F-E-5

STATUS REPORT
ELECTROFISHING DAMAGE TO RAINBOW TROUT

by: MDFWP ELECTROFISHING COMMITTEE
3/20/89

BACKGROUND: A paper published in the winter, 1988 North American Journal of Fisheries Management indicated that large rainbow trout suffered 44-67% incidence of spinal damage in a field test on the Colorado River using a boom-shocker and Coffelt VVP 15. Norm Sharber, who coauthored that paper, had recently acquired Coffelt Electronics and along with his two sons now operates the company. The significance of that publication to Montana biologists was this; despite attempts to reduce spinal damage problems nearly half of all large rainbow collected were injured by electrofishing.

In August of 1988, a newspaper article appeared in the Fairbanks Alaska paper which described a study on the Kenai River that was suspended when it was learned that over half of all large rainbow captured were injured by electrofishing. We obtained the more comprehensive results of that study from the Alaska Department of Fish and Game. The work was conducted under the guidance of Jim Reynolds who co-taught the electrofishing seminar we held in Bozeman three years ago. The research was partly flawed due to escape of some fish in the study group, but nonetheless the results were disturbing. Reynolds' work identified major voltage spikes in the VVP 15 waveform and he suspected the equipment was the problem. Alaska suspended the operation pending further research.

At this point the MDFWP electrofishing committee composed of Larry Peterman, Dick Vincent, and Wade Fredenberg began to research the issue and decided there was cause for concern in Montana. We felt an aggressive evaluation of the problem and modifications to resolve it were needed. A three-point program was outlined and undertaken as follows:

TESTING:

1.) Crew Leader Survey - A telephone survey of electrofishing crew leaders around the state confirmed that most had observed limited spinal damage in electrofished rainbow populations and had seen evidence of it in either direct mortality or fish captured later with crooked backs. Reported problems were restricted to the use of pulse DC current and were noted to occur almost exclusively with rainbow trout. Most crew leaders felt that somewhat less than 5% of the fish had been damaged in past work and that very few life-threatening injuries had occurred.

2.) Waveform Analysis - We employed Harley Leach, an MSU engineering prof who also builds electrofishing equipment (Fisher/Leach Boxes), to test our equipment and determine if voltage spikes were occurring. We also examined the waveforms to check for consistency between similar units. Results of that analysis are available in a separate report with examples shown in the Appendix of this report.

We discovered that the VVP 15 we tested produced a square waveform with short duration voltage spikes of up to 2,800 volts (49,000 watts). This confirmed the Alaska test results. The Fisher and Leach boxes as well as the VVP 2C produced similar half-sine waveforms with no spiking (see Appendix). The Fisher/Leach units and the VVP 15 set on straight DC produced a rippled waveform with low amplitude oscillations but no spiking.

3.) <u>Missouri River Tests</u> - Steve Leathe conducted field tests on the Missouri River. Samples of 14-17 inch rainbow trout were collected at night on 11/8/88. A separate report on these results is attached.

In summary, 151 fish were collected and only one suffered direct mortality (0.6%). None of the other 150 fish showed any external evidence of spinal damage. Autopsy results were much different. Virtually every fish showed evidence of localized hemmorhaging along the spine. In the two sample populations collected with a VVP 2C (one with Coffelt electrospheres and the other with stainless steel strand electrodes) 46% and 49% injury rates were detected by autopsy. X-rays revealed an even higher but consistent rate of damage at 67% and 69%, respectively. The X-rays were analyzed by Norm Sharber in a blind test and were consistent with findings of injury rates on the Colorado River, although generally the injuries on the Missouri were less severe and for the most part probably not life-threatening.

In the control sample, fish collected with a VVP 15 on straight DC settings suffered an injury rate of 14% based on autopsy and 20% based on X-ray. These rates were considerably lower than for fish shocked with pulse.

