Appendix B: Experimental Guidance Devices: NMFS Position Statements

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EXPERIMENTAL FISH GUIDANCE DEVICES: POSITION STATEMENT OF NATIONAL MARINE FISHERIES SERVICE NORTHWEST REGION JANUARY 1995

NMFS Northwest Region Position Paper on Experimental Technology for Managing Downstream Salmonid

Summary

NMFS believes that positive-exclusion barrier screens, as described below, are appropriate for utilization in the protection of downstream migrant salmon at all intakes. However, the process described herein delineates an approach whereby experimental behavioral guidance devices can be evaluated and (if comparable performance is confirmed to the satisfaction of NMFS) installed in lieu of screens.

Introduction

Numerous stocks of salmon and steelhead trout in Pacific Northwest streams are at low levels and many stocks continue to decline. Idaho sockeye salmon and Snake River spring, summer, and fall chinook are listed as "endangered" under the Endangered Species Act. Petitions for additional listings are pending. It is essential to provide maximum protection for all salmonid juveniles to halt and reverse overall population declines.

The death and injury of juvenile fish at water diversion intakes have long been identified as a major source of fish mortality [Spencer, 1928; Hatton, 1939; Hallock and Woert, 1959; Hallock, 1987]. Fish diverted into power turbines incur up to 40 percent immediate mortality, while also experiencing injury, disorientation and delay of migration that may increase predation related losses [Bell, 1991]. Fish entrained into agricultural and municipal water diversions experience 100 percent mortality. Diversion mortality is the major cause of decline in some fish populations. For the purposes of this document, diversion losses include turbine, irrigation, municipal, and all other potential fish losses related to the use of water by man.

Positive-exclusion barrier screens which screen the entire diversion flow have long been used to prevent or reduce entrainment of juvenile fish for diversions of up to 3,000 cfs. In recent decades, design improvements have been implemented to increase the biological effectiveness of positive-exclusion screen and bypass systems by taking advantage of known behavioral responses to hydraulic conditions. Recent evaluations have consistently demonstrated high success rates (typically greater than 98 percent) at moving juvenile salmonids past intakes with a minimum of delay, loss, or injury.

(For diversion flows over 3,000 cfs, such as at Columbia River main-stem turbine intakes, submerged traveling screens or bar screens are commonly used. These are not considered positive-exclusion screens in the context of this position statement.)

The past few decades have also seen considerable effort in developing "startle" systems to elicit a taxis (response) by the fish, with an ultimate goal of reducing entrainment. This paper addresses research performed to avoid losses at intakes and presents a position statement reviewing and implementing future fish protection measures.

Juveniles at Intakes

Entrainment, impingement, and delay/predation are the primary contributors to the mortality of juvenile migrating salmonids. Entrainment occurs when fish are drawn into the diversion canal or turbine intake. Impingement occurs when a fish is not able to avoid contact with a screen surface, trashrack, or debris at the intake. This can cause bruising, descaling, and other injuries. Impingement, if prolonged, repeated, or occurring at high velocities, also causes direct mortality. Predation (which is the leading cause of mortality at some diversion sites) occurs when fish are preyed upon by aquatic or avian animals. Delay at intakes increases predation by stressing or disorienting fish and/or by providing habitat for predators.

Positive-exclusion screen and bypass systems (PESBS)

Design criteria for PESBS have been developed, tested, and proven to minimize adverse impacts to fish at diversion sites. Screens with small openings and fish-tight seals are positioned at a slight angle to flow. This orientation allows fish to be guided to safety at the downstream end of the screen, while they resist being impinged on the screen face. These screens are effective at preventing entrainment [Pearce and Lee, 1991]. Carefully designed bypass systems minimize fish exposure to screens and provide hydraulic conditions that safely return fish to the river, thereby preventing impingement [Rainey, 1985]. The PESBS are designed to minimize entrainment, impingement, and delay/predation, from the point of diversion through the facility to the bypass outfall.

