Statistical and Biological Study Design Options to Evaluate New Turbine Runners Designed for Safer Fish Passage at Ice Harbor Dam on the Lower Snake River, Washington

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Executive Summary

New turbine runners designed for safer fish passage will be installed in Units 1, 2 and 3 at Ice Harbor Lock and Dam. Installation of the new runners will begin in 2015 with completion anticipated in 2018. Unit 2 will receive a fixed blade runner and will be the first installed. Unit 1 and Unit 3 will receive identical adjustable blade (Kaplan) runners. Installation of Unit 2 will be complete in early 2016; Units 3 and 1 will be complete in 2017 and 2018 respectively. These new turbine runners are designed to reduce risk of injury to juvenile fish caused by mechanisms such as blade strike and shear, as well as pressure injuries known as barotrauma. Extensive computational fluid dynamics (CFD) and physical hydraulic modeling efforts have focused on achieving good hydraulic conditions with minimum pressures of 83kPa to 103kPa. Maintaining nadir pressures ≥ 83kPa will greatly reduce risk of pressure related injury and mortality experienced by turbine passed juvenile salmonids.

Once installed the new turbine runners require a biological evaluation to establish the biological performance and to validate the design process and criteria. The biological study design should produce precise, accurate survival estimates with the least associated bias possible. A combination of balloon tag and acoustic telemetry study methods will provide turbine survival estimates encompassing both direct and indirect effects of turbine passage. These study methods have been Regionally accepted and used to establish the most recent estimates of turbine passage survival at the lower Snake and Columbia River dams.

Turbine pressure and acceleration data will be collected. These data will be used correlate conditions fish experience as they pass through the turbines with injury and mortality. These data provide evidence of blade strike, shear, and pressure and will also be used to determine how well the new turbine designs meet the biological criteria, and for comparison with and validation of CFD model results.

Pertinent factors are discussed for consideration in choosing and implementing each study design. Statistical analysis methods and preliminary sample sizes associated with these study designs are presented, as well as design assumptions and biases, project operations, and sample season considerations. Internal and external acoustic and balloon tagging methods, release locations for upstream releases and direct turbine intake releases, and acoustic detection array locations are discussed as well.

This document may be used to help plan and implement other possible study designs and technologies to evaluate turbine and full dam passage survival as applicable; however, the most feasible option for biologically testing the new Ice Harbor Dam turbines may be a paired release study with direct turbine intake release of the study fish. Release locations and apparatus, tag types, turbine operations will be discussed and finalized among the USACE and participating Regional technical leads.

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Table of Contents

List of Tables

List of Figures

List of Definitions

Barotrauma – injuries sustained from exposure to severe pressure changes. Fish may suffer barotrauma as a result of passing through low pressure regions typically near the suction side of the turbine runner blades.

Direct Injury – injury caused by blade strike, shear, pinch, scrape, or any other mechanical or hydraulic caused injury directly related to turbine passage (see *mechanical injury*)

Direct Mortality – Mortality caused by direct exposure to mechanical and/or hydraulic forces within turbine passage environment

Direct Release – Release of fish into a turbine intake through a pipe extended down the gatewell from the powerhouse deck

Direct Survival – Survival estimates of fish passing through the turbine without the accounting of morality caused by immediate downstream effects such as predation. Representative of fish exposure to mechanical injury mechanisms, excluding pressure.

Indirect Injury – injuries sustain through turbine passage or as a result of turbine passage which include disorientation or other sub-lethal injuries not immediately detectable such as barotrauma which may increase the rate of downstream predation.

Intake – Approach into the dam that conveys water to the turbine runner

Kaplan – A propeller style turbine runner with adjustable blades

Mechanical Injury – Injury caused by interaction between fish and mechanical components of the turbine runner (see *direct injury*)

Mortal Injury – Injury that will result in immediate or delayed mortality caused by the direct effects of turbine passage

Nadir – lowest pressure a fish or particle would be exposed to during turbine passage. The Nadir pressure of any streamline generally occurs below the turbine runner.

Overall Survival – Total turbine passage survival accounting for mortality resulting from all aspects of turbine passage including delayed mortality and downstream predation resulting from sub-lethal injuries sustained during turbine passage.

Relative Survival – Survival estimates relative to a base condition derived from a specific condition or mechanism which may not account for all factors affecting survival

Runner – Hub and blade apparatus connected to the generator shaft that interacts with the water to turn the generator and produce power

Scroll Case – Chamber around the turbine runner where water enters the turbine unit

Subyearling Chinook Salmon – Juvenile fall Chinook salmon

Turbine – An enclosed rotary type of prime mover that drives an electric generator to produce power. The term “turbine” is often interchanged with “Turbine Unit”. The Turbine Unit is generally encompasses all of the hydraulic components within the water passage way and extends from the waters inlet (intake) through to the waters outlet (draft-tube).

Volitional – The act of making a choice or decision; willful or instinctual action

Yearling Chinook Salmon – Juvenile spring Chinook salmon

List of Acronyms and Abbreviations

AIC	Akaike's Information Criteria
ANODEV	Analysis of Deviance
ANOVA	Analysis of Variance
BiOp	Biological Opinion
BRZ	Boat Restricted Zone
CFD	Computational Fluid Dynamics
cm	centimeter
CMFE	Condition Malady-Free Estimate
dB	Decibel
ERDC	Engineering Research and Development Center
FCRPS	Federal Columbia River Power System
FL	Fork Length
FOP	Fish Operations Plan
FPP	Fish Passage Plan
GDACS	Generic Data Acquisition Control System
h	Hour
JBS	Juvenile Bypass System
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer
kPa	kilopascal
L	liter
m	meter
mm	millimeter
mL	milliliter
MW	Megawatt
NMFS	National Marine Fisheries Service
PNNL	Pacific Northwest National Laboratory
RCC	Reservoir Control Center
SE	standard error
STS	submersible traveling screen
TDG	Total Dissolved Gas
TSP	Turbine Survival Program
TST	Turbine Survival Test
VI	Visual Implant

1.0 Introduction

New turbine runners designed for safer fish passage will be installed in Units 1, 2 and 3 at Ice Harbor Lock and Dam. Installation of the new runners will begin in 2015 with completion anticipated in 2018. The Unit 2 turbine runner is a fixed blade runner and will be the first installed. Unit 1 and Unit 3 turbine runners will be identical adjustable blade runners. Installation of Unit 2 will be complete in early 2016; Units 3 and 1 will be complete in 2017 and 2018 respectively. The purpose of designing and installing these “test turbines” was to fine-tune the turbine design process, develop new turbine runners to provide the safest fish passage possible for any species passing Ice Harbor Dam, and evaluate the outcome of this design process through turbine survival studies.

The new turbine runners will undergo biological testing to estimate passage survival and the effects of the turbine environment on juvenile salmonids. Biological testing is expected to occur in units 1 and 2 in 2016 subsequent to the new unit 2 runner install. Unit 1 will serve as the baseline existing condition. A combination of units 2 and 3 or only units 3 may be tested in 2017 subsequent to the new unit runner install. While several different passage survival study designs are available, each provides a varying degree of complexity and accuracy, some of which may not appropriately satisfy study objectives.

As technology has advanced since early passage survival studies, the ability to produce more accurate, precise estimates has greatly improved. Studies have shifted to include route-specific survival estimates and the mechanism of fish mortality (Bickford and Skalski 2000). Presently, the need to produce passage survival estimates in a manner that is physically reproducible yielding statistically sound results is important to fisheries managers and the US Army Corps of Engineers. With the production of new turbine runners designed using fish passage criteria, sound passage survival study designs are necessary to effectively evaluate improvements in turbine runner design and steer future turbine runner design efforts.

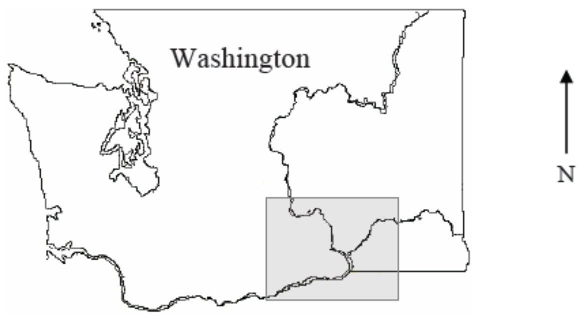
When selecting a study design the objectives of the study should be carefully considered. Study designs that are too simple may not provide statistically significant or conclusive results where a clear result may exist. Conversely, Study designs that are too complex may provide a wealth of information that is unnecessary for satisfying the study objectives. In either case resources are squandered, although there may be greater risk involved with selecting a study design that is too simple.

Efficient and accurate passage survival estimates require more detailed and complex study designs such as the Virtual with Paired Release-Recapture model proposed by Skalski et al. (2010) and Skalski (2011). The virtual release model provides survival estimates with greater accuracy and reduced standard error relative to single and paired release-recapture and route-specific models (Skalski et al. 2010).

This document may be used to help plan and implement other possible study designs and technologies to evaluate turbine and full dam passage survival as applicable and provides insight to three acoustic telemetry study designs, as well as discussion of considerations for available JSATS tag types, balloon tag studies, Sensor Fish releases, study periods, dam operations, and aquatic and avian predation concerns. The scope of this report has been limited to yearling and subyearling Chinook salmon and juvenile steelhead as the majority of passage and survival studies at lower Columbia and Snake River dams have been conducted with these species.

2.0 Site Description (USACE 2013a)

Ice Harbor Dam began operation in 1961 and is located approximately 15km upstream of the confluence of the Columbia and Snake Rivers near Burbank, Washington (Figure 1). The Project was authorized by Section 2 of the River and Harbor Act of 1945 (Public Law 79-14, 79th Congress, 1st Session). The dam is 860.1m long with a navigation lock and ten spill bays which span 179.8m (Figure 2). Presently the powerhouse holds six Allis Chalmers Kaplan hydropower turbine units numbered 1-6 from south to north, although unit 2 is currently fixed at 29 degrees as a temporary repair from mechanical failure. Units 1-3 and 4-6 have different spiral cases and runner designs and are capable of producing 90 and 111MW, respectively. Each unit intake has three bays labeled A, B, and C from south to north. Each unit intake is equipped with a standard-length submersible traveling screen (STS) to bypass juvenile out-migrants from the turbine units into the juvenile bypass system (JBS).The full Project contains 1447.2 hectares and the resulting pool named Lake Sacajawea.



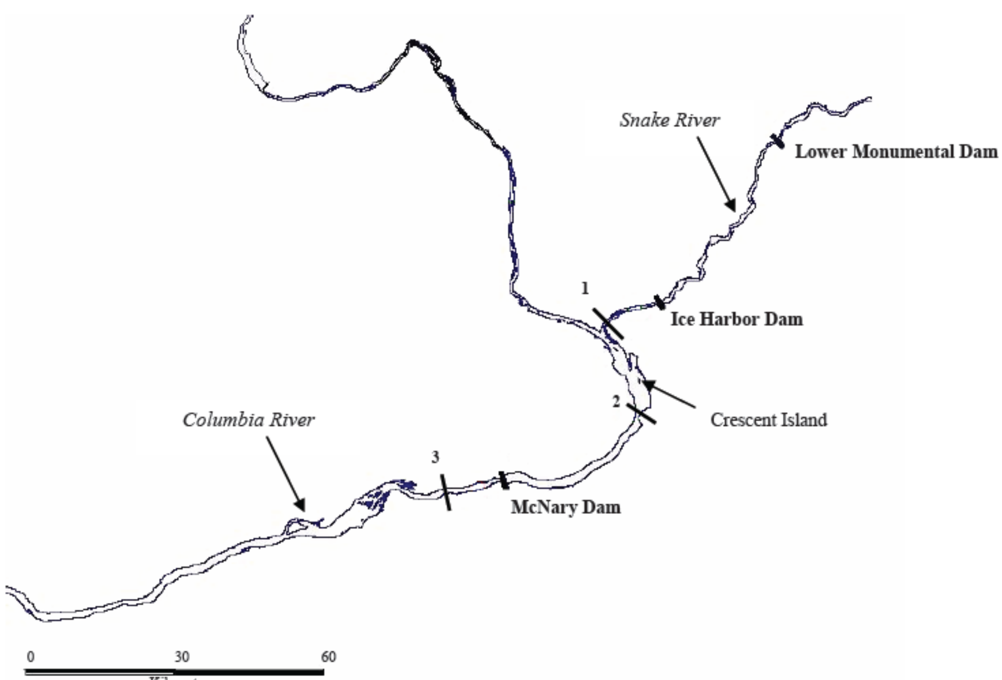


Figure 1 Location of Ice Harbor Dam on the Lower Snake River, Washington, USA (Ogden et al. 2005)

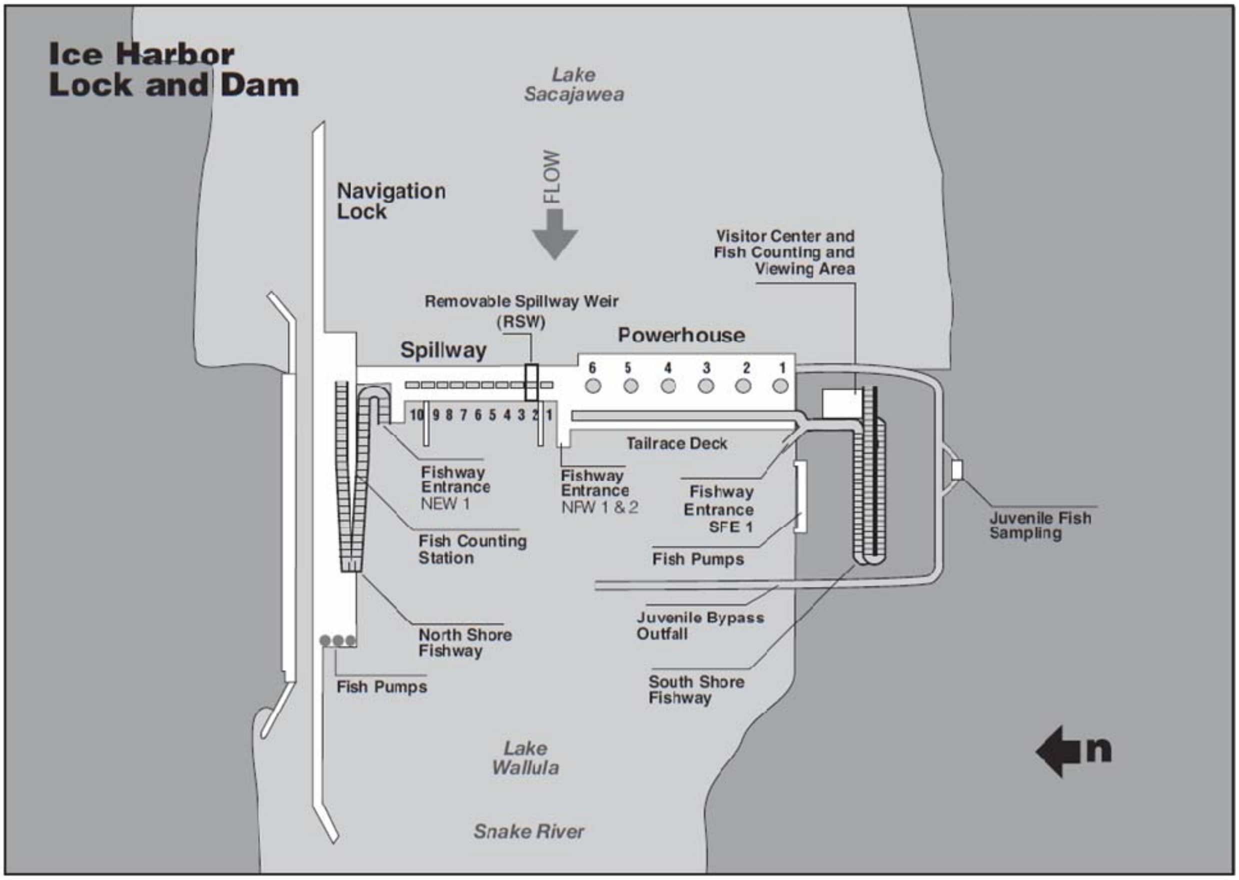


Figure 2 General Diagram of Ice Harbor Lock and Dam (USACE 2013b)

2.1 Current Operations (USACE 2013b)

Currently, Section 6 (Ice Harbor Dam) of the Fish Passage Plan (FPP) (USACE 2013b) requires all turbine units to be operated within 1% of best efficiency from April 1 through October 31 as specified in the load shaping guidelines (Table 1). When in operation, units will be operated to enhance adult and juvenile fish passage from March 1 through November 30. During this time period units will be operated as needed to meet generation requirements in the priority order shown in Table IHR-4 of the FPP. Model studies of Ice Harbor Dam show that spilling at lower river flows can cause eddying in front of the powerhouse. To provide the best fish passage conditions during periods of spill, it is important that the units operate in a specific operating order to minimize eddying conditions. The original and desired unit prioritization is 1, 3, 6, 4, 2, and 5.

These guidelines allow some deviation from the 1% operating range for coordinated fishery measures, some maintenance activities, system reliability needs, and emergency generation requirements. Tables with operating ranges for Kaplan units 1 and 3, 4-6 and the fixed Unit 2 within the 1% operating range at various head levels are contained in the FPP. Additionally, STS are required to be in for the period of approximately April 1st to December 15th. These screens divert a significant portion of fish entering the powerhouse into the gatewells and subsequently the JBS.

Table 1 Ice Harbor operations detailed in the BiOp (NMFS 2008) and Fish Passage Plan (USACE 2013b)

Spring Spill (Day/Night)	Summer Spill (Day/Night)	Turbine Ops
April 3-28 (45 kcfs/Gas Cap) **April 28-June 20** (30%/30% vs 45 kcfs/Gas Cap)	**June 21-July 13** (30%/30% vs 45 kcfs/Gas Cap) **July 13-August 31** (45 kcfs/Gas Cap; approximate Gas Cap range 79-95 kcfs)	1% of Best Efficiency (hard constraint 4/1-10/31) Minimum Generation: Units 1, 3-6 (8.5-10.3 kcfs) Unit 2 (11.3-13.1 kcfs)

The Ice Harbor powerhouse may be required to keep one generating turbine unit on line at all times to maintain power system reliability. During low flows there may not be enough river flow to meet this generation requirement and required minimum spill for juvenile fish passage. Under these circumstances, the power generation requirement for system stability takes precedence over the minimum spill requirement. At Ice Harbor, minimum generation requirements are 8.5-10.3 thousand cubic feet per second (kcfs) for turbine Units 1 and 3-6 and 11.3-13.1kcfs for turbine Unit 2. These minimum discharge requirements are in place to maintain project operation. In the late summer, mean minimum daily discharge for Ice Harbor is between 8 and 9kcfs although 95% of the time the Snake River discharge never drops below 12kcfs at Ice Harbor.

Spill operations at Ice Harbor have been designated during the fish passage season to increase spillway passage and bolster survival of juveniles out-migrating, as well as adults that fall back or kelts migrating downstream. The USACE will manage spill levels for fish passage to avoid exceeding 120% total dissolved gas (TDG) in project tailraces, and 115% TDG in the forebay of the next project downstream consistent with the current State of Washington TDG limits. These limits are referred to as gas caps. Spill operations presented in Table 1 are planned and assume average runoff conditions; however, adjustments to these spill rates may be necessary for the following reasons.

1. Low runoff conditions that may require adjustments in spill level while maintaining project minimum generation requirements.
2. High runoff conditions where flows exceed the powerhouse hydraulic capacity with the specified spill rates.
3. Navigation safety concerns.
4. Generation unit outages that reduce the powerhouse hydraulic capacity.
5. Power system or other emergencies that reduce powerhouse outflow.
6. Lack of power demand resulting in an increase in spill levels.

The USACE Reservoir Control Center (RCC) is responsible for daily management of spill operations responsive to changing TDG conditions. In order to manage gas cap spill levels consistent with the states' TDG saturation limits, the RCC establishes the TDG spill caps for the lower Columbia and Snake River projects on a daily basis throughout the fish passage season. The resultant TDG spill caps are set to provide TDG saturation levels that are not expected to exceed the 120%/115% TDG limits, which are measured as the average of the highest 12 hourly readings for each day.

Spill operations differ between day and night, as well as spring and summer (Table 1). Unless otherwise specified, spill will transition to summer operations at 0001 hours, or shortly after midnight, at each project on the day after spring spill ends. The USACE will initiate spill at 0001 hours, or shortly after midnight, at each of the projects on the start dates specified in the project sections below. Spill caps will be established at levels specified in the FPP Fish Operations Plan (FOP; USACE 2013b) and will continue unless conditions require changing to maintain TDG. Summer spill changes to straight 45kcfs by day and gas cap by night at Ice Harbor in mid July. Nighttime spill hours are 1800-0500.

2.2 Turbine Runner Design and Replacement

Units 1, 2 and 3 at Ice Harbor Dam are scheduled for replacement with new turbine runners designed for safer fish passage. Modifications to the draft tubes and stay vanes may occur for these units at this time as well. The new runners, and other components, are currently being designed by Voith Hydro, and model tested at the USACE Engineer Research and Development Center (ERDC) in Vicksburg, Mississippi.

Biological design criteria to reduce injuries and mortality, both direct (mechanical and pressure related) and indirect (disorientation, sub-lethal barotrauma, predation), is being used to design the new Ice Harbor test turbines. Aside from mechanical injuries, fish experience an abrupt pressure drop as they pass from the pressure side (tope side) to the suction side (bottom side) of the turbine runner blades. The lowest pressure in the flow path is referred to as the pressure “nadir”. Pressures experienced by fish passing through the turbine may vary with fish distribution across the runner blades, project head, operation, and tailrace elevation (runner submergence).

Criteria established for the new turbine runners limits the pressure nadir to a minimum of 83kPa; however, the design team has chosen a more conservative goal value of 103kPa. Atmospheric pressure is approximately 101kPa; therefore, maintaining higher nadir pressures reduces the disparity in the ratio of pressure change (acclimation pressure divided by nadir pressure). A decrease in pressure by ½ is equal to a ratio pressure change of 2 and also an expansion of the swim bladder by a factor of 2. For example, if a fish passing through a turbine goes from surface pressure (101 kPa) prior to turbine passage to a nadir pressure that is half of surface pressure (50.5 kPa) the volume of the pre-existing gas in the body doubles. For this reason, the goal of the new turbine designs to maintain nadir pressures equivalent to or greater than surface pressure (101 kPa) will greatly reduce the risk of barotrauma on turbine passed fish.

Efforts to reduce these low pressures have led to tradeoffs in turbine design where larger blades increase the nadir pressure but may increase the potential for strike. Multiple iterations for each design allow for tradeoff adjustment. Adjusting specifications such as blade size, runner vertical placement in the unit, blade shape, and leading edge thickness all influence the flow quality (how smoothly water may flow through the turbine runner as defined by CFD), pressure severity and potential for strike. The final runner designs and their performance will be a product of finely tuning each specification to provide the best overall passage conditions for fish. For this reason, once a prototype runner has been developed it is critical that an evaluation of the design be conducted to determine how well the new runners meet design criteria.

Biological testing of the new turbine units is also necessary to estimate fish passage survival and compare to other existing runners to justify the added cost of design, manufacture and installation necessary to meet the newly established biological criteria. Biological test results will also be correlated to Computational Fluid Dynamics (CFD) and physical model data to validate these as effective design tools to assure biological design goals are attained in future design efforts.

While the following information regarding various study designs is geared for juvenile Chinook salmon and steelhead, the new turbine runners were designed with the intent to provide a passage and survival benefit to all species, both salmonid and non-salmonid. Reducing strike and increasing nadir pressures will provide a benefit to all species passing. For example, laboratory study results suggest that species such as juvenile brook and Pacific lamprey are not susceptible to barotrauma associated with severe low pressures (Colotelo et al. 2012) leaving strike and shear as potential sources of injury. It may be hypothesized that juvenile lamprey will approach the turbine near the intake floor making it more likely to pass near the blade tip. Improving strike and shear potential at the blade tip will provide a survival benefit to juvenile lamprey, and any other species passing the turbine runner at this location.

3.0 Biological Study Objectives

The objectives of a biological study of the new turbine runner designs are based on the design criteria, CFD, and physical model data used to develop the new turbine runners and expected passage survival that may be realized from the biological design criteria. Estimating survival of turbine passed fish will provide the most common, applicable measure of passage route performance and will be comparable to estimates derived from other FCRPS dams. While defining the relative performance contribution of particular design elements is desired, increased survival is the main goal of the new runner designs. As previously mentioned, species tested are limited to Chinook salmon and steelhead smolts.

3.1 Primary Objectives

1) Estimate overall survival of yearling and subyearling Chinook and juvenile steelhead through the new turbines

Acoustic telemetry release-recapture methods should be employed for this objective to allow for study fish to become acclimated to river conditions prior to approaching and passing through turbines. Turbines will operate normally as scheduled for this objective.

1.1 Study periods (either or both may be tested):

1.2.1 **March-May:** Spring passage conditions that may provide lower predation rates with cooler water temperatures. Note: highest river discharges generally occur in May/June. (Spring spill begins in April, however, March is considered for a pre-spill spring study)

1.2.2 **June-August:** Summer passage conditions providing greater predation rates with warmer water temperatures

1.2.3 **Considerations:** No spill or reduced spill; no screens or bypass; run-of-river or hatchery fish; Biological Opinion (BiOp) required turbine operations, and potentially test operations outside the 1% range

2) Estimate survival difference between new and existing turbines

2.1 Test for significant differences in overall survival estimated with acoustic telemetry release-recapture studies among turbine operations.

H_0: There will be no significant difference in turbine passage survival among the new and existing turbines at Ice Harbor Dam for yearling and subyearling Chinook salmon and steelhead

H_a: Turbine passage survival will be significantly different through the new turbines relative to existing turbines at Ice Harbor Dam for yearling and subyearling Chinook salmon and steelhead

3) Evaluate differences in direct injury and relative survival between new and existing runners at the following turbine operations:

- Lower 1%
- Peak Efficiency
- Upper 1%
- Best operating point for fish passage

*Turbine operations to be tested are subject to change and will be finalized by the USACE technical leads after model testing is complete.

3.1 Direct mortality, injury, loss of equilibrium, shear, scrape, pinch, etc.

3.2 Determined using balloon tag study

3.2.1 Primary Objectives

1) Estimate direct injury of turbine passed fish at selected turbine operations

2) Relate direct injuries to specific mechanisms within the turbine unit (i. e. blade strike, shear, etc.) if possible.

H_0 : There will be no significant difference in direct injury and relative survival of turbine passed fish among operations with the new turbines

H_a : There will be a significant difference in direct injury and relative survival of turbine passed fish among operations with the new turbines

3.2.2 Secondary Objective

1) Compare the results of the primary objectives with previous balloon tag studies to determine if benefits (reduced mechanical and pressure injuries) of the new turbine designs can be quantified and compared to existing turbines.

H_0 : There will be no significant difference in direct injury and relative survival of turbine passed fish among operations between new and existing turbine designs

H_a : There will be a significant difference in direct injury and relative survival of turbine passed fish among operations between new and existing turbine designs

4) **Evaluate How Well the New Runner Meets Strike and Pressure Criteria**

4.1 Determined using sensor fish

- Validate CFD modeling and pressure criteria
- Validate ERDC Bead Strike Analysis (USACE Task)

3.2 Secondary Objective

1) Evaluate benefits of turbine design features (if we have enough evidence to attribute increased survival to particular turbine environment features (i.e., stay vane modifications, runner strike, runner pressure, draft tube floor fill, etc.)). This may be accomplished with data collected by Sensor Fish releases coupled with CFD and direct injury and survival study data.

4.0 Statistical Study Designs (Acoustic Telemetry Studies)

Telemetry study designs are implemented at Federal Columbia River Power System (FCRPS) projects for many reasons including the following: 1) Estimate dam survival ("performance standard") of juvenile salmonids; 2) Evaluate fish passage through or over newly constructed or modified structures that may directly influence fish passage and survival; and 3) Evaluate specific passage routes for survival and potential for improvement.

