Appendix A: Overview of Fish Passage and Protection Technologies in the Columbia River Basin

A

ABSTRACT[1]

Commercial exploitation of Columbia River salmon and steelhead began in the mid-1800s. Concurrent with commercial exploitation of adult fish was modification and destruction of spawning and rearing habitat by various landuse practices. In addition, survivorship of downstream migrants was negatively affected by unscreened irrigation diversions and entrainment of smolt in irrigation water. By 1920, prior to construction of mainstem dams, it was clear that the salmonid stocks of the Columbia River had been reduced significantly.

Construction of mainstem dams created additional challenges to the migration of adult and juvenile fish in addition to causing additional habitat degradation. The single most significant impact to Columbia River salmon stocks was the construction of Grand Coulee Dam, which was built without fish ladders and eliminated all the stocks originating above the dam site.

Fish passage research began with the study of the Bonneville Dam fish ladders, which passed adult migrants very successfully. During the early stages of dam construction conventional wisdom was that juvenile fish were not injured during passage through hydro turbines so smolt passage through dams was not a topic of research. The U.S. Army Corps of Engineers (COE) built a research laboratory at Bonneville Dam that was used for 30 years to study the behavioral response of adult migrants to elements of fish ladder design. The research conducted at the laboratory made major contributions to the success of fish ladders at other Columbia River Dams. Although adult migration behavior research continues to the present, its focus is on broader ecological questions.

Research of juvenile fish passage began with development and evaluation of screens for irrigation diversions. Continued research in this area for over half a century has resulted in irrigation diversion screens that are effective in preventing juvenile migrants from being entrained in irriga-

[1] This appendix is derived from T.J. Carlson, "Overview of Aspects of the Development of Adult and Juvenile Migrating Fish Passage and Protection Technologies Within the Columbia River Basin," unpublished contractor report prepared for the Office of Technology Assessment, U.S. Congress, Washington, DC, July 1995.

tion water. Current research efforts are focused on evaluation of behavioral barriers using infrasound that will reduce the movement of juveniles past the headworks of irrigation diversions.

Juvenile fish passage research at mainstem dams has been mostly concerned with prevention of juveniles from passing through turbines. Since the early 1960s turbine intake screens have been in development to divert juveniles from turbine intakes and into bypass facilities for return to the river or transport. Most of the mainstem dams have been equipped with intake screens, and a major portion of the juveniles passing down the Snake River are collected for transport.

Investigations conducted in the 1960s showed that surface oriented flows were effective under some conditions in attracting juvenile migrants to alternative bypass routes prior to turbine passage. Subsequent research has further developed surface collection of smolts. Surface collection has been successfully developed at Wells Dam on the upper Columbia River, where over 90 percent of smolts are passed by the dam through modified spill bays utilizing less than 5 percent of the hydraulic capacity of the dam's powerhouse. Major surface collection research programs were initiated in 1995 by private utilities and the COE. Preliminary results are very encouraging and surface collection has become a major focus for current smolt passage research.

INTRODUCTION

The Columbia River is the second largest river in the continental United States in terms of volume, with a total length of over 1,200 miles. Historically, flows in the lower Columbia often exceed 200,000 cubic feet per second, with wild fluctuations following snow melt and rains in the spring. The Columbia drains 258,000 square miles, an area larger than several states. The watershed extends into four Northwest states: Washington, Oregon, Montana, and Idaho.

Documented exploration of the Columbia River by Europeans began in the late 1700s with Capt. Robert Gray, who crossed the Columbia River bar, a treacherous area of strong currents and turbulent water, and explored parts of the lower Columbia in the spring of 1792. It was Capt. Gray who gave the river its European name. Several years later, in 1805, Lewis and Clark traveled down the Columbia, reaching the Pacific Coast in November. The reports of Lewis and Clark documented the many rapids and falls in the Columbia River that initially were simply hazards to navigation but later were exploited for hydropower production. They also documented the richness of the salmon and steelhead runs to the river and their use by the native population (21,43,45).