PESBS have been installed and evaluated at numerous facilities [Abernethy, et al., 1989; 1990; Rainey, 1990; Johnson, 1988]. A variety of screen types (e.g., fixed-vertical, drum, fixed-inclined) and screen materials (e.g., woven cloth [mesh], perforated plate, profile wire), have proven effective, when used in the context of a satisfactory design for the specific site. Facilities designed to previously referenced criteria consistently resulted in a guidance efficiency of over 98 percent [Hosey, 1990; Neitzel, 1985; 1986; 1990a; 1990b; 1990c; 1990d; 1991].

The main detriment of PESBS is cost. At diversions of several hundred cubic feet per second and greater, the low velocity requirement and structural complexity can drive the cost of fish passage to over $1 million. At the headworks, the need to clean the screen, remove trash, control sediment, and provide regular maintenance (e.g., seasonal installation, replacing seals, etc.) also increases costs.

Behavioral devices

Due to the high costs of PESBS, there has been considerable effort since 1960 to develop less expensive behavioral devices as a substitute for positive fish protection [EPRI, 1986]. A behavioral device, as opposed to a conventional screen, requires a volitional taxis on the part of the fish to avoid entrainment. Some devices were investigated with the hope of attracting fish to a desired area while others were designed to repel fish. Most studies focused on soliciting a behavioral response, usually noticeable agitation, from the fish.

Investigations of prototype startle-response devices document that fish guidance efficiencies are consistently much lower than for conventional screens. Experiments show that there may be a large behavioral variation between individual fish of the same size and species to startle responses. Therefore, it cannot be predicted that a fish will always move toward or away from that stimulus. Until shown conclusively in laboratory studies, it should not be assumed that fish can discern where a signal is coming from and what constitutes the clear path to safety.

If juvenile fish respond to a behavioral device, limited size and swimming ability may preclude small fish from avoiding entrainment (even if they have the understanding of where to go and have the desire to get there). Another concern is repeated exposure; fish may no longer react to a signal after an acclimation period. In addition to vagaries in the response of individual fish, behavioral variations due to species, life stage, and water quality conditions can be expected.

Another observation is that past field tests of behavioral devices have been deployed without consideration of how controlled ambient hydraulic conditions (i.e., the use of a training wall to create uniform flow conditions, while minimizing stagnant zones or eddies that can increase exposure to predation) can optimize fish guidance and safe passage away from the intake. Failure to consider that hydraulic conditions can play a big role in guiding fish away from the intake is either the result of the desire to minimize costs or the assumption that behavioral devices can overcome the tendency for poor guidance associated with marginal hydraulic conditions. The provision of satisfactory hydraulic conditions is a key element of PESBS designs.

The primary motivation for selection of behavioral devices relates to costs. However, much of the cost in PESBS is related to construction of physical structures to provide hydraulic conditions which are known to optimize fish guidance. Paradoxically, complementing the behavioral device with hydraulic control structures needed to optimize juvenile passage will compromise much of the cost advantage relative to PESBS.

Skepticism about behavioral devices, at this stage of their development, is supported by the fact that few are currently being used in the field and those that have been installed and evaluated seldom show consistent guidance efficiencies over 60 percent [Vogel, 1988; EPRI, 1986]. The louver system is an example of a behavioral device with a poor record. Entrainment rates were high, even with favorable hydraulic conditions, due to the presence of smaller fish. Entrainment can be high, particularly when operated over a wide range of hydraulic conditions [Vogel, 1988; Cramer, 1973; Bates, 1961]. Due to their poor performance, most of these systems were eventually replaced by PESBS.

