COMPENDIUM OF LITERATURE RELATED TO MECHANICAL INJURY OF FISH IN DAM SPILLWAYS
- DRAFT SUMMARY -

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Introduction

Water falling over the spillways of dams into plunge pools can produce gas saturation values which exceed those occurring under normal equilibrium with atmospheric pressure. Gas supersaturation can result in gas bubble trauma (GBT); (Alderdice and Jensen 1985), which can occur in fish and other aquatic organisms. This condition occurs when dissolved gases diffuse into microscopic nucleation sites or hollow cavities and form bubbles. These bubbles can form in all body compartments and disrupt neurological, vascular, respiratory, and osmoregulatory processes. Bubbles may form embolisms under the skin of fish, resulting in bacterial, viral, and fungal infections (Weitkamp and Katz 1980). Injury and mortality can also result in fish and aquatic invertebrates from increased buoyancy caused by gas bubble formation.

Gas supersaturation was observed below newly-completed spillways of dams in the lower Columbia River in the late 1960's (COE 1996). GBT resulting from supersaturation first became evident on the Columbia River at the McNary spawning channel in 1962 (Westgard 1964), and became more evident in the Columbia River system during the mid-1960's (Weitkamp and Katz 1980). Spilling is currently being employed to improve downstream passage and survival of juvenile salmonids in the Columbia and Snake rivers. Originally, spillways were only used when river discharges exceed the capacity of the powerhouse, or when regional power demands were substantially smaller than the generating capacity of the Snake and Columbia river dams. The duration and magnitude of spilling has increased in order to improve juvenile fish survival through powerhouse turbines; turbines have been operated at reduced capacity in recently years to reduce turbine injury and mortality. Increased spilling has also been used to improve the downstream survival of smolts passing through impoundments on the Columbia and Snake rivers. The Corps of Engineers (COE) has been spilling at eight lower Columbia River and lower Snake River dams to improve downstream passage survival of juvenile salmon and steelhead, as requested by the National Marine Fisheries Service (NMFS); (COE 1996).

A number of different methods have been developed to reduce the impacts of GBT on migrating juvenile and adult salmonids passing through hydroelectric dams located on the Columbia and Snake rivers. The two factors most responsible for elevated total dissolved gas (TDG) levels are discharge and plunge pool depth (COE 1994; 1995). Reducing the depth of the stilling basin decreases the potential for entrained air to go into solution. Changes in spill patterns have been employed to reduce total dissolved gas (TDG) levels, but were not found to be effective in achieving this goal (COE 1996). Perforated bulkheads in “skeleton bays” (bays without turbines installed) were tested in the early 1970’s to alleviate gas supersaturation problems on the Columbia River. This method was successful in lowering TDG levels, but high velocities emanating from the bulkheads resulted in mortality to migrating salmonids (Long et al. 1975). Potential gas abatement alternatives involving structural modifications to Columbia and Snake River dams currently being evaluated by the COE include 1) spillway deflectors, 2) raised stilling basins, 3) raised tailwaters, 4) flip buckets, 5) revised spillway shape, 6) submerged sluiceways, 7) covered spillways, and 8) auxiliary passageways (COE 1996). Of these structural alternatives, spillway deflectors have been the most commonly employed method for reducing TDG levels below lower Columbia River and lower Snake River dams.

Spillway deflectors or "flip lips" were added to several COE dams during the mid-1970’s to reduce gas saturation levels during periods of spill, including Bonneville, McNary, Lower Monumental, Little Goose, and Lower Granite dams (COE 1996). These devices direct most of the water passing over the spillway into a horizontal plume or jet near the surface of the stilling basin. This plume is characterized by highly turbulent conditions and shear zones (i.e., extremely high water velocities near the surface moving adjacent to lower water velocities). Sublethal impacts to fish in the Columbia and Snake rivers have been observed from TDG levels ranging from 100 to 110 percent saturation. Lethal impacts to fish generally occur before 115 percent TDG saturation. Consequently, it is important for gas abatement measure to bring TDG levels down below 115 percent to effectively reduce mortality, and below 110 percent to effectively reduce injury. The most important benefit of spillway deflectors and other gas abatement methods to juvenile salmonids is reduction of TDG levels to sublethal levels (i.e., 115 percent TDG).

Though intended to reduce GBT related injury and mortality to juvenile and adult salmonids, some gas abatement measures may themselves result in injury and mortality to fish. Gas abatement measures such as flow deflectors may produce hydraulic conditions which delay the upstream passage of adult fish (e.g., inability to locate fish passageways); (COE 1984). For the purposes of evaluating the potential impacts of gas abatement measures on fish, injury has be divided into three types:

- *Immediate Mechanical Injury*. This type of injury occurs while fish are passing over the spillway, or immediately (i.e., 30 seconds) after entering the stilling basin from the spillway.

- *Short Term Delayed Injury* . This type of injury occurs after fish have passed over the spillway, but prior to leaving the spillway and stilling basin environment.

- *Longer Term Injury* . This type of injury occurs after fish leave the spillway and stilling basin environment, but which can be attributed to physical impacts and modifications in behavior occurring from exposure to conditions in the spillway, stilling basin, and tailrace.

A summary of literature reviewed to date addressing each type of injury will be provided in the following sections of this report.

Immediate Mechanical Injury

Immediate mechanical injuries and mortalities to fish within the spillway can be attributed to scraping and abrasion with spillway structures including flip lips and flip buckets, striking objects in the spillway, rapid deceleration, and forcefully striking the water surface (COE 1996). Injury and mortality can also result from exposure to highly turbulent conditions including back-roll in the stilling basin, and exposure to shear velocities or high velocity jets immediately downstream of the spillway in the stilling basin. High turbulence may indirectly injure or kill fish by suspending debris which either strike or abrade fish. Fish can also be injured after striking rocky substrates in the stilling basin and sections of the river downstream of the spillway in which highly turbulent conditions are present.

The first spillway survival tests of juvenile salmonids were conducted in 1955 and 1956 at McNary Dam with juvenile chinook salmon (Shoeneman and Junge 1956; Schoeneman et al. 1961). The average mortality rate of fish passing over spillways was estimated to be 2 percent, with a 95-percent confidence interval from 0 to 4 percent. Holmes (1962) estimated spillway survival of subyearling juvenile chinook salmon at Bonneville Dam to range from 96 to 97 percent. In more recent experiments at Bonneville Dam, fish passing through spillways had a significantly higher survival than fish passing through turbines or the bypass system (Ledgerwood et al. 1990; 1991). Yearling chinook salmon smolts passing through the spillways of Little Goose Dam had survival rates exceeding 96 percent in experiments conducted in 1993 (Iwamoto et al. 1994).

Studies of spillway mortality, including those by Johnson and Dawley (1974) and Long et al. (1975), have been used to establish a 2-percent spill mortality estimate for Columbia and Snake River dams. The effects of spillway flow deflectors on juvenile fish survival were first evaluated on the Columbia River in 1974 at Bonneville Dam (Johnsen and Dawley 1974).

Juvenile fish survival was compared between spillway bays with and without flow deflectors (i.e., "flip-lips") at this dam during July and August. The data collected during this study suggested that survival was not significantly different between "test" groups of fish passing through spillways possessing flow deflectors and "control" groups passing through spillways without deflectors. This study suggested that spillway survival could be 4 percent lower in spillways with deflectors, though this difference was not statistically significant. Based upon the results of their statistical analysis, the authors of this study concluded that spillway deflectors were not detrimental to juvenile salmon survival.

A paired test was conducted at Lower Monumental Dam by NMFS (Iwamoto et al. 1994) during the May through June 1994 spill period. Statistical analysis of data collected from PIT-tagged fish suggested there is no difference in survival rates of fish passing through spillways with deflectors and those of fish passing through spillways without deflectors.

Results of other studies suggest that higher survival rates occur in spillway bays having flow deflectors compared to adjacent bays without deflectors. Survival of juvenile steelhead was compared between bays with and without flow deflectors at Lower Monumental Dam (Long et al. 1975). This study estimated fish mortality to be 2 percent in bays having flow deflectors, and 27 percent in bays not having flow deflectors. The lower mortality observed in bays having flow deflectors was attributed to reduced TDG levels and subsequently lowered gas supersaturation related mortality.

Relevant data can be found in the literature regarding immediate injuries to fish, which are caused by factors including rapid deceleration, pressure differentials, striking impacts, shearing effects, and turbulence. After conducting a comprehensive review of existing data, Bell (1972) estimated that survival rates range from 93 and 98 percent for fish passing through spillways. Bell suggested that survival rates are primarily a function of tailrace hydraulics, especially as related to the presence of shear zones in the spillway basin. Shear zones result from the release of high velocity waters in the upper water column of the spillway bay. High velocity jets and shear zones caused by flow deflectors can result in direct physical injury to fish. Injuries to fish in shear zones may be equivalent to those under free-fall conditions (Bell 1972).

Shear zone injuries occur when fish move from very high velocity to lower velocity layers in the water column. This situation can occur when a fish moves from the rapidly moving water of spillway into the slower waters of a stilling basin, or when a fish migrates upstream from the deeper waters of the stilling basin into the velocity jet emanating from the flow deflector. Studies conducted by Groves (1972) indicate that salmon fry can be injured by velocity jets exceeding 30 fps. Juvenile salmon become injured by velocity jets which exceed 55 fps, with high mortality rates observed above 75 fps (Johnson 1970; 1972a; 1972b). Studies of free-falling juvenile fish indicate that survival is very high (i.e., 98 percent) a velocities less than 50 fps (Bell 1972). Survival is very low at velocities greater than 80 fps. Survival rates of fish in stilling basins likely vary as a function of the flow volume, turbulence, and the shape of the spilling basin (COE 1994).

Mortality is almost certain when a fish strikes a fixed object in the spillway such an energy dissipating baffle (Bell 1972). Fish can be injured by abrasion when moving against gas abatement structures in a spillway such as flip buckets (COE 1996). For example, mortality of coho salmon juveniles was observed to be higher in spillways having flip buckets with rough surfaces compared to those with smooth surfaces.

Short Term Delayed Injury

Short term delayed injury includes striking injuries and abrasion with suspended and bottom substrates in highly turbulent areas of the stilling basin, and delayed impacts of shear velocities and high turbulence on fish moving through the stilling basin. This type of injury is more likely as the area affected by high turbulence increases, a function of discharge as well as the energy dissipation characteristics of the stilling basin. Unfortunately, very little information is available concerning the relative impact of short term delayed injury on fish, especially as related to gas abatement measures such as flow deflectors. The largest problem in evaluating this type of injury is isolating it from other types of injury, such as that occurring during passage over the spillway. For example, juvenile fish collected at Little Goose Dam show increased rates of descaling and injury when Lower Granite Dam (located upstream) has been spilling (COE 1994). However, it is unclear whether these injuries directly resulted from passage over the spillway, or from the highly turbulent conditions occurring in free-flowing sections of the river during spill conditions.

Short term delayed injury and mortality may be low compared to that occurring over the spillway itself (i.e., immediate injury). Juvenile salmon released directly into a spillway pool at Baker Dam were found experience very few injuries, while those released from the crest the spillway of this dam experienced a much higher injury rate (Hamilton and Andrew 1954).

