FINAL REPORT

Innovative Technology for Marine Mammal Deterrence in the Columbia River Basin: Summary Report of Research Results

Prepared by:

Carl Burger
Smith-Root, Inc.
14014 NE Salmon Creek Avenue
Vancouver, WA 98686
360-573-0202

Based on Research Support and Studies Conducted by:

Patrick Simpson, Scientific Fishery Systems, Anchorage, AK
Jenifer Zeligs, Moss Landing Marine Labs, Moss Landing, CA
Matthew Mesa et al., USGS Columbia River Research Laboratory, Cook, WA
Kenneth Ostrand et al., USFWS Abernathy Fish Technology Center, Longview, WA
F. Michael Holliman, Lee Carstensen and Lisa Harlan Smith-Root, Inc., Vancouver, WA

Submitted to:

Anne Creason and Scott Bettin
Bonneville Power Administration
Fish and Wildlife Division
Portland, OR

Project Number: 2007-524-00
Contract Number: 43248

Date of Submission: 22 July 2010

Background

This project (funded by the Bonneville Power Administration; BPA) resulted from an "Innovative Technology" proposal submitted to the Northwest Power and Conservation Council by Smith-Root, Inc. (SRI), Vancouver, WA (Smith-Root, Inc. 2007). This work element was originally proposed as a demonstration project to evaluate whether a sonar-integrated, non-lethal electrical array could be used to assist management agencies in addressing marine mammal predation issues on ESA-listed fish populations in the Columbia River Basin. The intent was to selectively inhibit the upstream movements of pinnipeds in search of prey, without injuring the marine mammals or adversely affecting the migratory behavior of anadromous fishes. Accordingly the goal was to deploy, operate and test the integration of two well-known technologies (sonar tracking and electric guidance fields) for their combined abilities to deter marine mammal fish predation only when needed (the integrated hydroacoustics system would cue the intermittent use of the electrical array to operate for brief time intervals only when marine mammals attempted to move upstream of the electric array). The intended focus was to use the sonar-operated, non-lethal electric field to deter predation by California sea lions (*Zalophus californianus*) and other marine mammals on salmon (*Oncorhynchus spp*) and white sturgeon (*Acipenser transmontanus*) at Bonneville Dam on the Columbia River and in other Pacific Northwest river systems.

Partner's Forums were hosted by SRI in late 2007 (Appendix 1) and early 2009 (Appendix 2) in efforts to convene briefing meetings among permit-issuing agencies and natural resource co-managers representing state, federal and tribal interests. The Partner Forums were used to introduce the proposed technology to agency leaders, to gauge the extent and type of permits required, and to brief these partners on salient research results and findings. Following the first Partner's Forum, a step-wise progression of research milestones was mandated (established as "go/no-go" criteria) to gauge the ability of the proposed technology to successfully meet key "proof-of-concept" benchmarks and permit-related requirements before any riverine deployment of the integrated technology would be allowed. These "go/no-go" criteria included the following seven research requirements and study goals:

- <u>Sonar Tests (Simpson 2008)</u>: Demonstrate that a combined broad-band and split-beam sonar system can successfully discriminate California sea lions from fish targets (based on obtaining, testing and evaluating a library of shapes and forms from live pinnipeds and fish).

- <u>Sea Lion Tests With and Without Food Present (Zeligs and Burger 2008)</u>: Build upon non-project data collected on harbor seals (*Phoca vitulina*) in Canada. Conduct a study to assess the effects of the proposed non-lethal electric deterrence array on captive California sea lions, with and without food present in the test pool (results presented in Appendix 3 commencing on page 27).

- <u>Steelhead Tests (Mesa and Copeland 2009)</u>: Based on the demonstrable deterrence of California sea lions even with food present, test the non-lethal array on the behavior of adult hatchery steelhead (*O. mykiss*) at the sea lion deterrence level.

- Pacific Lamprey Tests (Mesa and Copeland 2009): Test the non-lethal electric array on the behavior of adult lampreys (*Entoshpenus tridentata*) at the sea lion deterrence level.

- White Sturgeon Tests (Ostrand et al. 2009): Test the ability of the non-lethal array's "soft-start" technology to induce a behavioral change among benthic-oriented white sturgeon adults (i.e. to induce their movement away from the array's electrodes) to minimize exposure to the most intense part of the electric field as the array "ramps up" in power.

- Simulated Electric Fields for Columbia River Deployments (Holliman 2009): Model the voltage gradients expected to occur with a deterrence array deployed in the Columbia River at depths up to 14 m over a lineal upstream-downstream distance of 40 m in conductivities approximating 150 micro Siemens per centimeter (µS/cm).

- Spring Chinook "UMT" Tests (Mesa and Dixon 2010): Test the array on adult spring Chinook salmon (*O. tshawytscha*) in an *in-situ* environment at one of Bonneville Dam's Upstream Migrant Tunnels (UMT) in a flowing-water environment during peak spring migration periods.

Research Protocols and Results

The originally envisioned demonstration project (a passive, intermittently used electric field, operated only during sea lion arrival events) was not developed, largely because of the associated research deemed necessary to satisfy permitting requirements. Instead, the project's focus became the mandated research work elements: the individually listed "go/no-go" criteria identified above. The studies conducted on sea lions and fish evaluated a constantly operating electric field as a "worst-case" measure of the field's effects. The salient research findings are:

- Sonar Tests: A library of sea lion and fish "shapes and forms" was assembled from sonar deployments and readings obtained in Astoria (East Mooring Basin) and Newport, Oregon (Oregon Coast Aquarium). The data collected (Simpson 2008) were processed using Principal Components Analysis to determine the separability of echoes and classification accuracy using analytical "training" and testing protocols. Based on 160 "test tracks" (representing thousands of echo data points for both high- and low-frequency broadband sonar), there were no misclassifications of marine mammals between marine mammal and fish samples (Tables 1-A and 1-C). There were only three misclassifications (out of 154 test tracks) in discriminating white sturgeon from Pacific salmon (Table 1-D).

  Conclusion: The proposed hydroacoustic system is capable of accurately discriminating marine mammals from other targets based on the unique swimming patterns and lung morphology of pinnipeds, thus providing a potential tool for operating a passive electrical array as a cueing technology for intermittent marine mammal deterrence.

A lengthy report of the sonar test findings was submitted to BPA previously (Simpson 2008).

Table 1. Summary of sonar test tracks used to discriminate sea lions from fish (and salmon from sturgeon) based on sonar library images obtained in the field. Based on 30 high-frequency (135 to 195 kHz) and 130 low- frequency (60 to 120 kHz) test tracks involving sea lions (see 1-A and 1-C), there were no misclassifications between marine mammal and fish targets (these test tracks involved thousands of echo relocation points). All data are from Simpson, 2008.

Table 1-A. HF Classification Results for Each of 30 HF Stage-One Test Tracks

	Fish	Sea Lion
Fish	18	0
Sea Lion	0	12
TOTAL	**18**	**12**

Table 1-B. HF Classification Results for Each of 33 HF Stage-Two Test Tracks

	Salmon	Sturgeon
Salmon	28	0
Sturgeon	0	5
TOTAL	**28**	**5**

Table 1-C. LF Classification Results for Each of 130 LF Stage-One Test Tracks

	Fish	Sea Lion
Fish	121	0
Sea Lion	0	9
TOTAL	**121**	9

Table 1-D. LF Classification Results for Each of 121 LF Stage-Two Test Tracks

	Salmon	Sturgeon
Salmon	105	3
Sturgeon	0	13
TOTAL	**105**	**16**

- Sea Lion Tests With and Without Food Present: Four California sea lions were tested for deterrence reactions to a mild field of non-lethal, pulsed DC electricity at Moss Landing Marine Labs, Moss Landing CA (Zeligs and Burger 2008). The electric field was generated by an underwater electrode array across one end of a rectangular, 12.5 x 6.4-m vinyl test pool filled with fresh water. Each test subject was able to detect an electric gradient introduced at a frequency of 2 pulses per second (2 Hz) at pulse widths that ranged from 80 to 290 microseconds (µs; or 0.00008 to 0.00029 seconds) in water having a conductivity of 509 µS/cm. Pulse width manipulations were used to vary the strength of the field for additional deterrence tests. Strong deterrence reactions (without food present) were exhibited at pulse widths from 80 to 320 µs; strong deterrence reactions *with food present* (three of four animals were evaluated) occurred at pulse widths from 160 to 440 µs (Table 2). The voltage gradient that deterred California sea lions with or without food present was 0.6 V/cm (expressed as an equivalent value for Columbia River waters based on Power Transfer Theory). **See Appendix 3 (page 27) for further detail.**

  Conclusion: The non-lethal field resulted in strong deterrence reactions. The voltage gradients causing deterrence responses in California sea lions are far lower than those capable of directly injuring fish, based on a review of the electrofishing literature (see for example Reynolds and Holliman 2004; Holliman and Reynolds 2002; McMichael et al. 1998). These sea lion deterrence results provided a basis from which to evaluate the sea lion deterrence field on fish behavior.

Table 2. *Attributes of California sea lions exposed to a 50-V non-lethal, underwater electric field at a pulse frequency of 2 Hz to detect deterrence reactions with and without food present.*

					DC Pulse Width (µs) Causing:		
Animal	**Name**	**Sex (Age)**	**Length (cm)**	**Weight (kg)**	*Detection*	*Strong Deterrence*	*Food Deterrence*
1	Beaver	Male (29)	206.6	158	110-170	320	NA
2	Ariel	Female (6)	165.5	80	80	80	160
3	Nemo	Male (10)	207.0	132	80	80	160
4	Jonah	Male (10)	200.8	126	80	110	440

- <u>Steelhead Tests</u>: Experiments with steelhead were conducted at the Cowlitz Trout Hatchery in Washington (Mesa and Copeland 2009). Up to 180 fish were tested in groups of three or six individuals (versus control groups of similar sizes) at various combinations of voltage gradients ranging from 0.6 to 1.9 V/cm in a concrete hatchery holding pond equipped with a bottom-mounted, Smith-Root electrode array at one end. Adult hatchery steelhead successfully passed through the electric array when it was set at levels equivalent to those used to deter California sea lions (0.6 V/cm, 2 Hz and 400µs pulse width). At applied voltage gradients ranging from 0.8 to 1.1 V/cm (with pulse frequency and pulse width held at 2 Hz and 400 µs), 67-87% of steelhead successfully passed the array but passage rate was significantly lower than that of control fish when the data at gradients > 0.6 V/cm were pooled for statistical analysis (Mesa and Copeland 2009). Increases in pulse frequency (from 2 Hz to 3 Hz) deterred steelhead passage as did increases in pulse width (from 400 µs to either 10 or 20 milliseconds; ms). There was no significant difference in severity of hemorrhage between test and control fish exposed to an excessively high gradient of 1.9 V/cm, indicating that pre-test netting and handling may have caused hemorrhages in both groups. Steelhead exposed to a very high gradient (1.9 V/cm) showed no x-ray evidence of spinal injury (Mesa and Copeland 2009).

  Conclusion: Adult steelhead successfully passed through the electric array at the sea lion deterrence level (0.6 V/cm). Steelhead movement began to be adversely affected at 0.8 V/cm (13% of test fish) with fish more noticeably deterred at higher test ranges.