There has been considerable discussion of the historical size of salmon and steelhead runs to the Columbia River. Estimates range from highs around 35 million to lows in the region of 6 to 7 million. For planning purposes, the Northwest Power Planning Council (NPPC), created by act of Congress in 1980 to develop and oversee implementation of a program for restoration of Columbia River stocks, estimated that the historical run sizes ranged between 12.5 to 13 million fish (59). Current run sizes are on the order of 2.5 million fish, which amounts to a loss, on average, of approximately 10 million fish (43). Research continues to try to better understand the historical production of Columbia River Basin salmon and steelhead. Discussion of the historical carrying capacity of the Columbia River Basin is of more than academic interest as efforts to restore habitat and recover stocks begin to focus on identification of critical habitat for restoration and targets for stocking levels. Of particular interest are recent efforts at template analyses of the many habitat features and climatic trends that influence ecosystem carrying capacity and discussions of the recovery potential of discreet stocks (38).

Although certainly exploited through aboriginal times, intensive commercial exploitation of salmon and steelhead didn't begin until the mid-1800s. Early efforts at commercial exploitation of salmon by salting and shipping to eastern U.S. markets were unsuccessful because of poor product quality. However, the introduction of canning in 1866 provided the means to preserve salmon quality over the long periods required for shipping while delivering a desirable product at low cost. With this innovation the commercial exploitation of salmon and steelhead started in earnest. Unlike today, the large quantities of salmon available and low cost of production made salmon a cheap food for the working class (43).

Analysts partition the historical commercial exploitation of Columbia River salmon and steelhead into several phases. The period from 1866 to present may be divided into four phases: initial development of the fishery (1866-1888); a period of sustained harvest with an average annual catch of about 25 million pounds (1888-1922); resource decline with an average annual harvest of 15 million pounds (1923-1958); and maintenance at a depressed level of production of about 5 million pounds (1958 to present) (38). Additional declines recently may indicate a new lower level of production and a fifth phase of exploitation. Another, similar analysis utilizes essentially the same periods with the exception of dividing the period of decline (1923-1958) into two segments bracketing the years prior to and following mainstem dam construction (46).

Exploitation rates, the percentage of the total run caught, at the height of commercial exploitation are estimated to have been in excess of 80 percent compared to estimated aboriginal exploitation rates of approximately 15 percent (19). Beginning with commercial exploitation and continuing in some cases until the mid-1940s, a wide range of traps, nets, and other miscellaneous fishing gear were utilized to capture fish. As late as the 1940s, gear such as large seines were used to take up to 70,000 pounds of salmon on single days. Such gear was not outlawed by both Washington and Oregon until 1949 (21,43).

Coincident with commercial exploitation was widespread settlement of the Columbia River Basin with accompanying natural resource exploitation in the form of mining, logging, and agriculture. Use of the many tributaries to the Columbia and Snake Rivers by anadromous fish was very obvious to the early settlers, and the potential damage to fish stocks by inappropriate use of these rivers and streams was clear. As early as 1848 the Oregon Territory had laws prohibiting obstruction of access to spawning and rearing habitat by dams or other means. However, the laws were not rigorously enforced and many dams were constructed that were barriers to fish. By the early 1930s, prior to construction of mainstem dams, it was reported that dams on the Columbia River and its tributaries had eliminated access by fish to approximately 50 percent of the most valuable salmon production areas. In addition, because of the state of the art in design and operation of fish ladders, many early attempts at providing passage for adult migrants were failures. An example was Sunbeam Dam, constructed on a tributary to the Salmon River to provide electric power for gold dredges. While Idaho Fish and Game evaluated the dam's fish ladder as useless, the dam was permitted to operate for 20 years until 1934, earning the reputation of perhaps being the primary reason for loss of Redfish Lake sockeye salmon, now listed as an endangered species (43).

Significant dangers also existed for downstream migrants beginning during the earliest stages of settlement of the Columbia River Basin. As early as the 1870s large losses of smolt to irrigation diversions were observed. There were hundreds of larger irrigation diversions and perhaps thousands of smaller ones as farmers withdrew water for crops. Most of these diversions were unscreened, and untold millions of smolt and other juvenile fish were annually drawn into the diversions, ultimately ending up with the water on crops. In the early 1900s, laws passed much earlier but not rigorously enforced were amended, ordering irrigators and others operating water diversions to comply with screening laws. While many wanted to comply with the law, screening devices to do the job were not available. It wasn't until 1911 that a revolving drum screening device was invented and in evaluation (21). There were myriad other less obvious impacts to salmon populations from agricultural practice. An example is the loss of riparian vegetation by logging, the conduct of farming, or destruction by cattle. Loss of riparian cover probably caused heating of stream water, negatively impacting adult migration and degrading the rearing environment for juveniles.