Experimentation Process

However, there is potential for future development of new and acceptable screening and behavioral guidance devices that will safely pass fish at a rate comparable with PESBS. These new concepts are considered “experimental” until they have been through the process described herein and have been proven in a prototype evaluation validated by National Marine Fisheries Service (NMFS). These prototype evaluations should occur over the foreseeable range of adverse hydraulic and water quality conditions (e.g., temperature, dissolved oxygen). NMFS encourages research and development on experimental fish protection devices, and stipulates that the following elements should be addressed during the process of developing experimental juvenile passage protection concepts:

1) *Consider earlier research*. A thorough review of similar methods used in the past should be performed. Reasons for substandard performances should be clearly identified.
2) *Study plan*. A study plan should be developed and presented to NMFS for review and concurrence. It is essential that tests occur over a full range of possible hydraulic, biological, and ecological conditions that the device is expected to experience. Failure to receive

study plan endorsement from NMFS may result in disputable results and conclusions.

3) *Laboratory research.* Laboratory experiments under controlled conditions should be developed using species, size, and life stages intended to be protected. For behavioral devices, special attention must be directed at providing favorable hydraulic conditions and demonstrating that the device clearly induces the planned behavioral response. Studies should be repeated with the same test fish to examine any acclimation to the guidance device.
4) *Prototype units.* Once laboratory tests show high potential to equal or exceed success rates of state-of-the-art screening, it is appropriate to further examine the new device as a prototype under real field conditions. Field sites must be fully appropriate to (a) demonstrate performance at all expected operational and natural variables, (b) evaluate the species, or an acceptable surrogate, that would be exposed to the device under full operation, and (c) avoid unacceptable risk to depressed or listed stocks at the prototype locations.
5) *Study results.* Results of both laboratory tests and field prototype evaluations must demonstrate a level of performance equal to or exceeding that of PESBS before NMFS will support permanent installations.

Conclusions

During the course of the past few decades, we have seen an increase in the number of unscreened stream diversions, and this trend is likely to continue unless corrective measures are implemented. Concurrently, anadromous fish numbers have dwindled. Proven fish passage and protection facilities, which have demonstrated high guidance rates at other sites, can provide successful passage at most diversion intakes.

Periodically, major initiatives have been advanced to examine the feasibility of experimental guidance systems. Results were generally poor or inconclusive, with low guidance efficiencies attributable to the particular device used. Often results were based on a small sample size, or varied with operational conditions. In addition, unforeseen operational and maintenance problems (and safety hazards) were sometimes a byproduct.

Nevertheless, some of these experiments show potential. To further advance fish protection technology, NMFS will not oppose tests that proceed in accordance with the tiered process outlined above. To ensure no further detriment to any fish resource, including delays in implementation of acceptable passage facilities, experimental field testing should occur with the simultaneous design and development of a PESBS for that site. This conventional system should be scheduled for installation in a reasonable time frame, independent of the experimental efforts. In this manner, if the experimental guidance system once again does not prove to be as effective as a PESBS, a proven screen and bypass system can be implemented without additional delay and detriment to the resource.

Adopted January 6, 1995

WILLIAM STELLE, JR.

Regional Director

EXPERIMENTAL FISH GUIDANCE DEVICES: POSITION STATEMENT OF NATIONAL MARINE FISHERIES SERVICE SOUTHWEST REGION JANUARY 1994

NMFS Southwest Region Position Paper on Experimental Technology for Managing Downstream Salmonid Passage

Introduction

Numerous stocks of salmon and steelhead trout in California streams are at low levels and many stocks continue to decline. The Sacramento River winter-run chinook salmon is listed as "endangered" under the Federal Endangered Species Act. Petitions for additional listings are pending. It is essential to provide maximum protection for juveniles to halt and reverse these declines.

The injury or death of juvenile fish at water diversion intakes have long been identified as a major source of fish mortality [Spencer, 1928; Hatton, 1939; Hallock and Woert, 1959; Hallock, 1987]. Fish diverted into power turbines experience up to 40 percent mortality as well as injury, disorientation, and delay of migration [Bell, 1991], while those entrained into agricultural and municipal water diversions experience 100 percent mortality. Diversion mortality is the major cause of decline in some fish populations.