- <u>Pacific Lamprey Tests</u>: Adult Pacific lampreys (n=78) were collected during their upstream migration at Willamette Falls, OR. Tests were conducted at the USGS Columbia River Research Lab in a straight-sided annular tank having a miniaturized electrode array for study comparisons between test and control fish exposed to the deterrence field (Mesa and Copeland 2009). No difference was detected among lamprey passage rates during array on- and off-time comparisons in the miniature electric array at levels equivalent to those used to deter California sea lions (0.6 V/cm, 2 Hz and 400 µs). No difference was detected among lamprey passage rates during comparisons of array on and off times when the electric array was set at 1.35 V/cm, 2 Hz and 400 µs. The rate of lamprey passage was significantly lowered (by 80%) when the field's intensity was increased to 1.8 V/cm (Mesa and Copeland 2009).

Conclusion: The mean passage rate of lampreys between control and treatment groups did not differ significantly when exposed to voltage gradients of either 0.6 V/cm (the sea lion deterrence level) or double the sea lion deterrence level (1.35 V/cm). Passage rates declined by 80% when the voltage gradient was tripled (1.8 V/cm) in concert with a ten-fold increase in pulse width (to 5 milliseconds). Lampreys were more resilient to the electric field than either steelhead or white sturgeon (see below), based on the limited test ranges evaluated in the Mesa and Copeland (2009) study.

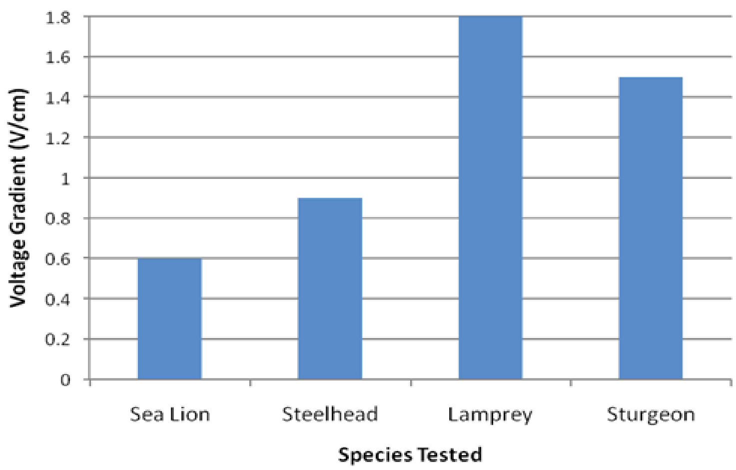
- <u>White Sturgeon Tests</u>: Captive adult white sturgeon (n=90) were exposed (in groups of 10 fish) to an electrode array and deterrence field in a concrete fish pond at the Abernathy Fish Technology Center, Longview, WA (Ostrand et al. 2009). The field tested (1.5 V/cm at 2 Hz and 400 µs) was greater (by design) than that used to deter sea lions at Moss Landing in an attempt to simulate field gradients near electrodes. Goals were to evaluate whether "soft-start" technology (a field where intensity is increased incrementally) could reduce sturgeon exposure to the electric array at startup.

  The field altered the behavior of the captive white sturgeon tested. Intermittent "soft-start" caused fish to avoid the field. When constantly operated, the 1.5-V/cm field appeared to cause narcosis/entrainment in 3 of 15 test fish exposed to long-term operation of the array and one mortality (after these three fish were exposed to the array for a constant 24 hours). However, hatchery pond environments lack the kind of "sweeping velocities" found in rivers in nature, where entrainment issues would be highly unlikely. Sturgeon subjected to continuous operation of the field spent less time over the array than control fish. The field using "soft-start" technology (pulse width gradually increased over a 3-second time interval) caused no mortality and resulted in sturgeon spending less time over the array area, even when the power was off. Although plasma lactate increases indicated sublethal stress, sturgeon exposure to acute electroshock produced little or no other changes in the physiological biochemistry based on the published results of the researchers. No significant tissue damage was detected among fish subjected to acute exposure (Ostrand et al. 2009)

  Conclusions: "Soft-start" technology altered sturgeon behavior. It appeared to keep fish away from the array during intermittent on-times (a goal of the technology's design). "Soft-start" exposure also moved sturgeon out of the array area at a rate significantly faster than that observed for control fish. The final report and publication (Ostrand et al. 2009) advise the use of intermittent array operation to reduce risks to sturgeon.

Figure 1 provides a summary graph of the gradient ranges where sea lion and fish deterrence (steelhead, Pacific lamprey and white sturgeon) were observed. Study results (see above) strongly suggest no effects on fish at the level (0.6 V/cm) where sea lion deterrence was observed (Figure 1). Steelhead began to become affected at 0.8 V/cm. Pacific lampreys were not affected until voltage gradients approximated a three-fold increase in intensity (1.8 V/cm).

Figure 1. Voltage Gradient Where Deterrence Was Observed



- <u>Simulated Electric Fields for Columbia River Deployments</u>: Using Power Transfer Theory as applied to electrofishing (Kolz 1989), SRI prepared a model for the possible deployment of an electrical deterrence array in the Columbia River based on the Moss Landing sea lion deterrence results, an assumed depth of 14 m and an assumed water conductivity of 150 µS/cm (Holliman 2009). Based on a design that would incorporate flat plate electrodes and an array that could span up to 40 m in upstream-downstream distance, the models present a range of expected voltage gradients (adjusted for Columbia River water conductivity) that fish and sea lions would experience at different Columbia River water depths (Holliman 2009). As expected, the resulting electric field would be greatest at depths in close proximity to electrodes, where "soft-start" technology would be used to protect benthic-oriented fish species. The design addressed the potential for construction of a bottom-mounted array deployment across a considerable section of river (e.g. one of Bonneville Dam's tailraces) where sea lion predation was most intense.

- <u>Spring Chinook "UMT" Tests</u>: A scaled model of the Smith-Root sea lion deterrence array was installed into the Upstream Migrant Tunnel (UMT) on the Washington side of Bonneville Dam near Power House #2 in early December, 2009. The array was evaluated for its effects on the behavior of adult spring Chinook salmon during upstream migrations in April, 2010. Scientists from the USGS Columbia River Research Lab (Mesa and Dixon 2010) oversaw these research studies. They exposed fish to constantly operated electric fields (either 30-minute or 120-minute "on" times) versus similar control intervals when the array was turned off. The number of fish targets observed via

DIDSON underwater camera was 1,340 (831 during constant "on" time periods versus 509 during control "off" periods of time). The researchers state that it was possible to have observed the same fish more than once if these unmarked fish made multiple attempts to cross the field.

Three electric gradient levels were tested: 0.14 V/cm (108 observations), 0.32 V/cm (81 observations) and 0.6 V/cm (642 observations). Overall, 83% of fish passed the array during "off" times whereas 77% of fish hesitated at the array entrance during "on" times at all levels, with stronger directional reversals at the 0.32 and 0.6 V/cm gradients than at the 0.14-V/cm level (Mesa and Dixon 2010). Only 4 to 5% of fish passed through the array when it was operational at any of the three test levels (0.14, 0.32 and 0.6 V/cm).

The authors acknowledge that all tests were done under what could be described as a "worst case scenario" (constant operation of the array) which contrasts with the intermittent-use design conceptualized by SRI in the original demonstration project proposal (i.e. the array would operate only for a brief time period of perhaps 15 to 20 seconds when a sea lion was detected moving upstream by sonar cueing technology). The authors also conclude that what really matters is what happens to each fish when the array is turned on, regardless of whether it operates intermittently or constantly. However, the original design proposed by SRI was intended to provide resource managers with the option of weighing the tradeoffs and risks when operating the deterrence field. These include the risk of brief, intermittent effects on a non-target species versus the overall risk at the fish population level … risks that include an increasing marine mammal predation rate on salmon by California sea lions (known to be at least 4%), and population-level impacts on sturgeon by a currently protected pinniped (the Steller sea lion; *Eumetopias jubatus*) whose numbers are rising on an annual basis at Bonneville Dam.

Conclusions: Passage of spring Chinook salmon adults was adversely affected in the UMT trials when the non-lethal sea lion deterrence array was operated at constant voltage gradients of 0.14, 0.32 and 0.6 V/cm, the three test levels examined in this research. These low-intensity electric arrays, however, may have the potential for use as barriers to keep fish or other animals out of certain hydropower facility areas (such as turbine intakes) and other power plant-related structures (such as cooling water canals).

This concludes Smith-Root's summary report to BPA. In all, seven research studies were completed to test the effects of a constantly operated electric field on four species of fish and on California sea lions, with additional research completed on a voltage gradient model and on the efficiency of a sonar cueing technology to operate the passive electric array. While there were little or no effects on steelhead, Pacific lampreys and white sturgeon at the sea lion deterrence gradient of 0.6 V/cm (assumed for sturgeon because this species successfully traversed much stronger fields), there were strong effects documented on spring Chinook tested *in-situ* at three voltage gradients at Bonneville Dam. Because of these unexpected effects on spring Chinook salmon migratory behavior, further deployments and tests are not anticipated.

<u>Overall Implications</u>: The research studies accomplished in this project suggest that steelhead, Pacific lampreys and sturgeon are not nearly as sensitive to the mild fields of pulsed DC that spring Chinook salmon adults reacted to, when exposed to a constantly operating electric field. A carefully operated, *intermittent* deterrence field could very well be the key to preventing the undesirable upstream movements and fish predation pressures caused by expanding numbers of pinnipeds on salmon and sturgeon populations in the Columbia River, if resource co-managers could also accept the risks of intermittent, non-lethal effects on spring Chinook movements in concert with each sea lion deterrence event.

Acknowledgements

Smith-Root, Inc. would like to thank the Bonneville Power Administration (especially BPA's Fish and Wildlife Division) and the Northwest Power and Conservation Council for the strong support they provided in funding this Innovative Technology project. We also want to express appreciation for the high quality research conducted in support of this project by the individual study authors (cited above) from Moss Landing Marine Labs, Scientific Fishery Systems, the U.S. Fish and Wildlife Service and the USGS Columbia River Research Lab. We thank the many state, federal and tribal agency co-managers and partners in the Columbia River Basin for their timely input and reviews, their permitting assistance, and their many recommendations that improved the overall quality of the research that was conducted. Finally, we thank the U.S. Army Corps of Engineers (particularly their Fisheries Office) whose logistical support was crucial to the ability to evaluate a scaled deployment of Smith-Root's technology at Bonneville Dam.

Literature Cited

Holliman, F.M. 2009. Electrical exposures in evaluations of the effects of electric fields on fish passage (in the context of sea lion deterrence on the Columbia River). Smith-Root Report submitted to Bonneville Power Administration as part of Project 2007-524-00, Contract 43248.

Holliman, F. M., and Reynolds, J. B. 2002. Electroshock-induced injury in juvenile white sturgeon. North American Journal of Fisheries Management 22: 494-499.

Kolz, A.L. 1989. A power transfer theory for electrofishing. U.S. Fish and Wildlife Service. Fish and Wildlife Technical Report 22: 1-11.

McMichael, G. A., A. L. Fritts, and T. N. Pearsons. 1998. Electrofishing injury to stream salmonids; injury assessment at the sample, reach, and stream scales. North American Journal of Fisheries Management 18: 894-904.

Mesa, M.G. and C.J. Dixon. 2010. Influence of a low-intensity electric sea lion deterrence system on the migratory behavior of fishes in the upstream migrant tunnel (UMT) at

Bonneville Dam. Final Report to Bonneville Power Administration, Portland, Oregon. Project No. 2007-524-00.

