1.0 INTRODUCTION

Juvenile salmonids migrating downstream in the Columbia River Basin encounter any or all of the following exit routes at hydro dams: turbines, spillways, and bypasses. There are two inter-related concerns associated with passage through any of these routes. One is the proportion of fish utilizing any of these routes during emigration. The second concern is the fish condition or survival associated with passage through these routes. Spill has been used to enhance overall survival of juvenile emigrants because of reported high survival, ≥98% (Schoeneman *et al.* 1961; Heinle and Olson 1981; Ledgerwood *et al.* 1990; EPRI 1992; Ferguson 1993), at hydro dams in the Columbia River Basin. However, a comparative account of fish condition or survival immediately after passage over a spillway equipped with a flow deflector and without a flow deflector is lacking in the literature. Flow deflectors have been reported to be effective in reducing gas supersaturation without causing decreased fish survival (Long *et al.* 1975; Johnson and Dawley 1974). Flow deflectors are concrete sills installed on the downstream face of a spillway to maximize the surface skimming effect of spilled water and prevent plunging to the bottom of the stilling basin thus reducing the pressure gradient that forces atmospheric gases into the solution (Ruggles and Murray 1983). Flow deflectors were installed at Bonneville Dam in 1975 to reduce gas supersaturation.

There are two primary components of estimating total mortality of juvenile salmonid emigrants entrained in various exit routes: direct and indirect effects. The direct effects are manifested immediately after passage as instantaneous fish mortality, injury, and loss of equilibrium; the indirect effects (e.g., predation, disease, physiological stress, etc.) may occur over an extended period and distance, individually, or in synergism. The most straightforward approach to estimate direct effects of passage is to introduce a known number of marked alive fish into a passage route, recapture them immediately after passage, and enumerate the alive and dead fish and carefully examine the condition of each fish. However, due to logistical constraints of sampling highly turbulent discharges of large hydro-dams it has been difficult to quantify the mortality/injury due to immediate effects of passage from that due to other extraneous stresses (e.g., handling, tagging, induction, recapture gear) and without adversely affecting the non-targeted species.

Spillway or bypass fish passage mortality rates (range 0 to 17%) that have been reported earlier (Schoeneman *et al.* 1961; Johnsen and Dawley 1974; Long *et al.* 1975; Heinle and Olson 1981; Ledgerwood *et al.* 1990) were derived from mark-recapture methodologies which did not separate the direct effects of passage from indirect effects. The recapture process occurred over several days, at distant locations, provided low recapture rates, and did not give investigators an opportunity to examine the fish condition immediately upon passage. All of the above factors expose fish, both treatment and controls, to other sources of mortality which may or may not be passage-related and thus are difficult to

isolate (Mathur *et al.* 1996a). Consequently, it is likely that the estimates derived from such an experimental protocol have embedded in them the effects of the direct, indirect, and other sources of mortality. From a practical standpoint of spillway design improvements, if any, precise estimation of direct effects embodied in the spillway configuration is needed.

Recent experiences have shown that the HI-Z Turb'N Tag recapture method (balloon tag) is a rapid and accurate method to estimate direct effects of passage within a pre-specified precision ($\varepsilon \pm 5\%$) and significance level ($\alpha=0.10$) at hydro dams such as those on the Lower Columbia River (Heisey *et al.* 1992,1993; Mathur and Heisey 1992,1993; Mathur *et al.* 1994, 1996b; RMC and Skalski 1994a,b; RMC *et al.* 1994). The method assures relatively high recapture rates and provides a direct means to separate passage related injury/mortality from that due to transport, holding, handling, marking/tagging, induction, and sampling. Additionally, it requires relatively small sample sizes to conduct a statistically reliable study, providing the opportunity to either use naturally migrating juveniles or hatchery-reared fish (Heisey *et al.* 1992; RMC and Skalski 1994a,b; RMC *et al.* 1994, 1995; Normandeau Associates 1995; Normandeau Associates *et al.* 1995). Since the HI-Z tag-recapture technique is chemically based, it is generally free from potential biases in recapture and survival probabilities associated with natural river flow and project operations, it is deemed suitable for estimating direct effects of passage through various exit routes (Heisey *et al.* 1992; Mathur *et al.* 1996a,b). The U.S. Army Corps of Engineers (ACOE), Portland, Oregon inquiry specifically identified the passage routes to be examined (e.g., spillways, sluices, and prototype spillway slot configurations); this methodology provided an opportunity to rapidly test these conditions. The ACOE, in its Request for Proposal, identified the following major technical criteria to be met by the proposed methodology for Bonneville Dam.