One method of reducing TDG levels, raising the spilling basin, can increase the length of the river within highly turbulent conditions occur. This might lead to conditions in which fish are more susceptible to short term delayed injury. However, a study of Atlantic salmon showed that very low mortality occurred in shallow stilling basins even in the presence of highly turbulent conditions (Ruggles 1985). Raised stilling basins should provide good survival conditions as long as highly turbulent conditions and excessive roll-back are controlled (COE 1996).

Longer Term Delayed Injury

Longer term delayed injuries include impacts which occur in the spillway and stilling basin environment, but which cannot be detected or recognized until later. Examples of this type of injury include abrasion and descaling of fish during spillway passage which later result in disease and mortality, disorientation of juvenile and adult fish during migration, and changes in behavior which increases susceptibility to predation.

Recent understandings of fish behavior and statistical design considerations suggest the need for new evaluations of spill survival, included delayed mortality and physical injury (COE 1994). Increased turbulence in the spilling basin caused during "real" spill events (compared to those occurring during “test spills” employed in some survival tests) may result in types of delayed mortality and long term physical injury not addressed in earlier studies (Fields 1966).

Disorientation and delayed upstream passage may be one of the most important types of long term impacts caused by gas abatement measures such as flow deflectors. These impacts result from the inability of fish to navigate the river channel and locate fishways within highly turbulent areas downriver from the spillway. Survival of upmigrating adult salmon and steelhead would benefit from reductions of TDG resulting from installation of flow deflectors. A reduction in TDG below 115 percent would reduce lethal impacts, while reduction below 110 percent would reduce sublethal impacts. However, flow deflectors could affect passage behavior and reduce entry success of adult fish into fishways by producing turbulent flow conditions in the vicinity of these fishways. Prolonged passage times caused by the inability of adult fish to locate and navigate fishways could result in increased exposure to elevated TDG levels, reducing or outweighing the benefits of deflectors. For example, spillway modeling of Ice Harbor Dam suggest that upstream passage could be hindered by "poor hydraulic conditions" at fishway entrances a result of proposed flow deflectors, and that these conditions would likely impede or block the upstream passage of migrating adult salmonids (COE 1994).

Contrary to this finding, studies conducted at Lower Monumental Dam suggest that the passage of adult fish is not impaired by flow deflectors (Monan and Liscom 1975). The adult passage time measured during spill periods in 1993 at Ice Harbor Dam, a dam without flow deflectors, was similar to those measured at three dams on the lower Snake River with deflectors (i.e., Lower Monumental, Little Goose, and Lower Granite); (ACOE 1994). This observation suggests that flow deflectors may not delay upstream migration of adult fish in this system.

Results of radio-tracking studies of adult fish conducted at Bonneville Dam in 1974 indicated that adult salmon and steelhead will swim into areas immediately below a spillway discharging water over a flow deflector (Monan and Liscom 1975). However, adult fish were not found to be killed or suffer debilitating injuries from exposure to the hydraulic conditions (i.e., turbulence and high surface velocities) found immediately below spillways with deflectors.

Spillway deflectors may result in a greater susceptibility of outmigrating juvenile salmonids to predatory birds and fish. Surface-oriented flows may make smolts more susceptible to avian predators (COE 1994). Deflectors are designed to concentrate flows higher in the water column, and result in turbulent conditions further downstream. Large numbers of feeding gulls have been observed in dams with spillway deflectors during daytime spill periods; these avian predators are attracted to concentrations of smolts near the surface in the tailrace.

Conclusions

Results of studies evaluating the impacts of gas abatement measures such as flow deflectors on juvenile and adult fish survival have not been consistent, and sometimes have contradictory conclusions. Differences in these results could be caused by a number of experimental factors, including experimental design and sample size, the fish species tested (e.g., steelhead versus chinook salmon), the magnitude of flows under which spills and subsequent survival are evaluated, and differences in the structures and hydraulic characteristics of the dams where the tests were conducted. The timing of the study (night versus day testing) could have biased the survival data obtained during some of the cited studies. In some situations, benefits provided by gas abatement measures such as flow deflectors (lowered TDG levels) could be reduced or outweighed by injuries and moralities attributed directly or indirectly to these measures. There is currently no data present which can be used to determine whether the injury observed during spill periods at Columbia and Snake river dams is directly related to the implementation of gas abatement measures such as flow deflectors, or whether these injuries are incidental to the hazardous conditions (e.g., high turbulence and suspended debris) occurring during spill events.

Of the three injury types considered in this literature review, immediate mechanical injury is the most studied and best understood. Gas abatement structures can result in a number of hazards to juvenile and adult fish, such as high velocity shear zones, which have been shown to injure and kill fish. It is uncertain whether the risk to fish from this type injury is compensated by reduced exposure to elevated TDG levels. Short term injury is certainly a potential threat to fish given the highly turbulent conditions found in the stilling basin and tailrace environments downstream of spillways with gas abatement structures. However, this type of injury has only been investigated by two studies reviewed to date, which suggested that short term injuries are likely to be minor compared to injuries occurring during and immediately after passing over a spillway. Long term delayed injury to fish is the least understood of the three types of injury evaluated. Indirect mortality effects of gas abatement devices, including flow deflectors, have not been addressed in any prior spillway passage injury and mortality studies (COE 1994).

Attachment 1 - Compendium of Literature Reviewed to Date

Reference Type: Technical Report
Record Number: 45
Author: Andrew, F.J., and G.H. Green
Year: 1958
Title: Sockeye and pink salmon investigations at the Seton Creek hydroelectric installation
Institution: International Pacific Salmon Fisheries Commission Progress Report
Type of Work: Progress Report
Injury Type: Immediate, short-term
Relevance: Tertiary; related primarily to pressure injuries. Discusses an energy-dissipating chamber.
Keywords: turbulence, pressure, abrasion, deflector grill
Abstract: The high mortality rate of 7.4 per cent suffered by fish passing through the fish-water sluice probably resulted from the combined adverse effects of pressure release, abrasion, and extreme turbulence. The high incidence of distended eyes indicated that these fish suffered from the adverse effects of the minor pressure release of 6 pounds per square inch in passing through the submerged gate at the upstream end of the energy-dissipating chamber. However, it is likely that turbulence and abrasion were major contributing factors. Impact or abrasion on the deflector grill located immediately downstream from the sluice might also have contributed to the mortality. The mean mortality rate of 1.2 per cent in-the tests of the siphon indicated that sockeye smolts suffered very little injury passing through this exit. The highest mortality rate suffered by any of the test groups was only 1.6 per cent. Pressure change was minor, as the pressure at the extreme top of the siphon was less than 2 pounds per square inch below atmospheric pressure. The average velocity, however, was 29 feet per second at the throat of the siphon. Abrasion on the concrete inner surface appeared to be the primary cause of injury.
Status: Copy In house

Reference Type: Technical Report
Record Number: 52
Author: Anon
Year: 1984
Title: Spillway deflectors at Bonneville, John Day, and McNary Dams on Columbia River, Oregon-Washington, and Ice Harbor, Lower Monumental and Little Goose Dams on Snake River, Washington
Institution: U.S. Army Corps of Engineers
Date: September 1984
Report Number: Technical Report 104-1
Abstract: Highly aerated water flowing over the spillways and plunging into the deep stilling basins of dams increases the nitrogen levels of the rivers to a supersaturated condition hazardous to migrating fish. The report presents data and results of model studies conducted in development of spillway deflectors for six projects on the lower Snake and Columbia Rivers. The deflectors prevent the plunging action and cause a more skimming-type flow near the surface of the stilling basin resulting in reduced nitrogen saturation levels. The models were used to design the deflector geometries and to assist in evaluating their effect on fishway attraction flow near the downstream fishway entrances at the project. Prototype measurements indicate that the deflectors have been effective in reducing nitrogen levels at the projects.
Status: Need to obtain a copy

Reference Type: Sub-Report
Record Number: 4
Author: Anonymous

Year: 1967
Title: Mortality of downstream migrant salmonids at West Linn Plant of Crown Zellerbach, Inc.
Publisher: Oregon State Game Commission
City: Portland, Oregon
Status: Need to obtain copy

Reference Type: Sub-Report
Record Number: 5
Author: Anonymous
Year: 1967
Title: Mortality of downstream migrant salmonids at Publishers Paper Plant at Willamette Falls
Publisher: Oregon State Game Commission
City: Portland, Oregon
Status: Need to obtain copy

Reference Type: Book
Record Number: 1
Author: Bell, M. C.
Year: 1972
Title: A compendium on the survival of fish passing through spillways and conduits.
Series Editor: Program, Fisheries Engineering Research
Publisher: U.S. Army Corps of Engineers
City: Palo Alto, California
Injury Type: Primarily immediate and short term
Relevance: High relevance to spillway and stilling basin designs, little direct relevance to flow deflectors
Keywords: spillway, stilling basin, pressure, abrasion, velocity, shearing
Abstract: The data reviewed cover information, both observed and recorded, on fish passage through spillways, natural falls, conduits and pipe systems. Experiments and observations were conducted under prototype and laboratory conditions. Factors that were considered are: species of fish, size of fish, condition of fish, numbers of predators, effects of diseases, food availability, feeding habits, behavior patterns, type of bucket or stilling basin, distance of fall (total head), velocity through gate, discharge (cfs), temperature, turbidity, type of recovery gear, methods of release.

The apparent assumptions made by the investigators were: (1) fin excision and other methods of identification did not cause unknown differential survival between groups of marked fish; (2) natural river mortality occurring between the test site and the point of recapture was the same for all lots of fish used in a particular series of tests or season; (3) natural and fishing mortalities in the ocean and rivers were the same for the lots of fish in a particular test. Depending upon the nature and objective of the individual investigation, the variables and assumptions will be involved in unique combinations and in each case they must be given appropriate consideration.

Data sheets numbered 70 to 114 and a table on page 121 were prepared and cover the information pertinent to many of the individual experiments, giving reference to the parallel items for each experiment. A graph on page 121 is taken from the report of the Corps of Engineers and sums up the results of a number of experiments conducted at the Bonneville project. The data covering the Cougar Dam experiments are on pages 27 to 30. This series of experiments did not lend itself to the compilation as prepared for the other experiments. The literature reviewed is listed in the bibliography, pages 46 to 50. A cross index of selected excerpts from the reports has been prepared and is included on pages 51 to 59. Comments of the experimenters are cross indexed under major headings, making it possible to compare results from the various tests. To assist further in interpreting the data, a

series of sketches depicting physical conditions through which the fish passed are shown on pages 116 to 120. By the use of the sketches, it is possible to visualize the physical conditions under which the tests were conducted and the changing conditions by which energy is dissipated as flowing water passes, or fa3-ls from a height, into a stilling pool. Also shown on the sheets are conditions under which the fish would be in free fall.
Notes: Studies contained in document pre-date Columbia River gas abatement measures, but injury determinations related to spillway and settling basin design remain pertinent to the potential mechanical injuries associated with current dam designs.

