32 V/cm at the surface, and extended upstream and downstream of the array, quickly decreasing to undetectable levels within 2-3 meters of the array.

Electric field measurements were used to determine whether the array was functioning properly, within desired operational parameters, and to quantify the strength of the electric field. Field strength measurements were taken at the water surface, regardless of array configuration. Measurements of voltage gradient (V/cm) were taken in numerous locations along various transects parallel to the shoreline, from a boat using an EFP-2 Electric Field Probe (SRI). Measurements were also taken with an experimental probe capable of measuring in three-dimensions (x, y, and z) simultaneously. The measurements taken with the 3-D probe are reported as the vector sum of the voltage gradients ($E = \sqrt{x^2 + y^2 + z^2}$). The EFP-2 probe is more sensitive to misalignment from 90 degree (relative to the electric field) because it measures V/cm in the x-axis only. The 3D probe measures in 3 directions simultaneously, therefore it should account for any misalignment (relative to the EFP-2) providing more robust measurements. Measurements of the electric field were taken at high tide on May 14, 2008 and during various stages of the tide cycle on June 4, 2008.

Water conductivity varied from 28 – 37 microSiemens/cm between April 27th and May 1st, 2008. Conductivity measurements taken at the 5th St. Bridge on the river bottom during a very high tide cycle on June 4, verified the lack of saltwater intrusion.

Two DIDSON acoustic cameras, a Short-range (30 m) and a Long-range (80 m), were used to record behaviour of seals and fish in the area of the active electrical array. Two ramps were fabricated and installed on the west shoreline to guide and position the DIDSON acoustic cameras in the water (Appendix C - Photo 3). This additionally allowed easy installation and removal, as the DIDSONs could not be left permanently in position due to security concerns. One was located downstream of the lower array and the other was located upstream of the upper array (Appendix A). The positioning of these ramps was not changed throughout the testing. The Long-range DIDSON initially was placed at the upstream ramp with the Short-range DIDSON at the downstream ramp, however the upstream ramp was located in water too shallow to allow continual operation of the DIDSON throughout the tidal cycle. As the Long-range DIDSON provided the best coverage of the interactions between seals and the electric array, it was moved to the downstream ramp after a few days. DIDSON imagery was collected during each evening the electric array was operated with the exception of the initial trial period of the 3-cable array.

During the field trials, a minimum of two safety observers were on site stationed near shore where visibility of the electrified zone was unobstructed. The electrical system for operating the arrays was equipped with a kill switch which the safety observer could have next to them while at the shoreline. The observer could turn off power to the array at a moments notice if there was any potential for a human interaction with the electrical field in the water. Signs were placed above and below the electrical arrays to alert river users of the presence of electricity in the water during the trial periods (Appendix C - Photo 5) and information notices were also placed in the local newspapers. The observers were also equipped with an air horn to get the attention of humans wanting to pass through the array location. Power was always turned off whenever humans approached the array. The observers also made visual observations of numbers and behaviour of seals in the vicinity of the electrical barrier, and periodically made counts of seals upriver of the electrical array. These were particularly useful in evaluating the effectiveness of the electrical barrier early in the study, when DIDSON acoustic camera installation was being developed and they were not always available.

At various times during initial start-up of the electric deterrent trails, and whenever array configurations were changed and/or when pulse width settings were increased, Dr. M. Haulena, Vancouver Aquarium veterinarian or Peter Olesiuk, DFO Marine Mammal Biologist; and staff from DFO Puntledge Hatchery and SRI were present to review parameters of the electric field and monitor seal and salmonid behaviour in response to the electric field at various pulse width settings. Given the lack of information on the effects of electrical currents on seals, the DFO Animal Care Committee (ACC) approval allowed for operation of the array at a maximum of 0.32 v/cm and 2.25 Hz with pulse widths starting at 1 msec (the maximum exposure in the 2007 trials) up to a maximum of 5 msec by 1 msec increments. Any increases in power setting required the mutual consent of Dr. Haulena and P. Olesiuk before implementing to ensure seals were not harmed or exposed to excessive stress.

4. RESULTS

4.1 Baseline Observations

Following observations and assessments conducted in the 1990s on seal predation on outmigrating fry and smolts (Olesiuk et al. 1995), it was strongly recommended that shielding of the lights at the 5th and 17th Street Bridges should be evaluated as a mitigative measure to deter seals from foraging beneath them. Predation on outmigrants was determined to be a relatively localized behaviour. With assistance from the City of Courtenay, modifications to the lights on the 5th Street Bridge were completed in the fall of 2007. This included turning off every second light on the bridge truss above the road, and erecting a shield around the remaining lights to prevent light from spilling beyond the bridge deck and into the river, significantly reducing the light shadow used by foraging seals.

Baseline observations of seal foraging behaviour were collected by Puntledge Hatchery personnel during the months of April and May 2008 before and during electric array operations. Surveys, using night vision equipment, were conducted between dawn and dusk during flood tides at five main areas of the Puntledge / Courtenay River: Condensory Road Bridge, Lewis Park tennis courts, 5th Street Bridge, Central Builders, and the 17th Street Bridge (Figure 2). The 2008 observations are compared to 2007 observations collected during the same months and illustrated in Figure 5.

It appears that the light shields were effective in reducing the number of seals feeding under the 5th Street Bridge. For the period prior to the start of the electric fence trial on April 27, the maximum number of seals observed during any given monitoring event was 4 in 2008 compared to 9 in 2007 and 10 in 2006. The average number of seals observed during this period was 5.2 in 2006, 3.7 in 2007 and 0.7 in 2008. It was noted that the light shields eliminated the distinct shadow line where seals had congregated to feed on outmigrating juvenile salmon in past years. Seals may have been displaced to other well lit areas of the river to feed such as the Lewis Park tennis courts upstream. A comparison of 2007 and 2008 observations at Lewis Park provides limited information due to the disproportionate sampling effort between the 2 years (Figure 6). These comparisons do not take into account other variables that may have influenced seal activity such as timing of juvenile salmon outmigrations, tide level and river discharge. The shielding of lights and displacement of seals from the 5th Street Bridge confounded the objective of assessing whether the electrical array would displace seals from a localized area, and we were only able to assess whether the array served as a barrier in blocking the upstream movement of seals.