Dam passage survival, defined as survival from the upstream face of the dam to a downstream location outside of project operation effects on hydraulic conditions is required to meet values ≥ 96% for spring stocks (yearling Chinook salmon and steelhead), and ≥ 93% for summer stocks (subyearling Chinook salmon) and should be estimated with a standard error (SE) of ≤ 1.5% (0.015) (NMFS 2008; Skalski 2011). These parameters are used with detection probabilities to achieve a precision ±0.03, 95% of the time (Normandeau et al. 2007, 2008; NMFS 2008; Skalski 2009; Skalski et al. 2009; Skalski 2011). In the case of BiOp specifications, precision should be calculated as follows.

$0.03 = 1.96 * SE(\hat{S}) \rightarrow SE(\hat{S}) = 0.0153$, or 0.015 (Skalski 2011)

While BiOp performance standards have been used to calculate sample sizes for this study, specific passage routes are not assigned a performance standard by the 2008 BiOp. The objectives of this study are centered around testing survival through new turbine units; however, using BiOp performance standards as a basis for sample size estimates and choosing a study design is acceptable for two reasons: 1) Calculating sample sizes using performance standards has been done in the past and provides a strong basis for calculating realistic preliminary estimates; and 2) Performance standards are realistic, Regionally accepted survival standards that have been set as a goal for overall dam passage survival.

SampleSize (University of Washington, Seattle, 2011) software was designed to produce sample size estimates for fish and wildlife release-recapture studies and was used to calculate preliminary sample sizes for the release-recapture models presented in this report. SampleSize software estimates sample size based on anticipated precision of estimates as a function of release sizes, detection probability and anticipated survival of fish volitionally passing a dam to include spillway, bypass, and powerhouse passage making sample size estimates directly applicable to acoustic telemetry studies. Passage survival and detection probabilities for yearling and subyearling Chinook salmon and juvenile steelhead were used from Skalski (2011) to run each model. An independent review of sample sizes estimated using SampleSize software is included as Appendix 1.0.

Three common study designs used to estimate survival at FCRPS projects are discussed in this section. Sample sizes, statistical design assumptions, and design biases are detailed for each study design.

Lessons learned from past studies support study designs that allow release of fish upstream of the dam of study sufficient enough to allow for normal distribution as the fish approach the dam. Skalski et al. (1998), Bickford and Skalski (2000), and Skalski et al. (2009) have defined some lessons from past studies.

Lesson 1) Smolts released in the immediate vicinity of the forebay do not pass a dam in the same spatial distribution as run-of-river fish;

Lesson 2) Paired upstream-downstream releases are needed to isolate survival to a specific river reach or section;

Lesson 3) Fish used for paired release studies must be similar in all aspects including origin and handling.

While these study design have most recently been implemented using acoustic telemetry methods, it should be understood that these methods do not differentiate among mortality sources. The primary goal is to estimate survival associated with dam (in this case turbine) passage. Smolt mortality associated with avian and piscivorous predation, as well as barotrauma is treated as a direct affect of the stress of turbine passage. Control releases do provide a correction factor for survival estimates given mortality is associated with surgically implanting tags or fish condition.

4.1 Single Release-Recapture Study Design

A maximum likelihood analysis of data collected under single release-recapture models is applicable to fisheries studies and the analysis methods of Cormack (1964) or a variation thereof (Jolly 1965; Seber 1965) have been employed for FCRPS salmonid passage survival studies in the past (Axel et al. 2003, 2008, 2010; Ogden et al. 2008) to estimate survival.

Figure 3 represents the single release-recapture study design and model assumptions are listed in Table 2.

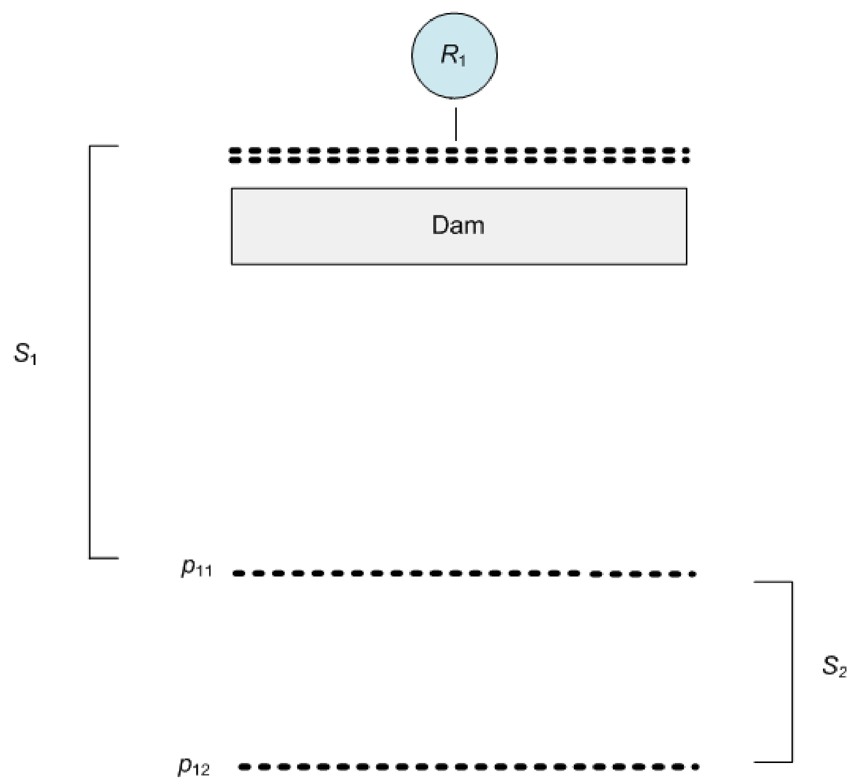


Figure 3 Single Release-Recapture study design (modified from Skalski 2009).

4.1.1 Design Concepts

The minimal design configuration is an upstream release site and two downstream detection sites with the uppermost detection facility capable of returning detected fish to the river (Skalski et al. 1998).

1) R1: Fish released upstream of dam face or direct release in the turbine intake in a location appropriate for passage through the desired turbine, location, etc.

2) Double 3D hydrophone arrays at the dam face will ensure detection of all fish reaching the dam/turbine for passage, and provide a vertical and horizontal distribution of approaching fish.

3) Below the dam, the fish will be detected at two subsequent arrays downstream and outside the hydraulic influence of the dam. Having the first detection array below the hydraulic influence of the dam is important to reduce the probability of detecting a dead fish as a false positive, or survivor. This study design will form a single release-recapture model estimate of survival.

4.1.2 Sample Release Sizes (Skalski 2011; SampleSize Software 2011)

4.1.2.1 Volitional Passage Estimates

The single release model was run accounting for two reaches (Figure 3) and one replicate for fish volitionally passing the dam (Appendix 1.1). Only one replicate was applied to the model because an estimate of variance was not available for input with more than one replicate. The lack of variance in the model caused sample sizes to be unrealistic (~ 50 fish per replicate) when the model was run with three replicates. The BiOp (NMFS 2008) performance standard for passage survival of 93% for subyearling and 96% for yearling Chinook salmon and steelhead was used as the survival statistic for sample size calculation. The average bypass proportion of subyearling and yearling Chinook salmon and steelhead from past studies was used as the input for “proportion removed”. Proportion removed does not account for mortality as survival parameters are already specified in the model. Detection probabilities of 90, 95, and 98% were used to run the single release model for subyearling and yearling Chinook salmon and steelhead.

Testing a range of sample sizes in the model (e. g. 200-500) provided standard errors (SE) used to create the curves in Figures 4 and 5. Subyearling sample size estimates and precision 95% ½ confidence intervals were 370 (±0.028; 90% detection), 310 (±0.029; 95% detection), and 290 (±0.029; 98% detection). Yearling Chinook and steelhead sample size estimates were 240 (±0.029; 90% detection), 190 (±0.029; 95% detection), and 170 (±0.029; 98% detection). Graphical representations of confidence intervals can be found in Appendix 1.1.

4.1.2.2 Direct Release Estimates

The SampleSize program provides an estimate for fish volitionally passing a dam; however, this estimate does not specifically account for directly releasing fish into the passage route of interest. For this reason the R statistical program (R Development Core Team 2008) and "pwr" package (Champely 2012) was used to run an analyses of variance (ANOVA) power analyses with 3 replicates (including potential controls), effect size = 0.05, and α = 0.05. The "effect size" is the magnitude of difference to be detected in the parameter of interest among study groups (Osmena 2010). In this case 0.05 indicates a small expected difference (i. e. ~ 5%) in passage survival between existing and new turbines. Target power (1-β) for sample sizes has been set at 0.80, which is often accepted for biological studies (Whitlock and Schluter 2009). Survival estimates obtained from a sample size with a power of at least 0.80 will, in theory, have sufficient power to provide a statistically significant survival estimate (α = 0.05) among treatments and between treatments and control groups. If survival estimates with this level of significance are achieved it will be possible to detect a difference in survival between the existing and newly designed turbine runners (if a difference exists) and reduce the possibility of making a Type II error by accepting a false null hypothesis (**H_0:** There will be no significant difference in turbine passage survival among the new and existing turbines at Ice Harbor Dam for yearling and subyearling Chinook salmon and steelhead).

The power analysis provided that a minimum sample size of 1285 fish had a power of 0.80. Sample sizes estimated using SampleSize software appear to provide appropriate precision for estimating survival through one turbine with upstream releases (Appendix 1.0); however, this is not consistent with the power analysis for direct release sample sizes. One explanation is that the power analysis includes replicates where the SampleSize software did not consider multiple releases. It is likely that that sample sizes estimated using SampleSize software are more appropriate for in-river acoustic telemetry studies given the parameters the model uses to estimate sample sizes. Regardless, treatment release groups must be large enough to reduce the risk of Type II error and it is recommended that a statistician estimate sample sizes appropriate for volitional passage and direct release to ensure appropriate power and precision.

4.1.3 Design Biases

Single release-recapture models provide biased survival estimates by systematically violating assumptions (Skalski et al. 2010). The single release model does not allow for separate estimation of dam survival from tailrace survival. Mortality that is experienced in the tailrace upon exiting the dam is not corrected for. Furthermore, estimates of project survival will be negatively biased in the presence of mortality that is caused by handling but occurs after release.

This scenario violates the assumption that fish released for the study are representative of the population of inference since the population at large does not experience mortality from handling and tagging. One way to remedy bias is with the addition of a second and third downstream release group that may be used to calculate out some of the bias in the single release survival estimate.

Table 2 Single Release-Recapture Model Assumptions

1	Test fish are representative of the population of inference (Skalski et al. 1998; Axel et al. 2003)
2	Test conditions are representative of the condition of inference (Skalski et al. 1998)
3	The number of fish released is exactly known (Skalski et al. 1998)
4	Tag codes are accurately recorded at the time of tagging and at all detection sites (Skalski et al. 1998)
5	For replicate studies, data from different releases are statistically independent (Skalski et al. 1998)
6	The fate of each individual is independent of the fates of all other fish (Skalski et al. 1998)
7	All fish in each release group have equal survival and detection probabilities (Iwomoto et al. 1994; Skalski et al. 1998)
8	Prior detection history has no effect on subsequent survival and detection probabilities (Skalski et al. 1998; Axel et al. 2010)
9	The tag and/or tagging method does not significantly affect the subsequent behavior or survival of the marked individual (Axel et al. 2003).

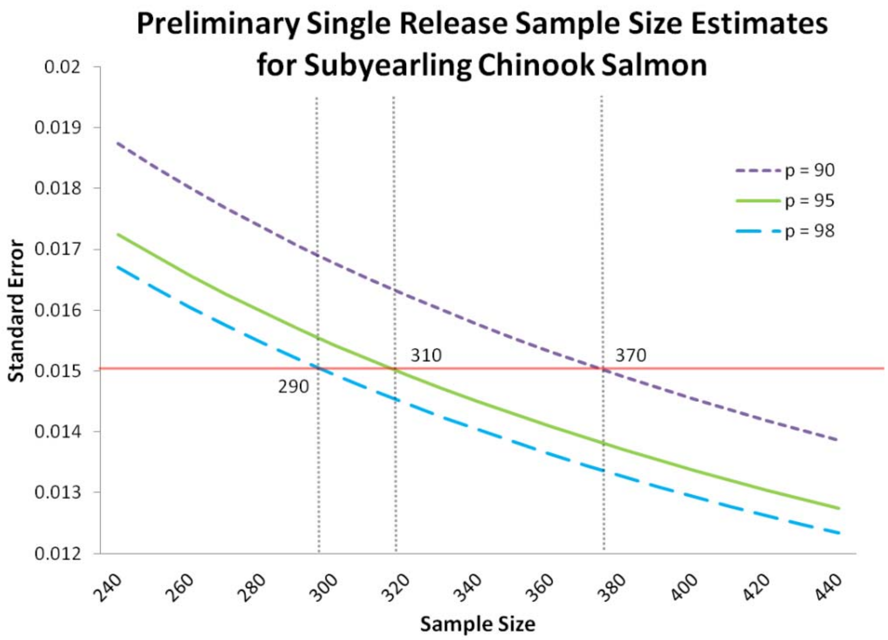


Figure 4 Single Release sample size estimates for subyearling Chinook salmon. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize single release model using BiOp (NMFS 2008) performance standard survival of 93%. Sample sizes were calculated to achieve a passage survival estimate with a SE of ≤0.015.

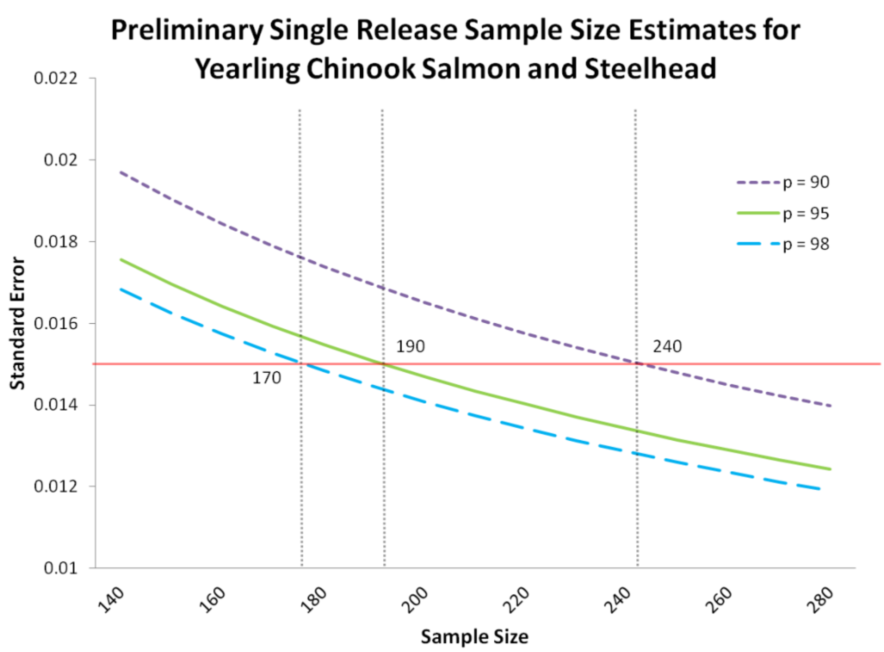


Figure 5 Single Release sample size estimates for yearling Chinook salmon and steelhead. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize single release model using BiOp (NMFS 2008) performance standard survival of 96%. Sample sizes were calculated to achieve a passage survival estimate with a SE of ≤0.015.

4.2 Paired Release-Recapture Study Design (Skalski 2011)

A maximum likelihood analysis of data collected under paired release-recapture models is applicable to fisheries studies and the analysis methods of Cormack (1964) or a variation thereof (Jolly 1965; Seber 1965) have been employed for FCRPS salmonid passage survival studies in the past (Mathur et al. 1996; Ogden et al. 2008) Joint likelihood analyses to estimate survival have also been implemented by Mathur et al. (1996).

Figure 6 represents the paired release-recapture study release design and model assumptions are listed in Table 3.

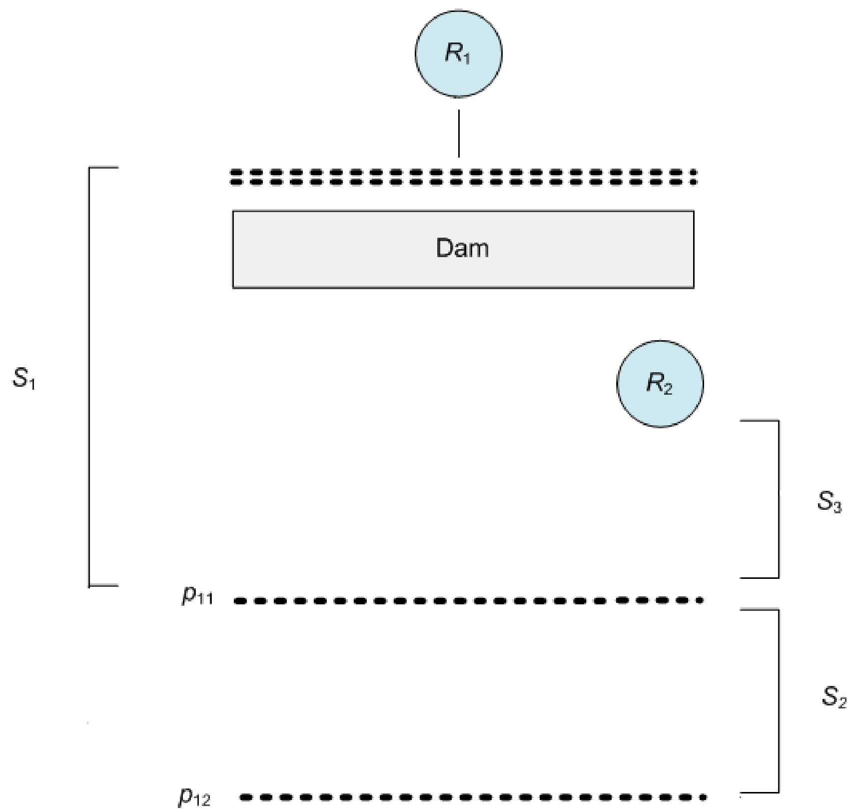


Figure 6 Paired Release-Recapture study design (modified from Skalski 2011)

4.2.1 Design Concepts

Paired release-recapture provides a more accurate survival estimate, as well as a greater variety of possible results.

1) R1: Fish released upstream of dam face or turbine intake in a location appropriate for passage through desired turbine, location, etc.

2) R2 and R3: Paired release group to estimate survival of fish passing through subsequent reaches between tailrace and pool without turbine passage bias

3) Double 3D hydrophone arrays at the dam face will ensure detection of all fish entering the turbine for passage, and provide a vertical and horizontal distribution of approaching fish.

4) First hydrophone array downstream sufficiently far to reduce risk of false positive survival detection of dead fish from release groups R1 and R2.

5) A third downstream detection array may be used to provide absolute survival estimates and a measure of detection efficiency.

6) S1 provides a turbine passage survival estimate; S2 provides a control tailrace reach survival estimate; S3 provides control survival estimate from first downstream hydrophone array to the pool array.

7) Two additional control releases downstream of the dam (R2 and R3) will be used to form a paired release-recapture model based estimate of survival. The single release survival estimate will be divided by the paired release survival to form the estimate of survival S2/S3 : $\frac{S_1 S_3}{S_2}$.

4.2.2 Sample Release Sizes (Skalski 2011; SampleSize Software 2011)

SampleSize (2011) software was used to calculate the proper sample size for the paired release-recapture model (Appendix 1.2). The BiOp (NMFS 2008) performance standard for passage survival of 93% for subyearling and 96% for yearling Chinook salmon and steelhead was used as the survival statistic for sample size calculation. The average bypass proportion of subyearling and yearling Chinook salmon and steelhead from past studies was used as the input for "proportion removed". Proportion removed does not account for mortality as survival parameters are already specified in the model. Detection probabilities of 90, 95, and 98% were used to run the single release model for subyearling and yearling Chinook salmon and steelhead (Appendix 1.2). The paired release-recapture model was run accounting for multiple reaches (Figure 6) and three replicates with release group sizes linked assuming volitional release of treatment fish. It should be noted that variance was not included in this model with three replicates; however, sample sizes estimated were within an appropriate range.

Testing a range of sample sizes provided SE used to create the curves in Figures 7 and 8. Subyearling sample size estimates and precision 95% ½ confidence intervals were 1170 (±0.005; $1\text{-}\beta = 0.99$; 90% detection), 1040 (±0.005; $1\text{-}\beta = 0.99$; 95% detection), and 1000 (±0.005; $1\text{-}\beta = 0.99$; 98% detection). Yearling Chinook and steelhead sample size estimates were 760 (±0.006; $1\text{-}\beta = 0.99$; 90% detection), 650 (±0.005; $1\text{-}\beta = 0.99$; 95% detection), and 620 (±0.005; $1\text{-}\beta = 0.99$; 98% detection). Graphical representations of confidence intervals can be found in Appendix 1.2. While these estimates should be confirmed by a statistician, they provide a good starting point for budgeting and planning.

4.2.3 Design Biases

While this design is more accurate than the single release-recapture, paired release-recapture models provide biased survival estimates by systematically violating assumptions (Skalski et al. 2010). The paired release model can account for bias by allowing for separate estimation of dam and tailrace survival dependent upon location of detection arrays and release location of fish. Again, estimates of turbine survival will be negatively biased in the presence of mortality that is caused by handling but occurs after release in the tailrace control group. This scenario violates the assumption that fish released for the study are representative of the population of inference; however, the paired release groups R2 and R3 will have tag effects expressed similarly and may be used to remove tagging mortality bias from turbine survival estimates.

Table 3 Paired Release-Recapture Model Assumptions

1	Treatment and control groups are evenly mixed and travel together through downstream reaches (Ogden et al. 2008).
2	The tag and/or tagging methods do not significantly affect the subsequent behavior of the marked individual (Guy et al. 1996; Axel et al. 2003; Ogden et al. 2008).
3	Fish that die as a result of passing through a passage route are not subsequently detected at a downstream array which is used to estimate survival for the passage route (Ogden et al. 2008)
4	Test fish are representative of the population of inference (Skalski et al. 1998; Axel et al. 2003; Ogden et al. 2008)
5	Test conditions are representative of the condition of inference (Skalski et al. 1998)
6	The number of fish released is exactly known (Skalski et al. 1998)
7	Tag codes are accurately recorded at the time of tagging and at all detection sites (Skalski et al. 1998)
8	For replicate studies, data from different releases are statistically independent (Skalski et al. 1998)
9	The fate of each individual is independent of the fates of all other fish (Skalski et al. 1998)
10	All fish in each release group have equal survival and detection probabilities (Iwomoto et al. 1994; Skalski et al. 1998; Ogden et al. 2008)
11	Prior detection history has no effect on subsequent survival and detection probabilities (Skalski et al. 1998; Axel et al. 2010)

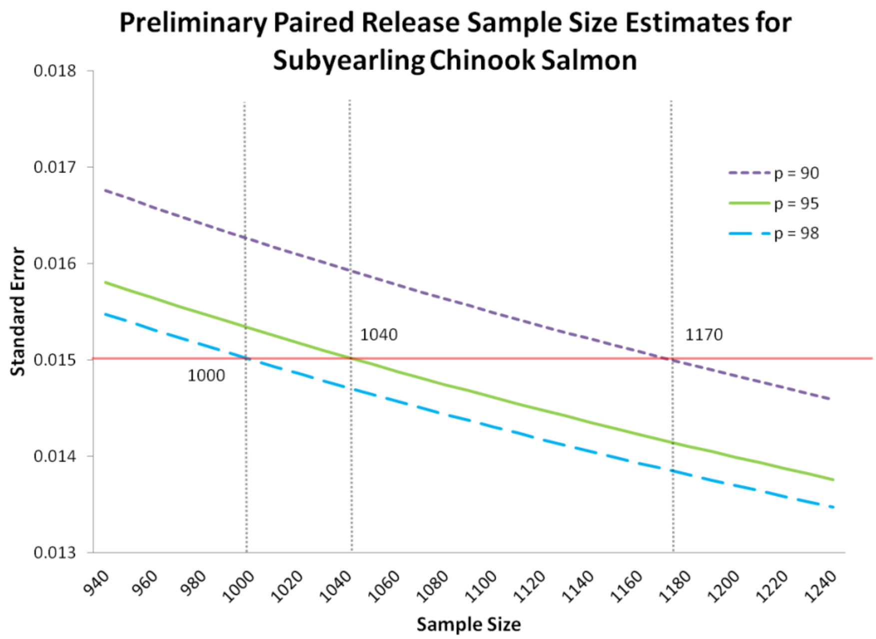


Figure 7 Paired Release sample size estimates for subyearling Chinook salmon. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize paired release model using BiOp (NMFS 2008) performance standard survival of 93%. Sample sizes were calculated to achieve a passage survival estimate with a SE of ≤0.015.

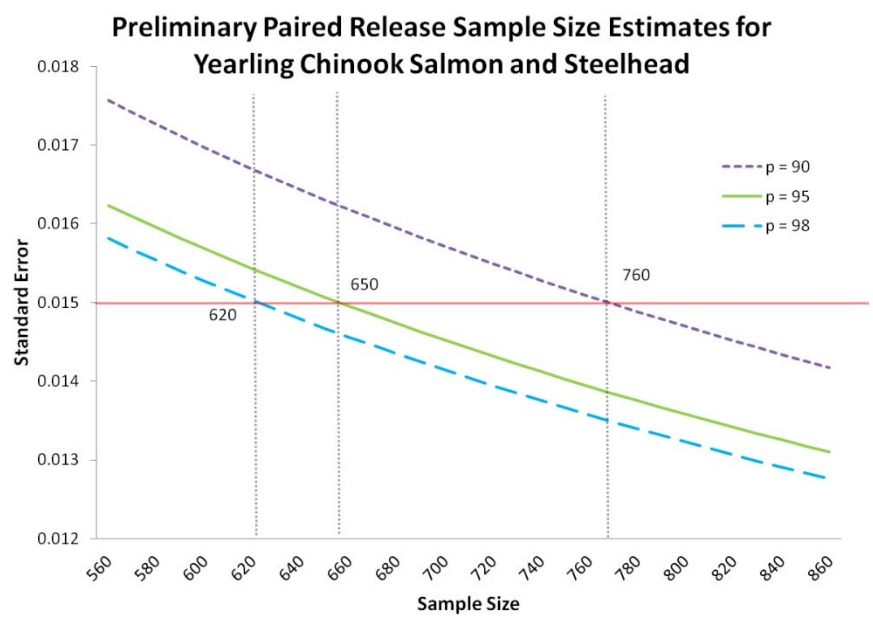


Figure 8 Paired Release sample size estimates for yearling Chinook salmon and steelhead. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize paired release model using BiOp (NMFS 2008) performance standard survival of 96%. Sample sizes were calculated to achieve a passage survival estimate with a SE of ≤0.015.

4.3 Virtual with Paired Release-Recapture Study Design (Skalski 2011; Appendix 2.0)

Paired release analysis can be used to estimate survival for tailrace release groups. A joint likelihood model can be used to estimate dam survival and the estimate of variance. Akaike's information criterion (AIC) and likelihood ratio tests can be used to determine the best model(s) for describing capture data and parameter estimates.

The virtual with paired release-recapture study design has been employed at Lower Columbia and Snake River dams for Performance Standard Testing (NMFS 2008) and typically does not account for particular operations such as a specific turbine load. Performance Standard Testing evaluates overall dam survival during spring and summer smolt outmigration under typical BiOp (NMFS 2008) mandated powerhouse and spillway discharges. This study design may also include multiple dam passages where the upstream release groups combine to create a large virtual release group at subsequent dams (Skalski 2009).

Figure 9 represents the virtual with paired release-recapture study release design and model assumptions are listed in Table 4.