Positive barrier screens have long been tested and used to prevent or reduce the loss of fish. Recent decades have seen an increase in the use and effectiveness of these screens and bypass systems; they take advantage carefully designed hydraulic conditions and known fish behavior. These positive systems are successful at moving juvenile salmonids past intakes with a minimum of delay, loss, or injury.

The past few decades have also seen much effort in developing “startle” systems to elicit a taxis (response) by the fish with an ultimate goal of reducing entrainment. This Position Statement addresses research designed to prevent fish losses at diversions and presents a tiered process for studying, reviewing, and implementing future fish protection measures.

Juveniles at Intakes

The three main causes of delay, injury, and loss of fish at water intakes are entrainment, impingement, and predation. Entrainment occurs when the fish is pulled into the diversion and passes into a canal or turbine. Impingement is where a fish comes in contact with a screen, a trashrack, or debris at the intake. This causes bruising, descaling, and other injuries. Impingement, if prolonged, repeated, or occurs at high velocities, also causes direct mortality. Predation also occurs. Intakes increase predation by stressing or disorienting fish and/or by providing habitat for fish and bird predators.

Positive barriers

Positive barrier screen systems and criteria for their design have been developed, tested, and proved to minimize harm caused at diversions. Positive barriers do not rely on active fish behavior; they prevent physical entrainment with a physical barrier. Screens with small openings and good seals are designed to work with hydraulic conditions at the site, providing velocities normal to the screen face and sufficient sweeping velocities to move fish past the screen. These screens are effective at preventing entrainment [Pearce and Lee, 1991]. Carefully designed bypass systems minimize fish exposure to screens and provide hydraulic conditions that return fish to the river, preventing both entrainment and impingement [Rainey, 1985]. The positive screen and fish bypass systems are designed to minimize predation, and to reduce mortality, stress, and delay from the point of diversion, through the bypass facility, and back to the river.

Carefully designed positive barrier screen and bypass systems have been installed and evaluated at numerous facilities [Abernethy, et al., 1989; 1990; Rainey, 1990; Johnson, 1988]. A variety of screen types (e.g., flat plate, chevron, drum) and screen materials (e.g., woven cloth, perforated plate, profile wire), have proved effective, taking into consideration their appropriateness for each site. Well-designed facilities consistently result in a guidance efficiency of over 95 percent [Hosey, 1990; Neitzel, 1985; 1986; 1990a; 1990b; 1990c; 1990d; 1991].

The main drawback to positive barrier screens is cost. At diversions of several hundred cubic feet per second or greater, the low velocity requirements and structural complexity can drive the cost for fish protection and the associated civil works over a million dollars. At the headwork, the need to clean the screen, remove trash, and provide regular maintenance (e.g., seasonal installation, replacing seals, etc.) also increase costs.

Behavioral devices

Due to higher costs of positive barrier screens, there has been much experimentation since 1960 to develop behavioral devices as a substitute for barrier screens [EPRI, 1986]. A behavioral device, as opposed to a positive (physical) barrier, requires a volitional taxis on the part of the fish to avoid entrainment. Early efforts were designed to either attract or repel fish. These studies focus on soliciting a behavioral response from the fish, usually noticeable agitation. Using these startle investigations to develop effective fish guidance systems has not been effective.

Experiments show that there is a large response variation between individual fish of the same size and species. Therefore, it cannot be predicted that a fish will always move toward or away from a certain stimulus. Even when such a movement is desired by a fish, it often cannot discern the source or direction of the signal and choose a safe escape route.

Many behavioral devices do not incorporate and use a controlled set of hydraulic conditions to assure fish guidance, as does the positive screen/bypass system. The devices can actually encourage fish movement that contrasts with the expected rheotactic response. Thus, the fish gets mixed signals about what direction to move. Another concern is repeated exposure; a fish may no longer react to a signal that initially was an attractant or repellent. In addition to the vagaries in the response of an individual fish, behavior variations are expected due to size, species, life stage, and water quality conditions.