Scattered experiments on survival rates of downstream migrants passing from various heights or under varying velocity conditions have been conducted at Pacific Northwest dams, natural falls and under laboratory conditions. Fish were subjected to a wide range of passage routes consisting of air free fall, falls within a column of water, major spillway gates, ogee shapes, straight chutes, enclosed pipelines and ski jump spillways. At points of deceleration they entered into energy dissipating areas, varying from formed baffled and non-baffled buckets to unformed stilling pools, some with and some without baffles.

Heights varied from 1.5 to 300 feet. Discharge volumes varied from zero (air drop) to prototype spills. No direct measurements were made of maximum velocities during the experiments, but are computed to be from 10 to 100 feet per second. It is evident that at some locations fish were recirculated and again subjected to the same conditions under which they first entered the energy dissipating areas. Injuries sustained included abrasions, eye damage, embolism, hemorrhaging and internal. Certain of these are typical of pressure-type injuries, as eye damage and hemorrhaging, but were found also to be common to injuries caused by scraping and shearing. The fish used in the tests varied in length, species and condition. The test periods were widely scattered and covered practically all seasons of the year. Temperature, which is a variable, vas not always recorded. Injuries were not always recorded. The percent recovery of test fish and control fish, if used, varied widely, from 100 percent under laboratory conditions to less than 1 percent under Columbia River conditions.

Methods for recovery of test and control fish varied from collection pools in laboratories to scoop and fyke nets in rivers, placed varying distances downstream from points of release. Control fish were not always used, and the period of holding of both test and control fish varied. Most of the fish were hatchery reared, although in certain tests wild fish were captured, marked and used for both test and control purposes. No appreciable difference in behavior of hatchery and wild fish was reported by the investigators. Because of handling procedures, it may be assumed that both test and control fish were accustomed to surface conditions or surface pressures. Significant results were obtained under these widely varying methods of recovery and from the percentages recovered.

The survival rate in most cases was based on the recapture of test and control fish; however, in two of the major experiments, and suggested in a third, the returns of adult fish were used to compute or verify survival rates. Where verification was used, the results substantiated the computed survival rate of the downstream migrants. A series of independent pressure tests was conducted under laboratory conditions, indicating that surface-accustomed fish are not seriously damaged when subjected to increased pressure and its release. Volumes of discharge, types of spillways, types of buckets, pressure change, impact, abrasion, velocity and shearing were assumed by the investigators to be related to the incidence of death and injury. It also could be assumed that there could be seasonal and temperature effects.

As the experiments were so widely scattered and conducted under such varying conditions, a common denominator is needed to compare the results, the most obvious of which would be deceleration within a water column with or without impact against baffles or walls, or from a direct drop. Shearing effects, caused by differences in velocity flow planes causing excessive acceleration or deceleration, may result in injury. These were not measured. Pressure changes, shearing and strikes, are inherent in turbulent areas so that retention time within an energy dissipating area is an important factor. Tine factors were not available for this report.

No experiments were recorded for fish striking directly on fixed objects; therefore, percent survival cannot be given but would be expected to be quite low at velocities of less than 20 fps. In constricted areas, where the rate of deceleration could be controlled by baffles or walls, the survival rate quickly approached zero when the velocities exceeded 40 fps, and probably were as low as 70 percent in the 20-30 fps range. This may not have resulted from a direct strike but from shearing or recirculation through the same area.

The survival rates of fish entering a pool from free fall were found to be 98-100 percent at velocities up to 50 fps, 80 percent at a velocity of 60 fps and probably zero at velocities of 80 fps and greater. Survival rates of fish entering a pool in a column of water, decelerating with the jet and without mechanical deflection, may equal survival under best free fall conditions. Survival rates of fish entering a pool within a column of water decelerating with the jet and deflected by a baffle is about 93 percent. Survival rates of fish through a hydraulic jump or large stilling pool in a single passage approaches the best conditions of the jet, 93-98 percent. Survival rates of fish striking a fixed baffle or object approaches zero.

The variability of spillway design permits only a general statement regarding operation for the most successful passage of fish. Additional testing, as described in the section on future testing, is needed before more precise criteria can be recommended. The reported tests indicate that to obtain the highest survival of downstream migrants spillways should be operated for minimum turbulence, back roll and energy dissipation per foot of gate width. Such may not be compatible with the best pattern of spill for the passage of upstream migrants. If there is a conflict, then the regulation schedule for downstream passage should be adhered to only during times of maximum downstream movement.
Status: In-house copy resides with P. Hilgert

Reference Type: Conference/Workshop
Record Number: 6
Author: Bell, M.C.
Year: 1974
Title: Fish passage through turbines, conduits, and spillway gates
Conference Name: Edited proceedings of the second workshop on entrainment and intake screening.
Editor: Jensen, L.D.
Publisher: Electric Power Research Institute
Conference Location: Palo Alto, California
Volume: Report 15
Pages: 251-261

Reference Type: Technical Report
Record Number: 54
Author: Bell, M.C.
Year: 1981
Title: Updated compendium on the success of passage of small fish through turbines
Institution: U.S. Army Corps of Engineers
Date: September 1981
Report Number: No. DACW-69-76-C-0254
Injury Type: N/A
Relevance: Tertiary; does not discuss mortality associated with spillway flow deflectors
Keywords: turbines,
Status: In-house copy at R2 library

Reference Type: Technical Report
Record Number: 33
Author: Blahm, T.H., R.J. McConnell, and G.R. Snyder

Year: 1973
Title: Effect of gas supersaturated Columbia River water on the survival of juvenile salmonids
Institution: National Marine Fisheries Service
Type of Work: Final Report
Report Number: Part 1

Reference Type: Journal Article
Record Number: 51
Author: Bouck, G.R. and S.D. Smith
Year: 1979
Title: Mortality of experimentally descaled coho salmon (Oncorhynchus kisutch) in fresh and salt water
Journal: Transactions of the American Fisheries Society
Volume: 108
Pages: 67-69
Injury Type: Long-term
Relevance: Tertiary; related to potential long term injury associated with physical abrasion in spillway and stilling basin.
Keywords: scale, descale, abrasion, physical injury
Abstract: Removal of slime from 25% of the body caused no deaths among smolts of coho salmon in fresh water or in seawater (28ppt). Removal of slime and scales from the same percentage of body area caused no deaths in fresh water, but 75% mortality within 10 days in seawater. The 10-day median tolerance limit was 10% scale removal immediately before the smolts entered seawater. Mortality was highest when the scales were removed from the area of the rib cage. Recovery of smolts in freshwater from a loss of scales that would be lethal in seawater occurred rapidly; 90% of the fish regained tolerance to seawater within 1 day.
Notes: Describes potential long-term mortality that might occur as a result from descaling of smolts striking flow deflectors while passing through spillways. Salt-water tests indicated that descaling presents a more serious threat to smolts entering the marine environment, rather than those healing in fresh water.
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 48
Author: Copp, H.D.
Year: 1968
Title: Stilling basin hydraulics and downstream fish mitigation
Institution: Washington State University
Date: April 1968
Type of Work: Research Report
Report Number: No. 66/9-47
Relevance: Tertiary; provides generalized description of energy dissipation in spillway
Keywords: spillway, stilling basin, pressure
Abstract: This report is the result of cursory investigation into the hydraulic characteristics of spillways. It is not intended to show all of the variables within the various types of buckets, nor is it intended to be a precise design study. To some degree, experienced judgment has been used in its preparation; therefore, direct comparisons of energy relationships should not be made. It is intended to indicate possible varying conditions to which fish are subjected when passing through a spillway and to illustrate one approach for determining the length of time that fish may spend in a given type of bucket. The reader is warned not to use these data as criteria for design of a particular spillway, or to extrapolate directly the variable, as only limited spillway criteria were considered. The methods suggested here, however, are applicable criteria for further study, if desired. The study does not indicate the recirculation pattern or the possible number of repeats that fish or other floating objects could encounter in

passing through such energy dissipators.

The kinetic energy level abruptly rises as the water flow cascades from under the spillway gate and down the spillway face. The level peaks at the upstream end of the jump or roller and then decreases to a magnitude equal to the tailwater level. The time of this decrease, insofar as an observation "object" is concerned, depends significantly on whether or not it becomes entrained in the roller. If deceleration is linear with time, uniform energy changes would occur from the peak level to the level encountered within the tailwater pool. This linear deceleration is highly unlikely; thus initial high deceleration rate is shown herein. If the object in question is a downstream migrant fish, the energy components may have different significance. Considering energy due to flow depth (pressure), two points merit primary attention. They are:

1) A rather abrupt drop in flow depth (and thus a pressure drop) occurs as the flow moves under the spillway gate. This probably is not considered significant, unless instantaneous drops or negative pressures are encountered

2) In most cases, the flow depth in the tailwater pool is considerably less than that in the reservoir pool at the spillway gate lip. At the gate, an overall pressure reduction occurs in a relatively short time span.

Both of these points may have profound influence on fish physiology provided that such fish have adjusted to the depth at the gate lip. Considering kinetic energy (velocity), rapid acceleration of flow occurs as it cascades from beneath the spillway gate and down the spillway face. Deceleration is not quite as rapid unless the roller is encountered or unless impact with basin boundaries occurs. Whether or not roller entrainment and/or impact occurs can only be speculated. In all the basins examined, the roller appears rather deep and, thus, entrainment seems probable. Any conclusions in this regard, however, are subject to interpretation by observers of hydraulic model tests or of prototype behavior. Impact in the Rocky Reach, Bonneville, and Ice Harbor basins appears to be a real possibility.
Status: Copy contained in appendices of Bell (1972)

Reference Type: Technical Report
Record Number: 8
Author: Dawley, E.M., L.G. Gilbreath, and R.D. Ledgerwood
Year: 1987
Title: Evaluation of juvenile salmonid survival through the second powerhouse turbines and downstream migrant bypass system at Bonneville Dam.
Institution: U.S. Army Corps of Engineers and National Marine Fisheries Service
Type of Work: Preliminary report

Reference Type: Technical Report
Record Number: 41
Author: Dawley, E.M., L.G. Gilbreath, and R.D. Ledgerwood
Year: 1988
Title: Evaluation of juvenile salmonid survival through the second powerhouse turbines and downstream migrant bypass system at Bonneville Dam, 1987
Institution: U.S. Army Corps of Engineers and National Marine Fisheries Service
Date: January 1988
Type of Work: Preliminary report
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 38
Author: Dawley, E.M., L.G. Gilbreath, R.G. Ledgerwood, P.J. Bentley, B.P. Sandford, and M.H. Schiewe
Year: 1989
Title: Survival of subyearling chinook salmon which have passed through the turbines, bypass system, and tailrace basin of Bonneville Dam Second Powerhouse, 1988
Institution: National Marine Fisheries Service report to U.S. Army Corps of Engineers
Date: December 1994
Report Number: DACW57-87-F-0323
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 44
Author: Donaldson, I.J.
Year: 1957
Title: Effect of structures at main Columbia River and certain other dams on downstream migration of fingerling salmon
Institution: U.S. Army Corps of Engineers, Fisheries Engineering Research Program
Injury Type: Immediate
Relevance: Secondary relevance to pressures associated with stilling basin
Keywords: pressure
Abstract: Tests were conducted at Bonneville and McNary Dams by the release of young fish enclosed in gossamer bags into the dam passages and retrieving them by means of previously-attached delayed-action auto-inflating balloons. The same method was used for control fish. These investigations have been generally termed "Balloon Experiments" in reference to the technique used. There was little or no significant mortality in passing pressure accommodated and non-pressurized fingerling salmon through the Bonneville and McNary Dam turbines. The spillway mortality data from Bonneville and McNary Dams are not conclusive. In associated experiments, no significant mortality resulted during the performance of laboratory tests wherein large numbers of fingerling salmon were caused to pass through a venturi where pressures ranged as low as 0.5 pounds per square inch absolute. Impact at 45.6 feet per second velocity in an 8-inch jet of water against a solid steel plate set both at 115-degree and 90degree angles caused no significant mortality to fingerling salmon. Forces generated when a stream of water, at approximately 100 pounds per square inch pressure, -were directed by means of a fire hose nozzle into a 55-gallon barrel of water quickly killed both free-swimming fingerling salmon and those in gossamer bags.
Status: Excerpt in house, original to be requested