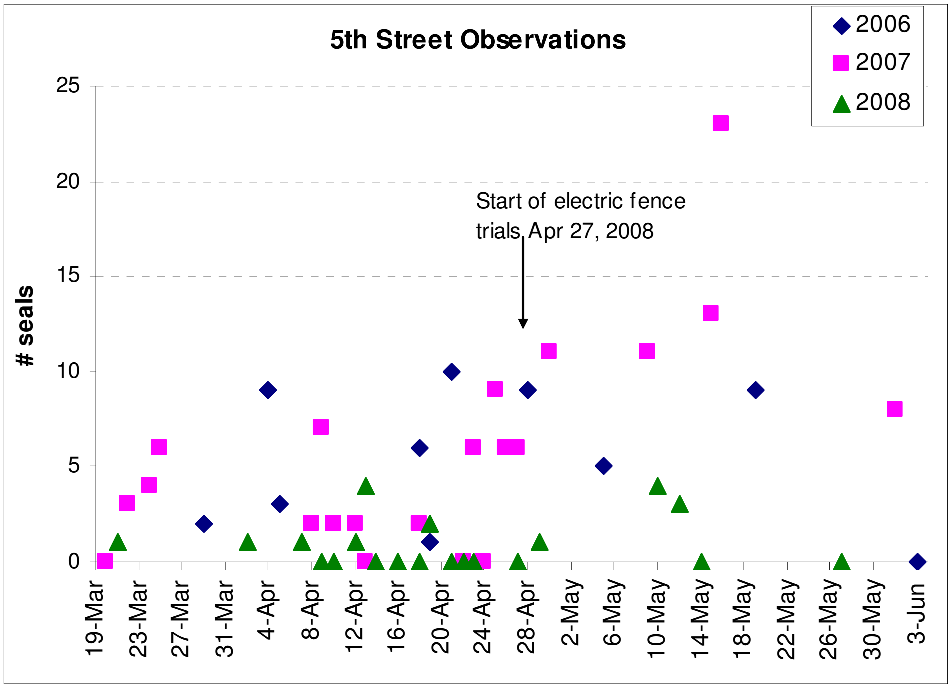

Figure 5. Observations of seals in the Puntledge (Courtenay) River at the 5th Street Bridge between April and June before lights were shielded (2006-2007) and after (2008). Commencement of the 2008 electric deterrent trials is noted. Trials in 2007 were conducted on April 12-13 and April 23-25

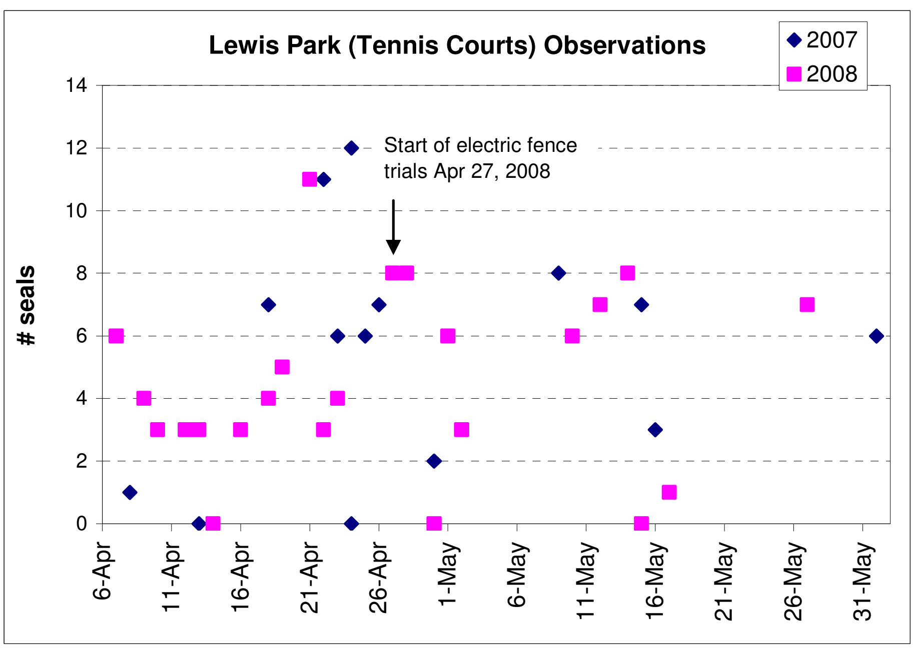

Figure 6. Observations of seals in the Puntledge (Courtenay) River at the Lewis Park Tennis Courts (upstream of the 5th Street Bridge), between April and June before lights were shielded (2007) and after (2008). Commencement of the 2008 electric deterrent trials is noted. Trials in 2007 were conducted on April 12-13 and April 23-25.

4.2 Phase II – electric deterrent trials during juvenile outmigration

"3 cable perpendicular" Array – electrodes perpendicular to stream flow

Tests of the "3-cable perpendicular" array commenced on April 27, 2008. The voltage gradient at the water surface over the electrode array was 0.3 V/cm with direct current (DC) pulsed at 2 Hz. The test commenced at the 1 msec pulse width setting and increased to a maximum of 2 msec by the second evening. This array configuration was similar to the array tested in the Puntledge River in 2007, but with only three cables placed perpendicular to the river flow rather than four as in 2007. Seals were observed to easily move upstream through the array at the 1 msec pulse width setting, although at the 2 msec setting, seal passage was deterred in 68% of the challenge attempts (Table 1).

Investigation of the electric field, using measurements of the voltage gradient at the water surface within the array, found a significant voltage drop over the centre cable of the array. Tests using this configuration were terminated when the inconsistencies in the electric field could not be rectified. One possible explanation for these inconsistencies was the potential presence of metal in the streambed since the location of the array differed slightly from its position in the 2007 study. Another possibility is operator error, as the pulse generators must be turned on in precise sequence to generate consistent electric fields.