In conclusion, the river tests revealed that electrofishing damage on large rainbow trout is more extensive than previously believed and generally is not externally visible. The effects of varying degrees of spinal damage on long-term survival, growth, and behavior of fish is unknown at this time. In the autopsies most fish showed localized hemmorhaging along the spine, usually just behind the dorsal fin. In severe cases the vertebrae were compressed and pulled out of alignment. The use of the VVP 2C in these tests produced high injury rates which contradicts the theory that waveform spikes are the source of the damage as Alaska concluded.

SOLUTIONS: We subsequently contacted Norm Sharber for discussion. He stated that he had the problem solved and would present new information to us which would help us to correct the problem. On February 17, 1989 the committee met in Billings with Norm Sharber. Following is a summary of the discussions that occurred at that meeting:

THEORY: Sharber explained that the neuromuscular response we call galvanotaxis (forced swimming in an electrical field) is well-substantiated by a study of cell physiology. Voltage intensity, pulse frequency, and pulse duration all play a role in stimulating the nerve fibers which lead to a muscle contraction. In order for a fish to swim the muscles must alternately contract and relax on opposite sides of its body. Overstimulation of the nerves results in a state of muscle tetany whereby all muscles are frozen in a contracted state. Sharber believes that this is when damage to the fish may occur due to the intensity of the muscular contractions. Along with tetany the fish may be knocked unconscious (narcotized). Fish that are tetanized and/or narcotized run the risk of being damaged. To date, evidence indicates that rainbow trout are particularly susceptible. Thus, the simple solution to spinal damage is to not overstimulate the fish to the point where they are tetanized and narcotized.

How do you avoid that situation? As mentioned previously the three key factors are duration, intensity, and frequency of pulses. We'll examine them individually.

PULSE DURATION: Through experimentation cell physiologists have determined that a nerve cell will not respond to a stimulus of less than one millisecond (msec) duration no matter how intense that stimulus is. Furthermore, stimulation in excess of six msecs is beyond what it takes to cause the nerve cell to "fire" in an all or nothing response. Sharber has tested a 5 msec pulse width and found it highly satisfactory for electrofishing. If this theory holds true then the voltage spikes seen on the VVP 15 waveform are detectable electronically but may have no real physiological consequences since the duration is much less than one msec and probably does not result in nerve stimulation. Thus, the "dirty" waveform of the VVP 15 may be insignificant. The key point: **Use a pulse duration of 5 msec.**

PULSE INTENSITY: The voltage required to stimulate a nerve cell will vary. Nerve fibers require varying threshold stimulus voltages and a higher level of stimulation is needed to cause a muscle contraction than to stimulate an individual cell. Consequently, there is no preset voltage that will do the job since field conditions vary. **The voltage applied should be the minimum amount that will cause galvanotaxis.** While higher power levels will increase the size and intensity of the electrofishing field it can also create an extremely high voltage gradient around the electrode. We are presently uncertain what role this may play in relation to spinal damage.

PULSE FREQUENCY: According to Sharber this factor is **the major key to resolving the problem of spinal damage.** An individual nerve cell can respond to a pulse frequency of up to 300 pulses per second but a large block of muscle cells can not respond at nearly that high a rate. Sharber conducted field tests on the Colorado River, which is very similar to the Bighorn. Using a VVP 15 at a pulse rate of 15 per second and 5 msec duration the rate of spinal damage to fish was less than 3%. It is noteworthy that the VVP 15 used in those tests included a spiking waveform. According to Sharber, the electrofishing effectiveness in terms of fish catching ability was not noticeably reduced under this methodology. The conclusion reached: **keep pulse rate to under 20 pulses per second and spinal damage will all but disappear.**

WAVEFORM: Nerve cells fire in an all or nothing response. Stimulus that is of insufficient voltage to cause the nerve to fire is essentially wasted. Thus, a square waveform with a straight leading edge reaches "firing" voltage instantaneously and then drops straight off. This is superior to a sine waveform which builds and tapers gradually. Committee members agree that the peak voltage is what shocks the fish and the theory is plausible but no evidence has been presented to date to indicate that a sine wave is more damaging to fish than a square wave. Sharber plans to evaluate a modified sine wave at 15 pulses per second to determine the relative injury rate between waveforms. At present this issue is unresolved.