- Fish recovery will be selective to eliminate any potential effects on non-study fish in the system;
- Methodology will provide differential fish condition, injury rate estimates (immediate and 48 h) for each test condition within $\varepsilon \leq \pm 5\%$ at the ($1-\alpha=90\%$) confidence level;
- Methodology will provide at least 80% recovery of marked fish;
- Fish recovery to be within one hour of release.

Tables 1-1 and 1-2 show a comparison of the study specifications set forth by the ACOE with those actually achieved via the usage of the balloon tag technique. It demonstrates that this technique equalled or exceeded the ACOE study specifications. Recapture rates were high, recapture times were less than 10 min, and low handling mortality was observed. None of the non-study fish were affected in these studies. The tag-recapture investigation did not require modifications either to the project or its operations or involve other non-experimental fishes. Estimates of mortality/injury were obtained within a precision (ε) level of $\leq \pm 5\%$ at ($1-\alpha=90\%$) confidence level using a relatively small sample size

(N=250). The source of injury and mortality to the test fish were identified (RMC 1994, RMC and Skalski 1994a,b).

The ACOE awarded the contract to Normandeau Associates, Inc. (NAI) to perform the fish condition investigation at Bonneville Dam using the balloon tag-recapture technique. In turn, NAI subcontracted Mid Columbia Consulting, Inc., East Wenatchee, Washington (MCC) to assist in procuring the experimental fish and provide field logistical support. Dr. John R. Skalski, Professor, University of Washington, Seattle, Washington was retained as a consulting statistician to assist in data analysis.

The specific objectives of the investigation were to (1) estimate the direct effects of passage on immediate (1 h) and 48 h relative survival of young chinook salmon (*Oncorhynchus tshawytcha*) within $\varepsilon \leq \pm 5\%$ ($1-\alpha=90\%$ confidence level); chinook salmon were introduced into a spillbay equipped with a flow deflector (spillbay 4) and one without a flow deflector (spillbay 2); and (2) identify the probable source and magnitude of injury/mortality. Additionally, treatment fish were released into ice and trash sluices of Bonneville Powerhouses 1 and 2 to obtain an idea on generalized passage problems, if any, without the specific intention to estimate survival within a specified precision level.

1.1 Study Site

Bonneville Dam is the first dam upriver (river mile 145 or 232 river km) on the main stem Columbia River (Figure 1-1) and is located east of Portland, Oregon. It consists of two powerhouses, a spillway, and a navigation lock. The first powerhouse was completed in 1938 and is located between the Oregon shore and Bradford Island (Figure 1-2). The second powerhouse was built in 1982, and is located between the Washington shore and Cascades Island (Figure 1-2). The spillway, consisting of 18 gates, each 50 ft wide, is located between the Bradford Island and Cascades Island, spanning the north channel. The spill gates are raised to allow excess river flow to pass under them at a depth of about 50 ft below the upstream water surface. Spill gates are typically raised 1 to 7 ft to facilitate downstream migration of juvenile salmonids.

In order to reduce the level of gas supersaturation produced by water passing over a spillway, ACOE had installed flow deflectors in 1975 on the downstream face of the spillway that direct the spilled flow along the surface of the tailrace rather than allowing it to plunge to the bottom of the spilling basin; these flow deflectors (also designated flip-lip) are at elevation 16 ft (msl). Thirteen of the 18 spillbays are equipped with flow deflectors. Spillbay 2 is not equipped with a flow deflector, while spillbay 4 is equipped with a flow deflector. Additionally, a double row of concrete dentates extend across the spillway to aid in energy dissipation. These flow dissipators are 14 ft wide at the base and slope up to a 2 ft width at the top. They are 6 ft above the bottom sill of the spillbay and their tops

should have been approximately 26 ft below the water surface when the fish passage tests were conducted. Figure 1-3 shows a schematic of a spillbay with a flow deflector and dentates. Spillbays 2 and 4 were studied for comparison of the potential effects of flow deflectors on fish survival and condition.