Mesa, M. G and E. S, Copeland. 2009. Influence of a weak field of pulsed DC electricity on the behavior and incidence of injury in adult steelhead and Pacific lamprey. Draft report to Bonneville Power Administration, Portland, Oregon. Project No. 2007-524-00.

Ostrand, K.G., W.G. Simpson, C.D. Suski, and A.J. Bryson. 2009. Experimental integrated non-lethal sea lion abatement: Potential behavioral and stress related effects on adult white sturgeon. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 1:363-377.

Reynolds, J. B., and F. M. Holliman. 2004. Injury of American eels captured by electrofishing and trap-netting. North American Journal of Fisheries Management 24: 686-689.

Simpson, P. 2008. A hydroacoustic cueing system for a sea lion deterrence array in the Columbia River Basin: target differentiation and range testing. Report submitted to Bonneville Power Administration as part of Project 2007-524-00, Contract 43248. (Also available from Patrick Simpson, Scientific Fisheries Systems, Inc., Anchorage, AK. Tel. 907-563-3474).

Smith-Root, Inc. 2007. Integrated non-lethal electric and sonar system to deter marine mammal predation on fish in the Columbia River system: a demonstration project. Proposal submitted to the Bonneville Power Administration FY 2007 Innovative Project Solicitation. See http://www.nwcouncil.org/fw/budget/innovate/proposal.asp?id=870.

Zeligs, J., and C. Burger 2008. Behavioral deterrence responses of captive California sea lions exposed to a mild, electric voltage gradient at Moss Landing Marine Labs, CA. Report submitted to Bonneville Power Administration as part of Project 2007-524-00, Contract 43248. (Also available from Dr. Jenifer Zeligs, Principle Investigator, Moss Landing Marine Labs. Tel. 831-771-4191).

Appendix 1

Minutes of Meeting Held with Partners in Vancouver, WA
September 28, 2007

Subject: Demonstration Project Briefing for Sea Lion Deterrence Concept (Marine Mammal Behavioral Guidance System) in the Columbia River Basin

Overall Summary, Action Items and Post-Meeting Perspectives

The subject meeting was convened at 11:05 am at Smith-Root's conference room in Vancouver, WA. Michael Fraidenburg (Dynamic Solutions Group) served as facilitator and asked each participant to introduce themselves and their backgrounds. Jeff Smith (Smith-Root's CEO) extended a welcome to the group and thanked them for coming. Mr. Fraidenburg outlined the agenda and expected deliverables (see Attachment 1) which included briefings on results of seal deterrence tests in British Columbia (Carl Burger), a presentation on the sonar technologies envisioned for the Columbia Basin demonstration project (Patrick Simpson), an opportunity for questions (with input on the possible roles to be played by interagency partners), a discussion to reach consensus for a project deployment site, and a discussion of the near- and long-term research needs in support of sea lion deterrence technology. (A list of meeting attendees is provided below in Attachment 2).

Resulting Action Items from Meeting's Conclusion:

Develop critical pathway of support research with timelines for the demonstration project to address prior to deployment, based on the following identified needs:

- [1]Make engineering site visits for installation feasibility at Bonneville Dam's Tailrace 1 and Willamette River near Falls (Jeff Smith and appropriate engineers);
- [1]Successfully complete sonar library and show ability to differentiate marine mammals and fish prior to implementing any demonstration project;
- Conduct pre-project tests on California sea lions with food-driven responses (Smith-Root Science Department);
- [1]Obtain cost proposal for 2008 research on salmon migration behavior (Matt Mesa and/or Jeff Johnson);
- Obtain cost proposal for 2008 sturgeon studies (Ken Ostrand; and/or CRITFC staff??);
- Obtain cost proposal for 2008 lamprey studies (Matt Mesa and Christina Luzier);
- [1]Incorporate these research elements into a critical pathway approach.

[1]These elements are within the proposal and budget submitted to NWPCC.

Relevant Technologies Not Addressed During Meeting:
Although not specifically discussed during our September 28 meeting, the following two considerations have relevance to the major concerns identified by the meeting attendees:

1) Concern for Sturgeon or Other Fish Species in Grid When It Turns On: Evidence was presented that fish injuries typically occur at levels much higher than the 2-Hz field proposed for the sea lion deterrence project. As added fish protection, it would be quite easy to also program an extremely low-level "tickler" pulse (analogous to those used by lamprey researchers during electrofishing) into the array's electronic settings so that any sensitive species could be deterred (without harm) prior to full-power operation. This "soft-start" engineering would enable delivery of the tickler pulse just prior to the point when sonar also tells the electric grid array to initialize for marine mammal deterrence. Such a setting could be programmed as a gradual "ramp up" series of pulses by the electric array over a few seconds of time, as it starts to turn on. This soft-start approach would serve as added protection for any sensitive fish species, particularly for any large sturgeon that could be present atop the electric grid (a concern raised at our meeting), when the grid turns on. (A second sonar array to monitor what is actually atop the array could be used in lieu of, or in tandem with, the soft-start technology.)

2) Need for Additional Studies and Concerns for Effects on Fish Migration: Any possible effects on salmon or other fish migration behavior would be known during the first couple of days of barrier deployment because sonar (either the broadband/slit-beam system envisioned, or DIDSON) would tell the operators and on-site monitors and partners whether any fish movements were being impeded. The sonar will be tracking fish as well as marine mammal movements. This approach reflects *the true nature* of a demonstration project (an in-situ attempt to show that the technology does indeed work as conceptualized and planned), *saving the added costs* of conducting an array of up-front ancillary studies to develop a fully proven implementation technology prior to its demonstration trials. Assuming that migrating fish can even detect a field as weak as 2 Hz (very recent British Columbia test-net studies suggest that migrations are not impeded), the risks would be limited to only the first few days of barrier testing, and only for the number of times that a pinniped triggers the array to turn on during a given day. If sonar observations indicated measurable effects on fish migrations or migration impedance, the project would then terminate until additional research could be conducted to alleviate that risk. *These two post-meeting responses are suggestions being offered by Smith-Root to allay the concerns and risks identified by attendees.*

Meeting Minutes

Agenda Item 1: Power Point on Seal Tests in B.C. (Carl Burger)
Results were summarized on deterrence testing in Canada utilizing both captive seals to determine a threshold behavioral response (Vancouver B.C. Aquarium) and on wild harbor seals at an active fish predation site (Puntledge River). The goals of the Columbia Basin demonstration project were also summarized. Key presentation points:

- Captive seals were deterred using an underwater electrode array having a DC pulse frequency of 2 Hz (2 pulses each second), and pulse widths of 200 and 400 microseconds (0.0002 and 0.0004 seconds). A video clip of the deterrence behavior was shown.

- Additional tests on wild seals were conducted at an active salmon predation area under the 5th Street Bridge (Puntledge River) in Courtenay, B.C. (Note: although not specifically mentioned in the presentation, active seal feeding on chum salmon fry in this area was determined by Dr. Peter Olesiuk, at time of testing). These tests used a pulse frequency of 2 Hz (2 pps) and a pulse width of one millisecond (0.001 seconds) in an underwater electrode array having a gradient from 0.01 v/cm to 0.32 v/cm (highest gradient measured at upstream end of array). Five seals were deterred from this area twice and 10-12 seals were prevented from accessing this predation site during a subsequent evening of tests. **Conclusions:** (1) seals are extremely sensitive to mild, underwater direct current at levels (2 Hz) considerably less than those capable of injuring fish (typically 30 Hz and higher); (2) seals were deterred from an active fish predation site; and (3) seals were prevented from accessing predation areas upstream of the deterrence array while it was operating.

- Recent tests using an "electrified" test gill net were shown. These tests were conducted in August on the Fraser River and used the same test levels (2 Hz pulse frequency; 1 millisecond pulse width) employed in the Puntledge River. These tests were implemented and evaluated by the Pacific Salmon Commission, Vancouver, B.C. The 50-fathom electrified portion of the net caught more than five times the number of salmon than the non-electrified 50-fathom portion, where seals were observed actively feeding on adult pink, sockeye and Chinook salmon. According to PSC biologists, these findings suggest a selective deterrence technology for seal predation that does not adversely affect salmon migrations, however additional testing is anticipated. The PSC test net results were included in the handouts and were also provided to NOAA and state managers on August 30, via email.

- The vision and design for the Columbia Basin is for a non-lethal, *passive* barrier array that only operates when sonar detects the presence of a marine mammal (default mode is "off") during a 3-4 week test period in the Willamette or similar system having sea lion predation problems. The array will differentiate marine mammals from salmon and sturgeon and will only operate as many times as a marine mammal challenges the array's field.

- The 2 Hz pulse frequency is well below levels capable of causing injury to fish. Large sturgeon would likely be deterred if they co-occurred in the same column of water where a sea lion approached the deterrence array. Engineering will also provide a further safeguard to protect large sturgeon if desired by resource managers: keep the array off whenever a large sturgeon co-occurs, and use other methods (selective management?) to deal with any marine mammal allowed to pass upriver.

- The proposed technology is not designed to replace selective management options; it is meant *to supplement* those actions.

- The Smith-Root array would also have capabilities to enumerate salmon via its sonar technology.

Agenda Item 2: Power Point on Sonar Technologies for Demonstration Project (Pat Simpson)
This technology will incorporate the use of two types of sonar, broadband and split-beam, each having different tracking and identification capabilities. Marine mammals will be differentiated from fish and other targets based on unique lung anatomy and swimming patterns. A step-down process was presented to separate pinnipeds, salmon and sturgeon, and to integrate artificial intelligence to cue operation of the passive electric barrier. A summary was provided of the iterative processes used in target identification and the complexities of the engineering steps that will be completed using examples from sonar evaluation studies previously conducted in Alaska and elsewhere.

Agenda Item 3: Ensuing Points, Issues, Concerns and Research Questions

- Must give attention to diving birds such as cormorants (Steve Jeffries) and to wildlife such as otters (Mary Hanson) during permitting process.

- Must identify effects (if any) on salmon, lamprey and sturgeon before implementing the project, and ability for sonar differentiation of sturgeon, sea lions, humans and fish (multiple responders). *(But see new perspectives provided on page 1 regarding "soft-start" technology and use of sonar to evaluate fish migration behavior during very first days of operation.)*

- Other discussion points led by facilitator: Use the concept of acceptable experimental risk instead of zero tolerance, and perhaps separate experimental risk from implementation risk?

- Sonar differentiation is not expected to be an issue. The purpose of a demonstration project is to evaluate the potential for a workable concept over a very short-duration test period, and then to redesign and re-engineer as needed, but not to have studied every possible consequence in detail, else this would be an implementation project of a well-refined technology (Carl Burger). The purpose is to give managers a new tool to conserve both salmon and sea lions by demonstrating whether it can work to deter marine mammals in the Basin. Circumstantial data indicate success with seals at levels below anything known to injure a fish. The group discussed the decision dilemma of requiring "no impact" from the proposed deterrence technology and accepting some technology impact, in exchange for reduced sea lion predation. The appropriate balance in tradeoff decision remains an open discussion.

- Any effects on PIT or radio tags? (None were known based on past studies.)

- Strong need to test this technology on a California sea lion (Steve Jeffries). Steve offered to check possible sources of test locations and mentioned Sea World, the San Antonio Zoo and the Marine Mammal Center in Sausalito as having potential animals available. He further indicated that tests involving the presence of food and food-driven behaviors would be best. He felt that seals in the Puntledge River are naïve animals that were evaluated without food present (however salmon juveniles were indeed present according to attending observers from DFO and the Puntledge Hatchery). Carl Burger mentioned that he had contacted Dr. Andrew Trites in B.C. who seemed interested in participating with tests on captive sea lions. The Oregon Coast Aquarium (Judy Tuttle) does not have test tanks or easy access to treatment locations.