Review of history shows that Columbia River Basin salmon and steelhead stocks had been very significantly reduced from historic levels prior to construction of mainstem dams. The losses resulted from a variety of land use practices common at the time. Nevertheless, the result was wide-scale habitat modification and destruction concurrent with dramatic reduction in adult returns through commercial exploitation, sport fishing, and high rates of juvenile mortality by agricultural practice.

The first dam on the mainstem Columbia River was Rock Island Dam, which was put into service in 1933. Rock Island was a private dam, constructed by the Washington Electric Company (21). The first federal dam on the Columbia was Bonneville Dam, completed in 1938. Bonneville was followed by Grand Coulee Dam in 1941. Considerable thought was put into the design of fish ladders for Bonneville Dam. It was realized at the time that their success would depend on their ability to attract adult migrants, so the ladder entrances were supplied with water in addition to that flowing through the ladders to provide attraction flow. The Bonneville design was successful and was studied and used as the basis for the design of many other fish ladders within the Columbia River Basin and elsewhere.

Grand Coulee Dam was another matter all together. A high reservoir elevation was needed to enable pumping of water for irrigation purposes, plus a high-head dam would have greater power production potential. Therefore, in spite of initial congressional intention for a low-head dam, Grand Coulee was eventually built as a high-head dam, almost 550 feet tall. The problem for salmon with a dam as high as Grand Coulee was that fish ladders were not considered feasible for dams over 100 feet high. As a result, fish ladders were not built as part of Grand Coulee Dam, and salmon runs to all of the upper Columbia River drainage, literally hundreds of miles of rivers and streams and thousands of square miles of habitat, were forever cut off from access.

During the three decades following construction of Grand Coulee, eight more large dams were constructed on the mainstem Columbia and four on the lower Snake River. All but four of these dams were built by the federal government. In 1937, near completion of construction of Bonneville Dam, the Bonneville Power Administration (BPA) was created to market the power of Bonneville Dam and was later responsible for marketing the power of the whole Columbia River federal hydropower system. The role of BPA was changed in a very marked way in 1980 when Congress, upon creation of the NPPC with passage of the Pacific Northwest Electric Power Planning and Conservation Act (Public Law 96-501), charged BPA with implementation of the Columbia River Basin Fish and Wildlife Program to be developed by NPPC for restoration of Columbia River salmon and steelhead stocks.

The design of mainstem dams was driven by several objectives: power production, irrigation, flood control, recreation, and navigation. Other uses were lower priority while the priority of the major objectives changed from time to time. The emphasis on power production for Bonneville and Grand Coulee Dams may have been a decisive factor in the United States winning the Second World War. The large amount of power available permitted high-volume production of aluminum for airplanes and diversion of large amounts of power to the Hanford Works, where nuclear materials for the first atomic bombs were manufactured. However, the sites selected and aspects of the designs of dams did have additional negative impacts for fish. In the Snake River, lobbying by the Inland Empire Waterways Association resulted in locating the lower Snake River dams on the mainstem Snake to enable barge transport all the way to Lewiston, Idaho. Mainstem sites were eventually selected even though the economic return from navigation was considerably lower than that from power production and the potential for power production was greater at tributary sites, which would have greatly reduced the impact to Columbia River Chinook salmon stocks (43,62).

From the earliest days of fish harvest and natural resource utilization within the Columbia River Basin, there were always advocates for fish and investigators working to find ways to lessen the impact of human activities on the fish. However, funding for fish passage research was very scarce in the early years, partially because state and federal agencies failed to appreciate the value of systematic fish passage research. Most progress in addressing fish passage issues was through trial and error experimentation by a small number of dedicated biologists. Fish passage research was also not given a higher priority because there was widespread belief that artificial propagation of salmon and steelhead could overcome habitat losses. It was common during the dam-building decades for habitat lost through dam construction to be mitigated by construction and operation of fish hatcheries. It would not be until the 1980s that the failings of this strategy were better understood.