"17-element parallel" Array – electrodes parallel to stream flow

Operation of the "17-element parallel" array commenced on April 30, 2008 at the 1 msec pulse width setting, increasing to the 5 msec pulse width setting by the third and final evening of testing. Measurements of the electric field, however, revealed inconsistencies and gaps in the voltage across the array which weakened the field strength significantly. Design modifications were attempted in situ but were not successful in producing a uniform electric field of 0.3 V/cm. At the highest 5 msec pulse width setting, results from DIDSON sonar imagery revealed that approximately 68% of the seals that approached the barrier from downstream were turned back compared to between 30 and 50 % at the lower pulse width settings (Table 1). Observers also noted distinctive behavioural responses in seals during both upstream and downstream passage through the array at the 2-3 msec pulse width settings, such as hesitation, splashing or porpoising at the surface, and circling within the array. At the highest settings of 4 and 5 msec, several seals were heard "grunting" as they encountered the electrical field, suggesting they experienced significant discomfort.

Schools of juvenile salmon were observed drifting passively over the array at night during these trials and appeared to be unaffected by the electric field. The operation of the 17-element array was terminated on May 2, 2008 when various wiring configurations failed to resolve the voltage gaps in the electric field.

Table 1. Summary of seal occurrences at electrical arrays on the Puntledge (Courtenay) River, based on DIDSON sonar images collected from April 28 - May 22, 2008.

Date	Didson Operational Time (24 hr clock)	Pulse Width (msec)	Array Config.	Upstream Blocks / Attempts	Downstream Blocks / Attempts	Approx. Discharge Gauge 8 + Tsolum (cms)	Tide Level During Period (m)	Direction	Comments
Apr 28	2245 - 0045	2	3-cable	15 / 22 (68%)	0 / 9 (0%)	37	3.6 - 4.4	rising	high tide (4.6m) occurred at 0200 on Apr29
Apr 30	1736-0047	2	17-element	4 / 13 (31%)	1 / 2 (50%)	25	2.65 - 3.9	falling then rising	low tide (2 m) occurred at 20:00
May 1	2015 - 2132	3	17-element	2 / 5 (40%)	0 / 9 (0%)	23	2.4 - 2.35	low tide	low tide (2.3 m) occurred at 21:00
	2132 - 0025	4	17-element	6 / 12 (50%)	0 / 8 (0%)	23	2.35 - 3.3	rising	high tide (4.6m) occurred at 0300 on May 2
May 2	1849 - 0236	5	17-element	32 / 47 (68%)	0 / 15 (0%)	24	3.5 - 4.3	falling then rising	low tide (2.5 m) occurred at 22:00
May 14	1855 - 1924	1	4-cable	0 / 1 (0%)	0	59	2.8 – 2.7	falling	data from visual and DIDSON
	1925 - 2042	2	4-cable	4 / 6 (67%)	0 / 1 (0%)	59	2.7 – 2.6	falling	data from visual and DIDSON
	2043 - 0200	3	4-cable	6 / 8 (75%)	0 / 9 (0%)	59	2.6 - 4.5	falling then rising	low tide (2.5 m) occurred at 21:00
May 15	1819 - 2145	4	4-cable	1 / 2 (50%)	0 / 1 (0%)	70	3.6 - 2.9	falling	2.9 m low tide at 21:00
	~2145 - 0130	3	4-cable	11 / 11 (100%)	0 / 3 (0%)	75	2.9 - 4.0	rising	4.5 m high tide at 03:00 May 16
May 16	1830 - 0500	3	4-cable	15 / 23 (65%)	0 / 17 (0%)	83	4.0 - 4.3	falling then rising	low tide (3.1 m) occurred at 23:00.
May 17	2034 - 0615	3	4-cable	16 / 20 (80%)	0 / 24 (0%)	99	3.95 - 3.85	falling - rising - falling	low tide (3.4 m) occurred at 23:00.
May 18	2028 - 0615	3	4-cable	23 / 32 (72%)	0 / 11 (0%)	88	4.35 - 3.9	falling - rising - falling	low tide (3.5 m) occurred at 24:00
May 19	2020 - 0615	3	4-cable	20 / 25 (80%)	0 / 23 (0%)	87	4.6 - 4.0	falling - rising - falling	low tide (3.6 m) occurred at 01:00 May 20
May 20	2028 - 0614	3	4-cable	62 / 72 (86%)	0 / 20 (0%)	59	4.75 - 4.2	falling then rising	low tide (3.7 m) occurred at 01:00 May 21
May 21	2022 - 0600	3	4-cable	25 / 33 (76%)	3 / 20 (15%)	56	4.75 - 4.1	falling then rising	low tide (3.7 m) occurred at 02:00 May 22
May 22	1957 - 2308	4	4-cable	13 / 25 (52%)	0 / 2 (0%)	53	4.5 - 4.6	rising then falling	high tide (4.8 m) occurred at 21:00
	2315 - 0300*	4	4-cable	1 / 1 (100%)	0 / 2 (0%)	54	4.55 - 3.7	falling	low tide (3.7 m) at 03:00

Notes: Array operation commenced during daylight hours on Apr 27, 2008 during which time issues with the electric fields and DIDSON operation were worked out. Occasionally visual observations were made during these two days, however they were insufficient to include in this summary. A Short-range and a Long-range DIDSON were used at various times throughout the tests. Data from the Long-range DIDSON were used for summarizing unless not available in which case data were used from the Short-range DIDSON. DIDSON images for April 28th were read by Lisa Harlan (Smith-Root, Inc.) and images for April 30 - May 22 were read by T. Defeo (DFO). Data were not verified by a second reader. Data summarized by L.. Harlan and only includes occurrences where species and final direction of seal movement were positively identified

* 2315-0300 Long Range operated at 20m to observe smolts. Seal passage during this time included in count.

“4 cable perpendicular” Array – electrodes perpendicular to stream flow

Operation of the “4-cable perpendicular” array commenced on May 14, 2008 at the 1 msec pulse width setting and quickly ramped up to 3 msec on the first evening as observations indicated seals were not harmed or exposed to excessive stress. On the first evening, only 1 seal was observed during the time the fence was operated at the 1 msec pulse width setting (30 minutes), and successfully passed through the array with some hesitation. The pulse width was then increased to 2 msec for 1 hour and 18 minutes, and 4 of 6 seals (67%) were blocked from upstream passage during this period (Table 1). A pulse width setting of 3 msec was employed for the remaining 5 hours and 17 minutes of the trial on May 14. During this period, 6 of the 8 seals (75%) that were observed approaching the array were prevented from continuing upstream. A gap may have been present in the array on the east side of the river where the electrodes were exposed at low tide. Some seals were observed challenging the array at multiple points, travelling horizontal to the array as if searching for a weak spot in the electric field.