Reference Type: Journal Article
Record Number: 50
Author: Ebel, W.J., H.L. Raymond, G.E. Monan, W.E. Farr, and G.K. Tanonaka
Year: 1975
Title: Effect of atmospheric gas supersaturation caused by dams on salmon and steelhead trout of the Snake and Columbia rivers, 1973
Journal: Fisheries Review, National Marine Fisheries Service
Volume: 7
Pages: 1-14
Status: Need to obtain a copy

Reference Type: Sub-Report

Record Number: 10
Author: Groves, A. B.
Year: 1972
Title: Effects of hydraulic shearing action on juvenile salmonids
Publisher: U.S. Army Corps of Engineers, North Pacific Division
City: Portland, Oregon
Status: Copy In House

Reference Type: Journal Article
Record Number: 9
Author: Hamilton, J.A.R., and F.J. Andrew
Year: 1954
Title: An investigation of the effect of Baker Dam on downstream migrant salmon
Journal: Bulletin of the International Pacific Salmon Fish Commission, Volume IV
Injury Type: Immediate, short-term
Relevance: Secondary importance; dated information that provides a general description of injuries sustained by smolts in the spillway and pool during spill.
Keywords: spillway, pool, turbulent
Abstract: The concrete face of the spillway is very rough, and this roughness in combination with the extreme turbulence and the high velocity could cause a great deal of injury through abrasion. Also, the high velocity flow of water over the rough spillway undoubtedly causes severe cavitation which could cause mortality. Perhaps the spreading of the flow in the bucket or curving section at the base of the spillway results in injuries from abrasion, turbulence and cavitation. Another possible source of injury is in the spillway pool where the energy of the spillway discharge is dissipated. This violently turbulent volume of water could conceivably injure the fish or aggravate existing injuries by tearing tissues or by scraping the fish on rough rocks. The frequency of injury to the two groups clearly shows that the group released into the pool suffered very few injuries and that these injuries were not serious compared with those suffered by the group released at the crest of the dam. Of the fish released into the pool, and recovered alive, 84.9 per cent were uninjured whereas only 40.5 per cent of the fish released into the spillway and recovered alive were uninjured. In addition, the high incidence of fish from the spillway release with missing scales and frayed fins indicates that these injuries, which may or may not be of importance, are caused in large part by the spillway. An injury caused while fish are enroute down the spillway may not in itself be lethal but the conditions in the pool may be such that the injury may be sufficiently aggravated to cause death. It may be concluded that the turbulence in the spillway pool was a minor cause of the total spillway mortality, although it may have aggravated existing injuries.

Taking into consideration the disproportionate availability of live and dead fish to the nets and the delayed effect of injuries, the mortalities to sockeye and coho migrants passing over the spillway during one gate of spill were estimated to be 63.5 per cent and 54.0 per cent respectively. All captured fish were examined for injuries and a study vas made to determine the possible causes of these injuries. Many fish that had passed over the spillway had superficial injuries such as damaged operculi, ruptured and crushed eyes, scraped and crushed heads, and scraped and torn body walls, which were directly attributable to the rough and irregular nature of the spillway face. Internal hemorrhaging and distended eyes were also evident, indicating that the fish also suffered from the effects of pressure change and cavitation. To determine the effect of the extremely turbulent spillway pool, a number of hatchery coho were released from a high-line bucket at the most turbulent point of the upstream end of the pool. In these special tests fish passing over the spillway had a mortality rate 2.5 times greater than fish released directly into the pool. Injuries to fish released over the spillway exceeded those sustained by fish released into the pool in number and severity. It was concluded that mortalities and injury to fish using the spillway exit were incurred primarily during the fall from crest to pool and were caused principally by abrasion and pressure change.
Status: Copy In House

Reference Type: Thesis
Record Number: 47
Author: Harvey, H.A.
Year: 1963
Title: Pressure in the early life history of sockeye salmon.
University: University of British Columbia
City: Vancouver, Canada
Thesis Type: Ph. D. thesis
Injury Type: Long-term
Relevance: tertiary
Keywords: pressure, embolism
Abstract: During the bulk of the studies, conducted from late March to early May, exposure to negative pressure resulted in a mortality which increased with increasing vacuum (Fig. 31 and 32). Groups of smolts were exposed suddenly to vacuum conditions from atmospheric, 50 psi and 300 psi above atmospheric pressure. The magnitude of the positive pressure had little or no effect on the resulting mortality. The two test series showed similar slopes (0-058 and 0.073) and intercepts (o.81 and 0.41). At pressures greater than 5 in Hg of vacuum (absolute pressure 633 mm Hg) mortalities were of the same order of magnitude as the control groups. The effect of the rate of reduction of pressure was tested over the range of 1.5 to 7,500 Psi per sec. Two series were conducted in 1959 and 1960 in which groups of 200 smolts were lowered from 300 Psi to atmospheric conditions. The results are shown in Fig. 33. There is some suggestion of slightly higher mortalities at the most rapid rate of decrease in pressure, but the maximum mortality of 1 per cent per week is within the extreme range of the control mortalities. Seasonal effect. The relatively small proportion of mortalities and injuries resulting from decompression changed suddenly during the course of the season. This change coincided with a temperature of 51oF in Sweltzer Creek, occurring about mid-May and coincident with the thermal stratification of Cultus Lake. Among smolts tested migrating from the lake, the mortality increased rapidly with increasing temperature as shown in Fig. 34. The smolts died inside the pressure chamber within a few minutes of being exposed to a sudden reduction in pressure below atmospheric conditions. In the fish examined, death was due to minute gas emboli most commonly lodged in the heart or ventral aorta. The highest mortalities recorded this way were in an abnormal condition for some time following testing with numerous fish lying on their sides for several hours.
Status: Reviewed from Bell (1972). Need to obtain a copy of full document.

Reference Type: Technical Report
Record Number: 36
Author: Holmes, H.B., and I.J. Donaldson
Year: 1961
Title: A study of the effect of pressure changes upon salmon fingerlings as applied to passage through spillway at Mayfield Dam, Cowlitz River, Washington
Institution: City of Tacoma
Date: April 1961
Status: To be obtained

Reference Type: Technical Report
Record Number: 43
Author: Johnsen, R.C. and E.M. Dawley
Year: 1974
Title: The effect of spillway flow deflectors at Bonneville Dam on total gas supersaturation and survival of juvenile salmon

Institution: National Marine Fisheries Service funded by U.S. Army Corps of Engineers
Date: December 1974
Type of Work: Final Report
Report Number: Contract No. DACW-57-74-F-0122
Injury Type: Immediate, short term
Relevance: Primary; highly relevant to smolt survival through spillway equipped with flow deflectors
Keywords: spillway, tailrace, deflector, survival, fall chinook
Abstract: Supersaturation of dissolved- gases in water of the Columbia River caused by spillway discharges was documented in the late 1960's as a problem to migrating salmon and steelhead trout. The Army Corps of Engineers funded several studies to determine ways of decreasing the amount of gas forced into solution as water passed through the dam. A spillway design termed "flip bucket" was evaluated for effect on dissolved gas at several discharges and found to be significantly better than the typical spillway design used on the Columbia River. Engineers of the Northwest Pacific Division utilized this concept and designed a flow deflector that could be attached to the standard spillbays. In theory, water passing over a spillway with deflector would move straight down stream and be deflected over the top of the stilling basin structures thus hydraulic pressures would be decreased and less entrained air would be forced into solution. A prototype flow deflector was placed at Bonneville Dam in 1971 and tested in 72 and 73 to determine whether dissolved gas concentrations would be reduced. These tests indicated a substantial reduction in the amount of supersaturation produced in comparison to standard spillways. As a result the Corps designed and built three additional deflectors at Bonneville to ascertain effects of multiple flow deflectors on; (1) dissolved gas content of discharges, and (2) anadromous fish passage through and around the spill discharge.
Notes: Results of this study indicated little difference in survival of fish passing over a standard spillway, a spillway modified with flow deflectors, and fish released directly into the tailrace. Researchers concluded that spillway deflectors were not detrimental to the survival and believe the effect of complete modification of the spillway at Bonneville Dam will not adversely affect survival of juvenile fall chinook passing through the spillway.
Status: Photocopy in house

Reference Type: Sub-Report
Record Number: 26
Author: Johnson, R.l.
Year: 1970
Title: Fingerling fish research effect of mortality of 67-fps velocity
Publisher: U.S. Army Corps of Engineers, North Pacific Division

Reference Type: Sub-Report
Record Number: 12
Author: Johnson, R. L.
Year: 1972
Title: Fingerling fish mortalities at 67 fps
Publisher: Army Corps of Engineers
City: Portland, Oregon

Reference Type: Sub-Report
Record Number: 13
Author: Johnson, R.L.
Year: 1972
Title: Fingerling fish research, high velocity flow through four-inch nozzle

Publisher: U.S Army Corps of Engineers, Fisheries Engineering Research Program
City: Portland, Oregon

Reference Type: Technical Report
Record Number: 49
Author: Johnson, R.C. and E.M. Dawley
Year: 1974
Title: Final Report. The effect of spillway flow deflectors at Bonneville Dam on the total gas supersaturation and survival of juvenile salmon
Institution: National Marine Fisheries Service
Status: Need to obtain a copy

Reference Type: Technical Report
Record Number: 53
Author: Junge, C.O. and B.E. Carnegie
Year: 1976
Title: Spillway studies, 1976
Institution: U.S. Army Corps of Engineers
Status: Need to obtain copy

Reference Type: Book Chapter
Record Number: 14
Author: Kostecki, P. and B. Kynard
Year: 1982
Title: Potential effects of scale loss on mortality of Atlantic salmon and juvenile clupeids
Book Title: Potential effects of Kaplan, Osberger, and bulb turbines on anadromous fish of the Northeast United States
Editor: W.E. Knapp, .B. Kynard, and S.P. Gloss,
Publisher: U.S. Fish and Wildlife Service
Volume: Newton Corner, Massachusetts

Reference Type: Technical Report
Record Number: 42
Author: Ledgerwood, R.D., E.M. Dawley, L.G. Gilbreath, L.T. Parker, B.P. Sandford, and S.J. Grabowski
Year: 1994
Title: Relative survival of subyearling chinook salmon at Bonneville Dam, 1992
Institution: National Marine Fisheries Service funded by U.S. Army Corps of Engineers
Date: December 1994
Injury Type: Short-term, long-term
Relevance: Tertiary; does not directly address issue of flow deflector-related mortality, but discusses associated sources of mortality (i.e., shear force injuries, physical contact injuries, and predation in the tailrace)
Keywords: predation, shear forces, tailrace
Abstract: The objective of this study was to compare relative survival among marked groups of subyearling chinook salmon released into the bypass system of Bonneville Dam First Powerhouse, the turbines at the First and Second Powerhouses, and at a site in swift water about 2.5 km downstream from the dam.