OVERVIEW OF COLUMBIA RIVER BASIN FISH PASSAGE RESEARCH: PAST TO PRESENT

Well-funded fish passage research did not really begin in the Columbia River Basin prior to initiation of construction of large mainstem dams. This came about because of an increasing realization in the 1930s by the public that the Columbia River fish stocks were in serious trouble. Incentive for fish passage research came from The Fish and Wildlife Coordination Act which was passed in 1934 and amended in 1946 and 1958. Initially the act required the U.S. Army Corps of Engineers (COE) and other water development agencies to consult with the states and the U.S. Fish and Wildlife Service about damage to natural resources. The later amendments placed increasing emphasis on natural resources, with the 1958 amendment requiring water development agencies to give conservation and enhancement of fish and wildlife equal consideration with other project objectives. Later in the 1970s, further emphasis was placed on fish and wildlife by the National Environmental Policy Act and the Endangered Species Act. Federal legislation has been augmented up to the present by the results of litigation such as the Boldt decision and the *United States* v. *Oregon* (21, 43).

Adult Fish Passage

The early years of fish passage research were focused on assisting upstream migration by adults. The first products of this effort were the successful fish ladders at Bonneville Dam (75). A very important factor during the early years of fish passage research was the existence of a fish passage laboratory at Bonneville Dam. The initial focus of the laboratory was to understand the apparent success of the Bonneville fish ladders, their success being a surprise to almost everyone involved. At the time of construction of the Bonneville ladders and, for that matter, a significant period following, virtually nothing was known about the design of fish ladders at the scales required for large dams that migrants would react favorably to and use. To meet these research needs the COE built the Bonneville Fisheries Engineering Research Laboratory in 1955. Significant amounts of fish passage research were conducted at the laboratory until its demise in 1985. Almost all of this work was basic fish behavioral research. Typical questions addressed included: the rate at which fish ascend fishways; maximum swimming velocities of fish; the optimum physical dimensions for fish ladders and other facilities; etc. (20).

Work on aspects of the migration of adult fish has been continuous over the intervening years and continues to the present. There has been a gradual transition from focus on issues related to the design and operation of fish ladders to resolution of uncertainties existing within a broader ecological context. Issues being addressed at present at several locations within the Columbia River Basin include habitat use, delays in passage at irrigation diversions, migration rates, substock separation, spawner success and production, including causes of prespawning mortality, and response of adults to factors such as flow manipulation for irrigation or power production, increased turbidity, and general decreased water quality due to irrigation (17,18,33,34,69). Adult passage work has been greatly assisted by developments in radio telemetry and the global positioning system. Improved instrumentation and deployment methods now permit adult migrants to be tracked over long distances with high spatial and temporal resolution. This work is permitting identification of problems that are limiting recovery of stocks as well as proving essential in developing strategies for other aspects of stock restoration. For example, an element of restoration of specific stocks may be hatchery supplementation. However, facilities for capture and holding of adult migrants must be located so that the stock of interest can be segregated from others. Fish tracking studies permit identification of those places within a watershed where a particular stock might be isolated for such purposes.

A system where wide adult migrant radio tracking study is to be performed beginning in 1996. The study will be funded by the COE and performed primarily by the National Marine Fisheries Services with cooperation by various other state and federal agencies, universities, and private utilities. The primary objective of the study is to observe the migratory behavior of adult salmon as they move through the hydropower system and onto their spawning grounds (25). Of particular interest are the delay of migrants at dams, fallback, straying, and prespawning mortality. The scope of the study includes the hydropower system as a whole, a considerable expansion in scope over most previous studies which tended to be project-specific, thereby very localized in comparison.

Juvenile Fish Passage

Protection of juvenile fish during downstream migration has historically focused in several areas. The areas of major investment in juvenile fish passage research have been: 1) protection from entrainment in irrigation diversions, 2) diversion from turbine intakes, 3) reduction in mortality due to predation, 4) reduction in exposure to high levels of dissolved gas, and 5) reduction in delay during outmigration. While listed as discreet juvenile fish passage concerns, there are interdependencies in the basic biology and behavior of juvenile fish between these elements. These interdependencies make experimentation to isolate an individual element quite difficult and also have resulted in overlap between research programs targeted on specific elements. This overview will be restricted to elements 1) and 2), with emphasis on diversion from turbine passage by surface collection.

The volume of research conducted in these areas, and others, to improve downstream passage for smolt has been huge. Literally hundreds of studies, almost all field studies, have been conducted within the last 40 years throughout the Columbia River Basin. These studies have greatly increased the knowledge base of the behavior and factors influencing the survivorship of smolt. The following sections will provide a brief overview of this work. This is not intended to be a synoptic review but rather an abbreviated guide to provide context for discussion of research currently in progress or planned for the immediate future.