Electric field measurements taken along transects at the water surface at 10:00:00 with an EFP-2 Electric Field Probe [predicted tide of 2.2 m at the Comox Station (#7965)], demonstrated maximum voltage gradients of 0.34, 0.32, and 0.31 V/cm along the west side, the east side, and center of the river, respectively. Electric field measurements along similar transects at 14:45:00 (predicted tide height of 3.5-3.6 m), revealed maximum voltage gradients of 0.20, 0.25, and 0.23 V/cm for the same locations described above. The difference in the field intensity at the surface was likely a reflection of tidally influenced changes in water depth.

The first trial at the 4 msec pulse width setting was conducted on the evening of May 15. During this test, the array was activated over one hour before dusk and before seals moved into the area. Peter Olesiuk was present during this trial and observed 3 seals approaching the array from downstream at dusk. One passed quickly through the array without difficulty. A second seal appeared to experience involuntary muscle contractions while trying to swim through the array and was unsuccessful at making further upstream progress and moved downstream. The third seal also entered the array at the hole along the east side of the river and experienced physical difficulty swimming through it. It appeared as if the seal was attempting to climb out of the water onto shore and was observed exhibiting the same muscle contractions as the second seal, but managed to proceed upstream. Since these physiological responses (involuntary muscle contractions) extended beyond the intended behaviour responses (avoidance of short-term discomfort or pain), it was recommended that further testing of the array at the 4 msec pulse setting be postponed until veterinarian, Dr. Haulena, could be present. Tests continued at the 3 msec setting for the remainder of that evening until May 22.

The second trial at the 4 msec pulse width setting was conducted on May 22. The array was activated at 1900 hrs and within a few minutes one seal surfaced upstream of the array suggesting it likely passed through the array. A few minutes later two more seals approached the array from downstream. One entered the array and became immobilized, experiencing the distinctive wholebody muscle contractions as seen previously. This seal remained in the array for close to one minute before it was able to proceed upstream. The second seal made a few attempts to enter the array but was turned back and disappeared downstream. About 10 minutes later two more seals approached and passed through the array successfully, possibly due to the weakening field strength as the river depth increased with a flooding tide. Many other seals that had been staging downstream of the array were observed passing upstream through the array as the tide increased during the evening. High tide of 4.8 m or 15.7 feet was at 21:00 hrs.

Measurements of the electric field conducted on June 4th though a large tide cycle (5.1 m / 16.7 ft.) confirmed that the strength of the electric field weakened over the array as the river depth increased from the rising tide (Figure 7). The measurements should best be regarded as indices for comparing changes related to tides since they were taken from a moving boat (speed not controlled, direction not exact, transects not reproduced exactly). Unfortunately, during the testing of the electric field an anchor line of the electrical array entangled the boat used in the testing. The entanglement disturbed the position of the array, the spacing of the electrodes, and the strength and distribution of the electric field relative to those during the trials with seals. That is, field strength measurements taken on 4 June 2008 do not reflect those present in the water column during the trials. These measurements do, however, demonstrate a significant relationship between tide and field strength at the water surface, where field strength at the surface decreased markedly as predicted tides increased.

During this high tide cycle, conductivity measurements confirm that there was no salt water intrusion into the area (no change in river conductivity readings at peak tide height), though at the 17th Street Bridge, full strength sea water was measured. Therefore the 5th Street Bridge location likely is the closest site to the estuary that could accommodate an electric deterrent installation.

DIDSON imagery collected during operation of the 4-cable array from May 14 to May 21 at the 3 msec pulse width setting indicate that between 65% and 100% of seals that approached the array from the downstream end were turned away (average = 79%). Similar to operation of the 17-element array, there appeared to be no adverse effect on outmigrating juveniles passing through the array, either from DIDSON imagery or from visual observations made on shore. The original study design proposed to assess potential physiological affects on juveniles by conducting fish health examinations on juveniles after passing through the array, and conducting a bioassay to assess seawater adaptability on chinook smolts after passing though the energized and disconnected array. However, this component was not completed after discussion with DFO veterinarian Dr. Christine MacWilliams. It was felt that any sublethal effects on juvenile salmonids exposed to the array would be extremely difficult to assess, and would not likely provide any meaningful information to the study.

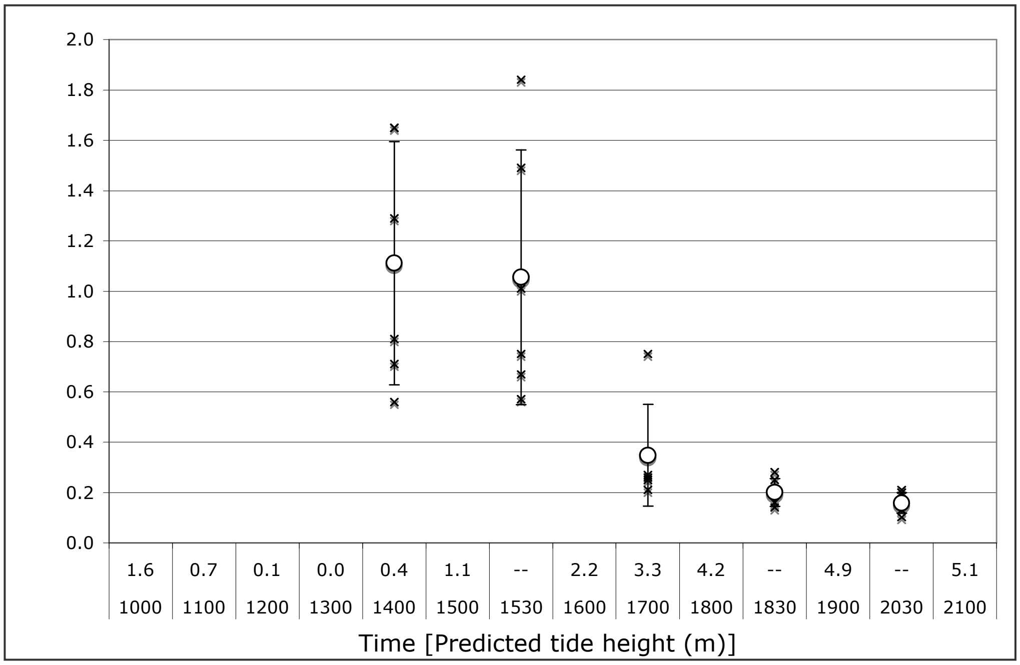

Figure 7. Electric field strength [voltage gradient (V/cm), y-axis] over the 4-electrode array, at the surface of the Puntledge (Courtenay) River, as a function of time and predicted tide height (x-axis) on 4 June 2008. The measurements were taken with the EFP-2 voltage probe at random intervals along six transects. Circles are averages with error bars of one standard deviation.