- Need to examine whether any "hot spots" are produced by the underwater electric field (Jeff Johnson). None were detected when field was mapped and measured at the Aquarium and in the Puntledge River test location. *(Subsequent discussions with SRI engineers indicate that "hot spots" can be avoided with modeling and adjustments.)*

- Conduct tests during April and May, when most sea lions are present (Steve Jeffries). Smith-Root had envisioned testing from late March through early April in attempts to avoid lamprey migrations (which should not be affected by a 2-Hz field).

- Need to ensure sonar "library" that considers and has capability to differentiate young (small) and old sea lions.

- Can electric field adapt to water quality and substrate changes? (The eventual Marine Mammal Behavioral Guidance System will include computer telemetry to automatically adjust settings for any water quality, conductivity or other changes. However, settings for the 3-4 week demonstration project would be done on-site, as needed, by round-the-clock attendees during the demonstration phase.)

- Possible issue of acclimation to the field by sea lions. (This suggests a need to evaluate effects at levels somewhat higher than 2 Hz and 1 millisecond.)

- Need to identify potential scenarios that address key uncertainties (Bill Maslen). Bill offered to provide what he thought were the key criteria to satisfy; Carl Burger offered the same. These include the behavioral responses of fishes (salmon, lamprey and sturgeon), ability of sonar to differentiate targets, and finding a location to evaluate the field on a California sea lion with food present. (Some of these were goals identified in the proposed demonstration project. The overall goal is to determine whether the fields used to successfully deter seals will also work on a sea lion.)

***Discussion of Possible Roles for Partners and Permitting Issues*:**

There are numerous permitting hoops to deal with (various responders).

It may be possible for WDFW and ODFW to partner with Smith-Root on Columbia Basin testing via Section 109 Nuisance Animal provisions (Steve Jeffries).

Agencies cannot be listed as partners with Smith-Root on their permit applications because it would be a conflict of interest for an agency to approve an action or an activity where that agency was already construed to be a partner or proposer (Mary Hanson).

ODFW will help/assist professionally to complete applications and can provide letters of support for the permit process (Charlie Corrarino).

USFWS can help with monitoring and evaluation (Jeff Johnson).

Smith-Root should consider withdrawing this proposal and resubmitting it in phases during the general NWPCC solicitation (Karl Weist).

Agenda Item 4: Discussion of Site Selection Criteria

Tentative site selection criteria were included in the agenda handout package. Carl Burger mentioned that Smith-Root had considered the Willamette River downstream of the Falls because it met all criteria and had a consistent number of about a dozen California sea lions present by March and April of each year. It was also attractive because of access, proximity, water quality, river width and other considerations. This site was also recommended by fishery user groups.

The Willamette was questioned (Charlie Corrarino) because a low run of Chinook was forecast for 2008 (*the demonstration project would not occur until 2009*).

Several attendees favored a deployment in the Columbia mainstem near Bonneville Dam (Power House 1 Forebay) because about 6 years of sea lion predation data have been accumulated, many animals are always present, a large infrastructure is present along with a good location for monitoring activities, and because the Power House 2 Forebay can serve as a control.

Smith-Root agreed to examine this location with hydroacoustic and construction engineers. Bryan Wright offered to provide GIS information on Bonneville (received). (*Subsequent to meeting, Robert Stansell offered to tour and demonstrate this potential site with Smith-Root engineers*.)

Bonneville deployment concerns include the inability to keep test equipment like underwater antennas in this high-velocity location (Matt Mesa), the likely higher costs associated with a 900-foot channel span (Jeff Smith), and the potential problems that highly reflective bubbles can cause for sonar detection (Pat Simpson). However, this site and the Willamette location will be examined in greater detail by Smith-Root engineers and Scientific Fishery Systems staff. Although there can be challenges with installing test equipment in turbulent environments, hydrological re-engineering can always address turbulence issues once the demonstration project's technology proves itself.

Hazing is ongoing in this location, lamprey peak passage is June and July, the depth is between 20-40 feet, and this site is least likely to have the highest peak flows (David Clugston and Robert Stansell). Large flow volumes could affect placement of the barrier array. The presence of Stellar sea lions in the area could complicate the permitting process.

Sonar could be dropped from project in lieu of using electrical array only, at Bonneville. This would yield an electric grid that would be operated manually, as needed, to deter animals.

Although there seemed to be consensus for a deployment at Bonneville, USACE supervisors have not been consulted and initial engineering requirements may be outside the scope of this experimental assessment of the electrical barrier's effectiveness to deter sea lions.

There is still some interest in the Willamette site (Guy Norman).

Agenda Item 5: Discussion of Research Needs
Any long-term location deployment must consider access of marine mammals to rivers.

Short-term research needs should address:

A test of electrical field effectiveness on California sea lions so that effects are known prior to demonstration project deployment. (This goal is the purpose of the demonstration project, however a serious attempt is being made to locate a test facility where sea lion food-driven responses and behaviors can be evaluated.)

Evaluate effects of a 2-Hz and higher field on salmon migration behavior. Matt Mesa mentioned possibilities at a site such as Little White Salmon River (Chinook salmon) and stated that other species and/or locations may also work to address this concern and issue, which was proposed as part of Smith-Root's Task 3 in the project proposal.

Evaluate effects of a 2-Hz and higher field on white sturgeon. Ken Ostrand mentioned that Abernathy has some large test fish that could address the research needs for this issue. Brad James also mentioned research possibilities at Yakima and possible interest from Blaine Parker at CRITFC.

Evaluate a 2-Hz and higher field on lamprey. Matt Mesa indicated the use of Y-maze tests to ascertain whether lamprey might be affected by the weak DC field. (*Subsequent discussions with Christina Luzier at FWS also examined possible lamprey studies in support of the demonstration project*.)

Carl Burger requested short statements/cost proposals from BRD, FWS and possibly CRITFC as soon as possible, with their estimated timelines to address the additional research needs for salmon, sturgeon and lamprey on a contractual basis.

Jeff Smith thanked Mike Fraidenburg and the participants for their participation. Jeff also stated his belief that all of us will work together on this challenge … and his sense from the meeting that the attending partners are amenable to helping Smith-Root when help is requested. There were many positive nods of concurrence and no visible nays. The meeting was adjourned at 2:20 pm.

Meeting Agenda, Deliverables & Take Home Messages

Sea Lion Project Meeting - September 28, 2007: Vancouver, WA

11:00 – 11:05 am: *Welcome and Introductions (Mike Fraidenburg[1]/ Jeff Smith[2]).*

11:05 – 11:20 am: *Power Point on Seal Deterrence Tests in B.C. (Carl Burger[3]).*

11:20 – 11:40 am: *Power Point on Sonar Technologies for Sea Lion Demonstration Project (Patrick Simpson[4]).*

11:40 am – 12:10 pm: *Opportunity for Questions and Answers, with Particular Reference to Research Issues and Needs, and Roles of Partners (All).*

12:10 – 1:00 pm: *Working Lunch to Discuss Project Location Criteria and Possible Sites for Demonstration Project (All).*

(1:00 – 2:00 pm: Meeting extended to address research needs in greater depth.)

[1]Mike Fraidenburg, Facilitator, Dynamic Solutions Group, Olympia, WA, 360-867-1140 (fraid@earthlink.net)
[2]Jeff Smith, CEO Smith-Root, Inc., Vancouver, WA, 360-573-0202, Extension 110 (jsmith@smith-root.com)
[3]Carl Burger, Senior Scientist, Smith-Root, Inc., 360-573-0202, Extension 112 (cvburger@smith-root.com)
[4]Pat Simpson, CEO Scientific Fishery Systems, Anchorage, AK, 907-563-3474 (pat@scifish.com)

Expected Deliverables

(1) Review of Site Selection Criteria and Amendments for Appropriate Site Location to Deploy Deterrence Technology (Goal: Oral Conclusion and Concurrence for Acceptable Demonstration Site).

(2) List of Partners / Cooperators to Help Guide, Monitor and Evaluate the Field Testing of the Proposed Deterrence Technology.

(3) List of Research Priorities and Cooperators (Near-Term & Long-Term).

Key Take-Home Messages Identified During Meeting

- This technology is meant *to supplement* (not replace) the selective management options available to fish and wildlife administrators for dealing with problem sea lions. It is a tool being developed for the agency manager and/or program administrator to decide where, when and how to deploy it.

- **This proposed Marine Mammal Behavioral Guidance System is non-lethal** (to pinnipeds, fish and humans). It uses non-injurious pulsed DC and is a low-energy array armed with a sonar detection system.

- The electrical guidance array is passive (it only turns on when sonar detects the presence of a pinniped). **The grid's default mode is "off."** Also, **its electric field is graduated** (strongest at upstream extremity) thus, pinnipeds receive a greater effect if they "fight the field").

- **The array operates at a pulse frequency of only 2 Hz (or 2 pps).** Most electrofishing surveys operate at 30 Hz to capture, handle and release fish alive. Most electric barriers operate at 10 Hz (to divert spawners or exclude invasives). NOAA recommends pulse frequencies NTE 70 Hz in waters containing listed species.

- The array will operate far below field levels capable of causing injury to fish. During each one-second time interval of operation (a few seconds are anticipated for a deterrence event), two pulses of DC would be introduced, each having a pulse width of only 0.001 seconds (meaning that electricity will be out of the water 99.8% of each second).

- Over and above the envisioned ability to deter problem animals, the technology's additional value will be in keeping younger, novice sea lions from recruiting into a population that has repeatedly learned where salmon congregate in the Columbia Basin.

- **Recreational river use is unimpeded and boats are unaffected** (DC current flows safely under and around metal-hulled boats where the current "shorts out").

- This approach reduces or eliminates the need for ineffective, costly hazing operations.

- The electric array will be positioned horizontally on the stream bottom and is unaffected by flow dynamics, debris, turbidity, depth or temperature. Multiple sonar transducer heads will be used (each capable of discerning sea lion presence for distances well over 400 feet).

- Prior to the testing conducted on seals in British Columbia, no previous information existed as to the effects of an underwater electric field on marine mammals.

- The proposed technology could provide side benefits to managers in enumerating salmon escapements at key locations in the Basin via hydroacoustics.

Appendix 2

Minutes of Meeting Held with Partners

Sea Lion Project Partner's Forum #2

Held at Vancouver Water Resources Center, Vancouver, WA (January 28, 2009)

Welcome, Introductions and Overview: Carl Burger reviewed the background of the non-lethal marine mammal deterrence project and its history in the Northwest Power and Conservation Council's Innovative Technology proposal process. He mentioned that the project's purpose was to provide fish and wildlife management agencies with non-lethal options for reducing predation on fish. He then provided a short presentation about the Marine Mammal Behavioral Guidance System which is being designed to pulse only twice per second, and only when sonar identifies an operational need. He acknowledged the funding and support provided for this work by the Bonneville Power Administration.

Carl updated attendees on progress made since the initial Partner's Forum (hosted at Smith-Root Inc. in Vancouver, WA) on September 28, 2007. At that time, co-managers suggested moving the proposed deployment site from the Willamette River to Bonneville Tailrace #1, and that several new studies be undertaken to evaluate sonar's ability to discriminate marine mammals, to assess the effects of the non-lethal electric array on sea lions with food present, and to examine effects of array operation on the behavior of salmonids, sturgeon and lamprey.