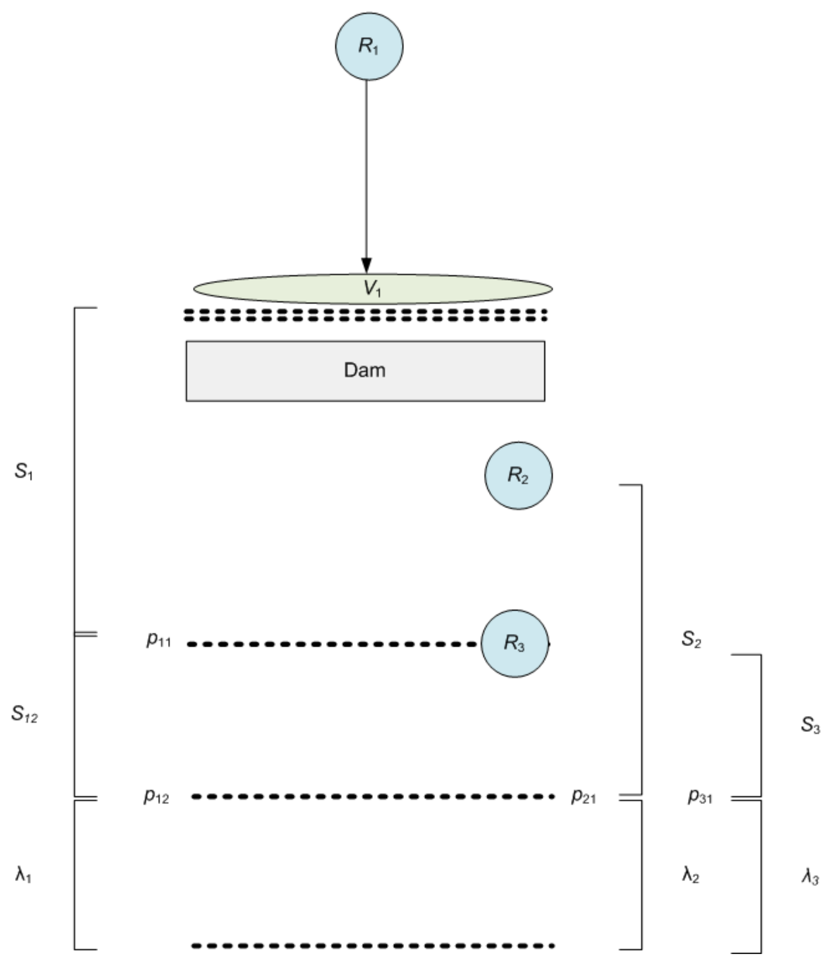


Figure 9 Virtual with Paired Release Release-Recapture Study Design (Skalski 2011)

4.3.1 Design Concepts

Release-Recapture Virtual with Paired Release design eliminates the most bias of the release-recapture designs and provides a variety of results.

1) R1 is initial release group sufficiently upstream to allow for depth acclimation and normal fish distribution as they travel toward the dam

2) V1 is the virtual release group where fish that survive the forebay are detected when they arrive at the dam face/turbine.

3) R2 and R3 are paired releases downstream of the dam to separate tailrace predation mortality from dam passage mortality.

4) The paired control releases downstream of the dam will be used to form a paired release-recapture model based estimate of survival. The single release survival estimate will be divided by the paired release survival to form the unbiased estimate of dam survival S2/S3 : $\frac{S_1 S_3}{S_2}$.

5) Double 3D hydrophone arrays at the dam face will ensure detection of all fish reaching the dam/turbine for passage, and provide a vertical and horizontal distribution of approaching fish.

6) A third downstream detection array may be used to provide absolute survival estimates containing no false positive detections.

7) S1 provides a turbine passage survival estimate; S2 provides a control tailrace reach survival estimate; S3 provides control survival estimate from first downstream hydrophone array to the pool array.

4.3.2 Sample Release Sizes (Skalski 2011; SampleSize Software 2011)

SampleSize (2011) software was used to calculate the proper sample size for the virtual with paired release-recapture model. The BiOp (NMFS 2008) performance standard for passage survival was used for the dam survival (Sdam) parameter, the S'_{11} parameter was taken from Skalski (2011), and 90, 95, and 98% detection probabilities were used to run the virtual with paired release model for yearling and subyearling Chinook salmon and juvenile steelhead (Appendix 1.3). Release group sizes were linked. Detection probability P_1 and P_2 were linked and S_{12} and λ remained constant at 95%. The virtual with paired release-recapture model did not require reaches or replicates be specified.

Testing a range of sample sizes provided SE used to create the curves in Figures 10 and 11. Subyearling sample size estimates and precision 95% ½ confidence intervals were 2590 (±0.029; 90% detection), 2550 (±0.029; 95% detection), and 2520 (±0.029; 98% detection). Yearling Chinook and steelhead sample size estimates were 1410 (±0.029; 90% detection), 1390 (±0.039; 95% detection), and 1370 (±0.029; 98% detection). Graphical representations of confidence intervals can be found in Appendix 1.3.

Virtual with paired release-recapture model methodology was detailed for Ice Harbor Dam by Skalski (2011) and estimated sample sizes of 2157-2537 were specified for subyearling Chinook salmon summer studies (Table 5). Skalski (2011) estimated sample sizes for spring yearling Chinook and steelhead studies were 1120-1192 (Table 5). Skalski (2011) averaged the best and worst case detection probability scenario sample sizes needed to obtain a SE of 0.015 and multiplied that value by 1.25 to account for unanticipated events, poor luck, and incorrect inputs into the sample size calculation.

The sample sizes estimated for the virtual with paired release-recapture in this study design are similar for subyearling Chinook and a bit higher for yearling Chinook and juvenile steelhead than those estimated by Skalski (2011). This study design did not inflate estimated sample sizes as Skalski (2011) did by multiplying the estimates by 1.25. While these estimates should be confirmed by a statistician and it is recommended that sample sizes are inflated according to the methods of Skalski (2011).

Table 4 Virtual with Paired Release-Recapture Model Assumptions (Skalski 2011)

1	Individuals marked for the study are a representative sample from the population of inference
2	All sample events are “instantaneous”
3	The fate of each individual is independent of the fate of all others
4	All tagged individuals alive at a sampling location have equal probability of survival to the end of that event
5	All tagged individuals alive at a sampling location have equal probability of being detected at on that event
6	All tags are correctly identified and the status of specimen correctly assessed
7	Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segment
8	Releases V1, R1, and R2 experience the same survival probabilities in the lower river segments they share in common
9	The virtual release group is constructed of tagged fish known to have passed through the dam
10	All fish arriving at the dam have an equal probability of inclusion in the virtual release group, independent of passage route through the dam

Table 5 Calculated sample sizes for releases R1, R2, and R3 based on best and worst case scenarios of survival/detection scenarios for compliance testing at Ice Harbor Dam (SE ≤ 0.015). Recommended values calculated by 1.25X{(best and worst case)/2} (Skalski 2011).

Stock	Release	Best Case	Worst Case	Recommended
Yearling Chinook, Steelhead	R1	945	962	1,192
	R2, R3 each	888	904	1,120
			Test Total	3,432
Subyearling Chinook	R1	2,017	2,041	2,537
	R2, R3 each	1,715	1,735	2,157
			Test Total	6,851
			Total for Three Species	13,715

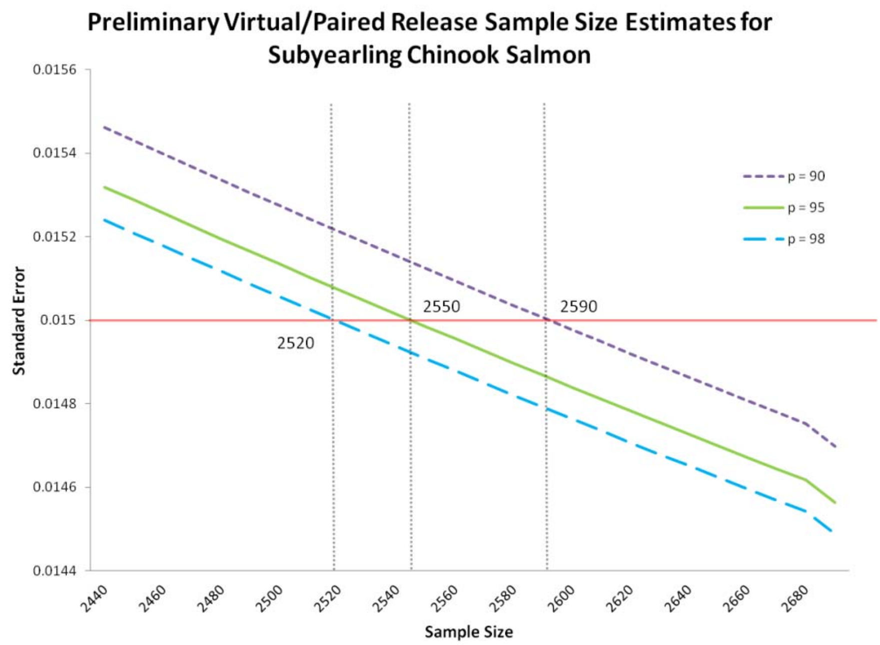


Figure 10 Virtual with Paired Release sample size estimates for subyearling Chinook salmon. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize virtual with paired release model using BiOp (NMFS 2008) performance standard survival of 93%. Sample sizes were calculated to achieve a passage survival estimate with a standard error of ≤0.015.

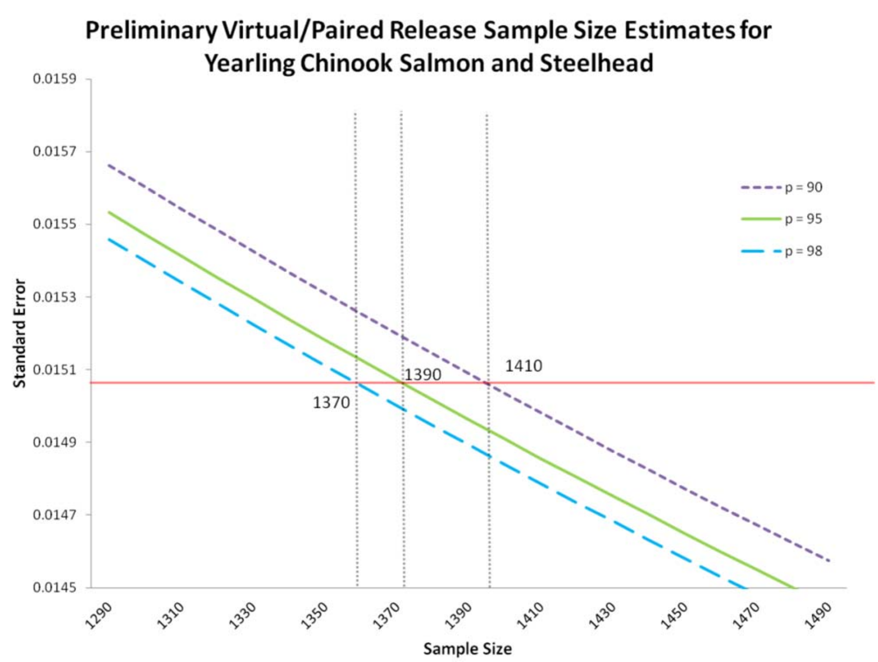


Figure 11 Virtual with Paired Release sample size estimates for yearling Chinook salmon and steelhead. Capture probabilities (p) of 90, 95, and 98% detection were selected to run the SampleSize virtual with paired release model using BiOp (NMFS 2008) performance standard survival of 96%. Sample sizes were calculated to achieve a passage survival estimate with a standard error of ≤0.015.

4.4 Likelihood Analyses for Survival Estimation

Likelihood analyses measure how well the data supports a specific value for a parameter and the probability of obtaining the observed data if the parameter equaled that value (Whitlock and Schluter 2009). The maximum likelihood estimate is the value of the parameter with the highest likelihood and subsequently the best estimate of the parameter (Whitlock and Schluter 2009). Maximum likelihood of a particular survival estimate may be determined as a function of detection probability and turbine operations.

Maximum likelihood was calculated by Mathur et al. (1996) as follows:

$$L(S,\tau,P_A,P_D|R_C,R_T,a_C,d_C,a_T,d_T) =$$

$$\binom{R_C}{a_C,d_C}(SP_A)^{a_C}((1-S)P_D)^{d_C}(1-SP_A-(1-S)P_D)^{R_C-a_C-d_C}$$

$$\times\binom{R_T}{a_T,d_T}(S\tau P_A)^{a_T}((1-S\tau)P_D)^{d_T}(1-S\tau P_A-(1-S\tau)P_D)^{R_T-a_T-d_T}$$

The generalized likelihood model (unequal recapture probabilities of alive, P_A, and dead fish, P_D) has four parameters (P_A, P_D, S, τ) and four minimum sufficient statistics (a_C, d_C, a_T, d_T). The maximum likelihood estimates are as follows:

$$\hat{\tau} = \frac{a_T R_C}{R_T a_C}$$

$$\hat{S} = \frac{R_T d_C a_C - R_C d_T a_C}{R_C d_C a_T - R_C d_T a_C}$$

$$\hat{P}_A = \frac{d_C a_T - d_T a_C}{R_T d_C - R_C d_T}$$

$$\hat{P}_D = \frac{d_C a_T - d_T a_C}{R_C a_T - R_T a_C}$$

The variance (Var) of the estimated turbine passage survival ($\hat{\tau}$) or mortality ($1-\hat{\tau}$) is

$$\mathrm{Var}(\hat{\tau}) = \mathrm{Var}(1-\hat{\tau}) = \frac{\hat{\tau}}{SP_A}\left(\frac{(1-S\hat{\tau}P_A)}{R_T} + \frac{(1-SP_A)\hat{\tau}}{R_C}\right)$$

and associated standard error (SE),

$$\mathrm{SE}(\hat{\tau}) = \mathrm{SE}(1-\hat{\tau}) = (\mathrm{Var}(\hat{\tau}))^{1/2} = (\mathrm{Var}(1-\hat{\tau}))^{1/2}$$

For the above calculations, P=precision; R_C = control release; R_T = treatment release; a_C = number of control fish recaptured alive; d_C = number of control fish recaptured or assumed dead; a_T = number of control fish recaptured alive; d_T = number of control fish recaptured or assumed dead; S = survival probability; P_A = probability of recapturing a fish alive; P_D = probability of recapturing a dead fish; τ = probability a treatment fish survives through the turbine; and 1- τ = turbine mortality.

Joint likelihood may be calculated for a virtual with paired release-recapture study to estimate S_{dam} (dam survival) and its variance directly by reordering the S_1 parameter (the first survival estimate downstream of the dam) to be a dam passage survival estimate including extra reach survival (Skalski 2011; Appendix 2.0). Skalski (2011) calculated the joint likelihood model as follows.

$$L = \binom{V_1}{\underset{\sim}{l}} \prod_{j=1}^{8} P_{1j}^{l_{1j}} \cdot \binom{R_2}{\underset{\sim}{m}} \prod_{j=1}^{4} P_{2j}^{m_{2j}} \binom{R_3}{\underset{\sim}{n}} \prod_{j=1}^{4} P_{3j}^{n_{3j}}$$

P_{ij} = probability of occurrence for the jth capture history for the ith release group,

l_{1j} = number of fish with capture history j for the first release group (V_1),

m_{2j} = number of fish with capture history j for the second release group (R_2),

n_{3j} = number of fish with capture history j for the third release group (R_3).

Further calculation may be required for release groups that have spent different time period's in-river, as well as testing tag, tag lot, and tagger effects (Skalski 2011).

5.0 Sample Size Discussion and Considerations

While sample sizes generated for biological studies may differ depending upon a particular calculation method and the population of inference and associated parameters, SampleSize software accounts for parameters that are important for precise, accurate dam passage survival estimates. Sample size estimates for study designs detailed in Section 4.0 were calculated for volitional fish passage and full dam survival estimates; however, specific turbine passage metrics through the new turbines are of importance for the Ice Harbor Dam biological study. While release groups upstream of Ice Harbor Dam may be the most appropriate for estimating dam passage survival this may not be the most feasible approach in terms of sample size for estimating specific turbine passage survival.

Sample season, dam operations and particular run or species (i. e. subyearling and yearling Chinook salmon and juvenile steelhead) affect survival estimates, route-specific passage proportions, and sample sizes. This section discusses examples of how operations, species and seasons affect sample size and subsequent costs for consideration in choosing a study design and justifying operations required to achieve meaningful results.

The sample size estimate calculated with SampleSize software for the paired release acoustic telemetry study design with 95% detection probability was used to conduct a power analysis for spring and summer studies. Release groups for the paired release study design in this section are treated as upstream releases allowing volitional dam passage.

The R statistical program (R Development Core Team 2008) and "pwr" package (Champely 2012) were used to run an ANOVA power analyses with the same parameters as used in Section 4.1 (3 groups to include controls, effect size = 0.05, and $\alpha = 0.05$). Target sample sizes were calculated to have a power of 0.80 which means providing 1285 fish per turbine unit using the above parameters to achieve statistically significant results. Survival estimates obtained with a sample size of at least 1285 fish will, in theory, have sufficient power to provide a statistically significant survival estimate among treatments and between treatments and control groups. If survival estimates with this level of significance are achieved it will be possible to detect a difference in survival between the existing and newly designed turbine runners (if a difference exists) and reduce the possibility of making a Type II error by accepting a false null hypothesis (**H_0:** There will be no significant difference in turbine passage survival among the new and existing turbines at Ice Harbor Dam for yearling and subyearling Chinook salmon and steelhead). While the sample size of 1285 fish is greater than estimated using SampleSize software it will be used to illustrate the importance of dam operations and seasons when planning and implementing a biological study.

Sample sizes were calculated based on route-specific passage proportions from past studies (Table 6) to estimate overall sample size necessary for turbines to receive enough fish to accurately estimate survival.

5.1 Study Periods and Operations

The biological study design could be implemented in several different seasons under various spill and powerhouse operations. Determining which season and operation condition(s) will be most beneficial to the study and the efficiency of project operations alike will be difficult. Choosing when and how to conduct the study will affect the accuracy and precision of resulting survival estimates and will be representative of conditions and runs associated with the particular periods.

Past studies have occurred during a variety of operations as detailed in Table 6. Turbine survival estimates at Ice Harbor Dam have not been reported in many past studies due to such a small proportion of fish passing through the powerhouse. Subyearling Chinook turbine survival at Ice Harbor Dam was estimated at 77.8% (95% CI = 68.5-87.0%) in 2008; however, this estimate was generated from a single release study with pooled estimates for all treatments (Axel et al. 2010). This single estimate since 2003 is likely not representative of actual turbine passage survival to date or survival through the newly designed turbine runners.

Many variables can affect the number of fish passing through turbines and operation may be more or less confounding depending upon study design. Project operations and study design will ultimately determine the number of study fish (tagged fish) necessary to achieve the desired sample size. Operations that allow more fish to pass through the turbines will obviously reduce the overall sample size necessary to achieve the power required for precise survival estimates. Direct releases into the turbine intakes require fewer fish per release group and are not affected by spill and bypass screens unlike studies that release fish upstream allowing alternate passage via the turbine intake bypass system, non-targeted turbines, and the spillway. The advantages and disadvantages of altering the level of spill and bypass screen operations are important to consider for proper study implementation to achieve the best results without directly affecting passage of the run-of-river populations during outmigration periods.

Current operations for fish passage are listed in Table 1 and are described in the BiOp (NMFS 2008) and FPP and Appendix E FOP (USACE 2013b).

5.1.1 Spring Pre-spill Study Period (March)

A pre-spill study would provide a more robust turbine survival estimate and make it more feasible relative to fish passage season requirements to adjust turbine operations. Spill operations mandated by the BiOp (NMFS 2008) and the FPP (USACE 2013b) will not need to be altered during this period and the peak of the run of yearling Chinook and juvenile steelhead will likely not have begun. This period is only applicable to yearling Chinook salmon and steelhead and a study during this period may only be possible if high river flows do not force spill.

Hatchery fish will be required for a pre-spill study period. During this period it may be difficult to determine fish performance due to the possibility of delayed migration. This period may be too early for these fish to actively migrate. Study fish may hold up in the forebay if fish are released upstream of the dam or in the downstream pool prior to reaching the last detection array.

Predation is likely to be lower during this period which would not be representative of typical outmigration conditions and may bias survival estimates high; however, the physical passage conditions would be representative of the spring emigration period. While pre-spill may not be an “in-season” period, river and powerhouse operating conditions would be comparable to spring migration conditions.

The possibility of releasing fish pre-spill and under normal operations prior to the typical spring outmigration peak would provide optimum conditions for turbine passage relative to project operations and sample size requirements. Also, the absence of bypass screens during this period will provide 100% turbine passage which would be beneficial to the study in terms of reducing the number of fish required to achieve statistically significant survival estimates. If fish were released for volitional passage a sample size of 7,710 fish would provide enough power to accurately and precisely estimate survival assuming the full powerhouse is in operation and fish are equally distributed across the powerhouse. Assuming two control releases of approximately 500 fish a total of 8,710 would be needed to test one turbine operation. The estimated cost of 8,710 Juvenile Salmonid Acoustic Telemetry System (JSATS) tags is $1,742,000.

5.1.2 Spring Spill Study Period (April 3rd – June 20th)

During the spring spill period, operations at Ice Harbor Dam require spilling of 45kcfs during daylight hours and gas cap at night which may be up to 95kcfs (Table 1). Ten year average daily project discharge between April 1st and June 20th, 2004-2011 at Ice Harbor was 89.56kcfs with 51.04kcfs spill (GDACS 2012). The 40 year average daily project discharge is approximately 90kcfs (Figure 12) during the spring period. Past studies have reported an average of 57% of yearling Chinook and juvenile steelhead passing via spillway at Ice Harbor (Axel et al. 2003, 2005, 2007a, 2007b). The remaining detected fish that enter the powerhouse are split between the JBS and turbine passage routes. The JBS screens may guide 79-88% of fish (depending on run) entering the powerhouse into the bypass system (Table 6) thus reducing the statistical power of the study by reducing the turbine passage sample size.

If screens were pulled, but spill remained, approximately 20% of study fish would pass through the turbine units compared to an average of about 4% with screens installed (Table 6).

If spill were reduced for up to 36 hour blocks (one block per turbine operation dependent upon river flow and run timing) the potential of passing up to 57% or more fish through the powerhouse (depending upon study design) will allow for a much more powerful study requiring fewer fish and tags. Adjusting spill in blocks has not been performed in past studies and may not be an acceptable operation. This would need to be coordinated with dam operations and Regional stakeholders during the fish passage season.

5.1.2.1 Influence of Spring Operations on Sample Size and Costs

Paired release sample sizes for yearling Chinook salmon and juvenile steelhead detailed in Section 4.2 were approximately 650 per release group with a 95% detection probability. This estimate was generated assuming treatment and control release groups were identical. For the majority of the spring spill season all 6 turbine units are in operation so full powerhouse passage is assumed.

Hypothetically, if 650 fish are volitionally released under a paired release-recapture study design with the full powerhouse and spillway in operation, 371 (57% for spring runs; Table 6) of those fish on average could pass via spillway leaving 279 fish for powerhouse passage. With screens in place approximately 12 fish (4%; Table 6) of the 279 fish entering the entire powerhouse would pass through turbines. Per unit turbine passage assuming equal horizontal distribution across the powerhouse is 12/6= **2** fish. The power of 2 fish passing through one turbine is 0.05. Under this operation 192,000 fish would need to enter the powerhouse to achieve the minimum sample size of 1285 fish per turbine unit and a power of 0.80. Assuming two control releases of approximately 500 fish a total of 193,000 fish would be needed to test one turbine operation. The estimated cost of 193,000 JSATS tags alone is greater than $38 million.

Conversely, operating the dam without spill or screens (representative of the March pre-spill period) 100% of the sample size (650 fish) would pass through turbines. Per unit passage would be 650/6=**108** fish. The power of 108 fish passing through one turbine is 0.10 which is still poor. Under this operation the sample size would need to be 7,710 to provide 1,285 fish per turbine unit. Assuming two control releases of approximately 500 fish a total of 8,710 fish would be needed to test one turbine operation. The estimated cost of 8,710 JSATS tags alone is $1,742,000. This is the most cost effective operation for a turbine survival study. Not only does this operation scenario greatly reduce the number of tags, fish and labor required to achieve meaningful results, but the cost of the study is approximately 22 times less expensive relative to fish and tagging requirements with the full project in operation.

It should be noted that operations without screens are not representative of typical fish passage operations; however, turbine survival estimates will be representative of turbine performance.

5.1.3 Summer Study Period (June 21st – August 31st)

During the summer spill period, operations at Ice Harbor Dam require alternating every three days between spilling of 30% river volume 24 hours per day and spilling 45kcfs during the day and gas cap at night which may be up to 95kcfs (Table 1). Ten year average daily project discharge between June 21st and August 31st, 2004-2011at Ice Harbor was 49.32kcfs with 28.73kcfs spill (GDACS 2012). The 40 year average daily project discharge is approximately 60kcfs (Figure 12) for the summer period. Past studies have reported an average of 58.6% of subyearling Chinook salmon passing via spillway at Ice Harbor Dam (Ogden et al. 2005, 2007, 2008; Axel et al. 2010). An in-season study with spill would produce a turbine survival estimate under normal operating conditions providing comparable estimates between new and old runners, but again, the bypass system would intercept the greater portion of powerhouse passed fish leading to an inaccurate and potentially imprecise turbine survival estimate due to small sample size.