4.3 Phase III – electric deterrent trials during adult migration

This component of the study was terminated following a review of DIDSON imagery collected on May 18, 2008 during operation of the 4-cable array at the 3 msec pulse width setting. The imagery identified 14 adult salmon targets approaching the array. Three adults proceeded upstream through the array, 6 turned around and went downstream and the remaining 5 fish appeared to stall at the downstream periphery of the array, but their eventual migration direction was inconclusive. The DIDSON sonars were operated on May 24 to observe adult migration with the electric array shut off. Nine adult salmon targets were confirmed with 8 proceeding upstream over the disconnected array and one turning back downstream. DIDSON images were verified by I. Matthews and G. Cronkite (DFO). Since the threatened summer chinook are the main migrating population during this time period, it had been agreed prior to the study that any observed obstruction to their upstream migration would result in an immediate suspension of further testing of the electric barrier.

4.4 Environmental Data

Hourly average river discharge data during the April – June study period were obtained from Environment Canada's two gauging stations: the Puntledge River station (WSC Gauge No. 08HB006) located below the BC Hydro Puntledge generating station (3.7 km upstream from the

Puntledge/Tsolum River confluence) and the Tsolum River station (WSC Gauge No. 08HB011) located approximately 2 km upstream of the confluence. Discharge from these two stations were totalled to provide an estimate of the discharge observed at the 5th Street Bridge with no correction for lag time for distances between gauge locations and the bridge location (Figure 8). Discharge in the river below the confluence was highest during the testing period of the 4-cable array from May 14 to May 22, 2008 (average discharge = 68.8 cms) and lowest during the baseline observations (average discharge = 21cms).

The mouth of the Puntledge River becomes accessible to seals at tides above 1.7 meters and as the tide rises, seals move progressively further upstream. At tides above 3.5 meters, seals are distributed along the tidally influenced lower 3.5 km of the river and some seals move more than 5 km upstream to the Puntledge salmon hatchery location. Testing periods of the 3 arrays from dusk to dawn corresponded to tide levels typically greater than 1.7 m (Table 1).

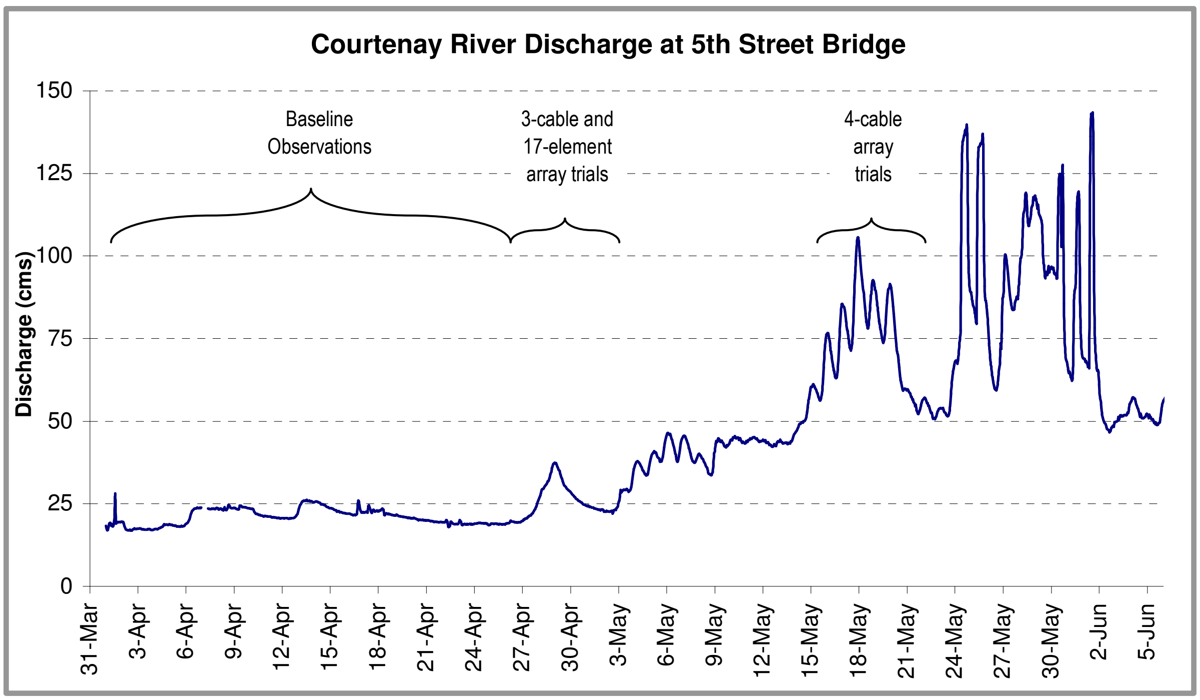

Figure 8. Hourly average discharge for the Puntledge (Courtenay) River (below the Puntledge/Tsolum River confluence) from April 1 – June 5, 2008, derived from the sum of Puntledge River discharge below the BC Hydro powerhouse and the Tsolum River discharge.

5. DISCUSSION

The key objectives of this study were to assess 1) whether an electrical array will serve as an effective barrier in blocking seal movements upstream of the array; 2) whether the strength of the electric field sufficient to deter seals affects the migratory behaviour of juvenile and adult salmon; and 3) whether there is a difference in the efficacy of the two types of arrays tested in this study. Originally, another objective was to assess whether the electrical array would be useful for displacing seals from a localized foraging area, but shielding of the 5th Street Bridge lights prior to the start of the study, which displaced seals from that preferred foraging location, precluded such an assessment.