Mechanisms affecting survival difference were thought to be water velocity in the bypass conduit and shear forces at the outlet of the bypass pipe. The following conclusions were based on one year of study, with special operating conditions of equal flow through both powerhouses implemented at Bonneville Dam in order to 1) attract predators equally to the two tailrace areas, 2) provide an unbiased comparison of survival among the various routes of juvenile fish passage as well as to minimize tailrace eddies, 3) provide high flows past the juvenile bypass outlet, and 4) allow adequate attraction flows to the various fishway entrances for upstream migrant adult salmonids. The regional drought that severely reduced river flow during 1992 may have created a worst scenario for salmonid survival due to heavy predation of test fish in the tailrace areas. It is important to consider a wide range of test conditions before formulating conclusions regarding the safest routes for juvenile salmon passing Bonneville Dam during the summer. Conclusions include:

1) Under the drought conditions of 1992, recoveries of marked subyearling chinook in the estuary indicated significantly reduced survival of fish released into the bypass system at the First Powerhouse compared to fish released into the First Powerhouse turbines or fish released downstream from the tailrace.

2) Fish passing through the Second Powerhouse turbines and tailrace had significantly reduced survival compared to fish passing through the First Powerhouse turbines and tailrace.

3) The downstream-released fish had significantly higher survival than all other release groups.

4) Tule stock subyearling chinook salmon used in this study were subjected to cold-water rearing and reduced rations to maintain a size range at release similar to normal summer migrants (upriver bright stock). However, test fish, particularly those from the final week of test releases, may have suffered extreme stress due to elevated Columbia River water temperatures resulting from the regional drought. While the immediate impacts of dam passage are thought to be fully expressed in mark-recovery differences among juvenile fish recovered at Jones Beach, the overall survival of test fish may have been reduced by temperature stress. This potential overall lower survival of test fish may affect comparisons among treatment groups using CWT data from adult contributions to the various ocean and river fisheries and returns to the lower river hatcheries.

5) Because 75 to 90% of the summer migrating juvenile salmon encountering the powerhouses at Bonneville Dam pass through turbines instead of bypass systems, and because of the significant difference between turbine plus tailrace passage survivals at the First and Second Powerhouses, it is extremely important to identify the safest passage route over a wide range of river flows.

Recommendations:

1) Tag recovery of adults should be compiled through 1997 to assess passage survival differences adequately.

2) The study should be repeated for 3 additional years to bracket a wide range of river flow and other physical conditions before making conclusions regarding the relative survival of summer migrating subyearling chinook salmon through the various passage routes at Bonneville Dam.

Notes: Full title listed inside report cover as " Relative survival of subsyearling chinook salmon after passage through first bypass system at the first powerhouse or a turbine at the first of second powerhouse and through tailrace basins at Bonneville Dam, 1992"

Status: Photocopy in house

Reference Type: Technical Report
Record Number: 25
Author: Liscom, K.L. and G.E. Monan
Year: 1976
Title: Radio tracking studies to evaluate the effect of the spillway deflectors at Lower Granite Dam on adult fish passage, 1975
Institution: National Marine Fisheries Service for the U.S. Army Corps of Engineers
Date: January 1976
Report Number: Delivery order No. DACW68-75-C-0112
Injury Type: N/A

Relevance: Primary with respect to adult passage
Keywords: adult passage, fallback, deflector, spillway
Abstract: The primary objectives of this study were to determine in a prototype situation: (1) to what degree adult salmon frequent the potentially dangerous area below the spillway deflectors, (2) if salmon are severely injured or killed by conditions created by the spillway deflectors, and (3) effects of hydraulic patterns from spillway deflectors on entry of adult salmon to fish collection facilities.

During the study period, 27 of the 30 radio-tagged chinook salmon were tracked in the study area at Lower Granite Dam. The remaining three were found below Little Goose Dam. One was recovered dead, and the other two were still swimming below Little Goose Dam when the study ended. Of the 27 tagged fish reaching the study area, 17 eventually passed over the dam during the 4 weeks of tracking. Two fish were tracked in the study area below the dam for several days and then the signals abruptly stopped. The remaining 8 fish were near the dam or in the vicinity at the time the study was terminated. Behavior below the dam was variable. When approaching the dam, the north shore was favored by 56% of the fish 33% entered along the south shore and 11% approached from mid-channel. Milling about below the dam was extensive, but certain preferred routes were apparent. All routes experienced back and forth movement with none used exclusively for any one direction. Holding areas were well defined with the "quiet" water area north of the locks and its extending wingwall the most frequently used. Of the total hours spent by tagged fish in the immediate area below Lower Granite Dam, 44% were spent in this area. All but two tagged fish reaching the dam spent some time in the "quiet" water. The mid-channel area just below the spill and powerhouse was used 12% of the time. At this point, the current from a large eddy in front of the powerhouse turned downstream and merged with the spill flows. Tagged fish determined as having been within the potentially dangerous spill area made 49%, of their entries into this area when spill was between 50,000 and 65,000 cfs. These conditions existed 24% of the total tracking time. Spill of 126,000 to 159,000 cfs was present 35% of the time and 161, of the entries were made then. The fact that some radio-tagged chinook were plotted close to the spill and maintained themselves in that location for some time, indicates that subsurface hydraulic conditions are present that fish can negotiate unharmed. Relatively little time was spent adjacent to, but downstream from the fishway entrances. Only 1.5% of the total time tagged fish spent in the area was spent in front of either fishway entrance. There were 88 entries made into the fishway entrances, 42 into the north entrance and 46 into the south entrance. Of the total entries, 19% resulted in fish passage over the dam. Most fish made more than one entry to the fishway before passage; 35% made one entry only. Both entrances were entered by 53%, of the tagged fish. Only 12%, of the fish entered a single entrance more than once before crossing the dam. On their final entrance before crossing the dam, 4 fish used the north entrance and 13 used the south. Once they made their final entrance, the fish spent an average of 4 hours negotiating the fishway and crossing the dam. Tagged fish did not show any interest in the north entrance until May 20. Up to that time, fish had made six entries into the south entrance resulting in two passages. On May 20, between 1500 and 1700 hours, the spill gates were regulated to change the spill pattern. To reduce flow by the north entrance, flow from bays 6-8 was reduced by 3% with like increases in the center area. Soon after, a tagged fish approached the north entrance and entered at 1745 hours. Tagged fish made use of the entrance from then on, resulting in 47% of the fish making their initial entry into the north entrance. However, while fish entered the fishway and moved up the channel initially, they were reluctant to continue through the tunnel under the spill section. During the early part of the study the lights in the tunnel were off. When the lights were turned on, the fish moved through more readily. During the remainder of the study, 30 trips were made from the north entrance through the tunnel into the powerhouse collection system. However, 87% ended with the fish exiting into the tailrace. The tunnel was also entered by four fish via the powerhouse collection system.
Notes: Conclusions drawn from this study were:

1. Spring chinook salmon swim near or into the discharge from a spillway with a total complement of deflectors.
2. Spring chinook salmon do not experience debilitating injuries when swimming of their own volition into the area immediately below a spillway discharging all water over deflectors at discharges up to 159,000 cfs.
3. Hydraulic patterns from spillway deflectors have an effect on entry of adult salmon to collection facilities. The patterns may be manipulated to enhance passage.

4. Fallback of salmon occurs at Lower Granite Dam, during periods of spill.
5. The fishway at Lower Granite Dam effectively passes adult spring chinook salmon.
6. Most fish reaching the powerhouse collection system, by way of the north entrance, return to the tailrace.

Status: Photocopy in house

Reference Type: Sub-Report
Record Number: 28
Author: Long, C.W., W.M. Marquette, and F.J. Ossiander
Year: 1972
Title: Survival of fingerlings passing through a perforated bulkhead and modified spillway at Lower Monumental Dam April-May 1972
Publisher: U.S. Army Corps of Engineers, North Pacific Division
City: Portland, Oregon