Turbine passage proportion was reported as high as 7.4% with no spill (Eppard et al. 1998) and averaged 2.2% under various spill treatments between 2004 and 2009 for subyearling Chinook salmon (Table 6; Ogden et al. 2005, 2007, 2008). Axel et al. (2010) reported that 27.8% of subyearlings passed via JBS. When combined with the turbine passage proportion it was estimated that 31.7% of subyearlings entered the powerhouse. Again, if screens were pulled it would lead to an average 13.2% increase in the number of released fish passing through the

Table 6 Summary of past study results at Ice Harbor Dam

Yearling Chinook

Year	Spill Treatment (day/night)	Operation	Spillway Passage %	Spillway Survival	RSW Passage %	RSW Survival	Juvenile Bypass Passage %	Juvenile Bypass Survival	Turbine Passage %	Turbine Survival	Concrete Passage Survival
2005	Bulk Spill	82% spill	98.5	97.1	---	---	1.1	N/A	0.4	N/A	96.8
2005	RSW	34% spill	48.6	95.8	29	97	15.7	99.7	6.7	N/A	96.1
2006	Gas Cap/45 kcfs day with RSW	58% spill	46.9	96.9	33.1	95.5	15.1	97.3	4.9	N/A	96.2
2006	30%-40% Spill with RSW	33% spill	22.1	98	51.3	94.7	19.1	98.3	7.5	N/A	96.1
2007	Gas Cap/45 kcfs day with RSW	68% spill	51.3	95.5	42	94.5	4.6	N/A	2.1	N/A	95.8
2007	30% Spill with RSW	31% spill	16	96.8	59	95.3	16.4	N/A	8.6	N/A	94.9
2008**	Gas Cap/45 kcfs day with RSW	63% spill	53.8	96	23.4	96.5	17.9	99.2	4.9	N/A	97.3
2008**	30% Spill with RSW	35% spill	21.3	97.4	34.3	92.6	37.8	95.4	6.6	N/A	95.3
2008	Pooled results		71{42.7}	96.6(0.953-0.978)	28.3	95.3(0.927-0.979)	23.9	97.7(0.954-1.000)	5.2	94.3(0.889-0.996)	96.6(0.96-0.98)
2009	30% Spill with RSW	30%	*76.6{19.7}	93.9(0.012)	56.9	93.9(0.016)	21.3	94.1(0.035)	2.1	N/A	94.1(0.02)
2009	BiOp Spill with RSW		*93.2{62}	92.5(0.017)	31.2	93.0(0.025)	5.8	85.4(0.054)	1	N/A	93.1(0.01)
2009	50% Spill with RSW	50%	*80.8{46.4}	92.1(0.016)	34.4	91.1(0.027)	16.2	86.1(0.047)	3	N/A	91.4(0.02)
2009	Average of 3 spill treatments		*83.5{42.7}	92.8	40.8	92.6	14.4	88.5	2.3	N/A	92.9
Mean			**58.7**	**95.5**	**38.6**	**94.3**	**16.1**	**94.2**	**4.3**		**95.1**

Mean Powerhouse Passage Proportion: **20.4**

Mean JBS/Turbine Proportions Without Spill: **78.9%/21.1%**

Steelhead

Year	Spill Treatment (day/night)	Operation	Spillway Passage %	Spillway Survival	RSW Passage %	RSW Survival	Juvenile Bypass Passage %	Juvenile Bypass Survival	Turbine Passage %	Turbine Survival	Concrete Passage Survival
2005	Bulk Spill	82% spill	96.9	100	---	---	2.3	---	0.8	N/A	99.3
2005	RSW	34% spill	30	98	47	98.5	20.8	101.5	2.2	N/A	97.3
2006	Gas Cap/45 kcfs day with RSW	58% spill	50	102.4	30.9	98.4	17.7	101	1.4	N/A	100.9
2006	30%-40% Spill with RSW	33% spill	23.9	101.9	37.5	101.7	36.6	99.7	2	N/A	100.7
2007	Gas Cap/45 kcfs day with RSW	68% spill	42	96.7	53.2	98	3.8	N/A	1.0	N/A	96.4
2007	30% Spill with RSW	31% spill	12	97.2	74.1	97	11.8	N/A	2.0	N/A	97.3
2008**	Gas Cap/45 kcfs day with RSW	63% spill	53.4	97.2	35.6	96.6	9.9	90.5	1.1	N/A	97.1
2008**	30% Spill with RSW	35% spill	20.9	97.1	56.4	96.7	21.5	94.9	1.2	N/A	96.2
2008	Pooled results		83.8{39.1}	97.3(0.962-0.985)	44.7	97(0.954-0.986)	15	97.1(0.947-0.996)	1.2	N/A	97(0.96-0.98)
2009	30% Spill with RSW	30%	*69.9{22.8}	94.0(0.012)	47.1	92.3(0.023)	29.6	94.4(0.021)	3	N/A	94.3(0.01)
2009	BiOp Spill with RSW		*88{61.1}	95.8(0.006)	26.9	92.7(0.022)	10.9	93.5(0.069)	9	N/A	95(0.01)
2009	50% Spill with RSW	50%	*72.2{42.6}	91.3(0.018)	29.6	88.5(0.034)	26.8	87.5(0.040)	4	N/A	90.1(0.02)
2009	Average of 3 spill treatments		*76.7{42.2}	93.7	34.5	91.2	22.4	91.8	0.3	N/A	93.1
Mean			**55.3**	**97.1**	**43.1**	**95.7**	**17.6**	**95.2**	**2.2**		**96.5**

Mean Powerhouse Passage Proportion: **19.9**

Mean JBS/Turbine Proportions Without Spill: **58.5%/11.5%**

Table 6 (continued) Summary of past study results at Ice Harbor Dam

Subyearling Chinook			Spillway		RSW		Juvenile Bypass		Turbine		Concrete Passage
Year	Spill Treatment (day/night)	Operation	Passage %	Survival	Passage %	Survival	Passage %	Survival	Passage %	Survival	Survival
2004	Bulk Spill		78.1	---	---	---	1.3	---	1	---	---
2004	Flat Spill		84.1	---	---	---	3	---	1	---	---
2005	Bulk Spill	84% spill	98.5	100	---	---	0.9	N/A	0.6	N/A	99.9
2005	RSW	46% spill	17.3	98.9	60	99.7	7.8	98.8	4.9	N/A	98.6
2006	Combined treatments	53.6% spill	26	98	68	98	4.2	N/A	1.8	N/A	97.7
2007	Gas Cap/45 kcfs day with RSW	73% spill	53.4	100.2	43.4	101.4	2.7	N/A	0.5	N/A	95.8
2007	30% spill with RSW	44% spill	9.9	102.1	73.7	102.9	11.6	N/A	4.8	N/A	95.5
2008**	Combined treatments	56% spill	41.6	94.2(0.926-0.958)	26.7	92(0.891-0.948)	27.8	92.9(0.903-0.956)	3.9	77.8(0.685-0.870)	93.3(0.92-.095)
2009	30% Spill with RSW	30%	*62{22.6}	88.5(0.015)	39.4	91.9(0.014)	34.6	95.8(0.015)	3.4	N/A	91.3(0.01)
2009	BiOp Spill with RSW		*92.8{69.2}	88.6(0.013)	23.6	87.7(0.016)	6.5	96.1(0.023)	0.7	N/A	89.6(0.02)
2009	Combined treatments		*77.4{45.9}	88.5(0.008)	31.5	90.6(0.011)	20.5	95.9(0.011)	2.0	N/A	90.4(0.01)
Mean			**58.6**	**95.4**	**45.8**	**95.4**	**11.0**	**95.9**	**2.2**		**94.7**

Mean Powerhouse Passage Proportion: **13.2**

Mean JBS/Turbine Proportions Without Spill: **83.3%/16.7%**

*Spillway - RSW passage is in { }
**All survival estimates for 2008 are single release.

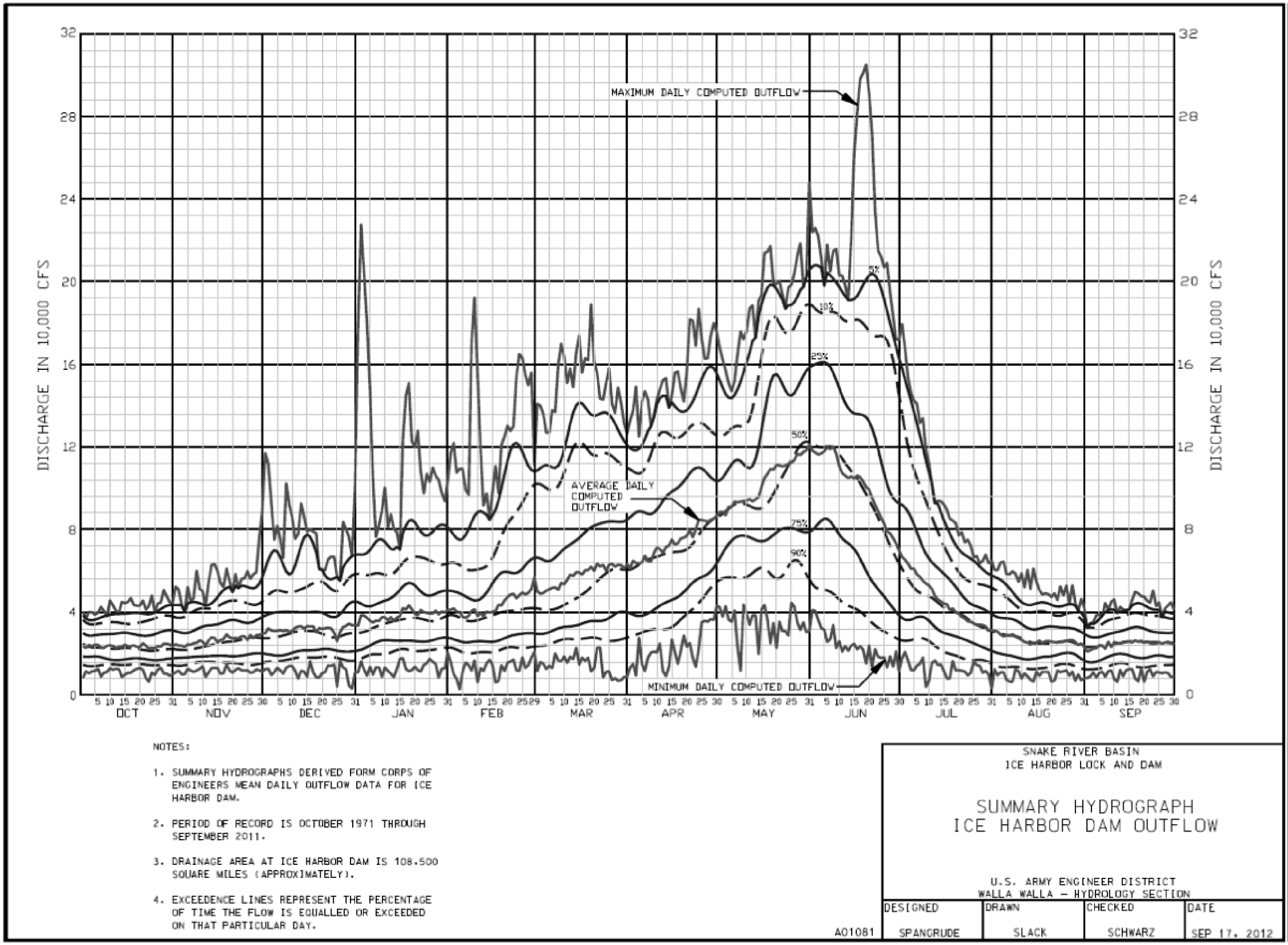


Figure 12 Ice Harbor Dam mean daily discharge for the period of October 1971-September 2011.

turbine units compared to an average of approximately 2% with screens installed (Table 6).

If spill were reduced or cut for up to 36 hour blocks (one block per operation dependent upon river flow and run timing) the potential of passing up to 59% more fish through the powerhouse (depending upon study design) will allow for a much more powerful study. Adjusting spill in blocks has not been performed in past studies and may not be an acceptable operation. This would need to be coordinated with dam operations and Regional stakeholders during the fish passage season.

5.1.3.1 Influence of Summer Operations on Sample Size and Costs

During the summer study period the full powerhouse is typically not in operation at Ice Harbor due to low flow conditions and mandatory spill requirements. Powerhouse operations during the summer fish passage season in 2011 went from full powerhouse operation into the beginning of July down to four units running by July 5th, three units by July 20th and one unit by July 26th. Powerhouse operations during the 2012 summer fish passage season were already down to five units by June 1st. Low flow conditions caused powerhouse loading to periodically run four to six units at once by June 10th, however, by June 29th, only four units were systematically loaded for power production and off-line much of the time. Only unit 1 operated by July 15th with no systematic loading of the remaining units. This variability in summer operations provides evidence that the full powerhouse may not be in operation during this study period so the following will be based on three units running as a more realistic powerhouse operation.

Paired release sample sizes for subyearling Chinook salmon detailed in Section 4.2 were approximately 1040 per release group with a 95% detection probability. This estimate was generated assuming treatment and control release groups were identical.

Hypothetically, if 1040 fish are volitionally released under a paired release-recapture study design with three turbines and the full spillway in operation, up to 614 (59%; Table 6) of those fish could pass via spillway leaving 426 for powerhouse passage. With screens in place only approximately 9 fish (2%; Table 6) of the 426 fish entering the entire powerhouse would pass through turbines. Per unit turbine passage assuming equal horizontal distribution across the powerhouse is 9/3=**3** fish. A sample size of 3 fish has a power 0.05. Under this operation 188,700 fish would need to enter the powerhouse to achieve the minimum sample size of 1285 fish per turbine unit and a power of 0.80. Assuming two control releases of approximately 500 fish a total of 189,700 fish would be needed to test one turbine operation. The cost of 189,700 JSATS tags alone is greater than $37 million.

Conversely, without spill or screens (equivalent to a September, no-spill summer study period) 100% of the sample size (1040 fish) would pass through turbines. Per unit passage would be 1040/3=**346** fish. The power of 346 fish passing through one turbine is 0.28 which is better, but still does not reach the target power of 0.80. Under this operation the sample size would need to be 3,855 to provide 1,285 fish per turbine unit. Assuming two control releases of approximately 500 fish a total of 4,855 fish would be needed to test one turbine operation. The estimated cost of 4,855 JSATS tags alone is $971,000. This is the most cost effective operation for a turbine survival study. Not only does this operation scenario greatly reduce the number of tags, fish and labor required to achieve meaningful results, but the cost of the study is approximately 40 times less expensive relative to fish and tagging requirements with the full project in operation.

It should be noted that operations without screens are not representative of typical fish passage operations; however, turbine survival estimates will be representative of turbine performance.

5.1.4 Seasons, Operations and Sample Size Conclusions

While the sample sizes and associated cost of JSATS tags in this section are hypothetical examples of the influence of project operations and different runs/seasons on sample size requirements and subsequent costs, they do elucidate the importance of proper planning, budgeting, and Regional cooperation and coordination. Based on the results of the power analyses, conducting the study either without spill or guidance screens in operation would provide the most feasible conditions for upstream releases allowing volitional fish passage (Table 7).

Power analyses were conducted and sample sizes estimated assuming equal horizontal distribution and passage of study fish across the powerhouse which is highly unlikely. It should be noted that the ANOVA power analysis is a simple analysis and does not account for ecological variation, acoustic detection probability, or survival parameters that may require larger sample sizes. The SampleSize software differs from the power analysis by evaluating sample size based on actual parameters of expected results and acoustic detection probability of the acoustic telemetry studies of interest.

As stated in Section 4.0, it is advised that a statistician formulate appropriate sample size estimates prior to conducting the biological study regardless of which design and release methodology is decided upon.

Table 7 Summary of hypothetical sample size estimates and associated costs for JSATS tags under different sample seasons and project operations. These estimates demonstrate the importance of proper planning and coordination when implementing acoustic telemetry studies.

	Spring Pre-Spill		**Spring Spill**		**Summer***	
Operations	**Sample Size**	**Est Cost** $^{+}$	**Sample Size**	**Est Cost** $^{+}$	**Sample Size**	**Est Cost** $^{+}$
Full PH and spill	NA	NA	193,750	> $38 mil	189,700	> $37 mil
No Spill	NA	NA	37,714	$7,542,800	24,083	$4,816,766
No Screens	NA	NA	18,930	$3,786,000	10,204	$2,040,975
No Spill/No Screens	8,710	$1,742,000	8,710	$1,742,000	4,855 $^{\varphi}$	$971,000 $^{\varphi}$

*Summer study period sample sizes estimated for only 3 turbine units operating

$^{+}$ Estimated cost based on the purchase of JSATS tags only at $200 each.

$^{\varphi}$ Equivalent to a summer post-spill study not detailed in Section 5.0

5.2 Predation Considerations

Spring and summer study periods at Ice Harbor Dam will provide different tailrace scenarios regarding predation for juvenile salmonids passing the project. There is evidence of predation being greater during summer outmigration rather than spring; however, this may not be clear among all projects, between the Lower Columbia and Snake Rivers, or between aquatic and avian predators. Predation effects on smolt survival should be considered when conducting survival studies with telemetry methods; however, telemetry methods do not allow for differentiating among factors of mortality when estimating survival.

5.2.1 Piscivorous Fish

Northern Pikeminnow (*Ptychocheilus oregonensis*) distribution was studied in the Lower Granite Dam tailrace during the 1992-1993 outmigration seasons (Isaak and Bjornn 1996). Density and distribution of radio-tagged pikeminnow coincided more with subyearling Chinook salmon outmigration than yearling Chinook and steelhead. Spring and summer periods were correlated with spill patterns. Results suggested that 91% of tagged pikeminnow occupied areas near the navigation lock and stilling basin during pre-spill periods while 71% occupied areas north of the navigation lock during spill periods. These fish migrated south of the navigation lock post-spill during late summer; hence, pikeminnow distribution was inversely related to river discharge.

Rieman et al. (1991) identified differences in densities of pikeminnow and Smallmouth Bass (*Micropterus dolomieu*) in the Lower Columbia and Snake Rivers and estimated approximately 85,000 pikeminnow and 35,000 smallmouth bass in the John Day pool within a three year study period sampling April-August. Highest predation rates were noted in July and August and pikeminnow accounted for 78% of salmonid loss where smallmouth bass accounted for only 9% (Rieman et al. 1991). Similarly, Zimmerman (1999) estimated pikeminnow consumed >84% juvenile salmonids across spring and summer seasons and study years in the Lower Columbia River.

Near Ice Harbor, smallmouth bass relied on juvenile salmonids for up to 59% of their diet (Tabor et al. 1993) and 66% at Lower Granite Dam (Zimmerman 1999) during spring samples. Necropsy provided evidence of an inverse relationship between pikeminnow and smallmouth bass predation compared to the findings of Rieman et al. (1991). Tabor et al. (1993) determined that smallmouth bass consumed approximately 1.87 smolts per day where pikeminnow consumed approximately 0.64 smolts per day overall. Larger smallmouth bass (≥280mm FL) among those sampled consumed the greatest number of smolts (mean = 3.31 smolts per specimen examined) where smaller pikeminnow (250-349mm FL) among those sampled consumed the greatest number of smolts (mean = 1.25 smolts per specimen examined). Tabor et al. (1993) also found predation rates for both smallmouth bass and pikeminnow decreased between May and June.

Ward et al. (1995) created a predation index for pikeminnow at Ice Harbor Dam via sampling and necropsy of specimens between April and August. The index was created such that index values increased with higher predation rates. Predation was typically higher during the summer months; however, the predation index for Ice Harbor Dam was 2 during spring and 0 during summer.

Complimentary to the findings of Tabor et al. (1993), Ward et al. (1995) found pikeminnow predation to be greatest among fish ≥250mm FL and this cohort showed moderate relative density in the Ice Harbor tailrace boat restriction zone (BRZ).

Overall, northern pikeminnow and smallmouth bass pose less predation threat to juvenile salmonids passing Snake River dams than Columbia River dams. Spring appears to have greater predation rates on the Lower Snake River (Tabor et al. 1993; Ward et al. 1995) although summer low flow periods may allow pikeminnow to capitalize on juvenile salmonids (Rieman et al. 1991; Zimmerman 1999). There is potential for piscivorous fish predation to moderately influence juvenile salmonid survival during both spring and summer periods dependent upon predator density, river discharge and water temperature.

5.2.2 Avian Predation

A synthesis report compiled by Roby et al. (2011) summarized the effects of avian predation on juvenile Chinook salmon by the Crescent Island Caspian Tern (*Hydroprogne caspia*) colony and the Foundation Island Double-Crested Cormorant (*Phalacrocorax auritus*) colony in the mid-Columbia River. These avian colonies are located near Pasco, Washington, and the mouth of the Snake River. Ice Harbor Dam is located near the mouth of the Snake River approximately 15.6 kilometers upstream of the Columbia River and the avian colonies of Crescent and Foundation Islands.

Lyons et al. (2011) estimated that approximately 1 million smolts were consumed annually by these two avian colonies during the study years of 2004-2009. Caspian terns relied on smolts for 63-70% of their diets, and often over 80% during the nesting season. This large proportion of salmonids in the tern diet decreased to ≤ 50% by July once young had fledged (Lyons et al. 2011). Cormorants consumed a smaller proportion of smolts with an average of 22% between April and early July, but up to 52% between late April and late May while feeding young (Lyons et al. 2011). With Ice Harbor Dam located so close to these two colonies the likelihood of increased avian predation during the spring (April-May) may be relatively high compared to the summer months.

Overall predation rates of spring, summer, and fall Chinook salmon by Crescent Island terns appears to be fairly constant across Snake River runs, while overall salmonid predation has been reported to range from 0.4-7.4% depending on species and stock (Evans et al. 2011). Predation rates from the Foundation Island cormorant colony on Snake River runs were 0.3-2.0% depending on species.

Overall findings stated in the synthesis report suggest that Caspian terns and double-crested cormorants are responsible for most predation losses of juvenile Chinook salmon in this mid-Columbia region (Roby et al. 2011). According to Lyons et al. (2011) spring migrants may experience higher avian predation rates; however, with overall predation rates of approximately 2.0% for all Snake River Chinook stocks (Evans et al. 2011) there may be very little noticeable effect on survival rates of study fish due to avian predation.

5.2.3 Predation Summary

Survival estimates will likely carry some degree of predation bias as study fish that passed through turbines without harm may still be preyed upon; however, an estimate of tailrace predation at Ice Harbor Dam is unknown for acoustic telemetry studies and may vary with tailrace conditions. The spring study period appears to have the greatest potential for predation to affect survival estimates at Ice Harbor Dam. Avian and piscivorous fish predation reportedly declines later in the summer despite the increase in northern pikeminnow distributions relative to the subyearling Chinook outmigration in July and August. A pre-spill study period would likely have lower predation rates due to cooler water temperature and avian colonies not being fully established. A late summer post-spill study would likely see moderate aquatic predation with reduced avian predation rates as young birds will have left the nest at this time.

Tailwater elevation, hydraulic conditions, and water temperature all play important roles in predation as well. Under full spill a large eddy may form downstream of the JBS outfall pipe. This eddy re-circulates upstream in front of the powerhouse and may provide more suitable conditions for predators. Later in the summer when spill and powerhouse operations are cut back a large area of stagnation and warmer water temperatures may occur between the powerhouse and spillway. This stagnation may provide suitable conditions for predators, both aquatic and avian, to mill around and target subyearling Chinook.

Relative to sample size estimates the survival probabilities used with SampleSize software should estimate sufficient sample sizes accounting for predation in the tailrace control survival estimates. As recommended by Skalski (2011) the sample size estimates should be increased by 1.25 to provide a cushion for errors that could include heavy predation, should it occur.

6.0 Proposed Tagging Methods (JSATS)

Tagging fish has been a common practice of fisheries management and research for many years, and, historically, tagging fish for behavioral studies has included many different tag types. Among those tag types are opercular buttons and straps, internal anchor, Peterson disc, and both internal and external radio tags (Guy et al. 1996) and acoustic transmitters. Currently, technological advancements and research have greatly reduced the size of transmitters. With smaller designs, external and internal options are much less stressful on fish which may lead to more accurate study results.

Relative to turbine survival estimates, the utility of smaller acoustic tags should prove superior to a larger tag, particularly with internal tags. Fish exposed to severe pressure changes within the runner environment during passage may be less likely to suffer barotraumas when tagged with smaller internal transmitters (Brown et al. 2009, 2012; Carlson et al. 2012). Results from Carlson et al. (2012) suggest that the ratio of pressure change (fish neutrally buoyant pressure/nadir pressure) coupled with tag burden greatly influence the probability of mortal injury from barotrauma (Figure 13).

Tagging methods used to conduct a turbine survival test (TST) should be considered prior to implementation. Tag choice may introduce unnecessary bias relative to tag burden causing less accurate survival estimates. The following are some tag options to consider for passage and survival studies at Ice Harbor Dam following replacement of turbine runners in Units 2 and 3. Pros and cons of external and internal tags are found in Tables 8 and 9, and general tagging assumptions in Table 10.

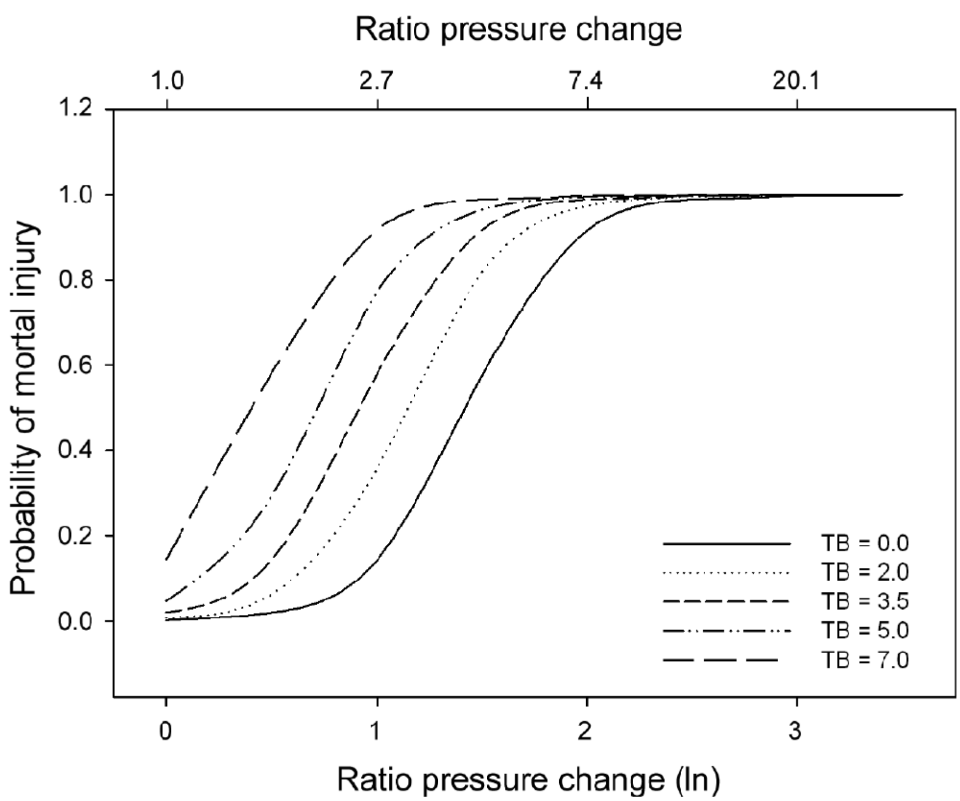


Figure 13 Probability of mortal injury and associated tag burden for juvenile Chinook salmon defined by the natural log or the ratio of pressure change (Carlson et al. 2012).

6.1 Internal tag (Carlson et al. 2010)

6.1.1 Tag Specifications

Researchers at Pacific Northwest National Laboratory (PNNL) are currently working toward an injectable JSATS acoustic transmitter. Current internal JSATS acoustic tags with a single battery and are small enough to keep tag burden fairly low (Single battery tag volume 0.11mL; tag burden (Median: 1.49%; Range: 0.27-4.69)) when surgically implanted in subyearling fall Chinook salmon. Conversely, tag burden associated with internal tags, regardless of magnitude, can be harmful to test specimens and may bias turbine survival estimates. Carlson et al. (2010) found tag burden, fish length, and condition factor all to be significant predictors of mortal injury in fish exposed to simulated turbine pressures ($P < 0.0001$).

6.1.2 Internal Tag Surgical Procedures

Fish handling and surgical procedures have been detailed by Axel et al. (2011; Appendix 3.0) and Deters et al. (2012) for the internal JSATS tag.

The posterior aspect of the incision should be 3-5mm anterior of the pelvic girdle. The incision should be made along the linea alba and should be approximately 5-6mm in length. Following insertion of the transmitter(s) the incision is closed with two interrupted sutures secured with a 1X1X1X1 knot (four single-wrap throws in alternating directions) using Ethicon Monocryl suture material.

Table 8 Pros and Cons of Internal JSATS Tag

Pro	Con
1 Well used, reliable tag; **2** Quantifiable tag burden/pressure effects = barotrauma mortality estimate/survival correction; **3** Tag life correction for survival estimates	**1** Tag burden still increases risk of injury; **2** Sub-lethal pressure injury due to tag burden not well quantified = higher survival est. variance

6.2 External Tag (Deng et al. 2011, 2012)

6.2.1 Laboratory Test Results and Specifications

In support of the USACE turbine survival program PNNL has developed and tested a neutrally buoyant external shell for JSATS acoustic tags (Figure 14). These tags provide no added mass to the fish, are less invasive than internal tags, and provide no unnatural pressure on internal organs during Nadir spike. Laboratory studies suggest that the Type A external tag applies minor hydrodynamic drag on fish and the mean critical swimming speed of juvenile Chinook salmon tagged with the Type A external tag is approximately 5cm/s slower than untagged control fish (Janak et al. 2012).

The JSATS transmitter source level when encased in the neutrally buoyant shell is approximately 153dB; an acceptable level for high detection probability. The unit dB refers to sound pressure regarding the signal transmitted by the JSATS tag and is defined as sound pressure level relative to 1 micro Pascal of force exerted on the JSATS receiver at 1m distance. The sound pressure level is usually defined using root mean square pressure.

Tag loss was moderate in laboratory studies at 5% (N=21; loss=1), and field studies at 10% (N=30, loss=3; Brown et al. 2013). No mortality was experienced during laboratory pressure and shear testing of fish carrying the external tag and field testing resulted in no significant differences in survival between internal and external tagged fish up to approximately 7 days in-river (Brown et al. 2013). Further, no significant difference in detection efficiency was found between internal and external tags (Brown et al. 2013).

6.2.2 External Tag Surgical Procedures

Fish handling and surgical procedures for the external tag are detailed in Deng et al. (2011, 2012).

Type A external tags should be attached anterior to the dorsal fin with two sutures, each with a 2X2X2X2 knot. Absorbable monofilament or Ethicon Vicryl Rapide absorbable suture material should be used (Deters et al. 2012). The Ethicon Vicryl Rapide is a faster absorbing suture material which will allow for faster tag release.