FURTHER STUDIES: We are planning to test the modified VVP 15 at 15 pulses per second on the Missouri River soon and will have an update bulletin following that test. If our test results mirror those of Sharber on the Colorado R. we can consider the spinal damage problem solved. The next step will be to modify our equipment to eliminate units with faulty waveforms and frequencies. Further testing on other species and on straight DC waveforms is also planned as well as on boom versus mobile electrode systems.

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INTERIM GUIDELINES: Until testing can be completed we recommend avoiding situations where rainbow trout over 10-12 inches long are subjected to high pulse rate DC electrofishing. Statewide, there are a variety of electrofishing units of all different makes and vintage but they can be lumped into four groups:

VVP 15 (VVP 10)-------------	17 units
VVP 2C (VVP 2E)-------------	10 units
Fisher/Leach----------------	11 units
Coffelt BP1C Backpack-------	12 units
TOTAL	50 units

Following is a summary of interim guidelines for the use of each type of unit where rainbow (or cutthroat) are being electrofished. These are temporary and will be modified as test results are compiled:

VVP 15 - A qualified OK to use as is on straight DC even though Missouri River testing indicated 20% spinal damage on this mode. Further testing is needed. The VVP 15 can be adjusted on pulse DC setting to approximate the recommended waveform and frequency. Adjust to 15 pulses per second (frequency adjust knob) and 7.5% duty cycle (pulse width adjust knob) to produce a 5 msec pulse.

Note: Be aware that the gauges produce a relatively crude indication of the true values and should not be relied upon. Sharber is presently modifying three of our boxes. They are being calibrated with an oscilloscope to 7.5% duty cycle, 5 msec pulse, and 15 pulses per second. We will use these boxes in our verification tests and if all goes well we should be able to modify all VVP 15's similarly.

VVP 2C - These produce a half-sine waveform which is fixed at 60 cycles per second. The frequency cannot be altered. We are investigating the potential to modify these boxes. **AVOID** using this box on large rainbow.

FISHER/LEACH: On straight DC this functions the same as the VVP 15. On pulse DC these boxes are electronically equivalent to the VVP 2C and should not be used on large rainbow trout.

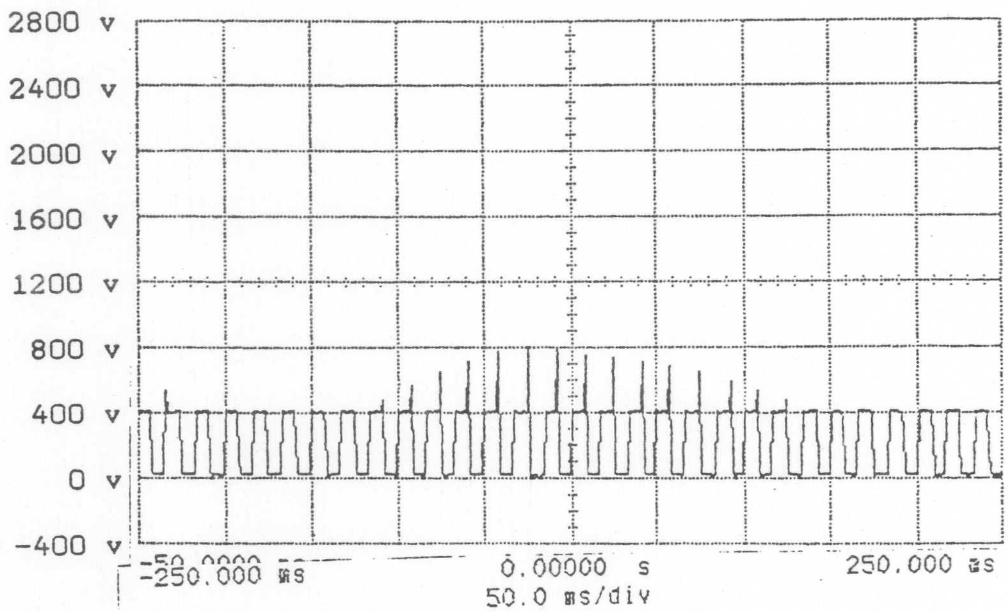
COFFELT BP1C BACKPACK - This unit has a generator which produces 200-250 cycle modified sine wave current. It presently cannot be altered but Sharber is working on a new Honda generator that may be OK. Region 3 will be testing a new battery unit this spring that may provide a viable alternative. For now, this unit should be avoided for use on large rainbow, particularly in spawning runs.