Irrigation Diversion Screening

As mentioned previously, it was apparent to all who looked back to as early as the mid- to late-1800s that juvenile migrants were being entrained in irrigation diversions and killed on farmers' fields. Early records also show tension between the states and the federal government during this time. Although the states of Washington and Oregon had irrigation diversion screening laws as early as 1894, the federal government was not required to comply with the laws. In 1911, Oregon petitioned the federal government for compliance with Oregon state irrigation diversion screening laws (21).

As an element of the Fish and Wildlife Program, NPPC has identified screening of irrigation diversions as a priority (58). Irrigation diversions range from small, a few cubic feet per second, to large, thousands of cubic feet per second. Irrigation diversion screens are typically located downstream from the headworks for the diversion, sometimes a considerable distance, e.g., several hundreds of meters. Screening facilities for midsize and larger diversions typically have capability at the screening facility for separation of smolt from irrigation water. Following separation, smolt are returned to the mainstream via a fish return conduit. The tolerances for the mechanical and hydrodynamic elements of screening facilities are quite tight and must be kept in tolerance if the facility is to function properly and protect migrants. Evaluations conducted to date indicate that screening facilities kept in tolerance do provide high levels of protection to migrants (1,23,35,47,48,49,50,51).

Present research of irrigation diversion screening includes development and evaluation of behavioral barriers to reduce the number of migrants passing through headworks and into diversion canals. The reason for wanting to reduce the number of smolt entering the diversion canal is to reduce handling of migrants. While screening facilities are effective, they do require that smolt be passed through facilities to separate them from irrigation flow, concentrated into a smaller volume of water, and returned to the mainstream. The effects on smolt behavior and health of these actions are not clear, but the general assessment is to avoid them if possible. The Bonneville Power Administration, in cooperation with COE, has funded research beginning in 1995 into behavioral barriers. An objective of this research is to evaluate the use of infrasound to divert smolt at the headworks of irrigation diversion canals (52). Initial laboratory experiments recently completed have demonstrated avoidance by juvenile Chinook salmon and steelhead of high-intensity, high-particle-displacement 10-Hz sound. In addition, limited observations at a small irrigation diversion on the Umatilla River during the 1995 smolt outmigration have shown repulsion of Chinook salmon smolt from entering the irrigation canal (68).

Turbine Intake Passage and Diversion

At the time of construction of Bonneville Dam, conventional wisdom was that there was little danger of juvenile fish being injured during passage through hydro turbines. By the 1940s it was clear that passage conditions for fish through turbines could range from good to awful. Initial experiments indicated that direct mortalities through turbines typical of the Columbia River hydropower system were in the range of 15 percent (43). Subsequently, considerable research of fish passage through turbines was conducted in Europe and the United States (2,24,44). As a consequence of this work, operating criteria for Columbia River hydrosystem turbines was developed, the most significant being the mandate for operation of turbines at peak efficiency during periods of smolt passage.

There is currently a renewed interest in the conditions fish face during passage through turbines. Both the federal government and private utilities are performing studies to reassess injuries to smolt during passage through turbines. Recent experiments indicate 90-96 percent survival of juvenile salmon during turbine passage and that the majority of injuries observed are due to mechanical strike (63,64,65). As a result of study findings, the owners of Rocky Reach Dam are having the runners of a turbine modified to reduce the gap between the runner and the hub. This gap has been identified as the probable source for many, perhaps the majority, of mechanic injuries to juvenile fish during passage (22). In a comparable effort, COE is in the planning stage of a program to develop turbines that minimize the mortality of juvenile fish (72). Interest in providing a safer passage environment for juvenile fish is due to the fact that turbine bypass measures have not been and are unlikely to prove 100 percent effective. This means that some percentage of smolt will always pass through turbines. Under some conditions and for some species more so than others, a considerable proportion of a species may pass through turbines even when turbine bypass measures are fully implemented because of variation in migratory behavior between species and behavioral responses to turbine bypass guidance mechanisms.