Bill Maslen (BPA) restated that the results of the research being presented are in response to the "go/no-go" decision point criteria, established to determine the potential effects of the deterrence technology on salmon, steelhead, sturgeon, and lamprey.

Results of Sonar Discrimination and Range Tests: Pat Simpson (Scientific Fishery Systems, Inc.) presented results of testing he conducted to address the go/no-go decision point on the sonar "library" development and the ability of hydroacoustics to accurately discriminate sea lions from other targets. Of 133 test tracks (using thousands of data points for both high and low-frequency sonar) there were no misclassifications of marine mammals and only a few misclassifications in discriminating among fish species. Additional testing and refinements are needed to evaluate narrowing the cone of coverage for the ability to completely span Bonneville Tailrace #1.

The question session clarified that, at present, sonar would be deployed on both sides of the Tailrace. Another question sought clarification about acceptable levels of misclassification and whether that can be adjusted. Pat Simpson explained that others would determine the acceptable level of error for the classifier and he would then adjust the equipment setup to achieve the desired level of correct classification. He also explained that the sound range in which his sonar operates is nearly identical to fish-finder technologies. It is much lower than the range of concern for whales and other marine mammals.

Results of Deterrence Array Tests on California Sea Lions, With and Without Food Present: Dr. Jenifer Zeligs (Moss Landing Marine Labs) presented results of the marine mammal testing she performed at her facilities (a consortium of Cal State University partners in Moss Landing, California). The test protocols identified (1) levels of the non-lethal electric field that were detectable by sea lions, (2) the levels that deterred them without food present, and (3) the deterrence levels required with food (herring and capelin) present. Dr. Zeligs presented a video of the study results. Sea lions could detect pulsed DC fields at frequencies as low as 2 Hz (2 pulses per second) and pulse widths as narrow as 0.00008 seconds (0.080 milliseconds each). Deterrence from the array end of the vinyl test pool was repeatedly documented at pulse frequencies of 2 Hz and pulse widths from 0.110 to 0.440 milliseconds, with and without food present. When food was presented at the lowest test levels, one sea lion bit a herring in half (allowing the other half to sink to the pool's bottom untouched), and another animal successfully took a whole fish. However sea lions were not successful in reaching the herring in four additional feeding trials when pulse widths were set at the higher end of the test spectrum (0.220 to 0.440 milliseconds).

The question session discussed the need for the electric array to span the entire Columbia River in order to be an effective deterrence. Steve Jeffries (WDFW) made the point that an array located across only Powerhouse 1 or 2 tailraces would probably just displace sea lions to the spillway, increasing predation there. Carl Burger re-emphasized the desire for a demonstration project to test proof of concept, as laid out in the original Innovative Technology proposal (suggesting a trial in the Willamette River). Bill Maslen pointed out that a demonstration project is only worth pursuing if it has the potential for long-term installation and that this needs to be part of the discussion.

Jenifer mentioned that exclusion from even 2/3 of the river would be a dramatic improvement from current conditions and that behavioral training methods (such as cross-conditioning), might help reduce predation in the unprotected area. Dr. Dave Casper (DVM, UC Santa Cruz) commented that the test starting level of 2 Hz at 0.080 milliseconds was undetectable when he put his hands in the water over the live array, whereas the animals could easily detect this level and had an immediate avoidance response. He felt that this reaction should be expected for all naïve animals but that the habituated animals may require a higher level of electric field. A discussion ensued regarding whether the problem is sea lion predation on ESA fish at Bonneville Dam or throughout the Columbia River. Points were made that the dam forms a human-caused predation site whereas predation in the river is natural, that predation "hot spots" occur throughout the Columbia River, that the Task Force has an "acceptable" predation level, that displacement of sea lions from Bonneville Dam will increase predation downriver, and that it is not possible to completely eliminate sea lion predation from the river. A question was posed regarding sea lions' possible response to the "soft start" technology to which Jenifer responded it would likely serve as a warning signal to leave the area immediately.

Effects of Array on Adult Steelhead: Dr. Matt Mesa (USGS, Columbia River Research Lab) presented results of tests he conducted on adult steelhead at the Cowlitz Trout Hatchery in Washington. Captive steelhead were exposed to various voltage gradients and pulse frequencies to assess the effects of the sea lion deterrence array on fish passage and behavior. Treatment levels included the gradient known to deter sea lions at Moss Landing (adjusted to compensate for water conductivity differences between Moss Landing and Cowlitz test environments). The electric field did not injure fish or stop steelhead movement over the array at power levels (electrical gradient of 0.6 V/cm, pulse width of 0.400 milliseconds, and pulse frequency equal to 2 Hz) equivalent to those used to deter California sea lions at Moss Landing. When extreme treatment levels were subsequently evaluated, the electric gradients to block steelhead movement over the Cowlitz test array required considerably higher power: frequencies of 2 or 3 Hz at pulse widths from 10 to 20 milliseconds. Similar to other research in support of addressing "go/no-go" decision points, this study involved captive animals that were tested in a hatchery environment.

The question session began with a discussion clarifying how the fields were measured and how they were described. The testing levels were targeting voltage gradients at the surface in the "electrical trough," so throughout the experiment the individual tests were referred to by the surface voltage gradient. A question was raised as to how well the steelhead, (which were about 8-lb fish), could represent effects on Chinook salmon which are much larger. Kerry Smith (Smith-Root, Inc.) stated it is much more difficult to stop Chinook salmon at electric barriers he services (using pulse frequencies up to 10 Hz and pulse widths up to 30 milliseconds) than it is to stop steelhead. The overall implication is that much greater field levels (than those used for sea lion deterrence) are necessary to block the upstream movements of fish.

<u>Post-Forum follow-up data</u>: *Pulsed DC at a frequency of 2 Hz and a pulse width of 32 milliseconds has been used to divert coho salmon spawners from the Quilcene River to Quilcine National Fish Hatchery (Hershberger et al. 1992). Smith-Root company records (K. Smith, personal communication) also indicate that fairly intense fields of pulsed DC are necessary to block, limit or guide the upstream migrations of various species of Pacific salmonids. These include Chinook salmon and steelhead at Abernathy Fish Technology Center (10 Hz at 1.0 millisecond), coho and chum salmon at Quilcene NFH (5 Hz at 2.0 milliseconds), coho salmon and steelhead at Eagle Creek NFH (10 Hz at 1.0 millisecond), and Chinook, coho and steelhead at the Quinault NFH (10 Hz at 1.0 millisecond). These levels (to block, limit or divert upstream migrations of adult Pacific salmonids) are considerably higher than the field (2 Hz at 0.400 milliseconds) used to deter California sea lions at Moss Landing Marine Labs.*

Special Presentation: *"Use of Electrified Gillnet to Deter Pacific Harbor Seal Predation on Salmon Used for Fraser River Stock Assessment."* Keith Forrest (Pacific Salmon Commission, Vancouver, B.C.) presented results of his seal deterrence work in Canada's Fraser River. Half of a 600-foot, test-fishing gill net was electrified with Smith-Root's marine mammal deterrence field while the other half served as an untreated control. The goal was to determine whether an electric gradient could be integrated with an actively fishing gill net to deter Pacific harbor seals from foraging on salmon caught in the net, and thereby improve PSC data used for the in-season management of Fraser River sockeye and pink salmon. The "electrified" end of the gill net used the same pulsed DC power levels that successfully deterred harbor seals in the Puntledge River, B.C. in 2007: a frequency of 2 Hz at a pulse width of 1.0 millisecond (Forrest et al., In Press).

Over a one-month period in 2007, the electrified end of the net consistently caught more than six times (6x) the number of Pacific salmon than the non-electrified control end, where harbor seals would reside and remove net-caught salmon (statistically significant results). A manuscript detailing these findings is about to be published in the North American Journal of Fishery Management (Forrest et al., In Press).

A question was asked about whether seals were taking salmon only from the non-electrified side of the gill net. Keith confirmed that this was the case and further explained that when a seal was taking a salmon out of the net it submerged about 10 feet of net, which was not observed to occur in the electrified section of net. A question was asked about behavior of salmon with the array located on the Puntledge River in 2008 (test levels were at 2 Hz and 1.0 to 3.0 millisecond pulse widths). Carl Burger responded that 11 of 14 Puntledge salmon that encountered the perpendicular array reacted by turning away (according to DIDSON images), however these fish were not tagged so their final distribution and movements in the Puntledge River could not be ascertained. Also, the array used in the Puntledge River was not a passive device cued by sonar. Rather, it remained "on" all the time. (Additional Cowlitz steelhead tests conducted by Smith-Root at high field levels showed many cases where fish hesitated and turned, only to circle back and completely cross the live array during subsequent re-trials.)

A question was asked about behavior of seals encountering the 2008 Puntledge array. Carl Burger explained that despite challenges from evaluating a new parallel array orientation and the weakening effects of stream-bottom metal and high tides on the field strength, the Puntledge array still deterred 76% of the seals encountering it during the 2008 trials. Two seals apparently displayed unusual behavior (twitching, seeming to be "stuck") at the highest setting (2 Hz at 3.0 milliseconds), a level at which Mr. Peter Olesiuk (DFO Marine Mammal Biologist) was uncomfortable. Dr. Mike Holliman (Smith-Root) responded that he also observed these same seals and, although they exhibited signs of distress, he did not think they were immobilized. Although there were several problems and challenges in 2008 (metal, higher-than-expected water that diluted the electric field and allowed a few seals to pass, etc.), much was learned about marine mammal deterrence and array parameters.

Several people made the point that the array is meant to be a behavioral deterrence for seals and sea lions, not a physical deterrence. This will require design and operational differences from the Puntledge River array, such as starting at *the highest* electrical level available and having a much longer array (measured in an upstream/downstream dimension) than that deployed in the Puntledge River. (The Puntledge array's upstream/downstream dimension was only 18 feet, meaning that seals moving at the upper end of their swimming ability might feel only a single pulse rather than the full, two-pulse-per-second design protocol as they moved upstream.) Discussion occurred regarding whether marine mammals could avoid the full effect of the field by keeping their heads out of the water. Jenifer Zeligs mentioned that sea lions can't hunt with their heads out of water. She felt that the field's effect on other parts of a sea lion's body would cause a reflexive reaction bringing the head back into the water.

There appear to be some different philosophies in operating the marine mammal deterrence technology. In the Puntledge River, B.C., the emphasis (both 2007 and 2008) has been to start at low field levels, determine step-wise animal thresholds, and gradually adjust field levels upwards, as needed. The approach recommended by Dr. Zeligs, however, is to start at the highest electrical field level available to researchers at the onset of trials, and to thus condition animals for aversion behavior (to make them feel immediate discomfort and leave the area). Longer (upstream/downstream dimension) fields should also be used so that sea lions will be exposed to more than just one or two pulses of electricity when attempting to rapidly move upstream.

Special Presentation on Manatee Deterrence: Jack Wingate (former Chief of Fisheries Research, MN DNR and Smith-Root Consultant) summarized a trip he and Carl Burger made to Jacksonville, Florida and to Silver Spring, MD last November to update the USFWS and the Marine Mammal Commission on potential uses of the non-lethal electric deterrence array for manatee conservation. Dr. Tim Ragen (Executive Director of MMC), Jim Lecky (Director of Office of Protected Resources, NOAA-Fisheries) and their staffs attended. There is interest in finding non-lethal technologies to protect the Florida manatee from anthropomorphic impacts.