Please refer any questions to Larry Peterman (444-3183), Wade Fredenberg (994-6938) or Steve Leathe (454-3441).

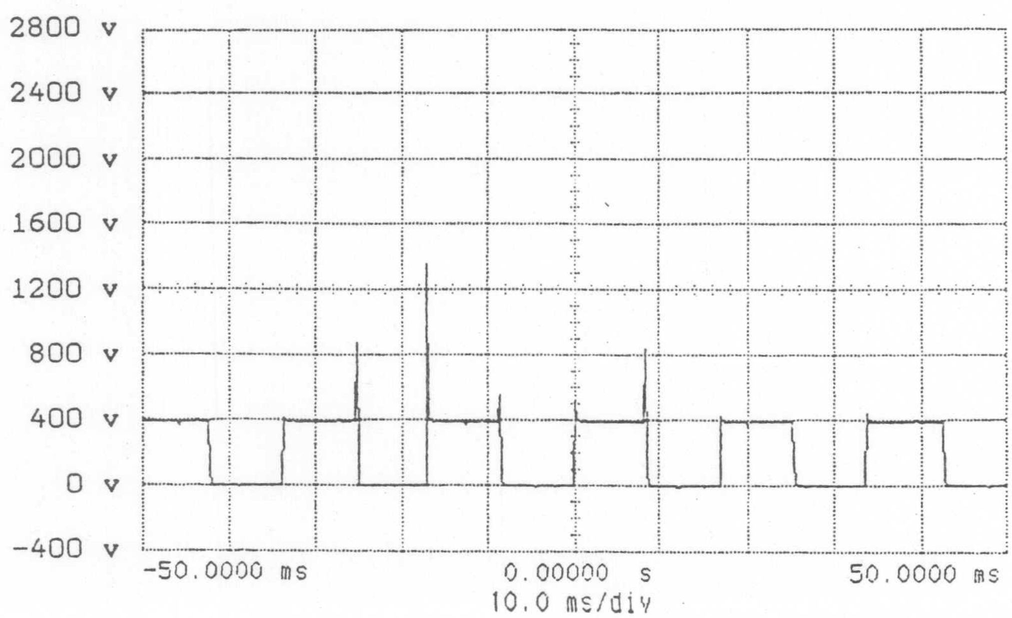
Appendix

VVP 15 - Square Waveforms

Coffelt VVP-15 # 5661 PULSE 1000 Watts @ 3 Amps