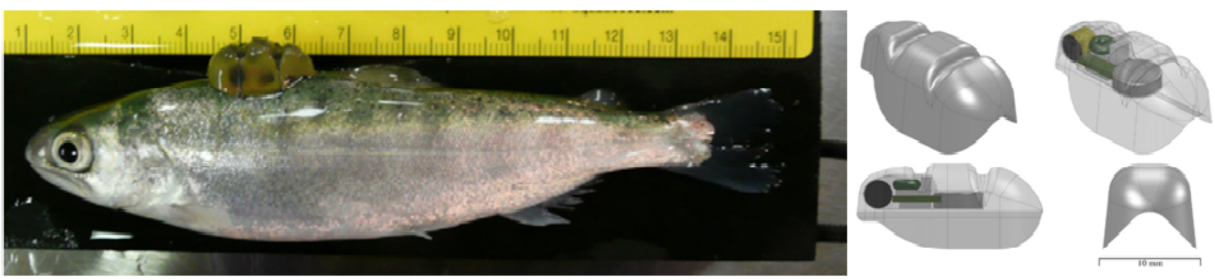


Figure 14 External JSATS Type A sutured to juvenile Chinook salmon (Deng et al. 2011).

Table 9 Pros and Cons of External JSATS Tags

Pro	Con
1 No internal injury or buoyancy issues related to tag burden	**1** Data from field test not yet analyzed
2 No internal surgery required	**2** Moderate tag loss possible

6.3 Injectable JSATS Tag

6.3.1 Tag Specifications

In March 2013 the prototype injectable JSATS tag is supposed to be ready for testing. The injectable JSATS tag will be comparable to a PIT tag in shape and slightly larger in size. If the injectable JSATS tag is ready for mass use for this biological study it may be the best option. The feasibility of injecting a JSATS tag into thousands of fish is great due to reduced handling and tagging effort required relative to surgically implanted or attached tags.

Injectable JSATS tags would also provide the same detection probability as the surgically implanted or attached tags with reduced tag burden. Although tag burden would still be present, a risk analysis would provide a good estimate of the extra mortality associated with this tag relative to turbine pressures and survival estimates.

Table 10 Tagging Assumptions (Guy et al. 1996)

1	Tagged fish can be recognized as such
2	Tagged fish will retain their tags
3	Mortality rates are relative between tagged fish and the population of inference
4	All tags are correctly identified and the status of specimen correctly assessed
5	Tags do not affect fish behavior

7.0 Balloon Tag Study

A balloon tag study to determine direct injury and mortality of turbine passage for the new unit 2 and 3 runners at Ice Harbor Dam (objectives 3 and 4) should follow methods of previous studies at Rocky Reach, Wanapum, and Ice Harbor Dams (Normandeau and Skalski 1996a, 1996b; Normandeau et al. 2008). Study fish should be directly released into the turbine intakes at predetermined elevations for the purpose of passing fish through general regions of the turbine runner. The same turbine operations tested in the acoustic telemetry study specified in objective 1 should be used for the balloon tag study. The release locations should be determined and/or verified through physical hydraulic model investigations using the ERDC 1:25 scale model Ice Harbor turbine.

The primary objectives of the balloon tag study are to 1) estimate direct injury of turbine passed fish at the appropriate turbine operations; and 2) relate direct injuries to specific mechanisms within the turbine unit (i. e. blade strike, shear, etc.). The secondary objective is to compare the results of the primary objectives with previous balloon tag studies to determine if benefits (reductions in injury do to strike and shear) of the new turbine designs can be quantified and compared to existing turbines.

7.1 Pre-Release Tagging and Fish Handling (Heisey et al. 1992; Normandeau and Skalski 1996b)

Lots of 5-10 fish should be randomly selected and moved to an adjacent tagging site. Fish displaying abnormal behavior, injury, fungal infection, or descaling (>20%) should not be used for the study. Specimens should be equipped with two deflated balloon tags and a radio tag**.** Tags should be attached with a stainless steel pin through the musculature below the dorsal and adipose fins (Figure 15). A uniquely numbered Visual Implant (VI) tag should be inserted in the post-ocular tissue for use in the 48h survival study, and identification of the fish given the loss of the radio tag.

Prior to release through the induction apparatus fish should be allowed to recover from anesthesia in a tub continuously supplied with ambient river water. Fish should be individually placed into the induction system holding tub. The expected inflation time of the balloon tags after injecting the appropriate volume of water is approximately 2-4 minutes which is adequate time for turbine passage. Actual turbine passage time may be less than one minute. The procedures used in handling, tagging, and recapturing of fish for treatment and control groups should be identical.

7.2 Release Groups

It is necessary to release groups of balloon tagged fish separate from those used to estimate survival in the acoustic telemetry study to properly assess direct injury relative to the new unit 2 and 3 runners at Ice Harbor Dam. The number of release groups will depend on release locations and number of different turbine operations to be tested. For example, if fish are to be release at three different elevations in each of three intake bays and four different turbine operations a minimum of 36 releases will be needed. Control release group(s) will be useful to calculate the effects of handling, tagging, induction, recapture, and additional recapture probability data (if needed) (Normandeau and Skalski 1996a).

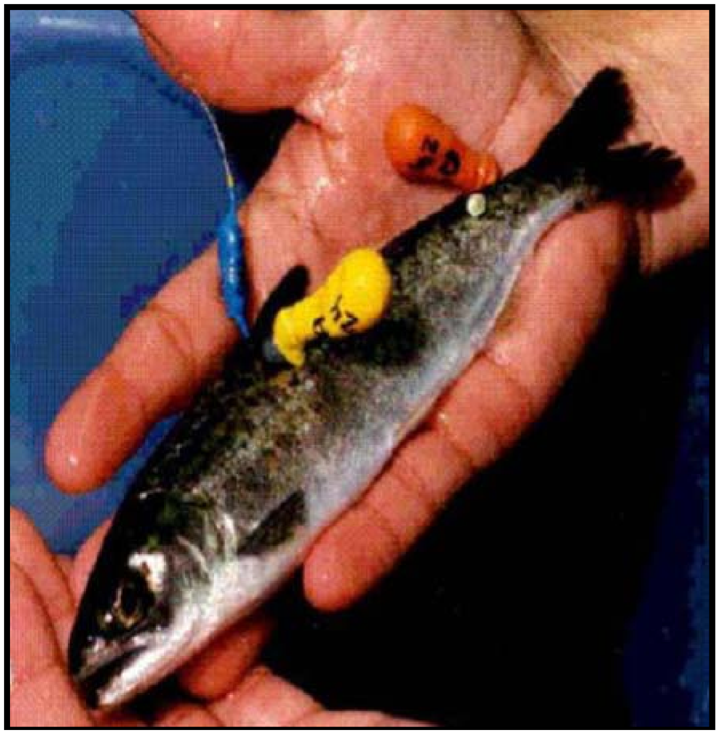


Figure 15 Balloon tagged Chinook smolt showing recommended tag locations (Carlson et al. 2008).

7.3 Release Locations

Release locations are important for direct release studies. Where a fish is released within the turbine intake may influence its passage route through the turbine unit. Different passage routes (i. e. blade-tip, mid-blade, hub) provide different survival probabilities as pressure, water velocity, and potential for strike on the turbine runner itself may vary depending upon where a fish passes. Release location should be considered with the objectives of the study. In the case of the Ice Harbor biological study, the TSP in coordination with ERDC personnel should determine which intake(s) and at what elevation the releases should occur. It may be that a single release location will be chosen to provide the greatest potential for fish to disperse from the release pipe and pass at any possible location.

7.3.1 Release Locations Previously Tested

Release locations will be determined by USACE and will consider best geometry, flow paths and discharge for fish passage, and past injury and survival data.

Mathur et al. (1996) performed a paired release-recapture study and directly injected fish 3.1m and 9.3m from intake ceiling at Rocky Reach Dam, 1993. These intake depths corresponded to the majority of fish entering the turbine intake within the top 6m of the intake ceiling while the remaining fish enter deeper according to Raemhild et al. (1985). The higher release location may have corresponded to a greater probability of mid-blade and hub passage where the lower release location may have corresponded to a greater probability of blade-tip passage.

Normandeau and Skalski (1996a) released fish at approximately 3 and 9 meters below the turbine intake ceiling in new and existing turbines for a survival comparison at Rocky Reach Dam. These release locations corresponded to those detailed by Mathur et al. (1996).

Normandeau et al. (2008) released fish equally into the intakes of turbine unit 3 at Ice Harbor Dam Releases occurred at elevations 327.5m mean sea level in intakes A and B, and 325.7m mean sea level in intake C (Figure 16). These release elevations were determined at ERDC using the Ice Harbor physical scale model and are representative of the flow path that an unguided fish may follow when passing through an Ice Harbor turbine. These may be the most appropriate release locations for the biological test of the new Ice Harbor turbine runners.

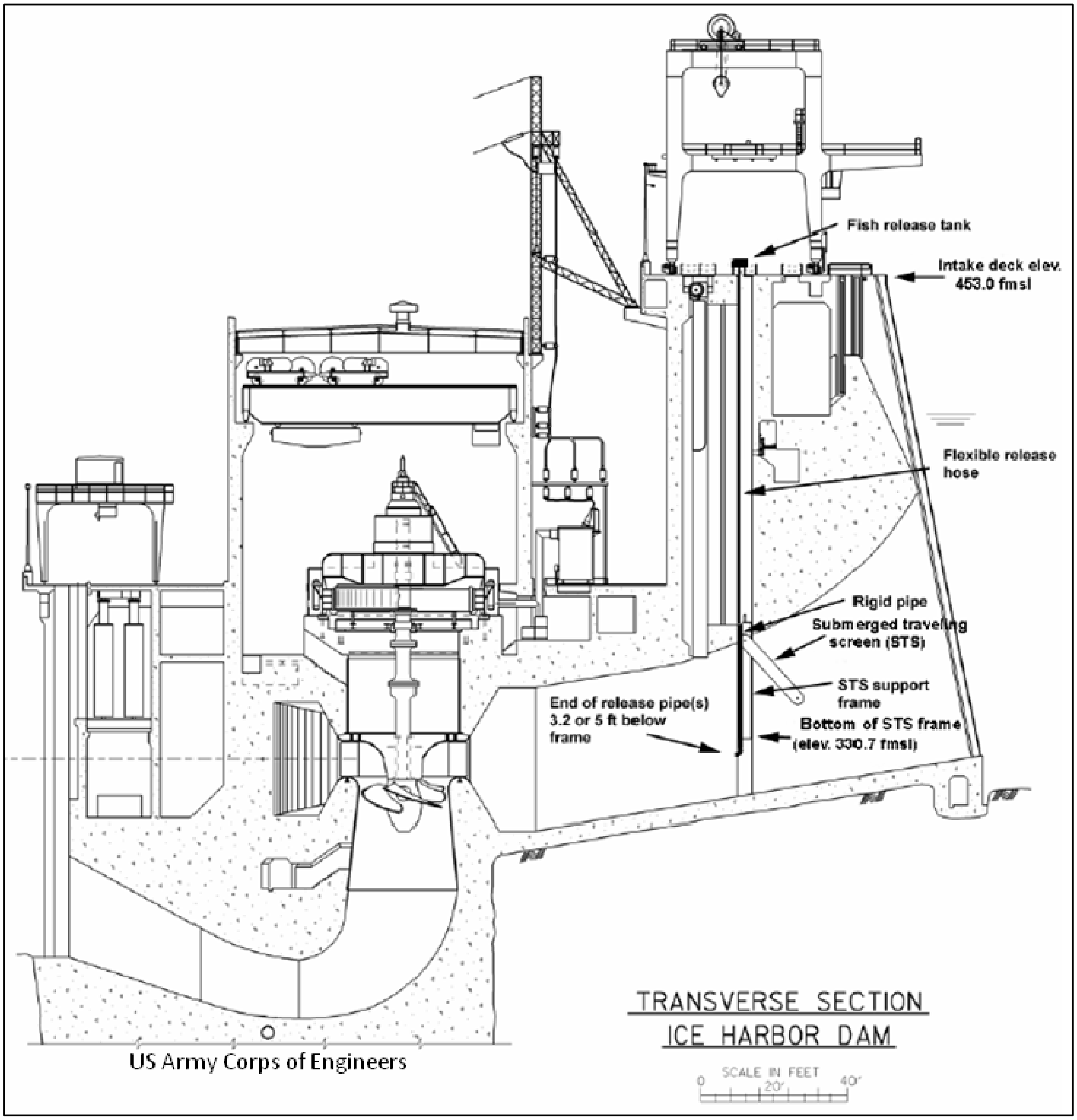


Figure 16 Cross-section of Ice Harbor Dam powerhouse and turbine unit 3 showing release locations for a balloon tag study (Normandeau et al. 2008).

7.4 Release Methodology (Normandeau et al. 2008)

Normandeau et al. (2008) fitted fish release pipes 76.2cm off center (toward the north) of the bypass screen frames in each turbine intake. Release pipes were placed such that fish would be released into the flow path that unguided fish were most likely to follow as determined by ERDC model evaluation. Release pipes were fabricated by the coupling of smooth walled rigid steel pipe and flexible 10.1cm diameter hose that directed the fish into each intake release point. Pipes were flushed with water to ensure that velocities exiting the pipe were similar to the velocities in the turbine intake to reduce the risk of injury to treatment fish as they exited the pipe.

Control fish should be released into the bypass exit flume as a means to evaluate handling, tagging, release, and recapture as well as provide additional data on recapture probability.

7.5 Recapture Tag Removal and Fish Handling (Heisey et al. 1992; Normandeau et al. 2008)

Fish should be located and recaptured by boat once the balloon tags inflate and buoy the fish to the surface. Recaptured fish should be placed into an on-board holding facility and the tag(s) removed by a pin puller (Heisey et al. 1992). Each fish should be examined for descaling and injuries and assigned codes relative to injury descriptions. Recaptured fish should be transferred to on-shore pools for estimating 48 h direct survival. Large circular pools should be located in a shaded area near the south shore Ice Harbor fish ladder. A flow-through system similar to the one used by Normandeau et al. (2008) should maintain approximately 1500L of water in each pool.

7.6 Pressure and Depth Acclimation Considerations

Pressure effects on migrating salmonids should be considered when conducting a balloon tag study. Migrating salmonids will have varying volumes of gas in the swim bladder as they migrate toward hydropower projects depending upon the depth at which they are acclimated (neutrally buoyant). Fish that are acclimated deeper will experience a greater risk of barotrauma. Depth acclimation of fish prior to release is ideal for properly satisfying the study objectives; however, depth acclimation for balloon tag studies is difficult for several reasons.

Tag inflation time is a sensitive matter. Tags must be created with the proper concentrations of chemicals and scientists must inject the correct volume of water into the tag to ensure inflation time is appropriate. Depth acclimation may require holding up to 24 hours at depth and delaying inflation of a balloon tag for this time period may not be feasible.

Furthermore, release mechanisms required to accomplish depth acclimation may cause startling of fish. After a long acclimation period this may cause fish to expel gas from the swim bladder prior to entering the turbine which nullifies the depth acclimation process. It is possible to depth acclimate fish using the Mobile Aquatic Barotrauma Laboratory but the potential for fish to startle and expel gas from the swim bladder upon removal from the pressure chambers and injection into the turbine intake is high. Also, the effort required to accomplish this is substantial and multiple acclimation depths may be appropriate.

While fish directly released into the turbine intakes may bias direct pressure related injury and relative survival estimates due to being surface pressure acclimated, this is the most feasible approach to releasing balloon tagged fish. A potential avenue to correct for pressure related injury bias would be to conduct a pressure risk assessment using the pressure study results (Brown et al. 2009, 2012; Carlson et al. 2010; Figure 13) and actual turbine pressure data from the test turbine units obtained from Sensor Fish (Carlson et al. 2008).

7.7 Sample Size (SampleSize Software 2011)

SampleSize (2011) software was used to calculate preliminary sample sizes for the balloon tag study (Appendix 1.4). Passage survival and detection probabilities for yearling and subyearling Chinook salmon and juvenile steelhead were calculated by holding control survival at 95% and treatment survival at 91.2% for subyearlings and 95% for yearling Chinook and steelhead. These survival estimates were the parameters used by Skalski (2011) to estimate sample sizes for a virtual with paired release-recapture study. The probability of capturing fish alive in the tailrace (actual model parameter) was fluctuated among 90, 95 and 98% similar to acoustic telemetry detection probability to provide a range of sample sizes appropriate for various tailrace conditions. Estimated sample sizes and associated live tailrace capture probabilities necessary to provide statically sound passage survival estimates for subyearling Chinook salmon are 1300 at 90%, 950 at 95%, and 750 at 98% (Figure 17), and 1250 at 90%, 850 at 95%, and 650 at 98% for yearling Chinook and steelhead (Figure 18).

These estimates appear to be high when compared to other balloon tag studies in the FCRPS and may be explained by the 95% control survival. A more comprehensive evaluation of balloon tag sample size requirements is presented in Table 11. A range of control and turbine survival percentages, as well as recapture rates were used to generate a range of sample sizes using SampleSize software that may provide a more simplistic means of choosing an appropriate sample size. Normandeau et al. (2008) provided a similar table with similar sample sizes calculated for higher turbine and control survival percentages and recapture rates. While the estimates provided in Figures 17 and 18 and Table 11 provide comprehensive preliminary sample sizes it is recommended that a statistician is consulted prior to study implementation.

7.8 Injury Classification of Recaptured Fish (Normandeau et al. 2007, 2008)

Injuries likely to be associated with direct contact with turbine runner blades or structural components are classified as mechanical and include: bruise, laceration, and severance of the fish body. Injuries likely to be attributed to shear forces are decapitation (with the isthmus attached to the body and a slanted wound), torn or flared opercula, and inverted or broken gill arches. The probable pressure related effects are manifested as hemorrhaged or ruptured/bulging eyes, swim bladder rupture, hemorrhaged internal organs, and embolism.

Injuries should be evaluated immediately following recapture and again later during a detailed examination after expiration of the 48h holding period. Immediate evaluation may provide assessment of some injuries, such as bleeding, which may no longer be evident at 48h. The 48h evaluation may also provide detection of other injuries which may not have been apparent or were overlooked during the evaluation immediately following fish recapture. Injury and descaling has been categorized by type, extent, and area of body. A fish was classified as descaled by Normandeau et al. (2007, 2008) if ≥ 20% of the scales were missing from one side. Fish without any visible injuries that were not actively swimming were classified as “loss of equilibrium”. This condition has been noted in past studies and often disappears within 10 to 15 minutes after recapture if the fish has no other apparent injuries.

Injuries may also be classified as minor or major following procedures established in laboratory studies (Table 12; PNNL et al. 2001).

7.9 Data Analysis (Normandeau et al. 2008)

Detailed analysis of data collected for direct injury classification is available from the above citation in Appendix 4.0.

Three different metrics were estimated from these data: (1) direct survival; (2) conditional probability of being malady-free (CMFE) given survival; and (3) the joint probability of survival (48h) and being malady-free.

Analysis of deviance (ANODEV) was used to compare turbine passage survival, CMFE estimates, and survival with CMFE estimates. The ANODEV was used to test the main effects of discharge, the main effects of turbine slot, and their interactions.

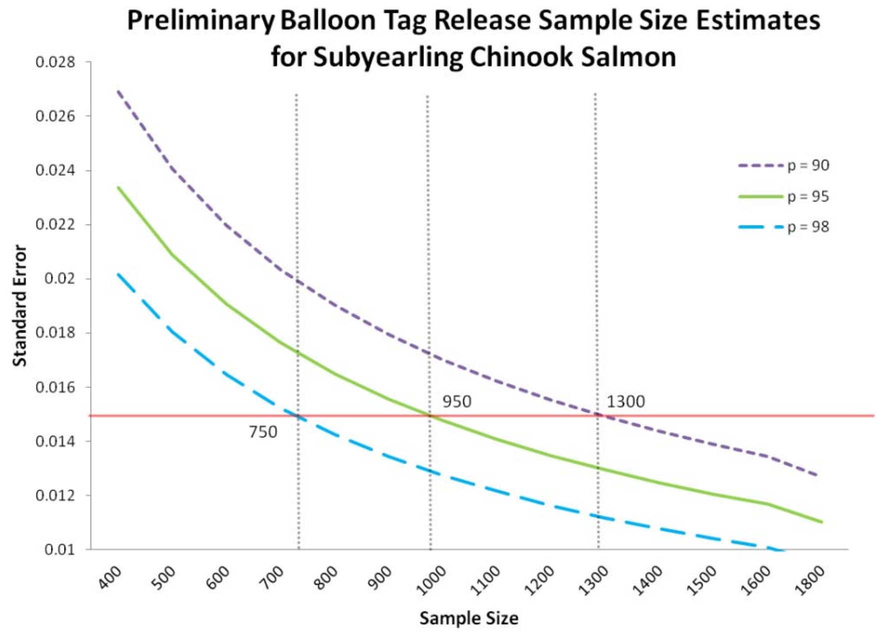


Figure 17 Plot of balloon tag study sample size for subyearling Chinook salmon. Probability of recapturing fish alive was used to mimic acoustic detection probability to generate sample size estimates.

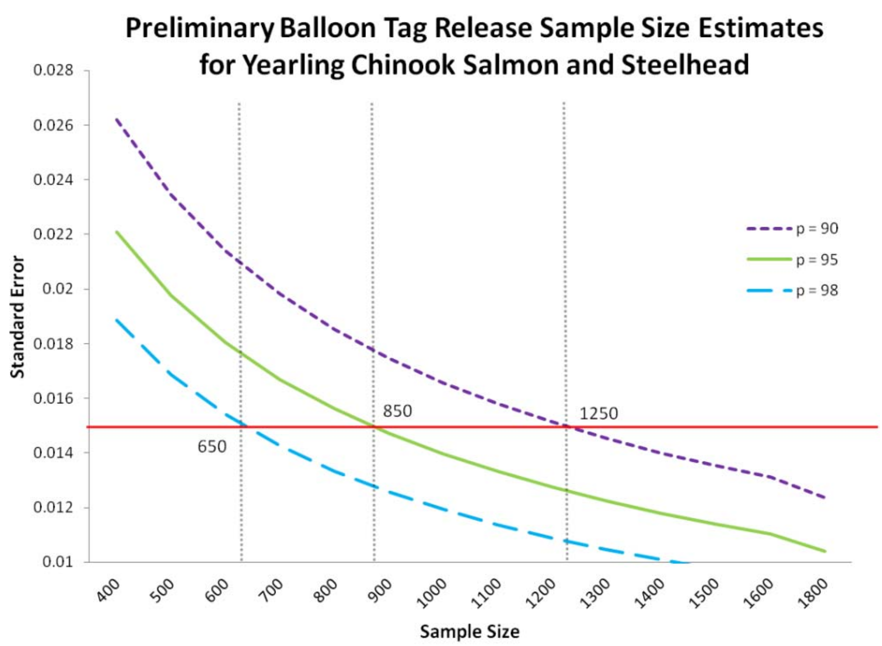


Figure 18 Plot of balloon tag study sample size estimates for yearling Chinook and juvenile steelhead. Probability of recapturing fish alive was used to mimic acoustic detection probability to generate sample size estimates.

Table 11 Balloon tag study sample size estimates encompassing a range of control and turbine survival percentages as well as recapture rates. This table provides a broad range of scenarios and associated samples sizes relative to previous FCRPS balloon tag studies.

	Estimated Turbine Survival					
Control Survival	**0.75**	**0.80**	**0.85**	**0.90**	**0.95**	**0.99**
	Capture Probability = 0.90					
0.90	950	950	930	910	870	830
0.95	800	770	740	700	650	610
0.98	700	670	640	600	550	470
	Capture Probability = 0.95					
0.90	860	830	780	730	670	610
0.95	690	650	600	540	460	400
0.98	600	560	510	440	370	300
	Capture Probability = 0.99					
0.90	760	710	650	570	480	400
0.95	600	540	470	390	300	210
0.98	520	460	380	300	210	130

Table 12 Fish Passage Major and Minor Injury Classification (PNNL et al. 2001)

1	A fish with only LOE is classified as major if the fish dies within 1 h; if it survives or dies beyond 1 h, it is classified as minor
2	A fish with no visible internal or external maladies is classified as a passage-related major injury if the fish dies within 1 h; if it dies beyond 1 h, it is classified as a non passage-related minor injury.
3	Any minor injury that leads to death within 1 h is classified as a major injury; if it lives or dies after 1 h, it remains a minor injury.
4	Hemorrhaged eye: minor if less than 50%; major if 50% or more.
5	Deformed pupil(s): major.
6	Bruises (size-dependent): major if 10% or more of fish body per side; otherwise minor.
7	Inverted or bleeding gills or gill arches: major.
8	Operculum tear at dorsal insertion: major if 5 mm or greater; otherwise minor.
9	Operculum folded under or torn off: major.
10	Scale loss: major if 20% or more of fish per side; otherwise minor.
11	Scraping (damage to epidermis): major if 10% or more per side of fish; otherwise minor.
12	Cuts and lacerations: generally classified as major. Small flaps of skin or skinned snouts: minor.
13	Internal hemorrhage or rupture of kidney, heart or other internal organs and/or
14	Multiple injuries: use worst injury.

8.0 Sensor Fish Study

The Sensor Fish (Figure 19) is an autonomous device developed by PNNL for the US Department of Energy and the USACE to better understand the physical conditions fish experience during passage through turbines, spillways, and alternative bypass routes (Deng et al. 2007). The current model's dimensions and weight are similar to a yearling salmon smolt. It is 24.5 millimeters (mm) in diameter, 90 mm long, has a dry weight of 43 grams, and is nearly neutrally buoyant in fresh water (slightly negatively buoyant). It provides in situ measurements of 3-dimensional (3D) accelerations, 3D rotational velocities, and pressure at a sample frequency of 2000 Hertz. The pressure-time histories recorded by these autonomous devices provide evidence of pressures throughout the turbine environment.

Figure 19 Sensor Fish equipped with balloon and radio tags (Carlson et al. 2008).

Sensor Fish should be released with groups of live fish during turbine survival or direct injury studies at Ice Harbor Dam to directly relate the turbine hydraulic environment to fish condition and survival. Releasing Sensor Fish during balloon tag studies will reduce labor needs for replicating the study methods. Releasing Sensor Fish during the balloon tag study will also provide specific data for the release locations and routes balloon tagged fish will experience during turbine passage. These release locations will be determined through data collected at ERDC during physical model evaluations. Results from the sensor fish releases can be compared to CFD models and will satisfy primary objective 4 (Section 3.0), and the secondary objective (Section 3.1).

Sensor Fish cost about $4,000 each (Ferris 2012) and it is recommended that 30 are released at Ice Harbor Dam with each balloon tag study release. Although Sensor Fish may be recaptured and released again, some may be lost in the tailrace or damaged during turbine passage making it feasible to have a surplus available for use if the need arises. The cost of 45 Sensor Fish is approximately $180,000.

9.0 Acoustic Telemetry Study (McMichael et al. 2011)

9.1 Equipment

To perform the studies detailed in this document, acoustic telemetry detection equipment must be installed at Ice Harbor Dam and discussion of such equipment will assume the implementation of the most rigorous biological study design with upstream releases, therefore detailing the greatest equipment needs (Appendix 5.0).

The JSATS tags to be used for this study are the acoustic transmitters that emit a source level of approximately 153.6dB (Deng et al. 2011, 2012). Two cabled arrays (Figure 20) will be used on the dam face. Each modular JSATS cabled dam-face array to be installed at Ice Harbor Dam consists of software, a computer, multifunction electronic cards including a global positioning system receiver, digital signal processing cards with field programmable logic gate capability, a signal conditioning interface, and up to four hydrophones and cables.

Omni-directional hydrophones utilizing a spherical ceramic element should be deployed at Ice Harbor Dam. These hydrophones provide a broader range of detection than previous models and should be housed inside an anechoic cone, otherwise referred to as baffles (Figure 20). These baffles have been designed to reduce ambient noise levels near operating powerhouses or spillways which can corrupt incoming acoustic tag signals.

Most hydrophones should be deployed in trolley pipes affixed to the forebay piers and concrete walls at Ice Harbor Dam. Two hydrophones will be deployed in each pipe location (shallow and deep elevation below water’s surface) to provide appropriate geometry to track tagged fish in three dimensions and assign route of passage. Each steel trolley will slide down a pipe guided by an extension arm that protrudes from the slot. The arm positions a cabled hydrophone perpendicular to the dam face.