Effects of Array on Adult Sturgeon: Dr. Ken Ostrand (USFWS Abernathy) presented results of tests he was asked to conduct on captive white sturgeon at the Abernathy Fish Technology Center. Smith-Root had designed a "soft-start" engineering protocol to gradually ramp-up the power of the array over a 3-second timeframe for sturgeon conservation. The goal was to determine whether sturgeon could be induced to leave the array area when the soft-start protocol initiated (to address situations where sturgeon might occupy bottom habitats on or near electrodes).

The test field provided by Smith-Root was three times more concentrated (1.5 V/cm) than the conductivity-compensated fields used to deter sea lions (0.6 V/cm). The soft-start technology caused no sturgeon mortality. It resulted in sturgeon spending less time over the electrical array and it appeared to keep sturgeon away from the array during intermittent "on" times (the desired outcome). When more extreme test parameters were evaluated (field was left on constantly), four sturgeon appeared to became narcotized over the array. These fish were left on or near the electrodes for a full 24 hours with the array in operation at 1.5 V/cm. One of the four fish died about 40 hours following this exposure. Similar to the steelhead research, the sturgeon study used captive, domesticated fish in a hatchery raceway environment where there were little or no "sweeping velocities" to flush any narcotized fish downstream to safety (as would occur in a riverine deployment).

A question was asked regarding why only one voltage gradient was tested and at a level 3 times higher than that tested at Moss Landing. Ken responded that they had a limited number of fish and were thus limited to testing an electric gradient based on the anticipated field strength at the electrode level of the conceptual demonstration array (where sturgeon are expected to occur). All test levels were adjusted for differences in conductivity between Moss Landing and the test location conditions. A question was asked regarding applicability of test results to larger sturgeon and Ken responded that it would depend on exposure time and amount, however he indicated that sturgeon are very hardy and resilient. Further testing would need to take place to properly evaluate the effects on very large sturgeon. A question was asked regarding recovery time and Ken responded that the fish exposed to soft start recovered in 2.7 seconds, and the fish exposed for 24 hours straight recovered in 2 1/2 hours.

Discussion took place regarding the length of time the electric field might be on if it turns on only when sea lions are challenging it. Pat Simpson explained how the sonar technology will be positioned to both turn it on (when sea lion upstream movement is detected) and turn it off (after upstream movement ceases).

<u>*Post-Forum follow-up note*</u>*: Smith-Root has not proposed that the field operate constantly (length of on times will be decided or specified by agency managers). Initial engineering design was for an "on" window not to exceed about 10 seconds (subject to the operational parameters to be specified by the co-managers). It has always been recognized that some tenacious animals might successfully navigate the array during the short operational window envisioned, however these animals can be dealt with via selective management options. The goal has always been to reduce sea lion predation, not necessarily to stop every sea lion in the Columbia River.*

Effects of Array on Pacific Lamprey: Dr. Matt Mesa presented results of tests on Pacific lamprey he and Elizabeth Copeland conducted at the USGS Lab in Cook Washington. Captive lampreys were exposed to various voltage gradients and frequencies to assess the effects of the sea lion deterrence array on fish passage and behavior. Similar to the other fish studies, treatment levels included the gradient known to deter sea lions at Moss Landing (adjusted to compensate for water conductivity differences between Moss Landing and the lamprey test environments). There was no discernable difference in lamprey passage when movements of control fish were compared to fish tested at power levels (0.6 V/cm, pulse width of 0.4 milliseconds, and pulse frequency of 2 Hz) equivalent to those used to deter California sea lions at Moss Landing. Similarly, there was no significant effect on fish passage between control and test groups of lamprey even when the voltage gradient was more than doubled (1.35 V/cm at 0.4 milliseconds at 2 Hz). During tests at extreme levels (3x the voltage gradient that deterred sea lions), fish passage over the array declined by 80% when power levels were increased to 1.8 V/cm at pulse widths of 5.0 milliseconds, levels that are considerably higher than those used to deter sea lions both for voltage gradient and pulse width.

A question was raised as to whether this level of electricity would affect egg viability and reproduction. Several people commented that with typical electrofishing this can be a concern, but not with low levels (such as those envisioned for sea lion deterrence or those used in electroanesthesia, which use different waveforms and lower amounts of power). A question was asked about the one lamprey that displayed unusual behavior, as to how common this was. Liz Copeland (USGS Columbia River Research Lab) replied that it was the only incident and that it occurred only at the highest (extreme) test level. The water velocity in the test tank was about 0.5cfs. A question was asked whether Matt or Ken saw fish trying to avoid the array by moving up in the water column. Ken said he occasionally saw attempts to move up to avoid the array however both his and Matt's test locations had fairly shallow water allowing little room for movement up in the water column.

(Post-Forum editor's note: Electroanesthisia systems are commonly used at state and federal fish hatcheries to sedate salmonid broodstocks without affecting egg quality, as confirmed in published literature.)

Presentation on Electric Field Dimensions Anticipated for Demonstration Project in Columbia Basin: Dr. Mike Holliman (Smith-Root, Inc.) presented an overview of electricity in water and the conceptual design for the demonstration project, taking questions throughout the presentation. The main result was that the field Smith-Root anticipates using in the Columbia River for sea lion deterrence (corrected for Columbia conductivity) will peak at 0.34 V/cm at the surface (versus the 1.5 V/cm and 0.6 V/cm fields tested on sturgeon and steelhead respectively). Although not intuitive, the electrical gradients generated by plate-like electrode arrays (of the size needed to span the distances and depths at Bonneville Tailrace #1) are actually more homogenous and less intense than the crude cable arrays evaluated in hatchery-like settings. In addition, these plate-like electrode arrays are often embedded in non-conductive shielding material to further lessen impacts to benthic-oriented species.

Matt Mesa asked how the levels tested on steelhead compared to typical voltage gradients used in backpack electrofishing. Mike responded that at the highest test levels used by Matt (some of the outliers tested during attempts to block all fish movement), that voltage gradients may have exceeded levels found near the anode during backpack electrofishing (about 5V/cm). Thus, backpack electrofishing (which stuns fish for non-lethal capture) uses levels greater than those designed for sea lion deterrence. The steelhead/lamprey tests included a range of values (by design) to which fish are unlikely to be exposed during marine mammal deterrence. This approach generated data on how high the gradients can be set without adversely affecting fish behavior.

A question was raised regarding the relationship of the size of electrode to the voltage gradient. Mike explained that as the size of the electrode increases the peak voltage gradient actually decreases (sharp, concentrated transitions near electrodes are greatly ameliorated by increased electrode size). Another question was asked about how the shape of the substrate affected the electric field. Mike responded that the shape is not nearly as important as how conductive it is. In response to another question Mike clarified that the voltage gradient profiles being presented were in a horizontal direction, but there is a voltage gradient in the vertical direction as well. A question was asked on how much the Columbia River's conductivity varies. Mike responded that he has not seen much data for the Columbia, but would be expect low variation due to the large water volume. A question was asked regarding water velocity and possible metal in the substrate and the effects on the electric field. The response was that water velocity has no effect on the electric field, however it is a design and construction consideration. Metal in the substrate could affect the electric field depending on its size, location, and orientation in relation to the electrodes. Ken Ostrand asked about shielding the electrodes. Lee Carstensen (Smith-Root, Inc.) answered that it is preferable to design the electrodes to where shielding is not necessary but that shielding can be employed if needed. Matt Mesa asked about the electrode design at the sea lamprey barrier at Pere Marquette, MI. Kerry Smith responded that it is presently operated at 10Hz, a 3-millisecond pulse width and about 4V/cm to stop the lamprey from passing upstream of the array.

<u>Post-Forum follow-up data</u>: *Initial research conducted for sea lamprey control in the Pere Marquette River, Michigan demonstrated that all upstream movement of sea lampreys was blocked at pulse frequencies of 3 Hz and pulse widths of 20 milliseconds, while downstream migrants (including spent adult steelhead that were x-rayed after traversing the live array) passed unharmed (Rozich 1989). A similar study of sea lampreys in the Ocqueoc River, Michigan demonstrated that "hot" fields of pulsed electric current were needed (a frequency of 2 Hz at 38-millisecond pulse widths) to stop all upstream movement by lampreys (Seelye 1989). A third barrier study used a pulse frequency of 10 Hz and a pulse width of 2 milliseconds to completely block the spawning migrations of adult sea lampreys in the Jordan River, Michigan (Swink 1998). These levels are much higher than those used to deter sea lions.*

To put these findings into perspective, the relative power (or percent duty cycles) can be computed and compared between these studies and the sea lion deterrence field (Table 1):

Treatment Locale	***Pulse Frequency***	***Pulse Period***	***Pulse Width***	***Relative Power (Duty Cycle %)***
Pere Marquette River	*3 Hz*	*333 ms*	*20.0 ms*	*6.0 %*
Ocqueoc River	*2 Hz*	*500 ms*	*38.0 ms*	*7.6 %*
Jordan River	*10 Hz*	*100 ms*	*2.0 ms*	*2.0 %*
Sea Lion Deterrence Level	*2 Hz*	*500 ms*	*0.4 ms*	*0.08 %*

Table 1. Comparison of power levels (percent duty cycles) between studies that documented sea lamprey blockage with those used to deter California sea lions at Moss Landing Marine Labs (and to evaluate effects on Pacific lamprey in USGS studies).

The power levels used to deter California sea lions are many orders of magnitude lower than those shown to block movements of lampreys.

"Next Steps" Discussion:

Richie Graves (NOAA-Fisheries) emphasized the seriousness of sea lion predation specifically in the mile or so below Bonneville Dam, describing this as an area of substantial loss of salmon. He would like to see further studies done evaluating effects on resident species and effects on migrational behavior of anadromous species. Discussion took place regarding the possibility of testing effects on migrational behavior at Bonneville Dam. Suggestions were made for in-situ testing in the Upstream Migrant Transport Channel near Power House #2, and/or immediately below the Dam. Matt Mesa expressed support for testing in this area because of the large amount of historical data and the suitability of the site for a block-pair test (plus the abandoned counting window on WA side). Concerns were raised regarding possible interactions of the electric field with boats, however because no boat traffic is allowed inside the BRZ (Boat Restricted Zone) this is not an issue. (Boat traffic is not affected by Smith-Root's concentrated array in the Chicago Ship Canal where carp movement has been blocked because no electrical potential exists when boats float into and over the field.)

A question was raised as to the level of confidence with this technology for stopping sea lions. Jenifer Zeligs stated that from a behaviorist's standpoint this technology provides an obnoxious stimulus that is sufficient to deter sea lions, although it may prove to be most effective on novice sea lions and not as effective on the sea lions already adapted to feeding below Bonneville Dam (the "hardened criminals"). There was some discussion on whether a test could be conducted on the adapted sea lions without affecting Steller sea lions prior to having a permanent installation. The point was made that the array could be operated selectively to not expose Stellers to the electric field. A question regarding the amount of distress experienced by the marine mammals in the electric field was raised and a counter-point made that this may be irrelevant as these animals are slated to be killed. Further discussions are needed if co-managers wish to consider permanent or additional deployment sites.

Robert Stansell (ACOE) feels this technology has potential to be a long-term solution but still has concerns regarding possible effects on sturgeon and lamprey. The Columbia River Inter-Tribal Fish Commission (per comment by Doug Hatch) does not favor further testing of the array.