Upon discovery that hydro turbines could kill and injure juvenile fish, considerable effort was made to develop methods to divert fish from turbine intakes. Early studies of the vertical distribution of smolt entering turbine intakes showed that many juvenile fish were located in the upper third of turbine intakes (39), although it was clear that smaller fish of all species and one or two species in total tended to be more deeply distributed (30,37). Experience with irrigation diversion screens and other similar screens led to development of a screen to be deployed in turbine intakes. Development continued through the 1960s, resulting in testing in 1969 of a prototype turbine intake screen at Ice Harbor Dam (40). Studies of prototype screens demonstrated that large numbers of juvenile fish could be diverted by turbine intake screens. When it was found that juvenile fish could be diverted and concentrated into bypass facilities, studies were initiated to evaluate the feasibility of transporting the juveniles to below Bonneville Dam, thereby eliminating their exposure to downstream dams. Initial evaluations showed positive results, and in 1971 a prototype collection and transportation system was evaluated at Little Goose Dam (43). At the present time, collector dams on the Columbia and Snake Rivers collect a significant portion of the total outmigration for transportation by truck and barge to below Bonneville Dam.

Development and evaluation of turbine intake screens continues to the present as the operation of those already installed is optimized and the design of those to be installed is refined. While most appear to be operating satisfactorily, not all intake screens are as effective as the vertical distribution of juvenile fish would imply. In general, it appears that juvenile fish respond to the modification of flow resulting from the presence of the intake screens, which, in at least the case of Rocky Reach Dam, rendered intake screening ineffective as a turbine bypass option (31,32). Visual observations of the behavior of smolt upon encounter with turbine intake screens has led to the hypothesis that the screens may act as hydromechanical sources of infrasound, which is detectable by salmonids and may be the stimulus for avoidance response (53,54).

There is considerable contention about the desirability of handling and transporting juvenile fish. While development, evaluation, and installation of turbine intake screens continue, other bypass alternatives are also being evaluated and, in the case of spill, utilized on a wide scale. The injury to fish during spill is thought to be significantly less than turbine passage and potentially even less than for fish diverted by intake screens and placed into bypass channels or otherwise handled (67). However, comparisons of the direct injury to smolt passing through turbines, spillways, and bypass systems have not been made at most dams. Assessment of smolt injury passing through dams via these various routes is an element of Phase II of the COE System Configuration Study Program which is at startup in 1995 (25).

Also an element of Phase II of the COE System Configuration Study is assessment of surface collection as a means of passing juvenile migrants past dams. The idea behind surface collection is to present a flow stimulus to downstream migrants that will take advantage of their natural outmigration behavior and lead them into a bypass leading around the dam or into collection facilities for transport. Surface collection is not a new concept and has been extensively tested with mediocre to poor success at scales considerably smaller than those required at mainstem Columbia River dams (27,28,61,66,70,74,73).

The impetus for retaining surface collection as a viable fish passage measure for mainstem Columbia and Snake River dams has been observations over the years of the high effectiveness and efficiency of ice and trash sluiceways, present at many Columbia River dams, under certain conditions as a means for bypassing migrants. Early investigation of the ice and trash sluiceway at Bonneville Dam indicated that during the day a large portion of total migrant passage was through the sluiceway, even through sluiceway flows were less than 5 percent of project total flow (41). This study lead to the recommendation that the ice and trash sluiceways at other projects be evaluated for downstream fish passage. In subsequent years similar studies were performed at The Dalles and Ice Harbor Dams (5,42,55,60). The findings in all these studies were similar. The sluiceways were very effective in passing migrants during the day, with effectiveness decreasing very markedly at night. While up to 80 percent of migrants passing the dam during the day might pass in sluiceway flows, sluiceway passage would drop to 20 percent or less of total passage at night. It soon became apparent that there were changes in the vertical distribution of migrants day to night and that there were probably other aspects of smolt behavior as well that determined the proportion of fish passing through sluiceways.

During the 1980s, in parallel with federally funded research to evaluate ice and trash sluiceways, Douglas County Public Utility District was evaluating modifications to its hydrocombine units at Wells Dam that might serve as a means to bypass smolt without using turbine intake screens. A hydrocombine is a unique design for a hydropower dam where the spill bays are located directly over the turbine units. Early studies of the distribution and passage behavior of smolt at Wells Dam indicated that the fish might pass in modified spill flows (3,4,5). Over the years between 1984 and 1993, Douglas County was able to develop a design for modification of spill bays and operation of the modified bays to achieve in excess of 90 percent passage of smolt in modified spill using approximately 5 percent of powerhouse hydraulic capacity (8,9,10,11,12,13,14,15,16,36).