With respect to the first and the third objectives, the observational data obtained from this study indicates that the establishment of an electric field at the 5th Street Bridge in the Puntledge River had a varying effect on upstream seal movement. Of the three array configurations tested in this study, the 4-cable array with electrodes positioned perpendicular to the river flow appeared to be the most effective in preventing the upstream passage of seals in the Puntledge River. At pulse width settings of 3 msec, 79% of the seals attempting to move upstream through this array were blocked.

One of the requirements of a seal deterrent system is that it be humane and not cause harm or undue stress to exposed animals. The original intent of the electric array was to inflict a short-term stimulus that caused enough discomfort for seals to want to avoid the area. However, pulse width settings greater than 3 msec (4-5 msec) appeared to cause physiological stress (muscle convulsions) in seals that were exposed to this electric field, leading the project team to recommend an upper threshold of 3 msec for future trials. It is important to note that electric fields in water are shaped by a number of parameters and it is this combination of variables as well as the physiological make-up of the animals that can result in the range of responses that were observed in seals. Future work may determine that pulse widths greater than 3 msec can be used when considered in combination with the other electrical parameters.

The effectiveness of the electric array was dependent on the strength of the field provided by the pulse width parameter, but may also have been dependent on the environmental conditions during which the array was operated. As the river depth over the array increased due to tidal inundation and/or increased discharge, the electric field weakened at the surface, potentially creating openings in the electric barrier that seals would exploit. Conversely, the field measurements indicate that at low tides and at the river's shallower margins, the electric field exceeded the 0.32 V/cm approved by the Animal Care Committee based on levels used in captive trials (Figure 7).

While the barrier may be considered effective at deterring the upstream movement of a large proportion of approaching seals, it was noted that even at the highest electrical field strengths tested some seals continued to challenge the array exposing themselves to significant physiological stress and potentially harmful levels. Moreover, it could not be determined from the DIDSON observations whether the same individual seals were challenging the array repetitively until they eventually made it through. Previous experience indicates that deterrents need to be nearly 100% effective to mitigate predation.

The commencement of trials at the lowest pulse width setting (1 msec) and ramping up gradually to higher levels (4-5 msec) has been criticized by Dr Jennifer Zeligs-Hurley (pers. comm.), a marine mammal behaviourist who has considerable experience with captive sea lions. She suggests that this approach essentially trains the seals to tolerate increasingly higher levels of electrical stimulus, and charge through the array at levels that may be harmful. This phenomenon has been documented in terrestrial animals interacting with underpowered electric fences (Poole et al. 2004; McKillop and Wilson 1999). However, permit approval for the Puntledge trial was conditional on starting at the lowest approved electrical settings and gradually increasing field strength to determine the upper threshold for invoking an acceptable behavioural response in seals. Given the physiological responses of seals at the highest setting and the wide range of voltage gradients along the array with changes in tide heights, further testing with captive animals should be conducted.

Based on the DIDSON images and shoreline observations, there was no apparent effect of the electrical field on juvenile salmon migration behaviour at the levels tested. Conversely, upstream migrating adults appeared to have been obstructed at levels that were considered effective at deterring seals. The delay and/or obstruction of 11 of 14 adult salmon targets in DIDSON imagery recorded on May 18 lead to a cessation of the trials, given the imperilled status of Puntledge summer chinook salmon. Further technology development and testing is needed to determine if an electric field can be deployed in the Puntledge River that will meet the dual objective of deterring seal predation while permitting unimpeded migration of both adult and juvenile salmonids.

While preventing seals from migrating upstream of the 5th Street Bridge to preferred feeding areas is the desired outcome, the displacement of seals from the 5th Street Bridge area to other foraging areas downstream continues to be an issue. There are other locations in the river where artificial lighting provides the distinctive shadow that seals utilize to their advantage such as the Central Builders parking lot downstream of the 5th Street Bridge and the 17th Street Bridge. Periodic observations at these two locations identified between 8 and 24 seals. Light shielding at the 5th Street Bridge installed in 2007 appears to have significantly reduced the number of seals foraging at this location. Efforts to design similar solutions in other well lit sections of the river should be explored with the City of Courtenay, Ministry of Transportation and other riverside property owners.

6. RECOMMENDATIONS

Based on what was learned from the 2008 trials in the Courtenay River, the project team recommends the following modifications to the study if further investigation of an electrical barrier is proposed:

1. Given the observed variability of the electric field during the 2008 trial, more field measurements should be conducted throughout the entire water column over a range of flow conditions to validate that a modified array design is generating the field strengths predicted by the models. This work should be done before testing with seals and fish present.

2. Conduct a survey of the river bottom in the area upstream of the 5th Street Bridge to determine the presence and extent of “scrap” metal that may be embedded in the sediment. Results from this survey will provide direction for re-location of the electrical array or removal of metal debris in order to ensure optimum operation of the array.

3. Deploy the most successful of the arrays tested in 2008 (4-cable array with electrodes perpendicular to stream flow) and increase the length of the electric field from 6 metres to a minimum of 15 metres (Dr. Jennifer Zeligs-Hurley, pers. comm.).

4. Commence trials at the maximum recommended pulse width setting of 3 msec to prevent seals from adapting to the electric field (Dr. Jennifer Zeligs-Hurley, pers. comm.). Increase the pulse frequency from 2 Hz to 5 Hz (beginning with 3 Hz). These levels are still significantly lower than levels known to injure fish (NMFS 2000).

5. Incorporate a secondary stimulus such as a visual strobe light or acoustic signal in the vicinity of the array so that seals can recognize the location of the array and choose to avoid the area.

6. Incorporate a water level sensor and relay that will automatically adjust the electrical power of the barrier with varying water depths. It is important to have a system in place that will allow for monitoring the electric field strength in real time such that field strength does not exceed ACC limits.

7. Develop instrumentation and protocols for acquiring reproducible measurements of the electric field at the water surface and at depth.