Steve Jeffries brought up a concern that sea lions will adapt to the field requiring an increase of the level of electricity to the point where it may affect fish passage. Carl Burger responded that this is why the researchers tested a range of electrical settings to allow for "wiggle room." Matt Mesa asked for clarification as to whether predation rates are higher at the Dam than areas downriver. Robert Stansell said the assumption is that fish are being delayed by Bonneville Dam, they do congregate below the Dam and are more prone to predation by marine mammals. Matt emphasized that the purpose of this deterrence array would be to reduce predation in an area where it is abnormally high. Keith Forrest pointed out that PSC will be testing effectiveness of a fully electrified gillnet on reducing seal predation this summer on the Fraser River, which will provide additional information as to whether seals adapt to the electric field.

Patty Crandell (USFWS Abernathy) raised the question whether exposure to an electric field might make sturgeon or other species more vulnerable to predation for a period of time after exposure. This may constitute an additional area for research. Jenifer Zeligs asked whether other methods of marine mammal deterrence have been tested for their impacts and effects on non-target co-occurring species. Mary Hansen responded that observations on non-target species showed no signs of obvious mortality however she noted no lab studies were conducted. Steve Jeffries indicated that seal bomb use is somewhat restricted regarding approved applications and that 80% of seal bombs are set off above the surface of the water.

Shane Scott (Fisheries Biologist and Smith-Root consultant) described a proposal to test the effects of the array on migrating salmon in-situ at the Upstream Migrant Transport Channel (UMTC) at Bonneville Dam. This proposal (favored by NOAA-Fisheries staff) would include the installation of an electrical array into the UMTC near Power House #2 to assess fish passage in-situ, under real-time flows during active spawning migrations. Power levels would be analogous to those used to deter sea lions. A study plan would be developed for regional review. Installation would have to happen before Feb 28th when the channel gets re-watered.

Carl Burger thanked participants and speakers for their excellent contributions. The meeting adjourned at 4:00 pm.

<u>References Cited (in Appendix 2)</u>

Hershberger, W. K. et al. 1992. Evaluation of a graduated electric field as a fish exclusion device. Final Report to Puget Sound Power and Light by Beak Consultants, Inc., Bellevue, WA. 29 pages.

K Smith, personal communication. Kerry Smith, Smith-Root, Inc., Vancouver, WA.

Forrest, K. W., J. D. Cave, C. G. Michielsens, M. Haulena, and D.V. Smith. In Press. Evaluation of an electrical gradient to deter seal predation on salmon caught in gillnet test fisheries. North American Journal of Fisheries Management.

Rozich, T. J. 1989. Evaluation of the Pere Marquette River electrical lamprey barrier. Report to Michigan Department of Natural Resources.

Seelye, J. G. 1989. Evaluation of the Ocqueoc River electrical weir for blocking sea lampreys. USGS Great Lakes Science Center Report, Hammond Bay Biological Station, Millersburg, MI.

Swink, W. D. 1998. Effectiveness of an electrical barrier in blocking a sea lamprey spawning migration on the Jordan River, Michigan. USGS Great Lakes Science Center Report, Hammond Bay Biological Station, Millersburg, MI.

Appendix 3

Behavioral Deterrence Responses of Captive California Sea Lions Exposed to a Mild, Electric Voltage Gradient at Moss Landing Marine Labs, CA

Principal Investigators: Dr. Jenifer Zeligs, Moss Landing Marine Labs & Carl Burger, Smith-Root, Inc.

***Summary Statement**: Four California sea lions were tested May 20-21, 2008 for deterrence reactions to a mild field of pulsed DC electricity at Moss Landing Marine Labs. The electric field was generated by an underwater electrode array across one end of a rectangular, vinyl test pool filled with fresh water. Each test subject was able to detect an electric gradient of 0.14 v/cm introduced at a frequency of 2 pulses per second (2 Hz) at pulse widths that ranged from 80 to 290 microseconds (0.00008 to 0.00029 seconds) at a water conductivity of 509 μS/cm. Pulse width manipulations were used to vary the strength of the field. Strong deterrence reactions (without food present) were exhibited at pulse widths from 80 to 320 μs. Strong deterrence reactions <u>with food present</u> (three of four animals were evaluated) occurred at pulse widths from 160 to 440 μs. These novel results may be useful to agencies and natural resource managers interested in developing non-lethal technologies to deter marine mammal predation on highly valued populations of anadromous and resident fishes.*

Background and Goals: Marine mammal predation on endangered fish populations has become a growing problem for natural resource management agencies at international scales (Yurk and Trites 2000; Carter et al. 2001; Middelmas et al. 2005). High levels of pinniped predation have the potential to affect the recovery of many threatened and endangered salmonid populations (London et al. 2002). Accordingly, a Marine Mammal Task Force recommended that NOAA approve a request from state natural resource managers (November, 2007) to allow selective management options (including lethal take) in efforts to reduce predation by California sea lions (*Zalophus californianu*s) on listed Columbia River salmonids. Although a new technology (a mild electric array that is a non-lethal deterrence strategy) was successfully tested on harbor seals (*Phoca vitulina*) in Canada (Cave 2007a and 2007b; unpublished), its effect on California sea lions was not known. Thus the goal of this study was to research and test the effects of an electric-deterrence technology (a weak field of pulsed DC electricity) on the behavior of four California sea lions held in captivity at Moss Landing Marine Labs. Our objectives for this study were to: (1) identify California sea lion sensitivities to electric fields; (2) identify variables of the electric field that will deter sea lions safely and at the lowest possible thresholds; and (3) (assuming that California sea lions are sensitive to electric fields) determine whether pulsed DC can be used to deter sea lions when food is present.

Test Protocols: The approach and study design were similar to those used in research conducted on phocid seals in Canada (2007), where successful deterrence behavior was achieved at low levels of pulsed DC current (Cave 2007a and 2007b; unpublished). Four California sea lions were tested independently (following acclimation to the test pool) for reactions to an underwater electrode array constructed across one end of a rectangular vinyl treatment pool. The pool measured 12.5m long, 6.4m wide and 1.2m deep (Fig. 1). The electrodes consisted of a pair of double-wide strips of adhesive aluminum tape (each pair consisted of two, 5 cm-wide strips of tape). One double-wide strip served as the anode and the other as the cathode, with 2-m spacing between positive and negative poles. The electrodes were cemented across the bottom of the south end of the treatment pool with water-tolerant adhesive (to minimize animal interactions with electrodes). Electrode strips were connected to a computer-controlled DC pulse generator unit (powered by a 240-v portable generator), with an instant on/off switch controllable by an attending marine mammal veterinarian. An additional pair of triple-wide aluminum strips (15 cm in total width, spaced 1 m north and 1 m south of the energized array, electrically "shorted" together, and not connected to a power source) served as "parasitic electrodes." The parasitics ensured that the field encompassed only a narrow cross-section of the pool's south end by attracting any stray electric current. Objectives were to evaluate responses of sea lions to an underwater electric field using extremely low voltage gradients (either 0.14 or 0.27 v/cm DC), a fixed pulse frequency of 2 Hz (one pulse each half-second), and variable pulse widths from 80 microseconds (µs) to 5 milliseconds (ms), with pulse-width manipulations used to intensify the field.

The electric field was mapped and measured for each of the two voltage gradients prior to testing. The conductivity during the test period (May 20-21, 2008) was measured at 509 µS/cm (water temperature ranged from 16.9 to 20.2 degrees C during the two days of testing). All tests were recorded by multiple observers and by two synched video cameras operated from scaffolding adjacent to the treatment pool. One of the cameras also recorded the voiced observations of the marine mammal behavioral physiologist. Although test animals were not starved prior to tests with food present, their daily feed rations were reduced by 25-50% for 1-2 days pre-test and their weights were closely monitored to insure that they remained healthy and normal.

Pool acclimation was allowed for 5-30 minutes prior to each experiment and was determined to be the point at which swimming over and around the array was regular and comfortable. Following pool acclimation, the initial test level for each independently evaluated sea lion was 0.14 v/cm at a pulse frequency of 2 Hz and a pulse width of 80 µs (the lowest level allowable by the equipment used). The study design was to increase the pulse width by 30-µs increments until the animal exhibited behavior (slight change in head posture or swimming pattern) indicative of awareness to the electric field. Once the initial detection level of each animal was determined, the level causing a deterrent reaction (sharp change in posture or swimming behavior) was then ascertained (using the incrementally higher pulse-widths). A deterrence reaction level was ascertained when the animal exhibited a strong avoidance behavior to the field (typically a sharp change in head posture and/or a rapid reversal in swimming direction and avoidance of the field area). The pulse width causing the first strong deterrence reaction was doubled for tests when food was introduced (to three of the four test animals only) to assess whether sea lions could also be deterred from accessing their customary food source (herring and capelin) while the electrode array operated. All tests were conducted under the oversight of Dr. Jenifer Zeligs and staff, and the Moss Landing Marine Mammal Veterinarian (Dr. David Casper). Other participants included Carl Burger, Lisa Harlan, Dave Smith and Kerry Smith of Smith-Root, and Scott Bettin and Lee Watts of the Bonneville Power Administration, the funding source for these tests.

Results and Discussion: Table 1 summarizes the physical data for each test animal and the DC pulse widths resulting in detection and deterrence reactions among California sea lions exposed to an underwater electric gradient of 0.14 v/cm at a pulse frequency of 2 Hz and a water conductivity of 509 µS/cm. Three of four test animals exhibited the ability to detect the field at the lowest pulse width available for testing with the pulse generator used in this study (80 µs), and two of those animals also exhibited strong deterrence at that level (80 µs). These data suggest that sea lions may be able to detect even lower electric field gradients than those tested at Moss Landing Marine Labs.

Table 1. Attributes of California sea lion test animals and the underwater electric field strengths (DC pulse widths) resulting in detection and deterrence behaviors with and without food present.

						DC Pulse Width (µs) Causing:		
Animal	**Name**	**Sex (Age)**	**Length (cm)**	**Weight (kg)**	**Comment**	*Detection*	*Strong Deterrence*	*Food Deterrence*
1	Beaver	Male (29)	206.6	158	Blind	110-170	320	NA
2	Ariel	Female (6)	165.5	80		80	80	160
3	Nemo	Male (10)	207.0	132	Neutered	80	80	160
4	Jonah	Male (10)	200.8	126		80	110	440

The largest of the three males tested (animal #1; Beaver) was blind and his unfamiliarity with the test tank made his behavior somewhat more difficult to interpret. This animal showed signs of detecting the field at pulse widths of 110 and 170 µs, suggesting his sensitivity was similar to other animals tested. However he did not show a strong deterrence reaction until pulse widths of 290 to 320 µs were administered. It was not practical to test this animal for deterrence with food present because its old-age-induced blindness precluded visual contacts with fish. Pulse widths at the higher end of our testing spectrum were also required to create a strong deterrence reaction by the un-neutered test male (animal #4; Jonah), possibly indicating that higher field strengths may be needed to deter large male sea lions. Animal #1 was successfully deterred three times from the electric array-end during trials at a pulse width of 320 µs (a level that led us to testing his sensitivity at a second and higher voltage gradient). Trials using the higher voltage gradient (0.27 v/cm at 2 Hz) with test animal #1 also showed detection/aversion behavior but at lower pulse widths (80 and 110 µs). Because all other animals showed strong deterrence even at the lower pulse widths of the lowest voltage gradient, it was not deemed necessary or appropriate to test them at the higher voltage gradient.