Wells Dam has become the model for downstream migrant passage using surface collection concepts. The characteristics of the modified hydrocombine spill bays have become the basis for other efforts. The combination that proved successful was a slot 16 feet wide and approximately 70 feet deep, located at the face of the dam upstream of the spill gate. The spill gate downstream of the slot is operated so that velocities through the slot average approximately 2 feet per second. As in the case of the successful Bonneville Dam fish ladder 50 years earlier, it is not understood why the Wells Dam smolt bypass system works. There are some clues, one of which is the vertical distribution of smolt relative to the depth of the bypass slots. It appears that during both day and night periods at least 80 percent of the smolt approaching Wells Dam are located at depths less than 70 feet (71).

During the smolt outmigration of 1995, Public Utility District No. 1 of Chelan County tested a surface collection prototype at its Rocky Reach Dam. Characteristics of the operation of the Rocky Reach prototype surface collector are modeled after the Wells Dam bypass but utilize a completely different approach since Rocky Reach is a classical hydropower dam with separate powerhouse and spill. The evaluation of this prototype is still underway at the writing of this report, but initial evaluation appears favorable. Preliminary data indicates that the surface collector prototype may have passed more than an order of magnitude more smolt than the prototype bypass based on turbine intake screens evaluated in previous years (over 1 million smolt compared to 75,000). Based on this favorable performance, Chelan County expects to expand the coverage of the powerhouse by the prototype for the 1996 outmigration and continue evaluation (22).

Also during the 1995 smolt outmigration, Public Utility District No. 2 of Grant County evaluated a surface collection prototype at Wanapum Dam on the mainstem Columbia River. The design of this surface collector is different from both the Wells Dam bypass and the Rocky Reach prototype but it still utilizes the water velocities at the entrance to the collector found effective for the Wells Dam bypass in addition to other elements of the Wells bypass. The evaluation of this prototype was just ending at the time of writing this report and no preliminary estimates of effectiveness are available. It is expected that Grant County will continue experimentation with surface collection next year since the benefits to both fish and hydropower generation are well worth the effort and cost if a successful design and operating criteria can be found.

The year 1995 is also the startup year for the COE Surface Collection Program. As elements of this program, surface collector prototypes are being evaluated at The Dalles and Ice Harbor Dams by the Portland and Walla Walla Districts of COE, respectively. A variety of slot configurations and operation criteria is in evaluation. Preliminary data about the effectiveness and efficiency of the various designs were not available at the writing of this report. The Corps' Surface Collection Program is scheduled to continue through fiscal year 1998 and to expand to include other mainstem dams. Advanced planning for engineering designs continues. Harza Northwest recently submitted a report of general concepts for surface bypass at Bonneville Dam (29).

The success of the Wells Dam bypass, the apparent success of the Rocky Reach surface collector prototype, and the history of the high effectiveness and efficiency of sluiceway bypass during the day assures that testing of surface collection will continue well into the future. Surface collection is a very attractive bypass option because of the possibility of passing a high proportion of smolt using a relatively small amount of water, leaving the rest for power production, and working with, not against, the natural behavior of smolt. Within the group of biologists and engineers working with surface collection in the Columbia River Basin there is a desire to conduct controlled experiments under larger-scale laboratory conditions, following the model of the Bonneville Fisheries Engineering Laboratory. In general, it is the feeling of most concerned that some laboratory testing is needed to understand why surface collection, or more precisely, flow attraction, works. The challenge at this time is that no facility exists within the Columbia River Basin suitable for such work. In lieu of such facilities, and the need to move forward aggressively with smolt passage improvements, the needed observations of fish behavior are being obtained at field scales using hydroacoustic, radio tracking, and video monitoring technologies.

For successful surface collection at least two things that depend upon the behavior of smolt must occur. One of these is that the smolt must be able to locate the collector, and the second is that the physical characteristics of the collector and the flow field its operations generate must attract, or at least not repel, smolt. Considerable effort has gone into review of available information about the behavior of smolt as they approach the various mainstem dams. Such information is critical to locating surface collectors so that the opportunity for discovery by smolt of the flow fields generated by their operation is maximized. However, review of information provided by previous studies of smolt behavior have been disappointing. Unambiguous models of smolt behavior on approach to a dam cannot be developed, and information about the behavior of smolt in accelerating flow fields is almost nonexistent (26). Large scale radio tracking studies are being considered to provide the necessary smolt behavior information.

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