In strong or accelerating water velocity fields, the swimming ability of a fish may prevent it from responding to a stimulus even if it attempts to do so. Other environmental cures (e.g., pursuing prey, avoiding predators, or attractive habitat) may cause a fish to ignore the signal.

A main motivation for opting to install behavioral devices is cost-savings. However, much of the cost in conventional systems is for the physical structure needed to provide proper hydraulic conditions. Paradoxically, complementing a behavioral device with its own structural requirements may lessen much of its cost advantage.

Present skepticism over behavioral devices is supported by the fact that few are currently being used in the field and those that have been installed and evaluated seldom exhibit consistent guidance efficiencies above 60 percent [Vogel, 1988; EPRI, 1986]. The louver system is an example of a behavioral device with a poor success record. In this case, even with the use of favorable hydraulics, performance is poor especially for small fish. Entrainment can be high, particularly when operated over a wide range of hydraulic conditions [Vogel, 1988; Cramer, 12973; Bates, 1961]. Due to their poor performance, some of these systems are already replaced by positive barriers.

Experimentation Process

However, there is potential for developing new positive screens as well as behavioral guidance devices for the future. Nonetheless, experimental technology must achieve, over the foreseeable range of adverse conditions, a consistent level of success that equals or exceeds that of the best available technology. It should be a deliberate, logical process. NMFS will not discourage research and development on experimental fish protection devices if the following tiered study process is incorporated:

1) *Consider earlier research.* A thorough review should be performed of past methods similar to that proposed. Reasons for substandard performances of these earlier methods should be clearly identified.
2) *Study plan.* A study plan should be developed and presented to NMFS for review and concurrence. It is essential that tests occur over a full range of possible hydraulic, biological, and ecological conditions that the device is expected to experience.
3) *Laboratory research.* Controlled laboratory experiments should be developed using species, size, and life stages intended to be protected (or acceptable surrogate species). For behavioral devices, special attention must be directed at providing favorable hydraulic conditions and demonstrating that the device clearly causes the planned behavioral response. Studies should be repeated with the same test fish to examine and habituation to the stimulus.
4) *Prototype units.* Once laboratory tests show high potential to equal or exceed success rates of state-of-the-art screening, it is appropriate to further examine the new device as a proto-

type under real field conditions. Field sites must be fully appropriate to 1) demonstrate all operation and natural variables expected to influence the device performance, 2) evaluate the species, or an acceptable surrogate, that would be exposed to the device under full operation, and 3) avoid unacceptable risk to resources at the prototype locations.

5) *Study results*. Results of both laboratory tests and prototype devices examined in the field must demonstrate a level of performance equal to or exceeding that of conventional, established technology before NMFS will support further installations.

Conclusions

In the course of the past few decades, we have seen increased demand for water diversions. This trend is likely to continue. Accompanying this demand is a corresponding decline of fisheries. Therefore, prudence dictates that fish protection facilities be held to the highest practicable level of performance.

A major effort was made to examine experimental guidance systems over several decades by a variety of funding agencies. The results were generally poor or inconclusive, with low guidance efficiencies attributable to the particular device used. Often results were based on a small sample size or varied with operation conditions. In addition, unforeseen operational and maintenance problems, including safety hazards, sometimes developed.

Nevertheless, some of these experiments show potential. To further improve fish protection technology, NMFS will not oppose tests that proceed in the tiered process outlined above. Further, to ensure no further detriment to fish, experimental field testing should be done with the simultaneous design of a positive barrier and bypass system for that site. This conventional system should be scheduled for installation immediately, if the experimental guidance system, once again, does not prove to be as effective as a conventional system.

Adopted January 11, 1994
GARY C. MATLOCK, PH.D.
Acting Regional Director

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