The tests conducted at Moss Landing Marine Labs were conservative efforts to assess the deterrence behavior of captive California sea lions without inducing excessive stress to the animals and without violating the trust relationships that have developed between animals and trainers. Thus, only limited trials were conducted. However, **tests with and without food present clearly demonstrated deterrence reactions among the test subjects.**

Deterrence Behavior with Food: In tests with food present, animal #2 (Ariel) was evaluated on three occasions with the field turned on at 160 µs (double the deterrence level observed without food present). A capelin was tossed near the array's northernmost electrode strip. This animal bit the fish in half before making a pronounced, sudden reversal in direction, allowing the uneaten portion of the fish to sink to the pool's bottom. This atypical behavior is very noteworthy. These trained animals never bite fish in half or allow anything uneaten to fall. This animal was dramatically distracted at that moment. A herring tossed near the northernmost electrode (leading edge of the field) was consumed by Ariel but a third fish tossed between the electrode strips and further into the field was charged and abandoned uneaten, while the female sea lion retreated to the pool's northern end, avoiding any re-exploration of the pool's electrode end. This behavior demonstrates the importance of creating a deep field with a gradient capable of deterring short incursions into and out of the field (or through the field).

Animal #3 (Nemo) exhibited a strong reaction to the field's lowest pulse-width setting (80 µs) and subsequently exhibited strong avoidance to the electrode end, even when the power was turned off. The reaction was deemed violent by observers, causing the animal to leap out of the pool to the safety of decking and to superstitiously "jump" over electrodes even when they were not charged. Because of this animal's extreme sensitivity to even the weakest of the test fields, only a single trial with food was attempted (at 160 µs). A herring was tossed into the southernmost end of the pool south of the electrode array. Although this animal raced towards the fish, it abruptly and sharply reversed direction as it swam into the area of the array and quickly retreated to the pool's north end where it leapt out of the tank. The herring was untouched. Nemo would not re-enter the test pool.

Animal #4 (Jonah) exhibited strong deterrence at 110 µs. Trials with food present commenced at 220 µs. This animal was deterred from taking the first herring thrown into the electrode array amid a pronounced behavioral deterrence reaction. A second fish was introduced and after a preliminary avoidance reaction, this animal circled and took the fish while exhibiting a strong reaction and a rapid retreat to the north where it immediately exited the pool. A third herring was thrown into the array at a higher operational setting (440 µs), as it was determined that although he clearly found the field aversive in previous trials, he was learning to tolerate the sensation for the opportunity of fish. This sea lion again charged towards the fish but immediately reversed direction as it encountered the array at 440 µs. The herring sank to the pool's bottom untouched. These trials demonstrate the necessity to use considerably higher intensity for motivated food deterrence (four times the detection level).

The voltage gradient levels that successfully deterred California sea lions at Moss Landing were lower than the levels observed to cause deterrence reactions among harbor seals in British Columbia, Canada in 2007 (Cave 2007a; unpublished). Captive harbor seals were deterred at 200 and 400 µs at the Vancouver B.C. Aquarium (at 0.28 v/cm and 2.25 Hz), however the conductivity of the test tank water in Canada (250 µS/cm) was half the conductivity at Moss Landing (509 µS/cm). Similarly, tests on wild harbor seals in the Puntledge River, B.C. (Cave 2007b; unpublished) showed that a pulse width of 1,000 µs (or 1 ms) was necessary to deter animals in river water having an extremely low conductivity (only 25 µS/cm, which is one-tenth the conductivity in the captive harbor seal trials). Additional research is needed to clarify relationships between marine mammal body resistance and effects of conductivity on deterrence, but data clearly indicate the necessity to control for conductivity variance when establishing deterrence levels for field tests.

***Conclusions and Recommendations*:** Based on results of the tests highlighted above, California sea lions are extremely sensitive to a mild, underwater field of pulsed DC electricity. The fields evaluated on sea lion test subjects were barely perceptible to the on-site veterinarian (who gradually immersed his hands into the water during operation up to 1,000 µs for a safety check). Results underscore that:

(1) California sea lions can detect underwater voltage gradients as weak as 0.14 v/cm (about 50 volts) pulsed twice per second at pulse widths as narrow as 80 µs (in water conductivities about 500 µS/cm).

(2) California sea lions exhibit strong deterrence behavior at pulse widths from 80 to 320 µs and strong deterrence in the presence of a preferred food source at pulse widths from 160 to 440 µs.

(3) The voltage gradients and test levels used during California sea lion tests are well below levels that directly injure fish based on published studies (McMichael et al. 1998; Holliman and Reynolds 2002; Reynolds and Holliman 2004) as well as levels used to harm, injure or shock mammalian species in animal damage control or agricultural applications (Blackmore and Petersen 1981; Lefcourt et al. 1986).

(4) Tests at Moss Landing demonstrate a potential to deter wild California sea lions with a graduated, underwater electric array, especially naive or “green” animals that have not previously experienced such an electric field. However, arrays deployed in the wild should be deep enough for marine mammals to experience multiple pulses as they approach an array during rapid swimming. Also, high initial pulse-width settings (adjusted for water conductivity) should be used at the outset of any deployments to avoid breaches of the field by animals that can quickly learn to endure pain if their challenges are successful.

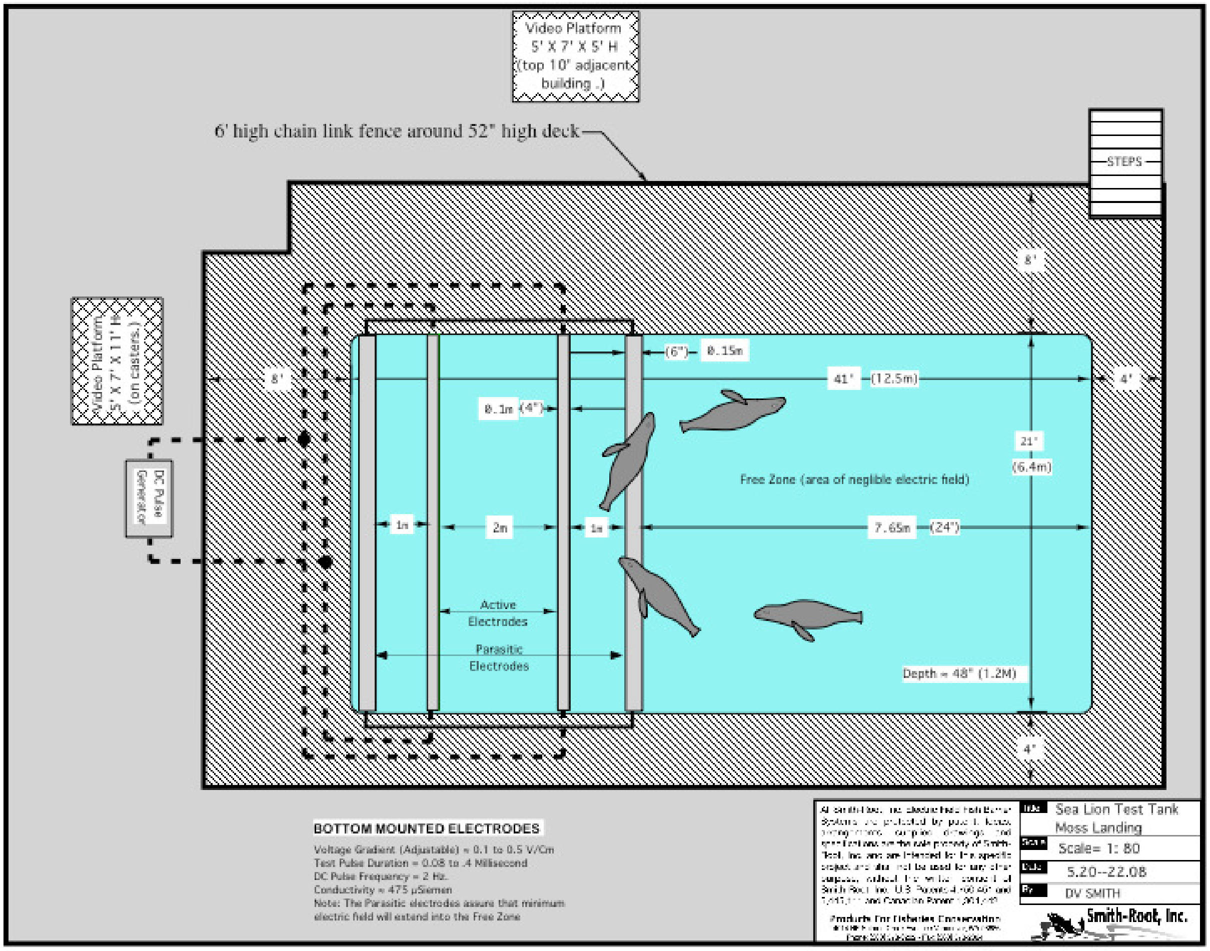


Figure 1. Sketch of vinyl, rectangular test pool used to evaluate the deterrence behaviors of four California sea lions exposed to a weak voltage gradient of pulsed DC electricity at Moss Landing, CA.

Literature Cited (in Appendix 3):

Blackmore, D., and Petersen, G. 1981. Stunning and slaughter of sheep and calves in New Zealand. The Veterinary Journal 29: 99-102.

Carter, T., G. Pierce, J. Hislop, J. Houseman, and P. Boyle. 2001. Predation by seals on salmonids in two Scottish estuaries. Fisheries Management and Ecology 8: 207-225.

Cave, J. 2007a (unpublished data). Evaluation of an electrical gradient as a seal deterrent, Vancouver Aquarium Study, March 27, 2007. Preliminary results. Pacific Salmon Commission, Vancouver, B.C. (available from cave@psc.org).

Cave, J. 2007b (unpublished data). Evaluation of an electrical gradient as a seal deterrent, Puntledge River Study, April 10-24, 2007. Preliminary results. Pacific Salmon Commission, Vancouver, B.C. (available from cave@psc.org).

Holliman, F. M., and Reynolds, J. B. 2002. Electroshock-induced injury in juvenile white sturgeon. North American Journal of Fisheries Management 22: 494-499.

Lefcourt, A., S. Kahl, and R. Akers. 1986. Correlation of indices of stress with intensity of electrical shock for cows. Journal of Dairy Science 69: 833-842.

London, J., M. Lance, and S. Jeffries. 2002. Observations of harbor seal predation on Hood Canal salmonids from 1998 to 2000.. Final Report: Studies of Expanding Pinniped Populations. Washington Dept Fish and Wildlife, PSMFC Contract 02-15.

McMichael, G. A., A. L. Fritts, and T. N. Pearsons. 1998. Electrofishing injury to stream salmonids; injury assessment at the sample, reach, and stream scales. North American Journal of Fisheries Management 18: 894-904.

Middlemas, S., T. Barton, J. Armstrong, and P. Thompson. 2005. Functional and aggregative responses of harbour seals to changes in salmonid abundance. Proceedings of the Royal Society, Biological Sciences 273: 193-198.

Reynolds, J. B., and F. M. Holliman. 2004. Injury of American eels captured by electrofishing and trap-netting. North American Journal of Fisheries Management 24: 686-689.

Yurk, H., and A. Trites. 2000. Experimental attempts to reduce predation by harbour seals on out-migrating juvenile salmonids. Transactions of the American Fisheries Society 129: 1360-1366.