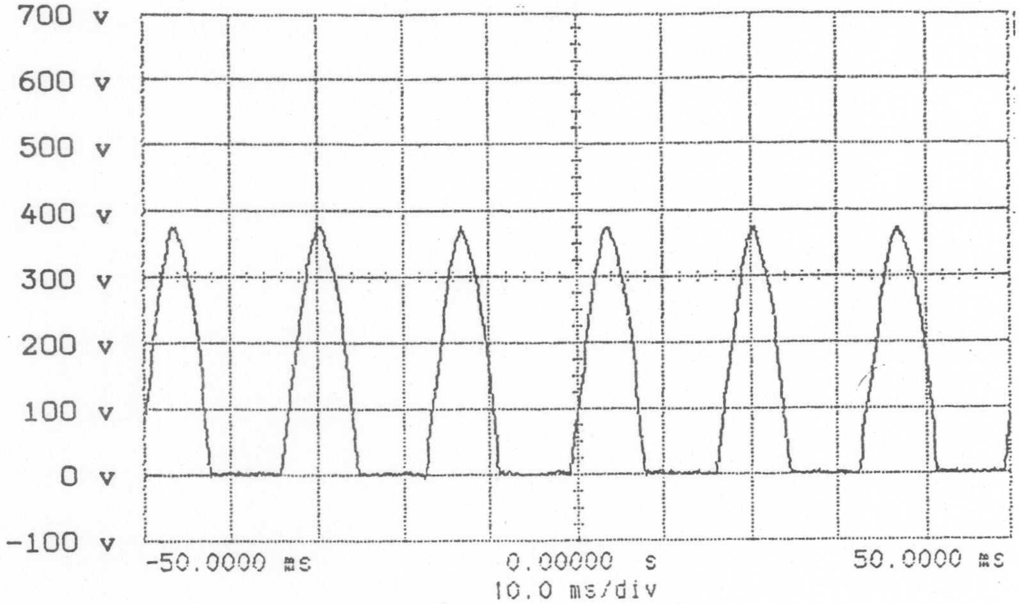


Coffelt VVP-15 # 5661 PULSE 1000 Watts @ 3 Amps

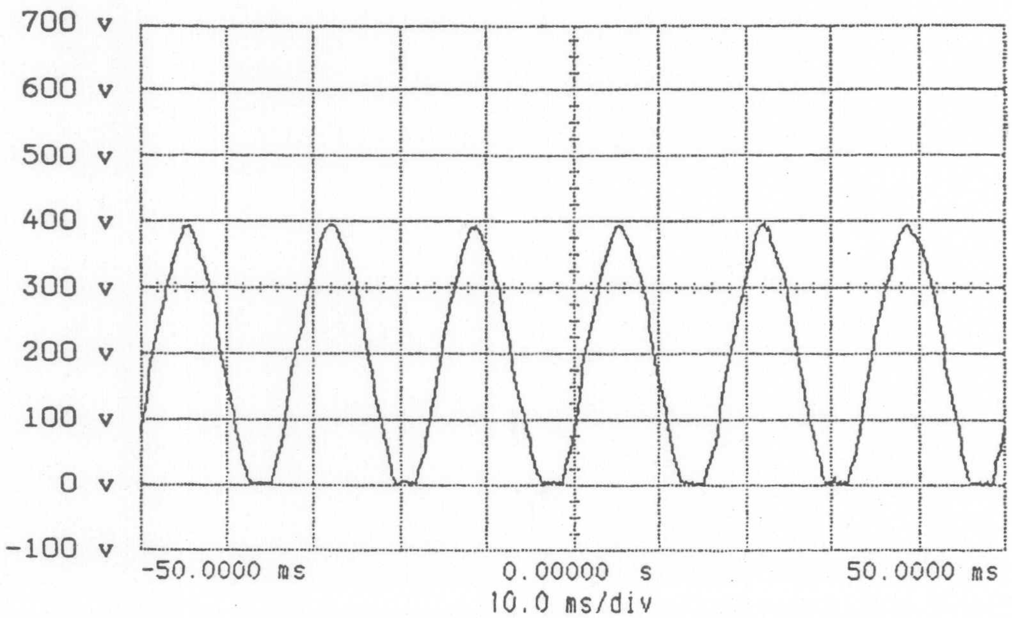


Sine WAVEFORMS

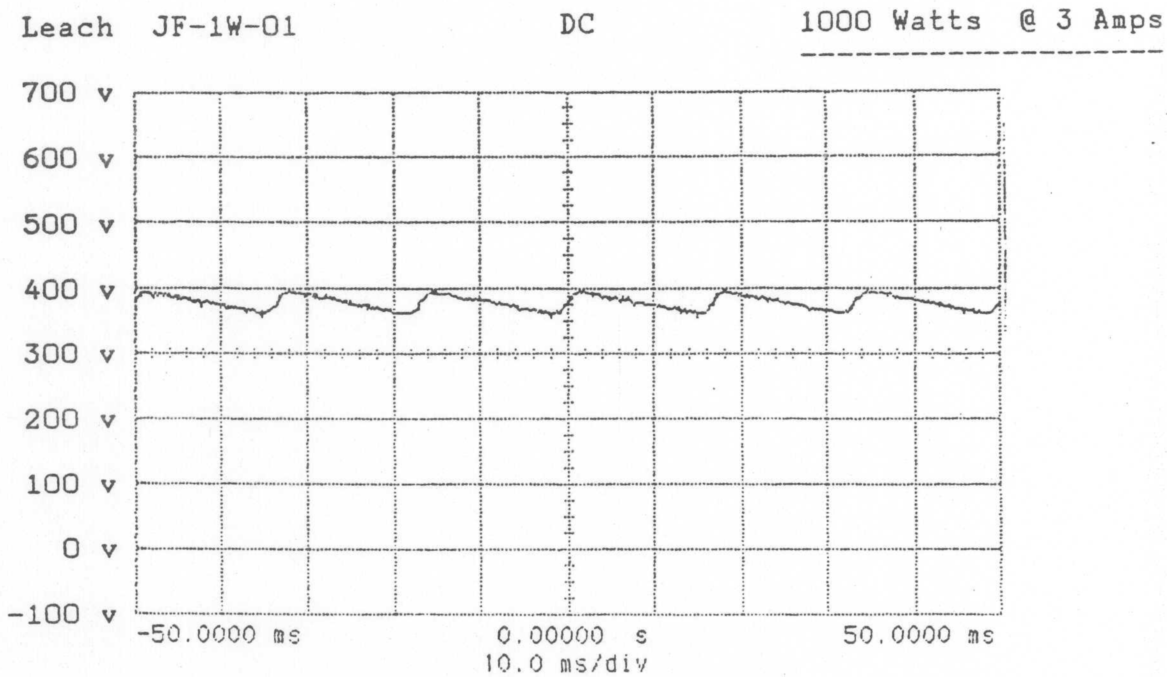
Coffelt VVP-2C # 8537 | 1000 Watts @ 3 Amps