Autonomous receivers (Figure 21) should be placed across the river in three different areas downstream of the tailrace (Appendix 6.0); the first of which should be placed sufficiently far down stream to avoid false positive detection of dead fish. Each autonomous receiver will require an acoustic release to deploy and retrieve them in the tailrace (Figure 21).

An array of autonomous receivers may also be placed in the immediate powerhouse tailrace to 3D track fish as they exit the draft tubes. This information may be collected with appropriate precision as studies by Deng (data on file) and Hogan et al. (2012) suggest. The application of information collected in the immediate powerhouse tailrace is directly related to draft tube and turbine boil hydraulics and fish egress. Understanding how fish behave in relation to the tailrace conditions upon exiting the draft tube may provide insight into tailrace mortality. Mortality in the tailrace may occur from a combination of factors such as entrainment in the draft tube backroll and flows drawn across the powerhouse into the spillway, eddying conditions leading to entrainment into auxiliary fish ladder water supply pumps, and aquatic and avian predation.

9.2 Data Collection

Data from the autonomous receivers will be stored on removable media. The data file is automatically named with the serial number of the receiver, including a header that identifies the equipment (manufacturer, serial number, firmware version) and labels for the comma-delimited data records that follow. Physical data will be recorded every 15 seconds (e. g. date, time, pressure, temperature, tilt) along with system integrity information (e. g. battery voltage). Tag detections will be recorded in text format along with pertinent information from the tag code (e. g. Tag ID, relative signal strength indication, threshold level, receive stream, and hexadecimal offset in seconds and fractions of seconds [in increments of 12 microseconds or less] from a standard epoch [e. g. 1/1/2000 12:00 am]).

Figure 20 Cabled array and hydrophone with baffle (McMichael et al. 2011)

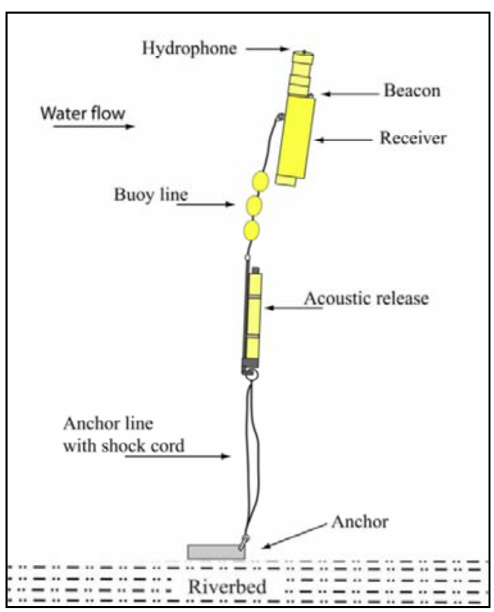


Figure 21 Example of an autonomous receiver and rigging assembly to be deployed in the tailrace at Ice Harbor Dam (McMichael et al. 2011)

10.0 Turbine Operations Previously Tested

Operations detailed below were tested in balloon tag studies. The purpose of highlighting these operations is to provide examples of operations of interest for fish passage and potential testing of the new runners for both acoustic telemetry and balloon tag studies. Operations within the 1% range are typical due to BiOp (NMFS 2008) and FPP (USACE 2013b) requirements but this may change with the 2014 BiOp that is currently in development.

Normandeau and Skalski (1996a) tested turbine loads at 60MW (8kcfs), 80MW (12kcfs), 100MW (16kcfs) which accounted for 80% of normal operation at Rocky Reach Dam. Testing was performed with an older Kaplan in unit 5, and a new Kaplan blade design in unit 6 to determine survival between new and existing runners.

Normandeau and Skalski (1996b) tested four turbine operating conditions with a 5 blade Kaplan runner in unit 9 at Wanapum Dam. Operations tested were 9kcfs (93.51% efficiency), 11kcfs (Peak 94.23%), 15kcfs (92.75% efficiency), and 17kcfs (cavitation mode 88.57% efficiency).

Normandeau et al. (2007) tested three turbine operations of Lower 1% (11.8kcfs), Peak (16.6kcfs), and Upper 1% (best geometry and operating limit 19.9kcfs).

Normandeau et al. (2008) used single releases of yearling Chinook salmon in a balloon tag study to test five different turbine operations in unit 3 at Ice Harbor Dam (Table 13). Survival was estimated to be highest at Peak, Intermediate, and Upper 1% operations; however, all survival estimates were ≥ 93%. Mean 48 hour survival estimates and SE among intakes A-C were 96% (SE = 0.026) at Peak, 97.6% (SE = 0.014) at Intermediate, and 96.7% (SE = 0.017) at the upper 1% with survival estimates through individual intakes being as high as 99%.

Table 13 Ice Harbor survival study turbine operation conditions previously tested (Normandeau et al. 2008)

Operating Condition	Turbine Performance	Turbine Discharge (kcfs)
Condition 1	Lower 1%	8.6
Condition 2	Peak	9.8
Condition 3	Intermediate	11.4
Condition 4	Upper 1%	12.6
Condition 5	Maximum	14.1

Other studies such as Axel et al. (2007b, 2008) tested complete dam passage at Ice Harbor Dam including turbine passage (units 1-5) under normal operating conditions given reduced, and BiOp spill treatments.

11.0 Fish Procurement

Run-of-river fish should be collected at Ice Harbor Dam, tagged and held on site for the acoustic telemetry portion of this study. Selection criteria used for performance standard testing should be exercised to ensure that study fish are representative of the run at large, as well as those used for biological testing at other projects. If collection at Ice Harbor Dam is not feasible, an alternative would be to collect fish at Lower Monumental Dam and release the fish in the tailrace at Lower Monumental, or transport them downstream to Ice Harbor depending on the study design being employed.

For balloon tag and direct release acoustic telemetry studies it may be suitable to follow the same procedure and methods employed by Normandeau et al. (2008) who utilized hatchery-reared subyearling Chinook salmon for a TST at Ice Harbor Dam. Fish were transported from the Little White Salmon National Fish Hatchery near Stevenson, Washington in a truck-mounted tank to the project site in lots of approximately 750 fish. Stocks from outside of the Snake River basin may only be used for Snake River balloon tag studies as these fish are all to be recaptured and removed from the system. For Lower Snake River acoustic telemetry studies it may be possible to secure Snake River stocks from Lyon's Ferry or Ringgold Hatchery. Hatchery fish are acceptable for direct release methods since migration behavior will not influence the passage of fish.

The transport truck used by Normandeau et al. (2008) was equipped with a recirculation system and supplemental oxygen supply. At the project site, fish were held in holding pools (~700-2300L capacity) continuously supplied with ambient river water. Fish were held a minimum of 24 h prior to tagging to allow acclimation to ambient conditions. Fish for the different test and control releases were drawn from the same group of fish assuring similar size and condition.

12.0 Sampling Logistics and Schedule

The new turbine runners will undergo biological testing to estimate passage survival and the effects of the turbine environment on juvenile salmonids. Biological testing is expected to occur in units 1 and 2 in 2016 subsequent to the new unit 2 runner install. Unit 1 will serve as the baseline existing condition. A combination of units 2 and 3 or only units 3 may be tested in 2017 subsequent to the new unit runner install.

Detailed scheduling will be important to properly executing a rigorous study requiring tagging and release of thousands of fish. An example schedule for implementation of a dam survival study employing acoustic telemetry equipment at Ice Harbor Dam is shown in Table 14 (McMichael et al. 2011). The example schedule has been detailed for a virtual with paired release-recapture study design to estimate full dam passage survival metrics for one year. A less rigorous study design may allow for a reduction in schedule; however, this schedule encompasses the expected time period required to adequately complete a survival study regardless of study design. Scheduling and logistics should be detailed by the awarded contractor and reviewed and agreed upon by the USACE technical leads.

Table 14 Example schedule for conducting a survival study at Ice Harbor Dam (McMichael et al. 2011).

	Activity Dates		FYXX												FYXX + 1		
Milestone Activity	Start	Finish	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Preparation	10/1/XX	3/31/XX															
Acceptance testing - autonomous receivers	2/1/XX	3/31/XX															
Acceptance testing - cabled receivers	2/1/XX	3/31/XX															
Acceptance testing - transmitters	2/1/XX	3/31/XX															
Fish tagging (yearlings, steelhead)	4/22/XX	5/24/XX															
Fish tagging (subyearlings)	6/1/XX	7/7/XX															
Data collection	4/22/XX	8/6/XX															
Data management	4/22/XX	10/31/XX + 1															
Analysis and reporting	5/6/XX	12/15/XX + 1															
Bi-Weekly Progress Reports	4/30/XX	8/30/XX															
Draft BiOp Report due - spring		9/30/XX															
Draft BiOp Report due - summer		12/15/XX + 1															

13.0 Study Implementation Discussion and Recommendations

Discussion and recommendations are based on best available scientific methods derived from literature review of previous studies in order to satisfy the specific objectives (Section 3.0) of the Ice Harbor turbine biological study. Considering study design, sample size, study period or season, species or run of interest, and dam operations can greatly influence achieved results of such a specific study. Objectives 1 and 2 require estimating survival through the new runners and estimating the survival difference between new and existing runners. The ability to satisfy these two important primary objectives will require the utmost attention to detail in implementation methods and data analysis. Stringent quality assurance and quality control (QA/QC) methods will be necessary. A QA/QC plan will be required and should detail every aspect of the study. A QA/QC outline can be found in Appendix 7.0.

Unit 1 should be considered for a baseline survival estimate. Baseline data will allow for direct comparison of data collected from the new unit 2 and 3 runners. Survival comparisons between the new and existing runners may be used to evaluate potential benefits to smolt passage provided by the new runner designs. Sensor Fish will also be released into the existing turbine runner to provide pressure and acceleration information that may be compared between the new and existing runners. The comparison of survival estimates and Sensor Fish data between the runners applies to objective 2, as well as the secondary objective to determine the benefits of particular features of the new turbines design for fish passage.

To ensure the greatest accuracy and precision possible it is recommended that efforts be taken regarding spill and powerhouse operations to provide the greatest proportion of study fish entering the turbine intakes possible. This may be achieved in several ways to include reduced or no spill, powerhouse unit priority adjustment, and potential removal of bypass screens. Any operations that deviate from the FPP (USACE 2013b) and BiOp (NMFS 2008) requirements will need to be coordinated thoroughly with the region requiring time, patience, and meticulous planning.

13.1 Release Locations and Methodology

13.1.1 Upstream In-River Releases

Release locations will vary depending on the study design implemented. For upstream releases allowing for normal distribution and volitional dam passage, release locations should be sufficiently far upstream to allow fish to acclimate to the river. Increasing the probability of turbine passage should be considered when choosing a release site. Consequently, upstream releases require larger sample sizes to account for mortality prior to arriving at the dam and the likelihood that fish will pass via other routes depending upon project operations.

An alternative to an extended upstream release may be to release fish a few kilometers upstream of the project to allow for somewhat normal distribution. Upstream releases closer to the dam may be more appropriate for horizontal distribution; however, vertical distribution will likely not occur as it would with a longer travel time to reach the dam. Given that little is known about the behavior of juvenile salmonids prior to entering the turbine intake and scroll case, it may be that vertical distribution and acclimation vary considerably at the dam face. Appendix 6.0 contains maps of possible release locations and acoustic detection arrays for an acoustic telemetry study design.

13.1.2 Direct Releases

Direct releases are another alternative to upstream releases and may be the most appropriate release method to evaluate turbine survival through specific units; however, the resulting survival estimate may be biased without fish being properly depth acclimated. One positive to directly introducing fish into the turbine intake is that sample sizes will remain relatively small since a high percentage of released fish will pass through the turbines.

Direct release elevations within a turbine intake may prove to be crucial to providing passage route specific information. Flow lines through and under the fish guidance screens may influence the path that a fish follows through the intake and into the scroll case. If that flow path is higher in the intake, fish will likely enter the scroll case higher and pass closer to the mid-blade or runner hub, while a fish following a lower flow path may pass the runner closer to the blade tip. Each location may provide different nadir distributions along the runner surface and result in different probabilities of injury and survival. Specific release elevations for a direct release study will likely be identical to those tested by Normandeau et al. (2008) as determined at ERDC with the 1:25 scale physical turbine model. Turbine runner route specific release locations will likely not be required as the release locations tested by Normandeau et al. (2008) were placed to provide a broad distribution of passage locations to evaluate the full range of turbine passage routes and conditions. The A and B turbine intakes will also likely be tested. A diagram of a direct release pipe and location within a turbine intake at Ice Harbor Dam is provided in Figure 16.

Although upstream releases are most desirable for obtaining turbine survival estimates, direct releases may be acceptable for two reasons. 1) surface acclimated fish are less susceptible to barotrauma than depth acclimated fish; hence, if a large proportion of directly released fish suffer barotrauma it may be indicative of a pressure problem with the runner design or operation; and 2) vertical distribution data may be applied to Sensor Fish pressures collected during the study to allow for an estimation of potential mortality from barotrauma associated with the new turbine runners. Sensor Fish pressure data has been previously used to expose fish in laboratory studies to realistic turbine pressure scenarios and the probability of mortal injury from barotrauma has been previously estimated (Figure 13). Sufficient vertical distribution data for yearling Chinook salmon are available from previous studies and have been summarized by Smith et al. (2010), although little data exists for subyearling Chinook salmon relative to powerhouse passage and operations. It is known that subyearling Chinook salmon migrate deeper than spring migrants (Ham et al. 2007; Adams and Evans 2011) and may make them more susceptible to barotrauma. A vertical distribution study between Little Goose and Lower Monumental Dams is planned to provide sufficient data for subyearling Chinook salmon. From the vertical distribution data, acclimation depth may be estimated for each run and the associated probability of mortal injury due to barotrauma may be calculated. This information may be applied to turbine survival estimates from the acoustic telemetry study providing a more accurate estimate of turbine survival.

13.2 Acoustic Telemetry Study Design Discussion

The approach for a biological study design that would produce the most accurate survival estimates would be to implement more complex study design such as the virtual with paired release-recapture design (Figure 9). This particular study design may be the most costly and complex but there are multiple reasons why this study design is appropriate; 1) Resulting survival estimates are the most accurate relative to route specific survival of juvenile Chinook salmon due to the fact that the assumptions of the design reduce survival estimate bias; and 2) There is a strong need for a standardized turbine survival study design that can be implemented at any project and provide ease of replication at individual or through multiple projects. Skalski et al. (2009) and Skalski (2011) present the virtual with paired release-recapture model to account for sample biases know to occur with simpler designs such as single release-recapture when estimating dam passage survival. This model is applicable to all passage survival studies, including those exploring multiple project passage effects on juvenile Chinook salmon.

The study design should consider the release of fish upstream of the dam sufficient enough to allow for normal depth acclimation and distribution rather than directly introducing fish into the turbine intakes. Having study fish enter the turbine intakes under the same behavior as they would during normal passage is necessary to reduce potential bias in survival estimates. Fish entering the turbine intakes volitionally are likely to be depth acclimated, change direction or depth, possibly expelling gas from the swim bladder, and orient themselves in a particular fashion to prepare for swift water with the increased velocity as they approach the scroll case.

Depth acclimation should be considered for accurately estimating turbine survival because fish that are directly released (surface pressure acclimated) do not contain comparable swim bladder gas volume relative to depth acclimated run-of-river fish. The probability of barotrauma varies with nadir, fish acclimation depth, and tag burden. Tag burden exacerbates the potential for incurring injury, particularly injuries sustained from barotrauma by crowding the internal organs (Figure 13). Added tag mass also requires depth acclimated fish to hold slightly more gas in the swim bladder to maintain neutral buoyancy. For these reasons turbine survival estimates may be biased high by direct release study designs as these studies do not capture potential barotrauma injuries.

The virtual with paired release-recapture model provides the least bias given proper sample sizes and release groups. The use of two downstream control releases provides absolute survival estimates by allowing separation of treatment effects associated with turbine passage from potential tag and tagger effects experienced by control releases. A simpler design may be more attractive to the region due to lower costs; however, if a simple study design is implemented and a significant bias in survival estimates is realized then the objectives of the study will not be met and resources squandered.

The alternatives to implementing the full virtual with paired release-recapture model may include a variation of the single or paired release-recapture designs. The single release design would involve single releases, either directly into the turbine intake or upstream from the turbine units of interest sufficient enough to allow for some depth acclimation and normal distribution. A control release of dead fish in the tailrace is a standard to determine the proportion of false positive detections that can be expected in subsequent hydrophone arrays to further improve the accuracy of survival estimates and test design assumptions. This is the most simple, least costly option; however, the survival estimates may suffer a greater degree of bias with this study design (Section 4.1.5).

At minimum a paired release-recapture design is necessary to produce statistically measurable and confident turbine passage metrics for new turbine runners at Ice Harbor Dam. The paired release study design would involve releases, either directly into the turbine intake or upstream from the turbine units of interest sufficient enough to allow for some depth acclimation and normal distribution. Paired control releases downstream of the dam would account for mortality associated with tagging providing a more accurate turbine survival estimate. This study design is more costly than the single release-recapture design but the results are more accurate and may be less biased. Further, paired releases are necessary to isolate survival estimates to turbine passage as noted in Section 4.0.

13.3 Tag Use Discussion

Methods for a biological study design that would produce the most accurate survival estimates may be to utilize the external JSATS tag developed by Deng et al. (2011) (Figure 14). The Objectives of this study specify estimates of turbine passage survival be generated for subyearling Chinook salmon as a worst-case scenario (Objective 1). Given the effects of barotrauma on juvenile Chinook salmon, tag burden has a measureable effect on survival estimates of turbine passed fish (Carlson et al. 2010). The use of the neutrally buoyant external JSATS tag provides the greatest potential for achieving highly accurate, minimally biased turbine survival estimates. The external JSATS tag may be new and field testing results are not yet available; however, removing the tag from the body cavity of the fish decreases the risk of internal organ damage from nadir spike (Brown et al. 2011). Although the new turbine runners for Ice Harbor are being designed with a minimum nadir of 83kPa, probability of mortal injury will still exist and may be experienced by internally tagged fish as a product of tag burden.

Conversely, the argument that internal tags should be used for the study is sensible for two reasons. 1) Using an internal tag will allow results that are directly comparable to previous turbine passage survival estimates; 2) The injectable JSATS tag may be available for the study and would be an appropriate substitute for the surgically implanted JSATS tag further reducing tag burden and the probability of mortal injury from nadir spike; and 3) The new runners are being designed to be safer for fish passage by keeping the nadir pressure high so if the prototype runner performs as designed there should be no significant difference in survival estimates between internally tagged fish passing through the turbine runner and those released in the tailrace control groups.

Regardless of the tag chosen to conduct the study, the results will provide a measure of turbine survival that will offer insight into the effectiveness of the new runner designs in providing a safer turbine passage route for juvenile salmonids at similar hydropower dams.

13.4 Balloon Tag Study Discussion

Implementation of a balloon tag study should begin by determining the operations and release locations of interest relative to physical and CFD model data. Balloon tag studies typically follow the basic concept of releasing fish into a turbine intake at predetermined elevations and intake bays and may be explained by two scenarios; 1) balloon tags typically inflate in 2-4 minutes (Normandeau et al. 2008) making it difficult to implement upstream releases with balloon tagged fish; and 2) balloon tag studies typically provide more accurate estimates of the injuries fish may experience within the turbine environment compared to survival estimates. Balloon tag studies provide relative survival estimates associated with mechanical injury; however, they do not capture the pressure component of the turbine environment. A calculation of the probability of mortal injury with Sensor Fish pressure data and appropriate fish acclimation depth information may provide a correction factor for survival estimates. It should be noted that much consideration has been given to depth acclimation of study fish prior to releasing them into the turbine; however, the difficulty in depth acclimating fish for a balloon tag study lies in the small sample window during which the balloon tag begins to inflate. It may not be feasible for fish to be tagged with balloon tags and subsequently held to achieve depth acclimation.

Sample size recommendations follow suit relative to the acoustic telemetry study design. If we assume a 95% recapture rate with 95% turbine survival and 98% control survival the calculated sample size is 370 per release group (Table 11). Recapture rate and control survival estimates should be conservative when choosing an appropriate sample size to ensure that enough fish are released to provide the appropriate power to avoid Type I or Type II error.

13.5 Study Turbine Operations

Currently, the FPP (USACE 2013b) specifies all turbine units to be operated within 1% of peak efficiency from April 1 through October 31 as specified in load shaping guidelines (Tables 15 and 16).

Past studies have focused on multiple turbine operations of interest within the 1% range such as those tested by Normandeau et al. (2007, 2008). While the operating range for the fixed blade unit 2 runner is likely to be very narrow, peak efficiency may be the only operation tested for this runner. Best geometry was tested by Normandeau et al. (2007) and provided survival was highest at this operating condition and it should be considered as an operating condition of interest for the unit 3 Kaplan runner upon install completion in 2017. This condition will likely be tested at ERDC in during physical model evaluations of the Kaplan turbine and recommendations for biological testing operations for the Kaplan runner will follow.

Past studies have also shown that highest survival does not necessarily coincide with peak operating efficiency (Normandeau and Skalski 1996a; Skalski et al. 2002, Normandeau et al. 2008). A best operating point for fish passage should be defined by physical and CFD model investigations and field verified prior to biological testing.

Operating conditions for the study must be discussed and agreed upon by the USACE technical leads and TSP and identified as feasible relative to the season/study period and minimum powerhouse discharge requirements. Testing turbine operations such as best geometry may or may not be feasible due to minimum powerhouse discharge and river volume during the spring pre-spill and summer post-outmigration peak. Testing operations outside the 1% limits is possible (and may be permitted for operation in the 2014 NMFS BiOp) considering the new turbine runners being designed to operate for best fish passage.

Table 15 1% best efficiency ranges for Ice Harbor Dam turbine Units 1 and 3 with and without screens (USACE 2013b).

Head (feet)	Units 1 & 3 with STSs				Units 1 & 3 with No STSs			
	1% Lower Limit		1% Upper Limit		1% Lower Limit		1% Upper Limit	
	(MW)	(cfs)	(MW)	(cfs)	(MW)	(cfs)	(MW)	(cfs)
85	**51.7**	**8,417**	**83.6**	**13,590**	**51.9**	**8340**	**89.9**	**14,452**
86	52.6	8,443	84.6	13,585	52.7	8367	91	14,447
87	53.4	8,469	85.6	13,580	53.5	8392	92	14,441
88	54.2	8,494	86.6	13,574	54.3	8417	93.1	14,436
89	55	8,518	87.6	13,569	55.1	8441	94.2	14,430
90	**55.8**	**8,542**	**88.6**	**13,563**	**55.9**	**8465**	**95.3**	**14,424**
91	56.5	8,548	89.8	13,585	56.6	8471	96.5	14,448
92	57.1	8,554	90.9	13,607	57.3	8477	97.8	14,471
93	57.8	8,559	92.1	13,628	58	8482	99	14,494
94	58.5	8,565	93.2	13,649	58.6	8,047	100.3	14,516
95	**59.2**	**8,570**	**94.4**	**13,669**	**59.3**	**8,052**	**101.5**	**14,537**
96	59.9	8,589	95.3	13,662	59	8,070	102.5	14,530
97	60.7	8,607	96.3	13,655	59	8,087	103.5	14,522
98	61.5	8,624	97.3	13,648	60	8,103	104.6	14,515
99	62.2	8,641	98.2	13,641	61	8,119	105.7	14,508
100	**63**	**8,658**	**99.2**	**13,634**	**62**	**8,135**	**106.7**	**14,500**
101	64	8,707	99.9	13,590	62	8,182	107.4	14,454
102	65	8,354	100.6	13,547	63	8,227	108.2	14,408
103	66	8,804	101.3	13,505	64	8,272	108.9	14,363
104	67	8,850	102	13,463	65	8,316	109.7	14,319
105	**68**	**8,896**	**102.6**	**13,422**	**66**	**8,359**	**110.4**	**14,275**

* **NOTE:** Table based on the 1978 model test and 2006 Unit 3 index test (IHR -5&6 revised 2008)

Table 16 1% best efficiency ranges for Ice Harbor Dam turbine Unit 2 with and without screens (USACE 2013b).

Head (feet)	Unit 2 with STSs				Unit 2 with No STSs			
	1% Lower Limit		1% Upper Limit		1% Lower Limit		1% Upper Limit	
	(MW)	(cfs)	(MW)	(cfs)	(MW)	(cfs)	(MW)	(cfs)
85	**67.6**	**10,986**	**72.9**	**11,854**	**68.7**	**11,032**	**74**	**11,896**
86	68.6	11,017	73.9	11,864	69.7	11,064	75	11,905
87	69.6	11,047	74.8	11,873	70.7	11,094	76	11,914
88	70.6	11,077	75.8	11,882	71.8	11,124	76.9	11,923
89	71.7	11,105	76.7	11,890	72.8	11,153	77.9	11,932
90	**72.7**	**11,133**	**77.7**	**11,899**	**73.8**	**11,181**	**78.8**	**11,940**
91	73.4	11,120	78.7	11,917	74.6	11,167	79.9	11,959
92	74.2	11,107	79.8	11,936	75.4	11,154	80.9	11,978
93	75	11,093	80.8	11,953	76.2	11,141	82	11,995
94	75.8	11,080	81.8	11,970	76.9	11,128	83.1	12,013
95	**76.5**	**11,068**	**82.9**	**11,987**	**77.7**	**11,115**	**84.1**	**12,029**
96	77.3	11,071	83.5	11,955	78.6	11,118	84.8	11,998
97	78.2	11,073	84.2	11,924	79.4	11,121	85.4	11,966
98	79	11,076	84.8	11,894	80.2	11,124	86.1	11,936
99	79.8	11,079	85.5	11,864	81.1	11,127	86.7	11,906
100	**80.6**	**11,082**	**86.1**	**11,835**	**81.9**	**11,130**	**87.4**	**11,877**
101	81.5	11,096	87.1	11,852	82.8	11,144	88.4	11,894
102	82.5	11,110	88.1	11,869	83.8	11,158	89.4	11,911
103	83.4	11,124	89.1	11,886	84.7	11,172	90.4	11,928
104	84.3	11,138	90.1	11,902	85.6	11,186	91.4	11,944
105	**85.2**	**11,151**	**91.1**	**11,918**	**86.5**	**11,199**	**92.4**	**11,960**

* **NOTE**: Based on the 1956 Model Test and 2008 Unit 2 Index Test (IHR new 2008).

14.0 Study Design Options

Options detailed below are listed in order of accuracy of results provided by the study (i. e. Option 1 is the most accurate design relative to subsequent options).

It is important that the study designs meet the objectives of the study; hence, the objectives are frequently referred to in this section. The study objectives from section 3.0 are briefly listed below for reference.

Primary Objectives:

1) Estimate survival of yearling and subyearling Chinook salmon and juvenile steelhead through new turbines
2) Estimate survival difference between new and existing turbines
3) Evaluate differences in direct injury between new and existing runners
4) Evaluate how well the new runner meets pressure criteria

Secondary Objective:

1) Evaluate benefits of turbine design features (if we have enough evidence to attribute increased survival to particular turbine environment features (i.e., stay vane modifications, runner strike, runner pressure, draft tube floor fill, etc.))

14.1 Option 1 (Virtual with Paired Release-Recapture)

The virtual with paired release-recapture design has the potential to satisfy study objectives 1 and 2 with the least bias. This study design is the most rigorous among those detailed in this document and would provide the most statistically accurate survival estimates. The most important aspect of this study design is releasing fish upstream of the dam far enough to allow for normal vertical and horizontal distribution relative to the run-of-river population at large. Proper depth acclimation of fish prior to approaching the dam would provide realistic turbine survival estimates by accounting for typical migration behavior and pressure exposure upon turbine passage.

This study design is more difficult to implement logistically than either the single or paired release-recapture designs, particularly when considering the possibility of replicates for evaluating specific turbine operations. Typically this study design is used for full dam passage survival studies and does not necessarily employ replicates.

14.1.1 Release Locations and Acoustic Detection Arrays

Possible release locations for the virtual with paired release-recapture study design are detailed in Appendix 6.0.