8. Given the variability in voltage gradient levels observed during field measurements, and the physiological response (muscle convulsions) caused by the electrical pulses, further work with captive animals is required to establish acceptable exposure levels and effects on seals.

7. REFERENCES

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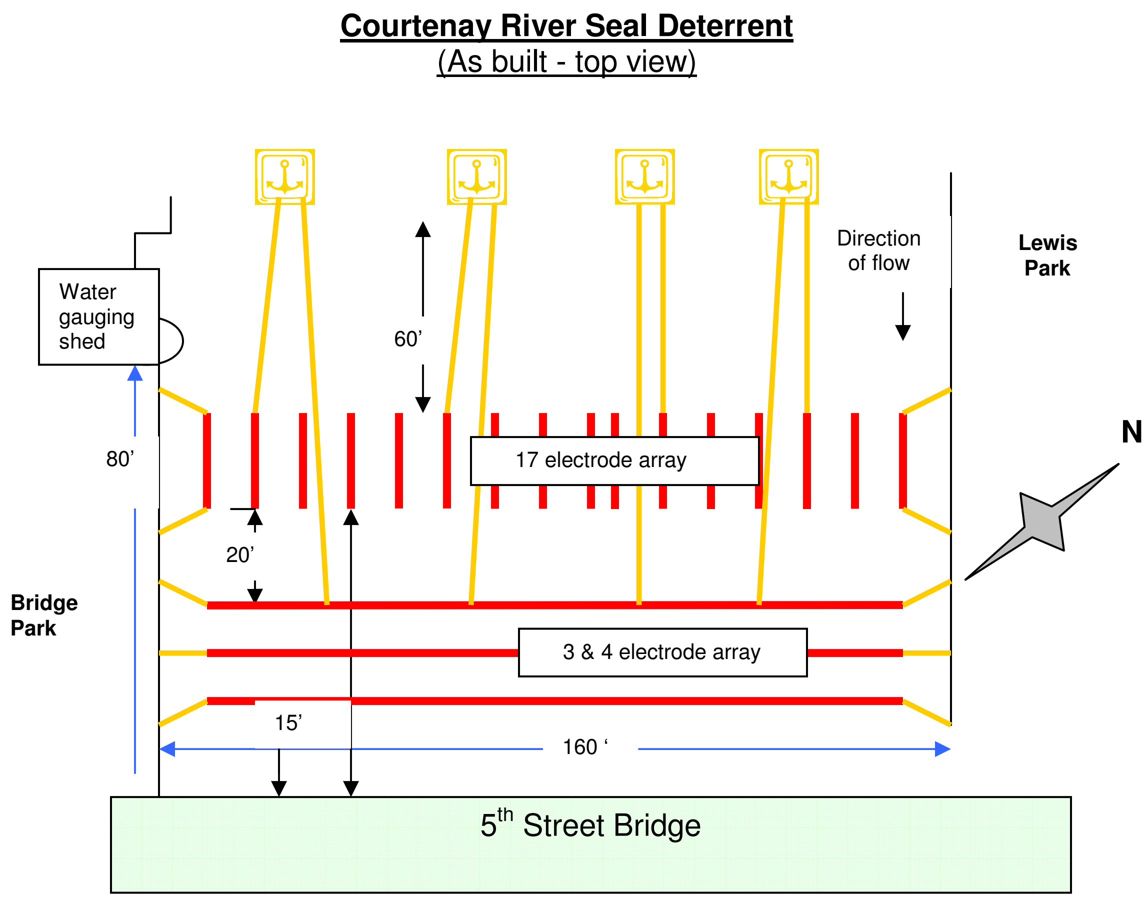
Personal Communications

Dr. Jennifer Zeligs-Hurley — Moss Landing Marine Labs, Monterrey, California

Appendix A. Schematic of anchor, signage, and DIDSON sonar camera locations.