Reference Type: Technical Report
Record Number: 15
Author: Long, C. W., F. J. Ossiander, T. E. Ruehle, and G. M. Matthews
Year: 1975
Title: Survival of coho salmon fingerlings passing through operating turbines with and without perforated bulkheads and of steelhead trout fingerlings passings through spillways with and without a flow deflector
Institution: Prepared for U.S. Army Corps of Engineers by National Marine Fisheries Service
Injury Type: Long-term
Relevance: Primary; direct assessment of smolt survival in standard versus deflector-equipped spillway
Keywords: deflector, spillway, steelhead, coho, survival
Abstract: Perforated bulkheads and spillway flow deflectors were designed by the Corps of Engineers to reduce the high levels of dissolved nitrogen and other gasses in the Snake and Columbia rivers caused by passage of water through standard spillways and low-head dams. The National Marine Fisheries Service, in cooperation with the Corps began studies at Lower Monumental Dam during the spring outmigration of salmon fingerlings in 1972. Results showed that perforated bulkheads installed in skeleton units caused high mortality (50%) to young fall chinook salmon, but flow deflectors with dentates were less harmful (less than 15% mortality). Studies in 1973, conducted with fingerling coho salmon, confirmed that skeleton units equipped with perforated bulkheads caused high mortalities and showed that coho had a higher survival in passing through a spillway equipped with a plain flow deflector than one having a flow deflector with dentates. Studies reported here measured survival of fingerling coho salmon through operating turbines with and without perforated bulkheads and survival of fingerling steelhead trout through spillways with and without flow deflectors.
Notes: Fish were released at Lower Monumental Dam and recovered at Ice Harbor and McNary Dams. Results indicated that survival of steelhead fingerlings was greater through spillways equipped with flow deflectors (2.2% mortality) versus standard spillways (27.5% mortality). Results imply that either the larger steelhead are significantly more susceptible to injury in a standard spillway, or the spillways at Lower Monumental Dam are more harmful than those at McNary Dam. In any event, the addition of flow deflectors to the ogee of existing spillways should result in significantly higher survival of steelhead that pass through spillways. Results of the turbine studies imply that perforated bulkheads can be used in operating turbines without causing a higher mortality than would be experienced by fish passing through a standard turbine operating in the range of 105-115% overload. We strongly suspect that the low survival through unit #2 for the second test condition was due primarily to the relatively high velocity through the bulkhead (58 ft/sec).
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 32
Author: Monan, G.E. and K.L. Liscom
Year: 1975
Title: Radio tracking studies to determine the effects of spillway deflectors and fallback on adults chinook salmon and steelhead trout at Bonneville Dam, 1974
Institution: National Marine Fisheries Service report to U.S. Army Corps of Engineers
Report Number: Contract # DACW57-74-F-0122
Injury Type: Long-term
Relevance: Primary with respect to adult upstream migration
Keywords: spillway, deflector, adult, fallback,
Abstract: Major modifications of spillways at dams in the Columbia and Snake Rivers have been proposed and initiated as part of an overall program for control of dissolved gas levels. Deflectors are being added to the spillways to prevent water passing over from plunging to depths. Prior to installation of spillway deflectors at all dams, fisheries agencies and the Corps desire to make certain that hydraulic conditions created by the modifications do not adversely affect survival and passage of fish at the projects. Initial studies at Lower Monumental Dam, where two of the eight spillbays had deflectors installed, revealed that while adult chinook salmon frequented to a limited degree the potentially dangerous area immediately below the modified spillbays, there was no evidence that fish were injured or their passage was impaired. Based on this finding with adults and on similar findings with juveniles, fishery agencies have recommended that additional spillbays be modified at major dams in the Columbia River Basin. Bonneville Dam is one of the dams scheduled for modification. Radio-tracking was chosen to study the effects the modifications had on adult salmon and steelhead trout. The primary objectives of the study were to determine: (1) whether adult salmon and steelhead trout frequent the potentially dangerous areas below the modified spillbays, and if so, (2) whether the fish are injured or killed by hydraulic conditions immediately below the deflectors. A secondary objective was to determine fish behavior in relation to fallback.
Notes: The following conclusions were made from data collected in this study:
1. Spring and summer chinook salmon and steelhead trout swim very close to or into the discharge from spillbays with deflectors installed.
2. Spring and summer chinook salmon, swimming of their own volition into the area immediately below a spillway discharging water over a spillway deflector, do not suffer debilitating injuries when discharges through the bays are in the range of 6,200-to 25,500 cfs.
3. Insufficient data were obtained for steelhead trout to indicate if debilitating injuries might or might not occur from flows immediately below a spillway deflector.
4. Fallback of salmon and steelhead trout during periods of spill is a substantial problem at Bonneville Dam.
5. Fish exiting the Bradford Island fishway into the forebay have the highest potential for falling back over the dam.
6. Fallback is primarily a consequence of fish following (for reasons unknown) a migration route from the exit of the Bradford Island fishway around Bradford Island to the vicinity of the spillway.
7. Fish in the vicinity of the spillway are more likely to fall back as spill volume increases.
8. Fallback does not result in a substantial mortality at Bonneville Dam; but it does delay the adult salmon in their upstream migration, and it contributes to greatly inflated fish counts.
9. The newly constructed vertical slot sections of the Bradford Island and Washington fishways effectively pass spring and summer chinook salmon and steelhead trout.
10. The side gate entrance to the "B" branch of the Bradford Island fishway is an important entry for spring and summer chinook salmon utilizing the "B" branch.
11. Steelhead trout can be tagged and tracked with internal-radio tags.
Status: Photocopy in house

Reference Type: Technical Report

Record Number: 24
Author: Monk, B.H., W.D. Muir, and R.F. Krcma
Year: 1986
Title: Studies to evaluate alternative methods of bypassing juvenile fish at the Dalles Dam-1985
Institution: National Marine Fisheries Service for U.S. Army Corps of Engineers
Date: June 1986
Type of Work: Final Report
Report Number: Contract DACW57-85-H-0001
Injury Type: N/A
Relevance: Tertiary
Keywords: screens, juvenile passage efficiency
Abstract: At the present time, juvenile salmonids passing The Dalles Dam on their downstream migration must pass through the turbines or be bypassed by means of the ice and trash sluiceway or spillway. During periods of no spill, Nichols (1979) estimated that passage through the sluiceway was about 40 to 60%. To increase the overall percent passage, a fingerling bypass system similar to that being used at other U.S. Army Corps of Engineers projects has been proposed. These systems consist of submersible traveling screens (STS) in the turbine intakes, vertical barrier screens and orifices in the gatewells, and a bypass channel (Fig. 1). In 1985, tests were conducted at The Dalles Dam to determine the benefits of this type of system.
Data from previous studies conducted by the Oregon Department of Fish and Wildlife (ODFW) indicated fewer yearling fish were usually found in the gatewells at the upstream end of the powerhouse at The Dalles Dam than at the downstream end (Fig. 2) (Nichols 1979). The data on subyearling chinook salmon, however, were insufficient to ascertain their distribution across the powerhouse. If the data for yearling fish could be verified and the same distribution was true for subyearlings, it might be possible to provide adequate protection for downstream migrants by installing screen systems in only a portion of the 22 turbine units.
In 1985, the National Marine Fisheries Service conducted a series of fish distribution and fish guiding efficiency tests to determine: (1) the benefits of an STS-type fingerling bypass system for The Dalles Dam and (2) if the system would need to be installed in all 22 turbine units or if installation in selected units would provide adequate protection. Vertical distribution and FGE studies were conducted to determine actual and potential fish guiding efficiencies (FGE) of an STS system. The vertical distribution studies would also help determine if there were actually less fish passing through parts of the powerhouse as other studies have indicated or if the fish were simply deeper in the water column which could give that impression. Horizontal distribution tests were conducted on subyearling chinook salmon to supplement the limited data obtained by Nichols (1979).
Notes: In 1985, FGE, vertical distribution, and horizontal distribution studies were conducted at The Dalles Dam to determine what portion of the powerhouse would need to be screened for adequate protection of migrating smolts. Major findings were:

1. Vertical distribution did not vary significantly between Units 2, 12, and 18 regardless of sluiceway/spill operations. These data lend credence to earlier ODFW data that suggest that a much higher proportion of the yearling salmon and steelhead migration passes through the downstream end of the powerhouse.
2. Vertical distribution studies showed that 83% of the steelhead, 67% of the yearling chinook salmon, 57% of the sockeye salmon, and only 22% of the subyearling chinook salmon were high enough in the turbine intake for interception by the standard STS.
3. As expected from vertical distribution results, FGE measurements on all species except steelhead were below the minimum acceptable level of 70%.
4. Sluiceway operations did not adversely effect FGE.
5. Steelhead were more surface oriented when the sluiceway and spill were operating.
6. In June, FGE for subyearling chinook salmon was 46%. By mid-July, FGE was only 8.4%. Similar low FGEs were found in July for subyearling chinook salmon at Bonneville and John Day Dams indicating it was a river-wide
problem. Above average water temperatures (> 74'F) for this time of year may have caused these fish to migrate at greater depths, seeking cooler water.
7. Descaling for most species remained low (< 5%) throughout the season for allconditions tested.

8. Lowering the STS 30 inches deeper in the intake significantly increased FGE from 8.4 to 13.9% for subyearling chinook salmon without a significant loss over the top of the STS.
9. Low water and fluctuating unit operation made it difficult to obtain any meaningful measures of horizontal distribution. The data obtained indicated larger numbers of fish were in Units 3 and 6, with fewer at the upstream end of the powerhouse. This may have resulted because of higher loading of units at the downstream end of the powerhouse.

Recommendations:
1. To reach the minimum level FGE (70%) at The Dalles Dam, standard STSs will probably have to be modified to intercept more flow.
2. The benefits of a lowered STS should be tested for yearling chinook salmon.
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 21
Author: Monk, B.H., W.D. Muir, and M.H. Gessel
Year: 1987
Title: Studies to evaluate alternative methods of bypassing juvenile fish at the Dalles Dam-1986
Institution: National Marine Fisheries Service for U.S. Army Corps of Engineers
Date: May 1987
Report Number: Contract DACW57-85-F-0295
Injury Type: N/A
Relevance: Tertiary
Keywords: guiding efficiency, bypass
Abstract: Juvenile salmonids passing the Dalles Dam on their downstream migration must pass through the turbines or be bypassed by means of the ice and trash sluiceway or spillway. During periods of no spill, Willis (1982) estimated that passage through the sluiceway was about 40%. To increase the overall percent passage, a fingerling bypass system similar to that being used at other U.S. Army Corps of Engineers (COE) projects was proposed. These systems consist of submersible traveling screens (STS) in the turbine intakes, vertical barrier screens and orifices in the gatewells, and a bypass channel. In 1986, the National Marine Fisheries Service, under contract to the COE, continued studies begun in 1985, to evaluate the potential benefits of this type of system. Fish guiding efficiency (FGE) test results obtained during 1985 indicated the use of a standard length STS would result in unacceptably low FGEs (<70%) for all salmonid species except steelhead. Vertical distribution (VD) tests conducted at the same time in Units 2, 12, and 18 showed that all salmonid species except steelhead were distributed too deeply in the turbine intakes to be intercepted by a standard length STS. Therefore, the STS would probably have to be either lengthened and/or lowered in the intake to increase FGE. Tests conducted with subyearling chinook salmon in 1985 compared the FGEs of a standard STS and an STS modified to operate 30 inches lower in the intake. During these tests, the lowered screen significantly increased the FGE for subyearling chinook salmon from 8.4 to 13.9% A similar proportionate increase would be more than sufficient to provide for acceptable FGEs for yearling salmonids. Therefore, in 1986, all testing was done with a 30-inch lowered STS to determine if similar benefits could be realized for spring chinook and sockeye salmon. Tests in 1985 were conducted from 16 to 21 April with the ice and trash sluiceway closed and from 30 April to 3 May with the sluiceway operating under normal conditions (0600 to 2200 h). In the later tests, the FGE for yearling chinook salmon increased by 12%. The FGE test schedule in 1986 was designed to determine if this increase was actually due to sluiceway operation or due to a change in vertical distribution of the later arriving migrants. In 1986, FGE studies were conducted in Unit 2 at The Dalles Dam to evaluate an STS modified to extend 30 inches lower in the gatewell in an effort to increase FGE for yearling chinook salmon to an acceptable target level of 70%.
Recommendations: To reach a minimum target level of 70% FGE for yearling chinook salmon at The Dalles Dam, it appears that either an extended STS will be required to intercept more flow or the vertical distribution of

the salmonids in the turbine intake will have to be altered by secondary mechanical devices similar to those being tested at other COE projects.
Notes:
1. The lowered STS tested in 1986 appeared to enhance FGE when compared to the standard STS tested at the same time in 1985. The increased FGE, from 43.5 to 55.6%, for yearling chinook salmon, was still well below the interim target FGE of 70%.
2. The FGE for the early run of yearling chinook salmon (primarily composed of Umatilla River and Deschutes River stocks) was significantly less than the FGE for the later-running yearling chinook salmon (primarily from the upper Columbia and Snake rivers). The early fish were also lower in the water column than the later fish. Apparently certain behavioral mechanisms that change during smoltification can affect the performance and position of fish in the water column and hence their tendency to be guided by the STS. Therefore, to correctly measure or compare FGES, between various STS types or between operating conditions at The Dalles Dam, the composition of the run should be considered.
3. Operating the sluiceway by opening the skimmer gates seems to draw off a percentage of the surface oriented yearling salmonids, as evidenced by significantly lower FGEs than measured with the sluiceway closed.
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 23
Author: Muir, W.D., R.N. Iwamoto, C.R. Pasley, B.P. Sandford, P.A. Ocker, and T.E. Ruehle
Year: 1995
Title: Relative survival of juvenile chinook salmon after passage through spillbays and the tailrace at Lower Monumental Dam, 1994
Institution: National Marine Fisheries Service funded by U.S. Army Corps of Engineers
Date: August 1995
Report Number: Contract E86940101
Relevance: Primary; direct assessments of smolt survival in spillbays with and without flow deflectors
Keywords: spillway, deflector, survival,
Abstract: Juvenile salmonids pass Lower Monumental Dam through spillbays, the bypass system, or turbines. Previous studies have indicated that among the different passage routes, survival was highest for fish passing via spillbays and bypasses, with lower survivals through turbines. The juvenile salmonid passage facilities at Lower Monumental Dam have been recently upgraded to include submersible traveling screens, vertical barrier screens, raised operating gates, a new collection channel, and a new juvenile bypass facility. The effects of these upgrades on passage survival has not been previously evaluated, and the most recent passage survival data was based on research conducted during the 1960s and 1970s. In 1994, the National Marine Fisheries Service initiated research to determine juvenile fish passage survival through the facility bypass, spillbay, and tailrace of Lower Monumental Dam. Specific objectives were to: 1) obtain statistically sound survival estimates on the passage of juvenile salmonids through spillbays, with and without flow deflectors, and the facility bypass; and, 2) compare the survival of dam-passage groups with fish released downstream from the dam.