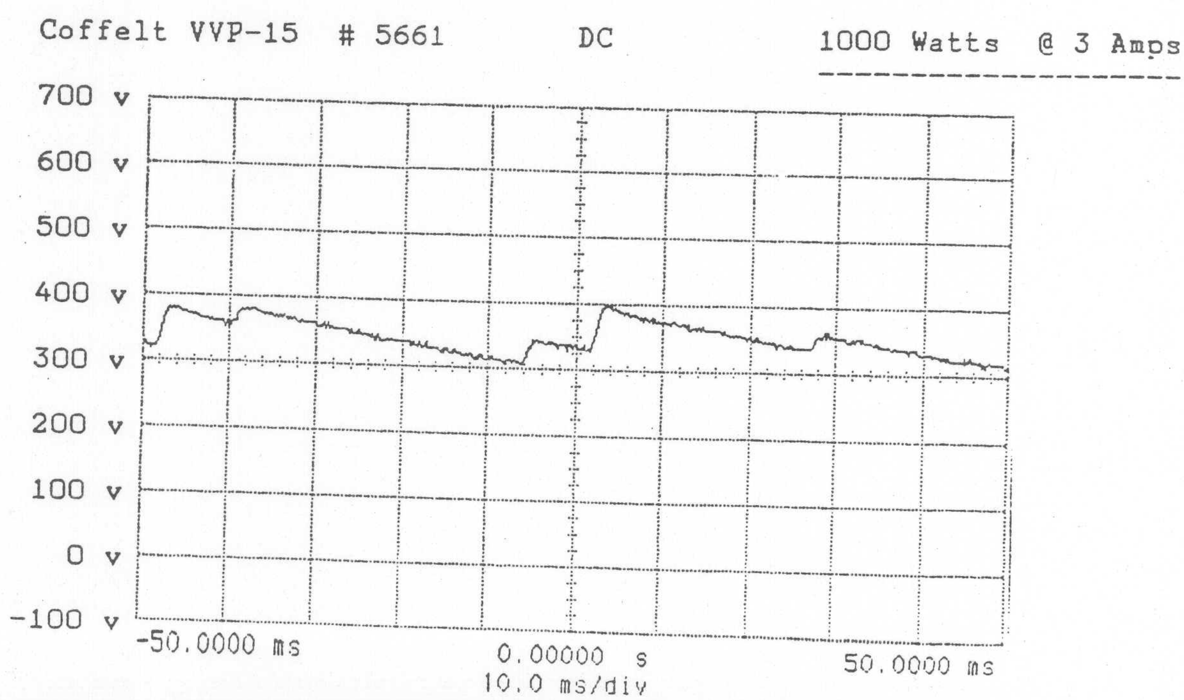


Leach loaner | FULL PULSE | 1000 Watts @ 3 Amps



"Straight" DC Waveforms





TEST #2
SPINAL INJURY RATE FOR RAINBOW TROUT IN RELATION TO WAVEFORM AND ELECTRODE ARRANGEMENT

PROCEDURES

Only rainbow trout ranging 14.0-17.0 inches total length were examined in this test. These fish were collected by elecrofishing the night of November 8, 1988 in the Hardy Creek section of the Missouri River using an 18-foot aluminum jet boat with the hull serving as the cathode. This section was chosen because it has not been electrofished since 1983 hence background injury levels would be expected to be low. Two Coffelt fiberglass booms were mounted on the front of the boat. "Strand" electrodes consisted of two 3/8-inch diameter stainless steel cables clamped at right angles to each other. These were suspended form each boom so that the four free ends from each boom were immersed to a depth of 6-8 inches in the water. The other electrodes used were Coffelt "Electrospheres" suspended from each boom and half immersed in water. Full immersion proved impractical from the standpoints of boat maneuverability and ability to effectively net fish. Electrospheres are hollow stainless steel spheres with a diameter of about 12 inches. Power was supplied by a Kawasaki 3200-watt 110/220-volt AC generator. A Coffelt VVP-2C (#8537) was used to produce pulsed DC using 110-volt input, and a VVP-15 (#900477) was used to produce "straight" DC using 220-volt input. River conductivity is typically around 375-400 micromhos in the fall. Experimental parameters are displayed in Table 1, readings were taken directly from meters on VVP's.