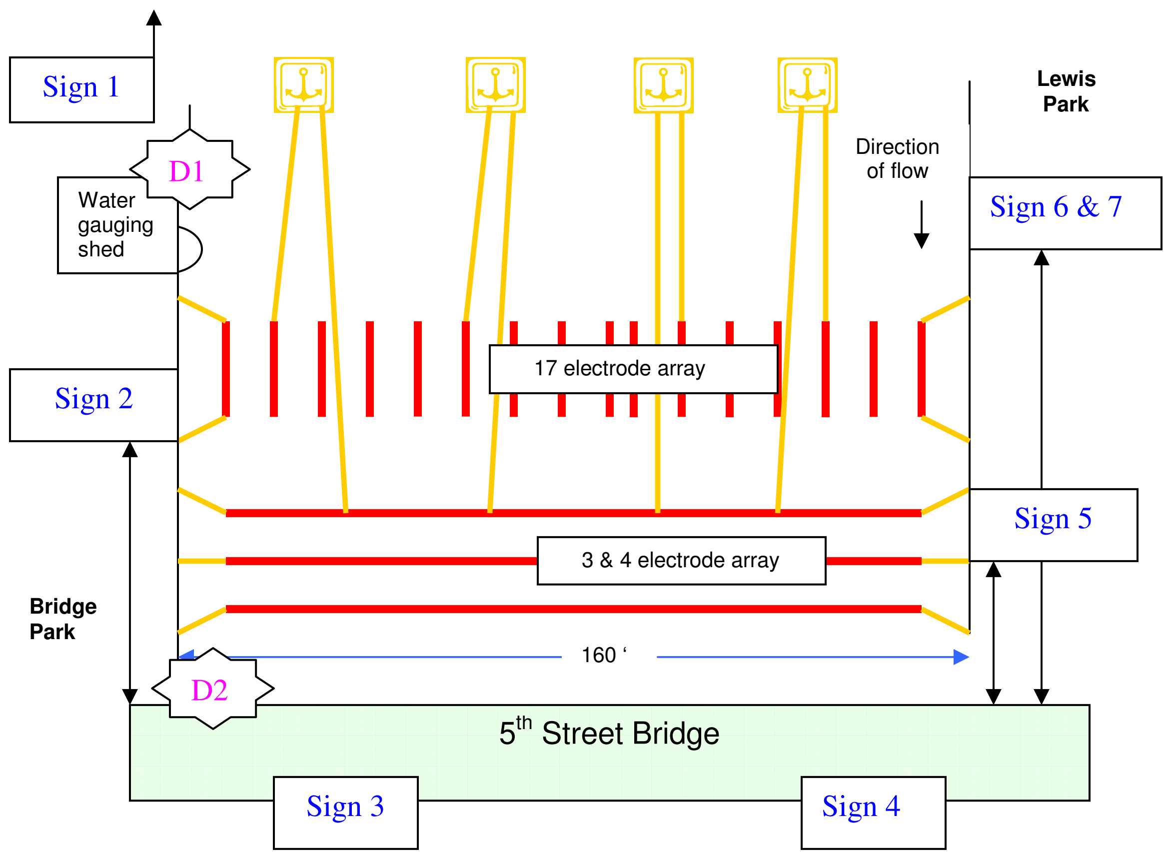


Anchoring set-up

- 4 anchors (30# ground line / halibut) spaced across river approximately 80'above the top end of the upstream array (new design - 17 electrode).
- Each anchor had 2 lines attached. 1 line was attached to upstream array & 1 line was attached to downstream array.
- Arrays were also attached to shore locations directly adjacent.

Appendix A (cont'd). Schematic of anchor, signage, and DIDSON sonar camera locations.

Puntledge River Seal Deterrent
(Signage & DIDSON Sonar locations)



Sign location:

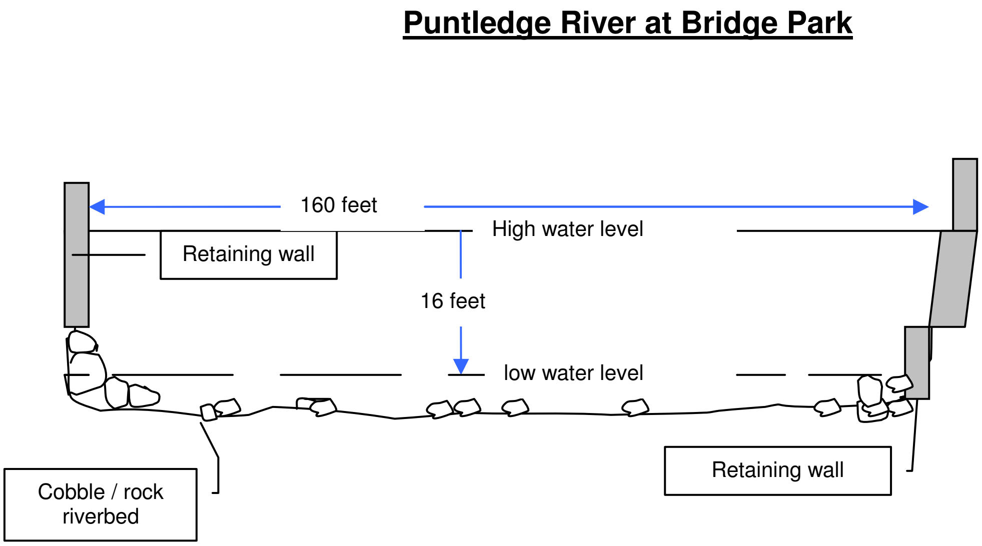
1) 125 ft. upstream from water gauging shed.
2) Immediately adjacent to arrays (river right)
3) Hanging from 5th St. Bridge walkway railing – river right.
4) Hanging from 5th St. Bridge walkway railing – river left.
5) Attached to railing adjacent to arrays.
6) Attached to stairway railing – downstream rail.
7) Attached to stairway railing – upstream rail.

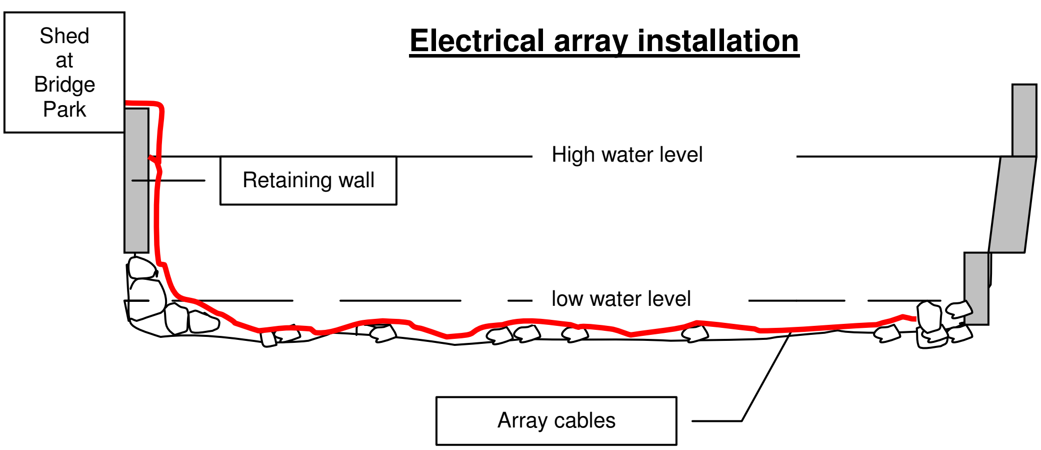
Signs 1, 2, 5, 6 & 7 were 1.5 ft. x 2 ft. Signs 3 & 4 were 2 ft. x 3 ft.

DIDSON Location

D1 – Short range model - immediately upstream from survey shed
D2 – Long range model – directly below upstream edge of bridge

Appendix B. Cross-section view of the Puntledge River looking upstream from the 5th Street bridge at the electrode array location.





Appendix C. Selected photos from the 2008 Seal Deterrent study.

Photo 1. Assembling and installing the 3-cable array, April 2008. Photo looking from east to west shore (river left to river right) at low tide.

Photo 2. Placement of the 3-cable array upstream of the 5th Street bridge prior to anchoring, April 2008. Photo looking downstream from west to east shore (river right to river left).

Photo 3. Placement of one of two DIDSON sonars and ramps for easy deployment and adjustment, upstream of the 5th Street bridge.

Photo 4. Secure metal building temporarily installed on the west side of the river to house all electronic and computer components necessary for the project.

Photo 5. Example of signage posted upstream, downstream and within the testing area of the electric arrays in the Puntledge River from April – June 2008.