1) R1 release is placed 24km upstream of Ice Harbor Dam. It may be possible to release fish closer to Ice harbor and still provide normal distribution and depth acclimation. An optional BRZ detection array would provide forebay residence time and the dam face array would provide the virtual release group made up of fish that survived from the R1 release location and within the forebay (if BRZ array is deployed).

2) R2 release site and egress detection array may be placed downstream of the dam near the tailrace exit between the tailrace BRZ and highway 12 bridge. This

release location will provide a tailrace control for turbine passage survival at the next subsequent detection array. Tailrace egress time may be estimated at this detection array as well.

3) R3 release site may be approximately 3.3km downstream of the Columbia-Snake River confluence. Detection of turbine passed fished and tailrace released fish can be compared to provide the first turbine passage survival estimate. The R3 release will provide a control to estimate tagging effects between the R2 and R3 release groups and survival between the R2 release site and the next detection arrays.

The detection array approximately 21km upstream of McNary will provide the reach survival, tagging effects, and final turbine passage survival.

The final detection array in the McNary Dam forebay will provide the final control survival estimate.

14.1.2 Sample Seasons, Dam Configuration, and Sample Sizes

It is recommended that a summer study period without spill or screens is implemented for subyearling Chinook salmon. There is potential for a summer or fall post-spill study to provide optimum tailrace conditions. These conditions are not representative of typical spring and summer flows and predator spatial distribution; however, conducting the study outside of fish passage season provides operations flexibility to set up ideal tailrace egress conditions. Further, a study during this period may result in an accurate account of turbine passage survival controlled for minimal tailrace predation. Final planning for a study during the late summer or fall will be done in cooperation with USACE technical leads.

As the SampleSize software suggests 2,590 subyearling Chinook should be released into each turbine intake to be able to detect a significant difference between survival estimates at $\alpha = 0.05$ and SE = 0.015 when the detection probability is approximately 90%. A total of 6,680 fish would be required to provide estimates for two turbine units (not operation specific) with paired control releases downstream. Control release groups were estimated to be approximately 500 fish. In this case the detection probability will be near 100% so total sample size would likely not need to be multiplied by 1.25 as Skalski (2011) suggests for providing a cushion for unforeseen errors. This number will double if testing spring and summer runs.

14.2 Option 2 (Paired Release-Recapture with Direct Release Option)

The paired release-recapture study design with direct release into the turbine intakes would satisfy study objectives 1 and 2 and provide statistically accurate survival estimates; however, a survival bias will occur due to the lack of depth acclimation prior to entering the turbine units.

This study design is simpler to implement than the virtual with paired release-recapture design and is more feasible on the premise of reduced sample size.

The most important aspect of this study design is reducing sample sizes relative to the virtual with paired release-recapture design while still providing a statistically defensible turbine survival estimate for specific operations.

14.2.1 Release Locations and Acoustic Detection Arrays

Possible release locations for the paired release-recapture study design are detailed in Appendix 6.0.

1) R1 release is directly into the unit 2 and 3 turbine intakes at Ice Harbor Dam (Figure 16).

2) R2 release site and egress detection array may be placed downstream of the dam near the tailrace exit between the tailrace BRZ and highway 12 bridge. This release location will provide a tailrace control for turbine passage survival at the next subsequent detection array. Tailrace egress time may be estimated at this detection array as well.

3) R3 release site may be approximately 3.3km downstream of the Columbia-Snake River confluence. Detection of turbine passed fished and tailrace released fish can be compared to provide the first turbine passage survival estimate. The R3 release will provide a control to estimate tag and tagger effects between the R2 and R3 release groups and survival between the R2 release site and the next detection arrays.

The detection array approximately 21km upstream of McNary will provide the reach survival, tag and tagger effects, and final turbine passage survival.

The final detection array in the McNary Dam forebay will provide the final control survival estimate.

Release elevation(s) should be determined by the USACE technical leads and TSP prior to study implementation; however, a mid-elevation release similar to the 9.3m (Mathur et al. 1996), or 325.7m mean sea level (Normandeau et al. 2008) used in the past should be considered for a single release point. A mid-elevation release will allow for the greatest probability of fish being distributed along the turbine blade to provide a survival estimate for all pressures and conditions not limited to a more specific runner passage route (i. e. blade tip, mid-blade, hub).

14.2.2 Sample Seasons, Dam Configuration, and Sample Sizes

A direct release study does not require sample sizes that account for project operations and seasons. Percent spill, bypass screens and river flow will not affect sample sizes for direct releases behind the intake screens. Release elevations and intakes similar to those tested by Normandeau et al. (2008) are likely to be tested again for this study. Turbine operation for the fixed blade runner is likely to be peak efficiency only given the narrow operating range for this runner; however, the unit 3 Kaplan runner will likely have lower 1%, peak efficiency, and upper 1% tests with the possibility of best geometry as well. These details will be finalized with the USACE technical leads prior to study implementation, but should be considered as presented here for the purpose of developing an implementation plan.

As the SampleSize software suggests 1170 subyearling Chinook should be released into each turbine intake to be able to detect a significant difference between survival estimates at $\alpha = 0.05$ and SE = 0.015 when the detection probability is approximately 90%. A total of 8,520 would be required to provide estimates for two turbine units and three operations with paired control releases. Control release groups were estimated to be approximately 500 fish. In this case the detection probability will be near 100% so total sample size would likely not need to be multiplied by 1.25 as Skalski (2011) suggests for providing a cushion for unforeseen errors. This number will double if testing spring and summer runs.

14.3 Option 3 (Single Release-Recapture with Direct Release Option)

The single release-recapture study design with direct release into the turbine intakes would satisfy objective 1; however, sufficient power to satisfy objective 2 is unlikely. A survival bias will occur due to the lack of depth acclimation prior to fish entering the turbine units, as well as the lack of sufficient control releases. Again, if the new turbine runner pressures are higher than 83kPa it is possible no statistically significant difference in survival between depth and surface acclimated fish would occur.

The single release design will be simple to implement relative to more rigorous designs due to the lack of sufficient controls to provide an accurate turbine survival estimate. A minimum of one control release downstream should be considered to provide an evaluation of the effect of tagging on survival. In this case the paired release study should be implemented.

Although turbine survival estimates may be available with this study design it is not recommended for evaluation of the new turbine runners at Ice Harbor Dam.

14.3.1 Release Locations and Acoustic Detection Arrays

Possible release locations for the single release-recapture study design are detailed in Appendix 6.0.

1) R1 release is directly into the unit 2 and 3 turbine intakes at Ice Harbor Dam.

2) R2 and R3 release locations would be sufficient for a control release and the detection array below the tailrace, below the confluence, and 21km upstream from McNary would be sufficient to provide survival estimates. The detection array approximately 21km upstream of McNary will provide the reach survival, tagging effects, and final turbine passage survival.

Release elevation(s) should be determined by the USACE technical leads and TSP prior to study implementation; however, a mid-elevation release similar to the 9.3m (Mathur et al. 1996), or 325.7m mean sea level (Normandeau et al. 2008) used in the past should be considered for a single release point. A mid-elevation release will allow for the greatest probability of fish being distributed along the turbine blade to provide a survival estimate for all pressures and conditions not limited to a more specific runner passage route (i. e. blade tip, mid-blade, hub).

14.3.2 Sample Seasons, Dam Configuration, and Sample Sizes

A direct release study does not require sample sizes that account for project operations and seasons. Percent spill, bypass screens and river flow will not affect sample sizes for direct releases behind the intake screens. Release elevations and intakes similar to those tested by Normandeau et al. (2008) are likely to be tested again for this study. Turbine operation for the fixed blade runner is likely to be peak efficiency only given the narrow operating range for this runner; however, the unit 3 Kaplan runner will likely have lower 1%, peak efficiency, and upper 1% tests with the possibility of best geometry as well. These details will be finalized with the USACE technical leads prior to study implementation, but should be considered as presented here for the purpose of developing an implementation plan.

As the SampleSize software suggests 370 subyearling Chinook should be released into each turbine intake to be able to detect a significant difference between survival estimates at $\alpha = 0.05$ and SE = 0.015 when the detection probability is approximately 90%. A total of 3,720 would be required to provide estimates for two turbine units and three operations with paired control releases. Control release groups were estimated to be approximately 500 fish. In this case the detection probability will be near 100% so total sample size would likely not need to be multiplied by 1.25 as Skalski (2011) suggests for providing a cushion for unforeseen errors. This number will double if testing spring and summer runs.

14.4 Tag Types (applicable to all study designs)

While external, surgically implanted, and injectable JSATS tags may all be available for this study, it is recommended that external JSATS tag be used for upstream releases, or injectable JSATS tags be used for direct releases to provide the least bias in turbine survival estimates relative to barotrauma for fish released. One concern with external tags is the feasibility of using these tags relative to their production and attachment time when a large quantity of tags and fish are required.

If the injectable JSATS tag is available it may be the most feasible option for the study requiring reduced fish handling time for tagging and overall production may be much simpler and more cost effective. The reduced tag burden would provide a more accurate turbine survival estimate. Reasonable calculation of the bias associated with barotrauma may be generated through probability of mortal injury calculation.

14.5 Sensor Fish Releases (applicable to all study designs)

A Sensor Fish Study will satisfy primary objective 4, and the secondary objective. Sensor Fish should be released directly into the turbine intakes behind the gatewell screens. The methods of Carlson et al. (2008) should be followed to include 30-60 sensor fish per release, each outfitted with a radio tag and two balloon tags. The direct release apparatus for the single or paired release-recapture study design will be sufficient for the Sensor Fish study. It should be noted that in the case of the virtual with paired release-recapture study design being implemented, planning for extra effort to fabricate and install direct release equipment will be required. Sensor Fish should be directly released in the same fashion as the fish used for the acoustic telemetry study (if applicable) to provide specific data for the conditions and environment that study fish were exposed to.

14.6 Balloon Tag Study (applicable to all study designs)

A balloon tag study will satisfy primary objective 3. A balloon tag study should be implemented similar to the methods detailed in section 7.0 relative to the various studies referenced. A sample size between 250-500 fish per release group will likely provide the appropriate power to obtain statistically significant results. The direct release apparatus for the single or paired release-recapture study design and Sensor Fish study will be sufficient for the balloon tag study.

Two or three balloon tags should be attached to each smolt along with a radio tag for ease of recovery and high recapture rates.

Turbine operations will be determined by the USACE technical leads and TSP prior to study implementation. Appropriate operations may not be contained within the 1% operating range.

Balloon tagged fish should be directly released in the same fashion as the fish used for the acoustic telemetry (if applicable) or Sensor Fish studies to provide specific data for the conditions and environment that study fish were exposed to.

14.7 Design Options Discussion

Among the study designs presented, the virtual with paired release-recapture will provide the most accurate survival estimates; however, the cost of conducting the study will be greater relative to the other two designs, particularly in regard to replicates. While multiple replicates of the virtual with paired release-recapture study would provide the best results for specific turbine operations, it is not feasible to implement this study design with the expectation of achieving particular turbine unit survival estimates under specific turbine operations if the dam is to be in full operation. The logistics required to complete the virtual with paired release-recapture study are too complicated for testing multiple turbine operations and would cost substantially more than the single or paired release-recapture designs. One of the main advantages of this test over the direct release is the natural depth acclimation and intake distribution.

The total number of fish required to complete the single and paired release-recapture studies may be similar depending upon if and where a control release occurred for the single release-recapture design. The difference in cost of implementing either of these studies would not be great due to the need for much of the same equipment for tagging, holding and transport of fish; however, the results provided by each of these designs may be significantly different.

The single release-recapture study design with direct release into the turbine intakes would satisfy objectives poorly for multiple reasons, mainly the lack of sufficient controls to provide an accurate turbine survival estimate. A minimum of one control release downstream should be considered to provide an evaluation of the effect of tagging on survival. A percentage of released fish may die from handling and tagging stress; hence, without proper downstream controls turbine passage mortality may not be separated from tagging mortality.

Although turbine survival estimates may be available from the single release study design it is not recommended for evaluation of the new turbine runners at Ice Harbor Dam. A tremendous effort has been put into designing these turbine runners for safer fish passage and to provide a process for future turbine replacement. To implement a study design that provides minimal accuracy of survival estimates would be a disservice to the design and cost investment in what may be a new era in propeller and Kaplan turbine design for fish passage.

From a feasibility and accuracy standpoint the paired release-recapture study design provides the most accurate results with the least amount of bias for the effort required to implement the study. It should be noted that the biological study to evaluate the new turbine runners at Ice Harbor Dam is being designed for the release of juvenile Chinook salmon and steelhead, the results of this biological study will be applicable to other salmonid species for the new turbine designs. Results may not be directly extrapolated to non-salmonid species, although passage and survival benefits of the new turbines are assumed to be experienced by other species such as juvenile lamprey.

14.8 Implementation Considerations

The above paired and single release study options have been discussed assuming a test of both units 1 and 2 for one year. The second year of study provides the option to study turbine units 2 and 3 or only unit 3. Testing 2 and 3 for two years will provide the existing unit 1 as a baseline and two years of survival estimates for the new unit 2 runner. It may be beneficial to have two years of data for unit 2 as a quality control method. If significant differences in survival estimates between years are detected there may be issues with the study design such as sample size, or with the actual implementation. Annual variability is expected; however, with similar river conditions between years survival estimates should not be significantly different. Testing only unit 3 the second year will provide one dataset for the existing unit 1 baseline, the new unit 2 fixed blade, and the new unit 3 Kaplan.

Implementation of the Sensor Fish and balloon tag studies will occur each year for each unit tested. Sensor Fish should be released with balloon tagged fish to capture information about the turbine conditions at the time of fish release. This may provide enough pressure and hydraulic information to make assumptions of the mechanisms of injury that caused any potential turbine mortality. Balloon tagged fish may be released at an appropriate time that is determined to be the most feasible.

These considerations may be further discussed among the USACE technical leads, SRWG, and contractor(s) prior to study implementation.

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Appendix 1.0

Independent review of sample sizes estimated using SampleSize Software

Review of Study Designs for Evaluation of New Turbine Runners at Ice Harbor Dam on the Lower Snake River, Washington

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This review was requested with a focus on Section 4 in the report by Trumbo et al. (2012). This section is called Statistical Study Designs and it includes discussions on three common designs used to estimate fish survival rates at Federal Columbia River Power System projects, where dam passage survival is defined as survival from the upstream face of a dam to a downward location past project operation effects on hydraulic conditions. It is required that for spring stocks (yearling Chinook and steelhead) this survival rate should be 96% or higher, while for summer stocks (subyearling Chinook) it is required that it should be 93% or higher. Also, for Biological Opinion specifications it is required that the standard error of estimated dam passage survival probabilities should be 0.015 or less. One question to be considered for the three designs is therefore what sample sizes are needed to estimate dam passage survival with this level of precision.

The three common sample designs are the single release design, the paired release design, and the virtual paired release design. These are now considered in turn. For these designs the number of fish needed for releases are shown in the Trumbo et al. (2012) report based on the SampleSize (2011) software. Here a different simulation based method is used and this confirms that the release sizes shown in that report are appropriate.

The Single Release Design

Figure 1 shows the single release design with two recapture locations after the initial release. There is one release either upstream of the dam, or possible made in such a way that a particular passage through the dam occurs. The probability of survival to the first detection location is S_1 and the probability of detection at that location is P_1. Then for fish that survive to the first detection location the probability of survival to the second detection location is S_2 and the probability of detection at that location is P_2.

In practice the probability of survival through the dam and to the first detection location will usually be estimated by a standard maximum likelihood method for mark-recapture data. However, for my simulation study on estimates for different numbers of fish released I used the Manly and Parr (1968) method which is simpler. With this method the value of P_1 is estimated by the proportion of fish known to be alive before and after passing the first detection location that are captured at that time. As fish were alive at the time of release they are known to have been alive when passing the first detection location if they are detected at the second detection location. Hence P_1 is estimated by the proportion of the fish detected at the second location that are also detected at the first location.

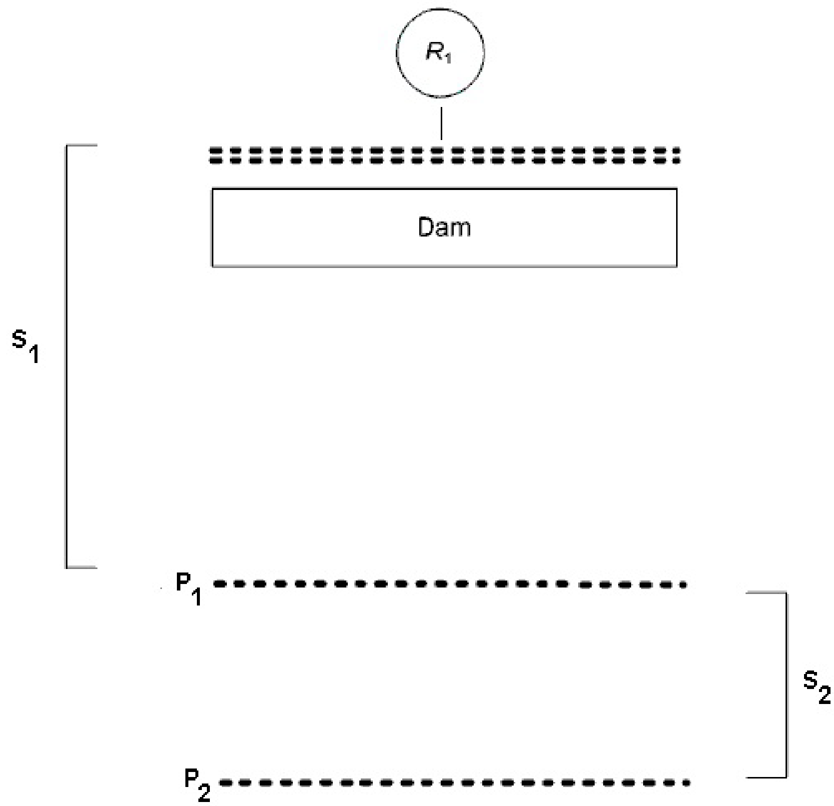


Figure 1 The single release mark-recapture design. The release is indicated by R_1 with two later detection locations with detection probabilities P_1 and P_2. The probability of survival to the first detection location below the dam is S_1 and the probability of surviving from there to the second location is S_2. A double 3D hydrophone array at the dam face ensures detection of all fish reaching the dam. This is a slightly modified version of Figure 3 in the Trumbo et al. (2012) report.

Once P_1 is estimated the number of fish surviving until the first detection location can be estimated by $n_1/\hat{P}_1$, where $\hat{P}_1$ is the estimate of P_1. Then a simple estimate of the survival probability S_1 is $\hat{S}_1 = (n_1/\hat{P}_1)/R$, where R is the number of fish released above the dam. As this is not a maximum likelihood estimate the standard error may be slightly higher than for the maximum likelihood estimate. However, this was not expected to be a problem because of the high detection rates that are assumed to apply.

Simulations

To investigate the number of fish that need to be released to estimate S_1 with a standard error of 0.015 I ran simulations for subyearling Chinook with S_1 = 0.93, S_2 = 0.95 and with P_1 and P_2 both set at 0.90, 0.95 or 0.98. This was intended to reproduce the results shown in Figure 4 of the Trumbo et al. (2012) report. I also ran simulations for yearling Chinook and steelhead with S_1 = 0.96, S_2 = 0.95 and again with P_1 and P_2 both set at 0.90, 0.95 and 0.98, where this was intended to reproduce the results shown in Figure 5 of the Trumbo et al. report.

The simulations involved generating a recapture record for a fish such that the probabilities of survival and capture are as specified for S_1, S_2, P_1 and P_2. This was done for releases of batches of 125, 250, 500, 1000 and 2000 fish and the corresponding estimates of S_1 were calculated for these simulated data sets. This was done with 5,000 releases for each of the batch sizes and the standard deviations of the simulated estimates were calculated. This then gives values for the standard errors that would be obtained for these numbers of different releases. The simulations were done in Excel using the add-on Resampling Stats for Excel available at www.resample.com.

Simulation Results

Figure 2 shows the simulation results obtained for subyearling Chinook. This shows that to obtain a standard error of 0.015 for the estimated survival rate $\hat{S}_1$ the number released should be approximately 400 with a detection probability of 0.90, about 350 with a detection probability of 0.95, and about 300 with a detection probability of 0.98. These agree quite well with the release numbers shown in Figure 4 of 370, 310 and 290, respectively, in the Trumbo et al. (2012) report.

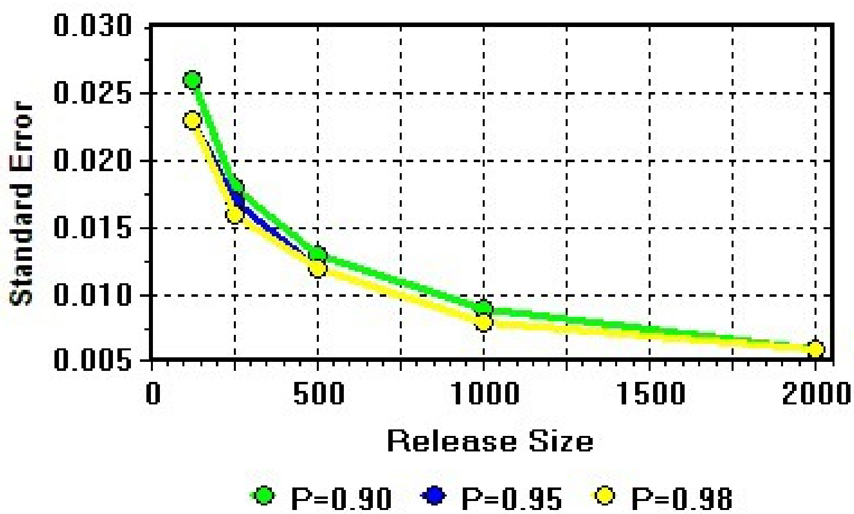


Figure 2 Simulation estimates of standard errors for estimates of S_1 obtained with different numbers of subyearling Chinook releases with survival rates of S_1 = 0.93 and S_2 = 0.95 with detection probabilities (P) of 0.90, 0.95 and 0.98.

Figure 3 shows the simulation results obtained for yearling Chinook and steelhead. This shows that to obtain a standard error of 0.015 for the estimated survival rate S_1 the number released should be approximately 250 with a detection probability of 0.90, about 200 with a detection probability of 0.95, and about 175 with a detection probability of 0.98.

These agree well with the release numbers shown in Figure 5 of 240, 190 and 170, respectively, in the Trumbo et al. (2012) report.

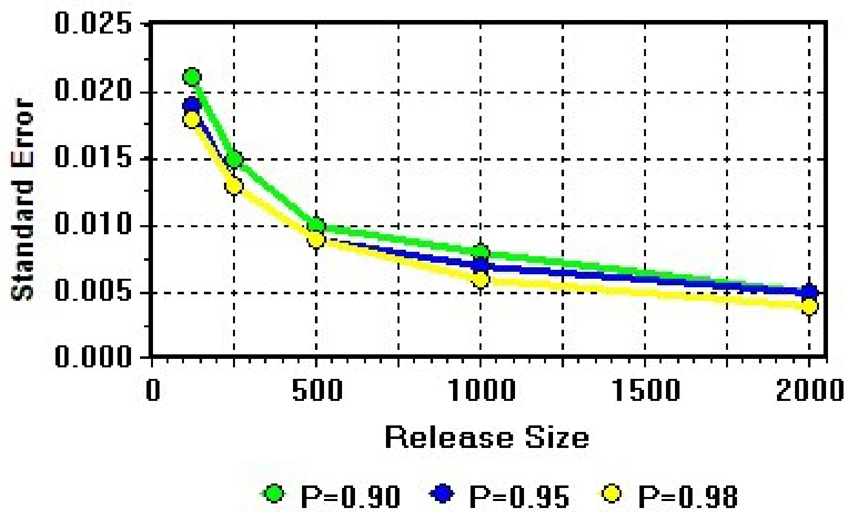


Figure 3 Simulation estimates of standard errors of estimates of S_1 obtained with different numbers of yearling Chinook and steelhead releases with survival rates of S_1 = 0.96 and S_2 = 0.95 with detection probabilities (P) of 0.90, 0.95 and 0.98.

This independent assessment of the release numbers required to obtain a standard error of 0.015 for the estimated probability of survival from above the dam to a detection location below the hydraulic influence of the dam again confirms that the numbers obtained for the Trumbo et al. (2012) report using the SampleSize program are realistic.

Power Analysis

I am not familiar with the R package for a power analysis with an analysis of variance, but I understand that the idea behind this was that the single release design might be used with three releases through existing turbines and three releases through new turbines to see if a statistically significant difference in survival rates is detected. Assuming this is the case I simulated four situations using Resampling Stats for Excel to see what power there will be to detect different true survival differences, assuming that the standard error of the survival probability estimate from one release is 0.015, as discussed above.

One Release Per Treatment

A comparison between the survival probabilities for two treatments can be done with just one release per treatment as the mark-recapture analyses provide standard errors for the estimated values. Assuming that these standard errors are approximately 0.015 the significance of the difference between the two survival estimates can be assess using the statistic $Z_1 = (\hat{S}_1 - \hat{S}_2) / \sqrt{(0.015^2 + 0.015^2)}$ where the numerator is the difference between the two survival estimates and the denominator is the standard error of this difference. If there is no real survival difference then Z will be approximately normally distributed with a mean of zero and a standard deviation of one. Hence a value of Z outside the range from -1.96 to +1.96 gives a significant difference at the 5% level. The probabilities of obtaining a significant difference (i.e., the power) with a range of true survival differences can then be estimated by generating many sets of data for different differences within the range and seeing how often a significant result is obtained. As the survival estimates will be approximately normally distributed the simulation just requires the generation of many random values from normal distributions.

Two Releases Per Treatment

With two releases per treatment the situation is similar to one release per treatment but the survival estimate for a treatment is now the average of two values, one for each release. The test statistic Z then becomes $Z_2 = (\hat{S}_1 - \hat{S}_2)/\sqrt{(0.015^2/2 + 0.015^2/2)}$ where $\hat{S}_i$ is the average survival for treatment i and the numerator is the standard error of the mean difference. Again, many values of Z_2 can be simulated easily assuming that the survival estimates from individual releases are normally distributed, with a range of true survival differences. This then allows the probabilities of obtaining a significant difference at the 5% level to be estimated for the range of real differences.

Three Releases Per Treatment

With three releases per treatment the situation is again similar. The test statistic for comparing the mean survival for the two treatments now becomes $Z_2 = (\hat{S}_1 - \hat{S}_2)/\sqrt{(0.015^2/3 + 0.015^2/3)}$ where $\hat{S}_i$ is the standard error of the mean difference. Many values for Z_3 can be simulated with different true mean survival differences and the probability of obtaining a significant difference can be estimated. With three releases per treatment there is, however, the possibility of estimating the standard error of the mean survival estimates from the data instead of using the values obtained from the mark-recapture analyses. The standard error of $(\hat{S}_1 - \hat{S}_2)$ is then estimated by $\surd \hat{S}_1^2/3 + \hat{S}_2^2/3)$ where S_i is the standard error of $\hat{S}_i$ estimated from the sample of three survival values for the ith treatment. The value of $Z_{3A} = (\hat{S}_1 - \hat{S}_2)$ / $\surd \hat{S}_1^2/3 + \hat{S}_2^2/3)$ will then approximately have a t-distribution with four degrees of freedom if there is no difference between the average survival rates with the two treatments. Again many sets of simulated data can be generated to estimate the probability of getting a significant difference (the power) for various true survival differences for the two treatments.

Power Analysis Results

Figure 4 shows the results obtained from simulation 10,000 sets of survival estimates with one, two and three releases per treatment and survival probability differences of 0.00, 0.01, 0.02, 0.03, 0.04 and 0.05 (i.e. with percentage differences from nothing up to 5%).

As expected the proportion of significant results is always about 0.05 when the two treatments have the same survival rates. It can be seen that if a power of 0.85 is desired for detecting a difference and there are three releases per treatment and the individual survival estimates have standard errors of 0.015 then this power will be obtained with a survival difference of about 0.038 or more, while with two releases per treatment this power is obtained for a survival difference of about 0.042. However, if the standard errors of survival estimates are estimated based on the replicate results then this power requires a true mean survival difference of about 0.05.