Rainbow specimens were individually numbered and wrapped after being anesthetized, measured and examined for external signs of injury. Fish were placed in padded containers to prevent spurious injury and were subsequently frozen. Specimens were individually X-rayed at a local veterinary clinic prior to thawing for autopsy. Autopsy included examining internal organs for evidence of trauma and examining skeletal structure after filleting muscle tissue from both sides. X-ray prints were sent to Norm Sharber at Coffelt Electronics for interpretation.

RESULTS

Only five of 151 fish examined at the time of collection showed external signs of trauma associated with electrofishing. Four of these showed minor 'brand' marks which can be likened to superficial burns. Three of the four branded fish were collected using "strands" and 110v pulse while the other was taken with "spheres" and the same electronics. One fish, taken with 220v straight DC, displayed continuous muscle tetany with no relaxation but showed no spinal damage in autopsy or on X-ray. No fish showed external evidence of spinal damage during field collection.

Table 1. Experimental parameters for tests conducted on the Hardy section of the Missouri River in November, 1988.

Rectifier type	Anode type	AC input	Output waveform	Dial setting	DC output
VVP-2C	Stands	110v	Pulse DC	110v	40v; 375 watts
VVP-2C	Sphere	110v	Pulse DC	110v	40v; 425 watts
VVP-15	Strands	220v	Straight DC	300v	7.6 amps

Although no obvious damage to internal organs was noted, three types of hemorrhaging were commonly found in the musculature of autopsied fish. All of the 151 rainbows examined displayed at least one type of hemorrhaging. A few (15 of 203) rainbows examined in Test #1 showed no evidence of spinal damage or hemorrhaging but all but two of these uninjured fish were less than 14 inches long.