Relative survivals averaged 0.984 for fish released into Spillbay 8 (without a flow deflector) and 0.927 for fish released into Spillbay 7 (with flow deflector). However, the difference was not statistically significant ($P = 0.1190$). The differences observed between the two conditions warrant further testing with increased replication to better define whether the addition of flow deflectors would benefit juvenile salmon passage. Spillbay evaluation should be repeated in future years to determine if there are differences in survival between the two types of spillbays by increasing the number of replicates. Bypass releases should be made during future years if conditions warrant to evaluate this route of passage.
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 22
Author: Park, D.L., J.R. Smith, E. Slatick, G.A. Swan, E.M. Dawley, and G.M. Matthews
Year: 1977
Title: Evaluation of fish protective facilities at Little Goose and Lower Granite Dams AND Nitrogen studies relating to protection of juvenile salmonids in the Columbia and Snake Rivers, 1976
Institution: National Marine Fisheries Service for U.S. Army Corps of Engineers
Date: March 1977
Type of Work: Final report of research
Report Number: Contract No. DACW68-75-C-0111
Injury Type: N/A
Relevance: Tertiary; contains measures of dissolved gas levels, but no evaluations of fish survival
Keywords: gas abatement, deflectors, supersaturation
Abstract: During 1976, the National Marine Fisheries Service (NMFS), under contract to the U.S. Army Corps of Engineers, continued to evaluate the following: (1) fish protective facilities for juvenile salmonids at Lower Granite and Little Goose Dams, (2) a mass transportation system for increasing survival of downstream migrant salmonids, and (3) dissolved gas abatement procedures in the Columbia and Snake Rivers. At Lower Granite Dam, emphasis was placed on traveling screen research and collection of smolts and their transportation by truck and aircraft. It is important to determine if transportation, found to be successful at Little Goose Dam, can be successfully employed further upstream nearer the smolt rearing areas. Experiments were also designed to determine if salt water is beneficial in alleviating stresses during transport, thereby increasing survival to the sea. Traveling screen research involved tests with the standard traveling screen and an adjustable angle traveling screen designed by the Corps of Engineers. Tests were made with the standard screen located in the bulkhead slot, and the adjustable angle screen located in the bulkhead slot and the fish screen slot. At Little Goose Dam, emphasis was placed on evaluating the mass transportation of juvenile salmonids. A portion of the smolts transported to Bonneville Dam were marked and some groups were hauled in salt water. We also continued to recover adults returning upriver from juvenile migrations marked and transported from Little Goose Dam in 1973 and from Lower Granite Dam in 1975. Throughout the study area, we also conducted research relating to the following: (1) the effects of stress on chinook salmon--includes data on descaling, gas bubble disease, and contagious diseases and (2) the levels of dissolved gasses in the Columbia and Snake Rivers especially as related to spillway flow deflectors at Little Goose and McNary Dams.
Notes: Summary:

1. The mass transport concept was broadened to include hauling from Lower Granite Dam. A total of 1.2 million salmonids were hauled from Lower Granite and Little Goose Dams to Bonneville Dam or the estuary (air transport) in 1976.
2. Transportation from Lower Granite Dam included a continuing investigation of trucking to provide a means of increasing survival of smolts collected at the upper dam. A new concept of transporting fingerling chinook salmon by air was begun. Testing the two transport systems resulted in marking 238,974 chinook salmon and 165,828 steelhead trout which were released in various locations. About one-half of the fish released below Bonneville Dam were transported in 5 ppt salt water. A significant reduction of delayed mortality after transport was achieved by using salt water.
3. Research was conducted at Lower Granite Dam to determine if fish disease as of significant magnitude to influence survival of transported chinook salmon smolts in 1976. In addition, about 1200 chinook salmon fingerlings were transported to and held directly in seawater to determine if any freshwater diseases were contributing to delayed mortality after the fish reached salt water. The combined results of the studies indicate that contagious diseases were not a serious factor influencing survival among transported chinook salmon in 1976.
4. Descaling or injury of chinook salmon smolts was monitored at the marking buildings at Lower Granite and Little Goose Dams. The descaling rate was 7% and 11.5%, respectively, indicating that steps need to be taken to reduce descaling--especially at Little Goose Dam.
5. Descaling attributed to standard traveling screens was monitored at Lower Granite Dam. The descaling rate was about 3.5%, which is down from the 6.4% reported last year.

6. A new adjustable angle traveling screen was tested at Lower Granite Dam. Spring tests were limited because of mechanical problems, but full-scale tests were accomplished in October-November. Best guidance and least descaling (hatchery-reared spring chinook) occurred with a lighted screen in the bulkhead slot at screen angles 50 to 650. Average recovery was 85% and descaling was nil. With screen lights off, guidance decreased to 75% and descaling increased slightly. Guidance at 450, the angle used on the standard screens, was significantly' less effective than the other angles tested (50 to 650). Poorest guidance occurred with the screen in the fish-screen slot. Turbine load (155 vs 125 megawatts) did not have a significant impact on guidance in the bulkhead slot. In the fish screen slot, better guidance was noted at 125 megawatts, but significance is doubtful since fewer tests were made.

7. Tests were conducted to determine the best orifice operating condition to provide egress of fingerlings from the gatewells at Lower Granite Dam. We concluded that both 8-inch orifices should be used with the orifice light on.

8. At Little Goose Dam mass transportation of smolts was emphasized. Further testing of transportation of fingerlings in salt water (10 ppt) was accomplished. About 850,000 fingerlings were counted, of which 188,000 chinook salmon and 129,000 steelhead trout were marked for mass transport (truck) experiments. The overall delayed mortality was down significantly from the 12% delayed mortality reported last year. Average delayed mortality of chinook salmon hauled in fresh water was 3 to 6% vs 4% for smolts hauled in salt water; no significant reduction of delayed mortality could be detected for smolts hauled in salt water. However, average transport mortality for chinook salmon and steelhead trout was noticeably lower in saltwater hauls than in freshwater hauls (<0.1% mortality in salt water vs about 0.5% in fresh water).

9. Adults returning from smolts released from tests at Lower Granite Dam in 1975 and from similar studies at Little Goose Dam in 1973 were captured at the trap facilities at Little Goose Dam. Returns of one-ocean chinook salmon and steelhead trout (75 and 200, respectively) from smolts transported from Lower Granite Dam in 1975 indicate a transport benefit ratio of 3.0 to 1 for chinook salmon and 2.5 to 1 for steelhead trout. Return of adults from releases of smolts from Little Goose Dam in 1973 are virtually complete. The transport benefit ratio for chinook salmon is 12.8 to 1 and 13.3 to 1 for steelhead trout. Transport from Lower Granite and Little Goose Dams is continuing to be encouraging as a solution for smolt passage problems on the lower Snake River.

10. Dissolved gas concentrations in the lower Snake and Columbia Rivers were monitored again this year. In addition, intensive N 2 sampling was carried out to evaluate the effectiveness of newly installed spill deflectors at Little Goose and McNary Dams. Concentrations of dissolved gasses in the Snake and Columbia Rivers were generally less than observed in previous years with similar river conditions. The spillway deflectors installed at Little Goose and McNary Dams were effective at reducing dissolved gas concentrations over a wide range of flows.

Status: Photocopy in house

Reference Type: Technical Report
Record Number: 20
Author: Park, D.L. and S. Achord
Year: 1987
Title: Evaluation of juvenile salmonid passage through the bypass system, turbine, and spillway at Lower Granite Dam-1986
Institution: U.S. Army Corps of Engineers and National Marine Fisheries Service
Type of Work: Annual report of research
Report Number: Contract DACW68-84-H-0034

Reference Type: Technical Report
Record Number: 17
Author: RMC Environmental Services
Year: 1992

Title: Juvenile blueback herring (Alosa aestivalis) survival in powerhouse/turbine passage and spillage over the dam at the Crescent hydroelectric project, New York
Institution: New York Power Authority

Reference Type: Technical Report
Record Number: 35
Author: Schoeneman, D.E. and C.O. Junge, Jr.
Year: 1954
Title: Investigations of mortalities to downstream migrant salmon at two dams on the Elwha River
Institution: Washington Department of Fisheries
Date: April 1954
Type of Work: Research Bulletin No. 3
Injury Type: immediate, short-term
Relevance: tertiary with historical relevance
Keywords: spillway, stilling basin
Abstract: At the Glines spillway, which has a free fall of 180 feet, no significant mortalities were noted for either of the two species studied. During the special study period with spill varying from 0 to 8 feet of gate opening the same results were obtained using chinook fingerling. At the Elwha spillway, which is the contained flow type with 100 feet of head, a pronounced chinook mortality was noted. It may seem unusual that the largest chinook mortalities occurred at the dam with the lowest head. It is pertinent to note that for a constant head the energy to be dissipated in the spillway varies directly with the amount of spilled water. The manner in which this energy is dissipated determines the mortality rates. Under small spill conditions with a free-fall type of spill, a part of the energy is dissipated by aerating action. Under sufficiently heavy spills, much of the energy must be dissipated in the pool below the spillway thus creating turbulence which may kill fish. In the free-fall spillway at Glines dam, the present study indicates that for spills of 8 feet or less, the manner in which the energy is dissipated causes no significant kill. It might be expected that in a contained type of spillway a formalized energy dissipater would kill fish. It was not possible to test this hypothesis at the Elwha dam because the spill strikes directly onto rocks. (See Table 22 for 63 percent survival.)