Type I hemorrhaging was localized in spots along the vertebral column and typically involved two to several vertebrae which were often slightly dislocated and/or cracked. No obvious spinal damage could be detected in as many as half of the fish having these spinal hemorrhages but for this analysis it was assumed some injury occurred. Type II hemorrhaging involved blood vessels along dorsal and ventral spinal processes and was found in 50-75% of fish examined. This type of injury was typically not associated with damage to bony structures. Hence fish with only Type II hemorrhaging were classified as having no spinal injury. A third type of hemorrhaging was found below the spine along the posterior 1/3 of the body and did not appear to be associated with spinal damage.

Electrosphere Versus Strands

Spinal injury rates for rainbows collected using either spherical or strand type anodes were virtually identical (Table 2). Of particular interest is the fact that this conclusion would be drawn regardless of whether fish were autopsied, X-rayed, or both. However, X-ray observations appeared to be less variable than autopsy observations. Injury rate did not appear to be size related with the 14.0 to 17.0 inch length range. X-ray examination consistently revealed a greater number of spinal injuries than autopsy but interpretation of spinal X-rays is a difficult or impossible task for untrained observers. Total injury rate from X-rays of 67-69% is virtually identical to Sharber's findings using the VVP-15 and pulsed DC.

Pulse DC versus "Smooth" DC

Incidence of spinal injury was dramatically lower in fish collected using smooth DC as compared to those collected using pulsed DC (Table 2). It appeared as though injury rate actually declined in larger fish collected with smooth DC but this may be an artifact related to small sample sizes. Although spinal injury rates were much lower than those obtained using pulse D.C., the incidence of hemorrhaging was still 100%. As was seen previously, more injuries were identified through X-ray analysis than via autopsy. The relative percentages of injury determined by the two methods (autopsy and X-ray) varied considerably between inch groups in all three samples (Table 2). However, the relationship between total injury rate determined by autopsy versus X-rays was remarkably consistent. It appears as though a factor of 1.43 could be used to expand autopsy results to approximate X-ray results.

Table 2. Spinal injury rates for rainbow trout collected using various electrofishing gear in the Hardy section of the Missouri River during November 1988.

Collection method	Length (inches)	No. fish collected	% Spinal injury based on autopsy	% Spinal injury based on x-ray
VVP 2C, pulsed DC, w/Electrosphere				
	14.0-14.9	25	60%	68%
	15.0-15.9	18	39%	72%
	16.0-16.9	8	38%	63%
	TOTAL	51	49%	69%
VVP 2C, pulsed DC, w/Strands				
	14.0-14.9	22	36%	68%
	15.0-15.9	14	50%	71%
	16.0-16.9	14	57%	62%
	TOTAL	50	46%	67%
VVP 15, straight DC, w/Strands				
	14.0-14.9	5	0%	20%
	15.0-15.9	19	21%	32%
	16.0-16.9	19	16%	16%
	17.0-17.9	7	0%	0%
	TOTAL	50	14%	20%

CONCLUSIONS

Spinal injury incidence was remarkably high in rainbow trout samples obtained using pulsed DC considering few external symptoms were observed. Questions remaining to be answered are how these injuries influence growth, behavior and survival of rainbow trout and to what degree do they influence the accuracy of mark-recapture population estimates. Spherical anodes did not appear to be more effective in capturing fish and did not offer an advantage from an injury standpoint in this situation. Besides being less expensive, the cable type anodes were easier to work around and did not offer nearly s much resistance to boat maneuvering. The use of smooth DC offers significant advantage from an injury standpoint but past attempts to use this waveform on the Missouri resulted in 25-50% reductions in nightly catches.