The natural migrational pattern of the unmarked chinook fingerlings and silver yearlings planted in lake Mills showed that chinook fingerlings will sound to a depth of 65 feet for egress when other exits are not available, but will choose a surface exit with a greater degree of frequency as the surface attraction increases. Yearling silvers, on the other hand, rarely sound to obtain egress from the forebay, but will remain in the lake until such time as a favorable exit is presented. This trend has also been noted in connection with research experiments at White river.
Notes: Reviewed on page 57 of M.C. Bell (1972). A compendium on survival of fish passing through spillways and conduits
Status: need to obtain copy

Reference Type: Technical Report
Record Number: 18
Author: Schoeneman, D.E., C.O. Junge Jr., W.E. Boxtick, and T.K. Meeking.
Year: 1955
Title: Research relating to mortality of downstream migrant salmon passing McNary Dam
Institution: Prepared for U.S. Army Corps of Engineers by Washington Department of Fisheries
Report Number: Contract DA 35026-Eng-20893

Reference Type: Journal Article

Record Number: 34
Author: Schoeneman, D.E., R.T. Pressey and C.O. Junge, Jr.
Year: 1961
Title: Mortalities of downstream migrant salmon at McNary Dam
Journal: Transactions of the American Fisheries Society
Volume: 90
Issue: 1
Pages: 58-72
Injury Type: Immediate and short-term
Relevance: Tertiary, lacks detailed information
Abstract: Studies conducted with live fingerling salmon in full-scale test apparatus indicated that few fish will be killed or injured as a result of rapid pressure changes as they pass underneath the spillway gates release of pressure occurring in approximately 5 milliseconds. Since the release of pressure vas considerably faster under the experimental conditions than would occur in a Kaplan turbine under similar head, it is concluded that this factor was not a cause of mortalities at McNary Dam. Another possible cause of mortality is the spilling process which generally takes place at Columbia River dams during the spring months when most fingerling salmon are migrating. When a spillway gate is raised, water from the forebay spurts under the gate and drops onto the concrete ogee section which carries it to the base of the dam where the tremendous force of the water is spent against the concrete energy dissipators. The cavitation which occurs at pitted areas in the concrete ogee section and the abrasive action of the rough concrete can cause injuries and possible mortalities. Tests on the effects of baffles eliminate the probability of any significant mortality due to fish striking the energy dissipators. If large quantities of water are being discharged, a back-roll may be created between the energy dissipators and the base of the spillway, with the possibility that fish caught in this back-roll could not escape and would be killed. Areas of danger mentioned above apply to almost every type of hydroelectric structure. The degree of severity, however, may be influenced by height and design of the structure, and the species and age of fish passing through it.
Notes: A general study that identifies potential factors responsible for juvenile fish mortality during passage over spillways and into stilling basins. Does not provide specific details.
Status: To be obtained

Reference Type: Technical Report
Record Number: 2
Author: U.S. Army Corps of Engineers
Year: 1956
Title: Effects of structures at main Columbia River and certain other dams on downstream migration of fingerling salmon
Type of Work: Research report

Reference Type: Technical Report
Record Number: 3
Author: U.S. Army Corps of Engineers
Year: 1960
Title: Effects of structures at main Columbia River dams on downstream migration of fingerlings
Institution: North Pacific Division
Type of Work: Progress report

Reference Type: Technical Report
Record Number: 19

Author: U.S. Army Corps of Engineers
Year: 1979
Title: Fifth progress report on fisheries engineering research program, 1973-1978
Institution: Fish and Wildlife Section
Date: September, 1979

Reference Type: Technical Report
Record Number: 31
Author: U.S. Army Corps of Engineers
Year: 1993
Title: Seventh progress report, fish passage development and evaluation program 1984-1990
Institution: U.S. Army Corps of Engineers
Date: July 1993

Reference Type: Technical Report
Record Number: 30
Author: U.S. Army Corps of Engineers
Year: 1994
Title: Ice Harbor spillway deflectors, preliminary letter report
Date: October 1994
Relevance: Primary
Keywords: deflectors, spillway, mortality
Abstract: The immediate installation of spillway deflectors on all ten bays at Ice Harbor is not needed because of the potential for adult passage problems observed and described by and Carnegie. It is not prudent to overrule these strong recommendations with the current, able information. Although this option would not cause problems with erosion within the basin, the risk to adult passage is too great without further investigations.

The installation of deflectors on either the center six or eight bays is not recommended out conducting hydraulic model testing to define the impacts of pier extensions on the nation of the stilling basin and on adult passage conditions. The dam safety concerns would also need to be addressed prior to allowing installation of deflectors on less than the full spillway.

However, spillway deflectors at Ice Harbor could provide a 5- to 10-percent reduction in dissolved gas supersaturation. For the most likely future operating scenarios, this could result in .improvements for both juvenile and adult migrating fish. Therefore, it is recommended that a plan combining features from three of the options identified in this report be pursued. The recommended plan is to prepare a design memorandum (DM) for installing spillway deflectors at Ice Harbor and concurrent with the completion of the DM and its review and approval period, prepare the plans and specifications. The DM preparation would include conducting necessary hydraulic model studies (using both a general and a spillway sectional model) to optimize various design aspects as well as to evaluate and minimize any adverse impacts on adult fish passage conditions. Possible field investigations to evaluate impacts to adult fish passage have also been included as part of the DM preparation. Concurrent work on the plans and specifications while completing and approving the DM is estimated to reduce the time to advertising the contract by about 4 months.

At this point, the most likely alternative to be recommended by the DM is to construct deflectors on the center eight spillway bays and to extend the two existing pier extensions to the end of the stilling basin. However, the existing pier extensions may already be sufficiently long to prevent stilling basin erosion similar to what has occurred at Lower Monumental Dam. The hydraulic model testing conducted as part of the DM preparation will be used to verify whether the existing pier extensions are adequate and to evaluate impacts of the various designs on adult fish passage.

Part of the recommended plan is to monitor the progress of the current regional study looking for more effective methods of obtaining reduced supersaturation levels downstream of each of the lower Columbia and lower Snake River dams (Gas Supersaturation Abatement Study). Besides generally monitoring the progress of the study team throughout the abatement study, the progress will be checked prior to completing the DM. Based on the current schedules this would occur shortly after the study team has completed the report for Phase 1. The results of Phase I would then be factored into the recommendation of the DM.

It should also be noted that if no stilling basin modifications are found that can provide acceptable adult fish passage conditions, then efforts toward constructing spillway deflectors would be terminated. Testing is also planned for next year to determine whether there are negative impacts on juvenile fish because of spillway deflectors.

The fully funded cost of preparing the DM and P&S is estimated at $1.3 minion and will take approximately 24 months. A large portion of the 24 months is attributable to the construction and testing of necessary hydraulic models to address adult fish passage concerns and to optimize design features (see Chart I on the next page). If the DM recommends installing eight deflectors on the center spillway bays and the two associated pier extensions, the total, fully funded cost is $7.0 million (including the costs of DM and P&S preparations). The time required for full implementation will depend on what modifications are finally selected, what length of work window is allowed, and when in the annual hydrologic cycle, approval and funding is received.
Status: Copy in house

Reference Type: Technical Report
Record Number: 37
Author: U.S. Army Corps of Engineers
Year: 1996
Title: Dissolved gas abatement study, Phase I
Date: April 1996
Type of Work: Technical Report
Report Number: Phase I
Relevance: Primary
Notes: Report provides a comprehensive analysis and summary of structural and operational changes made by the Corps to reduce total gas supersaturation in the Lower Snake and Columbia River; essentially a program to manage total dissolved gases. The report is a response to spilling at eight Lower Columbia and Lower Snake River Dams to improve survival of downstream migrating smolts. Contains explanation of structural alternatives considered for dissolved gas reduction in spillways, stilling basins, and tailraces below dams. Provides background information on Gas Bubble Disease in the Columbia River. Includes a stilling basin modification study at John Day and Ice Harbor Dams, and a summary of dissolved gas abatement studies in 1995.
Status: In house copy in white 3-ring binder

Reference Type: Sub-Report
Record Number: 46
Author: Vernon, E.H. and W.R. Hourston
Year: 1957
Title: A report on the effects of Cleveland Dam on seaward migrant coho and steelhead in Capilano River, 1953-56.
Publisher: U.S. Army Corps of Engineers
City: Portland, Oregon

Injury Type: Immediate
Relevance: stilling pool, spillway crest, tailwater elevation
Abstract: A plot of mortality against discharge indicated no relationship between these two factors, i.e. higher discharge did not result in higher mortalities, nor was the converse true. It would appear that any beneficial effects of higher tailwater elevation in the stilling pool at high discharges are offset by detrimental effects of high spillway velocities. Two tests were conducted while the drum gate was raised 2.8 feet above the spillway crest of 547 feet. With the gate in this martially raised position, considerable difference was noted in the flow over the spillway. The jet fell free from the crest for some 20 to 30 feet before striking the spillway face. The nap from this point downward showed greatly increased turbulence. However the two tests conducted with the gate raised on June 6 and 7, 1956 gave estimates of 50 and 71 percent mortality and thus do not reflect any significant change in the effects of the spillway on coho smolts. Since discharge and gate position cannot be shown to have any relation to spillway mortality, all estimates made in 1955 and 1956 may be combined to give a mean estimate of mortality for coho seaward migrants of 57 percent.
Notes: Review compiled from Bell (1972), other publication information was not given

Reference Type: Journal Article
Record Number: 40
Author: Weitkamp, D.E. and M. Katz
Year: 1980
Title: A review of dissolved gas supersaturation literature
Journal: Transactions of the American Fisheries Society
Volume: 109
Issue: 6
Pages: 659-702
Injury Type: N/A
Relevance: Tertiary; describes
Abstract: Dissolved gas supersaturation is a condition that results from natural and human-caused processes. Supersaturation can result in gas bubble disease which has been described in a wide variety of fishes and invertebrates. In recent years dissolved gas supersaturation resulting from dams and thermal discharges has produced mortalities of fishes in several cases. This review discusses most of the available literature dealing with dissolved gas supersaturation and the recorded cases of gas bubble disease. Various mechanical solutions to the problem of gas supersaturation are discussed.
Status: Photocopy in house

Reference Type: Technical Report
Record Number: 29
Author: White, R.G., G. Phillips, G. Liknes, J. Bammer, W. Connor, L. Fidler, T. Williams, and W.P. Dwyer
Year: 1991
Title: Effects of supersaturation of dissolved gases on the fishery of the Bighorn River downstream of the Yellowtail Afterbay Dam
Institution: Prepared for the U.S. Bureau of Reclamation by the U.S. Fish and Wildlife Service and Montana Department of Fish, Wildlife and Parks
Date: April 1991

Reference Type: Technical Report
Record Number: 39
Author: Wilhelms, S.C. and J.S. Gulliver
Year: 1994

Title: Self-aerated flow on Corps of Engineers spillways
Institution: U.S. Army Corps of Engineers
Date: May 1994
Type of Work: Final Report
Report Number: Technical report W-94-2
Injury Type: N/A
Relevance: Not applicable; objective was to describe description of self-aerated flow.
Abstract: Research in this document was conducted at the Hydraulics Laboratory and the St. Anthony Falls Hydraulic Laboratory. This report summarizes results of an investigation into the area of air entrainment at Corps of Engineers hydraulic structures.
Status: Library copy in house