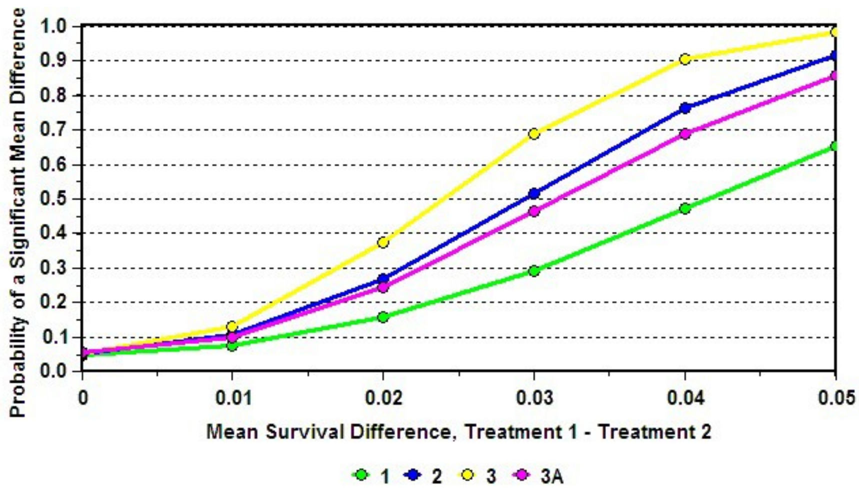


Figure 4 The probability of obtaining a difference significant at the 5% level between the mean survival estimates from two treatments. The situations considered were: 1, one release for each treatment assuming that the individual survival estimates have standard errors of 0.015; 2, two releases for each treatment assuming that the individual survival estimates have standard errors of 0.015; 3, three releases for each treatment assuming that the individual survival estimates have standard errors of 0.015; 3A, three releases for each treatment but with the standard errors of survival estimates estimated using the three available values for each treatment.

The Paired Release Design

Figure 5 shows the paired release design with three releases and three detection locations below the dam, as shown in Figure 6 in the Trumbo et al. (2012) draft final report. In this case there are assumed to be three survival rates of interest, which are the survival from release above the dam (R_1) to the first detection location (S_1), survival from the third release location (R_3) until the second detection location (S_2), and survival from the second release location (R_2) until the first detection location (S_3). The probabilities of detection at the first and second detection locations are P_1 and P_2, and the probability of surviving from the second detection location to the third and being detected is λ. This notation differs slightly from that in Figure 6 in the Trumbo et al. (2012) report. However, of more importance is the fact that the design is not the same as the paired release design assumed for the SampleSize (2011) program, which has only two releases and two detection locations, so that there is no R_3 release and λ is assumed to be zero.

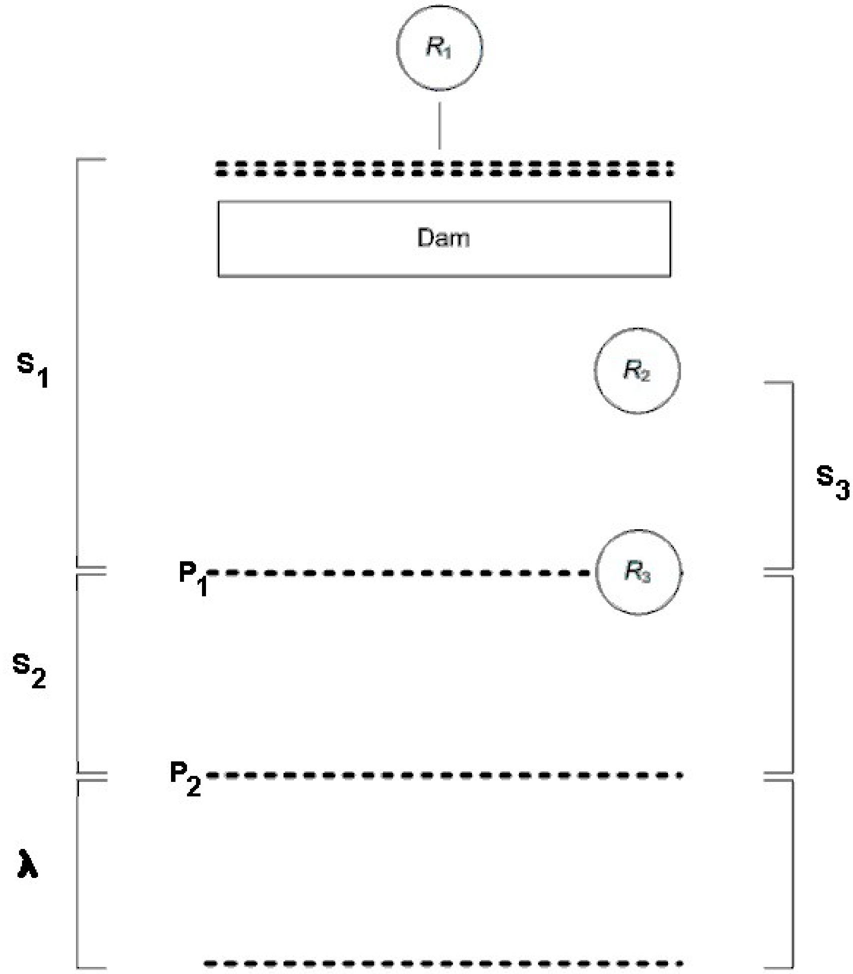


Figure 5 The paired release-recapture study design. Fish are released upstream of the dam face or in a location for passage through a desired part of the dam (R_1) just below the dam (R_2) and further downstream (R_3). Survival probabilities are S_1 for survival from above the dam to the first detection location, S_2 from there to the second detection location, and S_3 from the second release location until the first detection location. There is a third detection location further downstream and λ is the probability of surviving from the second detection location to there and being detected. This is a simplified version of Figure 6 in the Trumbo et al. (2012) report.

Because of this difference the situation considered here is the one used by the SampleSize program with R_3 and λ both zero. It is then still possible to estimate the value of P_1 just using the data from the first release using the Manly and Parr (1968) method. This is the proportion of the fish known to be alive at the first detection location because they were recorded at the second detection location. The estimated number from the first release that reached the first detection location is then $n_1/\hat{P}_1$ where n_1 is the number from this release recorded at the first detection location and $\hat{P}_1$ is the estimated detection probability. The estimated value of the survival probability from release above the dam to the first detection location is then $\hat{S}_1 = (n_1/\hat{P}_1)/R_1$, where R_1 is the number released. An estimated survival probability $\hat{S}_3$ from the second release location to the first detection location can be calculated in a similar way based on the detections of fish from this release at the first and second locations, and the probability of surviving from the first to the second release locations (i.e., surviving through the dam) can be then estimated by $\hat{S}_{Dam} = \hat{S}_3 / \hat{S}_1$.

These estimated survival values are not maximum likelihood estimates. If anything they are therefore expected to have somewhat higher standard errors than maximum likelihood estimates. Also, for the situations considered here no bypass removal are assumed, where this presumably reduces the effective number of fish in the first release and increases the standard errors somewhat.

Simulations

For simulations R_1 fish were assumed to be released above the dam with a survival probability of S_1 to the first detection location followed by a survival probability of S_2 to the second detection location, with the probability of a detection being the same at both locations. Each released fish then provided a generated recapture result. Similarly, R_2 fish were assumed to be released below the dam with a survival probability of S_3 to the first detection location followed by a survival probability of S_2 to the second detection location, with the detection probabilities being the same as for the fish released above the dam. Again each fish then provided a generated recapture result. The simulations were carried out in Resampling Stats for Excel, with each released fish providing one line of recapture data. A total of 10,000 sets of data were generated in this way for each different choice of values for the survival and capture probabilities, with each set of data analyzed using the Manly and Parr method as described above. This then produced the mean survival estimates and their standard errors that would be obtained if the paired release design was run 10,000 times.

Simulation Results

I found that simulating data based on the paired design with two releases and two recapture occasions and estimating survival rates by the Manly and Parr method confirms that the sample sizes determined using the SampleSize (2011) program and reported by Trumbo et al. (2012) are appropriate for the estimation of the survival probability through the dam with a standard error of about 0.015.

For subyearling Chinook salmon Figure 7 in the Trumbo et al. (2012) report shows that to estimate the survival through the dam with a standard error of 0.015 requires first and second releases of about 1,170 fish each when the detection probability is 0.90. It also shows that if this sample size is used with a detection probability of 0.95 or 0.98 then the standard error will be about 0.014. My independent simulation with this size for releases with 10,000 sets of simulated data and Manly and Parr survival estimates gives exactly the same results to three decimal places.

Similarly, for yearling Chinook and steelhead Figure 8 in the Trumbo et al. (2012) report shows that to estimate the survival through the dam with a standard error of 0.015 requires first and second releases of about 760 fish each when the detection probability is 0.90. It also shows that if this sample size is used with a detection probability of 0.95 or 0.98 then the standard error will be about 0.014. My independent simulation with this size for releases using Resampling Stats for Excel with 10,000 sets of simulated data and Manly and Parr survival estimates gives exactly the same results to three decimal places.

Based on this independent assessment I conclude that the release sample sizes proposed by Trumbo et al. (2012) are appropriate for the paired release design with only two releases and only two detection locations.

Power to Detect Differences From a Performance Standard

Suppose that the paired release design is run several times with the release numbers being chosen so that the standard error of the survival through the dam is 0.015 or better. Then there is interest in the power to detect significant differences between the estimated dam survival rates and the survival rate that is desired. For example, with subyearling Chinook the BiOp performance standard is a survival rate of 0.93. Therefore, if the paired release design is run several time then there would be interest in the probability of detecting whether the mean of the survival estimates obtained is significantly higher or lower than 0.93.

There are two ways that this might be assessed. First, if the dam survival estimates all have standard errors that are close to 0.015 from the mark-recapture analysis then the test statistic $Z = (\bar{S} - S_{PS})/(0.015/\sqrt{n})$ can be used, where $\bar{S}$ is the mean of the dam survival estimates from n repeats of the paired release design and S_{PS} is the performance standard. If the true dam survival equals the performance standard then Z will have a standard normal distribution. A value outside the range ± 1.96 then gives a significant difference at the 5% level. This method can if necessary be modified to allow for survival estimate standard errors that are not equal to 0.015, or that vary for different paired releases.

Alternatively, if there are at least two runs of the paired design then the standard deviation of the survival estimates can be estimated from the n observed values. The statistic $T = (\bar{S} - S_{PS})/(SD/\sqrt{n})$ then has a t-distribution of n-1 degrees of freedom, where SD is the estimated sample standard deviation from the n estimated survival rates.This second approach may be more appropriate than the first if there are quite large random changes in the dam survival rate from one release to the next but the average survival rate over time may still be close to S_{PS} .

It is a simple matter to estimate the power to detect different amounts of difference between the observed dam survival rates and the assumed performance standard using Resampling Stats for Excel. This does not depend on the performance standard itself, but rather just on the difference between the true average dam survival and the performance standard. Power values were estimated using 10,000 simulated sets of data with differences between the true mean dam survival and the performance standard of from nothing up to 0.05.

Simulation Results

Figure 6 shows the results obtained using the first method described above, i.e. assuming that $Z = (\bar{S} - S_{PS})/(0.015/\sqrt{n})$ has a standard normal distribution if the dam survival rate equals the performance standard. This figure shows that with all values of n (the number of release pairs) the probability of a significant result is 0.05 when the dam survival equals the performance standard, as should be the case. When a difference between the dam survival rate and the performance standard does exist the power to detect this increases with the number of releases and with the size of the difference, again as expected.

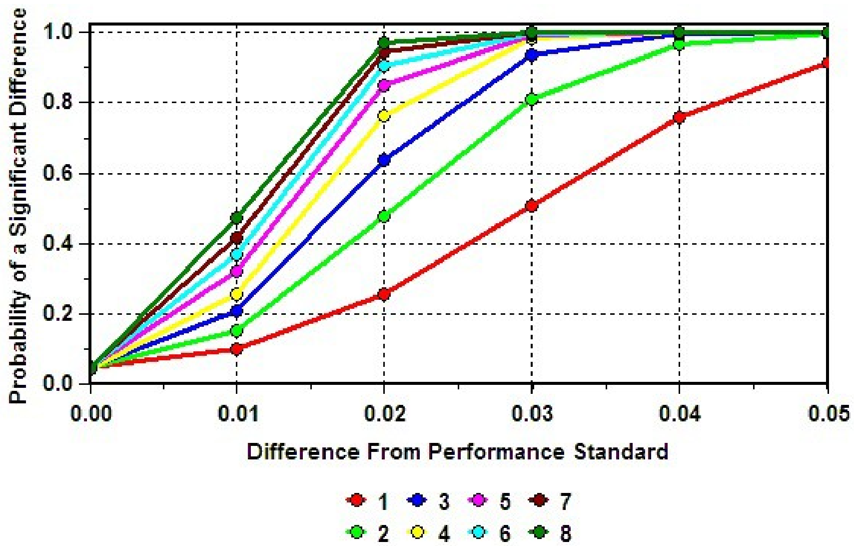


Figure 6 The probability of a significant result with from n = 1 to 8 repeats of the paired release design with differences between the dam survival rate from 0.00 up to 0.05, assuming that $Z = (\bar{S} - S_{PS})/(0.015/\sqrt{n})$ has a standard normal distribution if there is no difference. For example, with n=1 paired release the probability of detecting a difference of 0.01 (1%) is about 0.1 and the probability of detecting a difference of 0.05 (5%) is about 0.9.

Figure 7 is similar to Figure 6 but gives the probability of a significant result using the second method described above, which assumes that $T = (\bar{S} - S_{PS})/(SD/\sqrt{n})$ has a t-distribution with n - 1 degrees of freedom when the dam survival probability equals the performance standard. This method can only be used with at least n = 2 paired releases and has lower power than the first method to test for a significant result because of the need to estimate the standard deviation of sample survival probability estimates from only a small number of values.

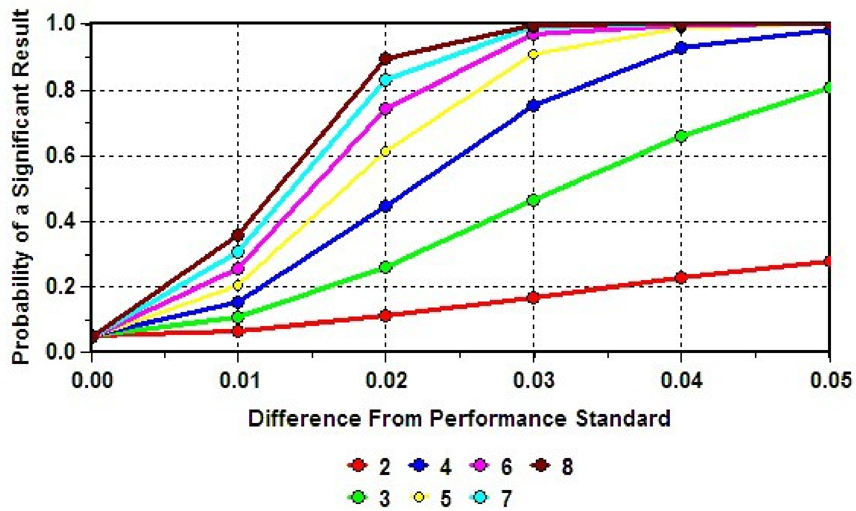


Figure 7 The probability of a significant result with from n = 2 to 8 repeats of the paired release design with differences between the dam survival rate from 0.00 up to 0.05, assuming that $T = (\bar{S} - S_{PS})/(SD/\sqrt{n})$ has a t-distribution with n-1 degrees if there is no difference. For example, with n = 2 paired releases the probability of detecting a difference of 0.01 (1%) is about 0.06 and the probability of detecting a difference of 0.05 (5%) is about 0.25.

The Virtual Paired Release Design

Figure 8 shows the virtual paired release design with three releases and three detection locations below the dam, with the virtual releases being the fish from the first release that survive to the face of the dam and are detected there. With this design there are three survival estimates of particular interest. These are the survival of the virtual release fish from the face of the dam to the first detection location (S_1), the survival of the second release fish until the second detection location (S_2), and the survival from the first to the second detection locations (S_3). Also, it is assumed that for all fish surviving until the second detection location the probability of surviving to the third detection location and being detected there is ë.

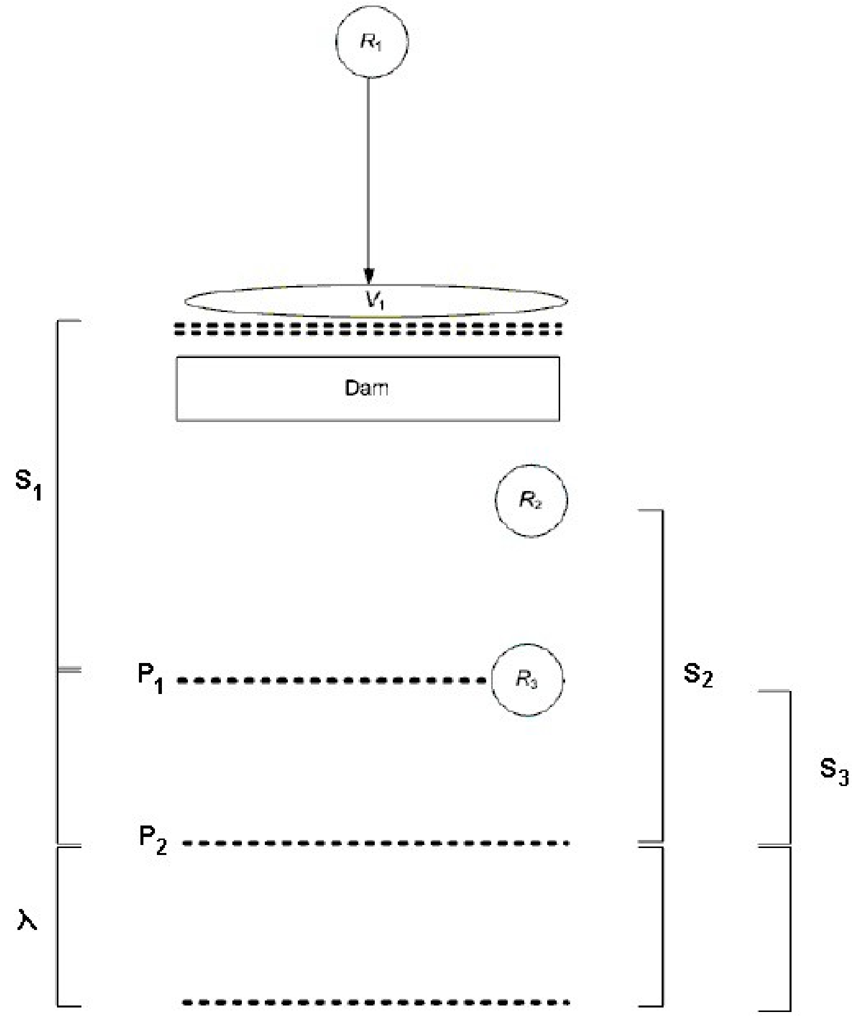


Figure 8 The virtual paired release-recapture study design. Fish are released upstream of the dam face (R_1), just below the dam (R_2) and further downstream (R_3). The virtual release (V_1) is then the fish from release R_1 that are detected going through the dam. Survival probabilities are S_1 for survival from entry to the dam to the first detection location, S_2 for survival from the second release location until the second detection location, and S_3 is the survival from the first to second detection locations. There is a third detection location further downstream and ë is the probability of surviving from the second detection location to there and being detected. This is a simplified version of Figure 9 in the Trumbo et al. (2012) report.

The detection probability P_1 can be estimated by the Manly and Parr (1968) method as the proportion of fish detected at the first detection location out of those known to have passed because they were released above this location and detected at least once below this location.

This probability can either be estimated separately for the V_1 and R_2 releases or for both of these releases together. Once P_1 is estimated the number of fish surviving to the first detection location from the virtual release is simply the number detected from that release at this location divided by the estimated value of P_1. The estimated value of S_1 is then the estimated number surviving divided by the number in the release. The other detection probability P_2 and the survival probabilities S_2 and S_3 can be estimated in a similar way. As for the single release and paired release designs, these are not maximum likelihood estimates and should have standard errors somewhat higher than those for maximum likelihood estimates.

Based on the design shown in Figure 8 it can be seen that the probability of a virtual release fish surviving until the second detection occasion is $S_1 \times S_3$. However, this should also equal the probability of surviving through the dam until the second release location and then surviving until the second detection location, i.e. $S_{Dam} * S_2$. This is then the basis for estimating the dam survival probability as $\hat{S}_{Dam} = (\hat{S}_1 * \hat{S}_3) / \hat{S}_2$ .It is this survival rate that will be of particular interest in terms of comparing the survival through dams with different characteristics.

Simulations

Resampling Stats for Excel was used to generate 10,000 sets of data with specified values for S_1, S_2, S_3, P_1, P_2 and λ. This was done first to simulate the results expected to be obtained with subyearling Chinook with a dam survival rate of 0.93, with the V_1, R_1 and R_2 releases all being of 2590 fish based on the results in Figure 10 of the Trumbo et al. (2012) report. It was then expected that the estimated dam survival would have a standard error of about 0.015 with a detection probability of 0.90 at the first detection location and slightly smaller standard errors with detection probabilities of 0.95 and 0.98.

Simulations were also done for yearling Chinook and steelhead with a dam survival rate of 0.96 and with the V_1, R_2 and R_3 releases of 1410 fish based on Figure 11 of the Trumbo et al. report. Again it was expected that with a detection probability of 0.90 this would give a standard error of about 0.015 for the dam survival probability estimates, with slightly lower standard errors with detection probabilities of 0.95 and 0.98.

Simulation Results

Figure 10 of the Trumbo et al. (2012) report show that with S_1 = 0.848, S_2 = 0.775 and S_3 = 0.850, so that the dam survival probability is S_{Dam} = (0.848 x 0.850)/0.775 = 0.93, and with P_1 = 0.90, P_2 = 0.95 and λ = 0.96 the estimated standard error from releases of 2590 subyearling Chinook should give a standard error of 0.015 for the dam survival estimate. Figure 10 in the report also suggests that if P_1 is higher at 0.95 or 0.98 then the standard error will still be 0.015 to three decimal places. Simulating 10,000 sets of data with each of the three values of 0.90, 0.95 and 0.98 for P_1 using Resampling Stats for Excel and estimation using the Manly and Parr (1968) methods gave exactly these results. This independent assessment therefore confirms that the release of 2590 subyearling Chinook with the other parameters as set should result in a standard error close to 0.015 for the estimated dam survival rate.

Figure 11 of the Trumbo et al. (2012) report show that with S_1 = 0.912, S_2 = 0.874 and S_3 = 0.920, so that the dam survival probability is S_{Dam} = (0.912 x 0.920)/0.874 = 0.96, and with P_1 = 0.90, P_2 = 0.95 and λ = 0.96 the estimated standard error from releases of 1410 yearling Chinook and steelhead should give a standard error of 0.015 for the dam survival estimate. Figure 11 in the report also suggests that if P_1 is higher at 0.95 or 0.98 then the standard error will still be 0.015 to three decimal places. Simulating 10,000 sets of data with each of the three values of 0.90, 0.95 and 0.98 for P_1 using Resampling Stats for Excel and estimation using the Manly and Parr (1968) methods gave exactly these results. This independent assessment therefore again confirms that the sample size suggested in the Trumbo et al. report is correct.

Conclusions

The only important concern that I have with the Trumbo et al. (2012) report is with Figure 6 and the Design Concepts section on the paired release design. According to the SampleSize computer package this design only has two releases and two detection locations below the dam, rather than the three releases and three detection locations shown in Figure 6. Also, my independent simulations of data from this design using Resampling Stats for Excel, with two releases and two detection locations and with estimation of the dam survival probability for each set of data, shows that the release numbers indicated by Figures 7 and 8 are appropriate for obtaining standard errors of 0.015 for dam survival estimates for that design rather than the design shown in Figure 6.

The release numbers shown in Figures 4 and 5 for the single release design and in Figures 10 and 11 for the virtual paired release are also confirmed by my independent simulation studies. In fact, the agreement with the results using the SampleSize computer package is surprisingly good considering that the estimation method that I used was simpler than maximum likelihood.

References

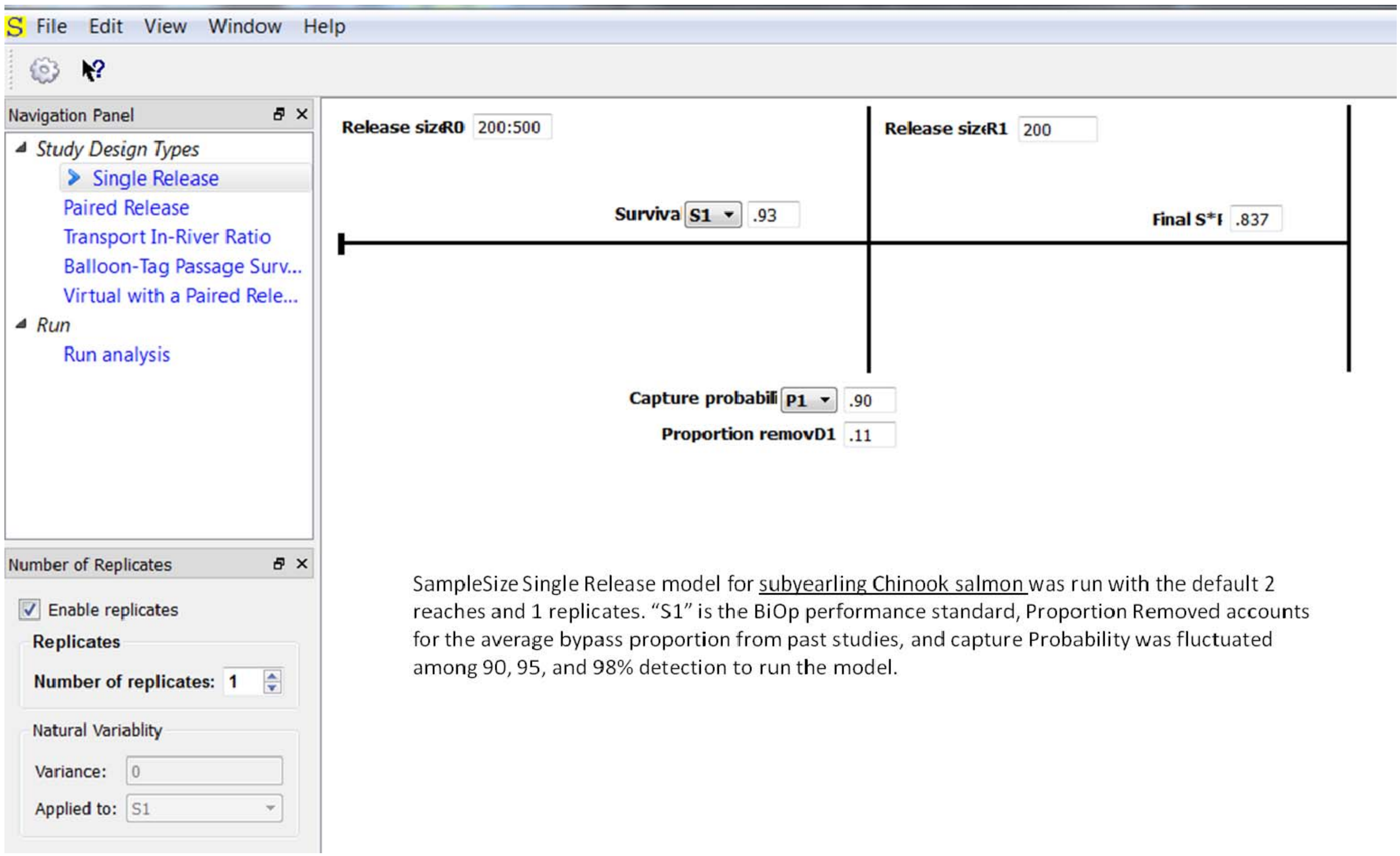
Manly, B.F.J. and Parr, M.J. (1968). A new method of estimating population size, survivorship, and birth rate from capture-recapture data. Transactions of the Society for British Entomology 18: 81-9.

SampleSize (2011). Sample Size: Survival Under Proportional Hazards, Version 2.0.9. University of Washington, Seattle.

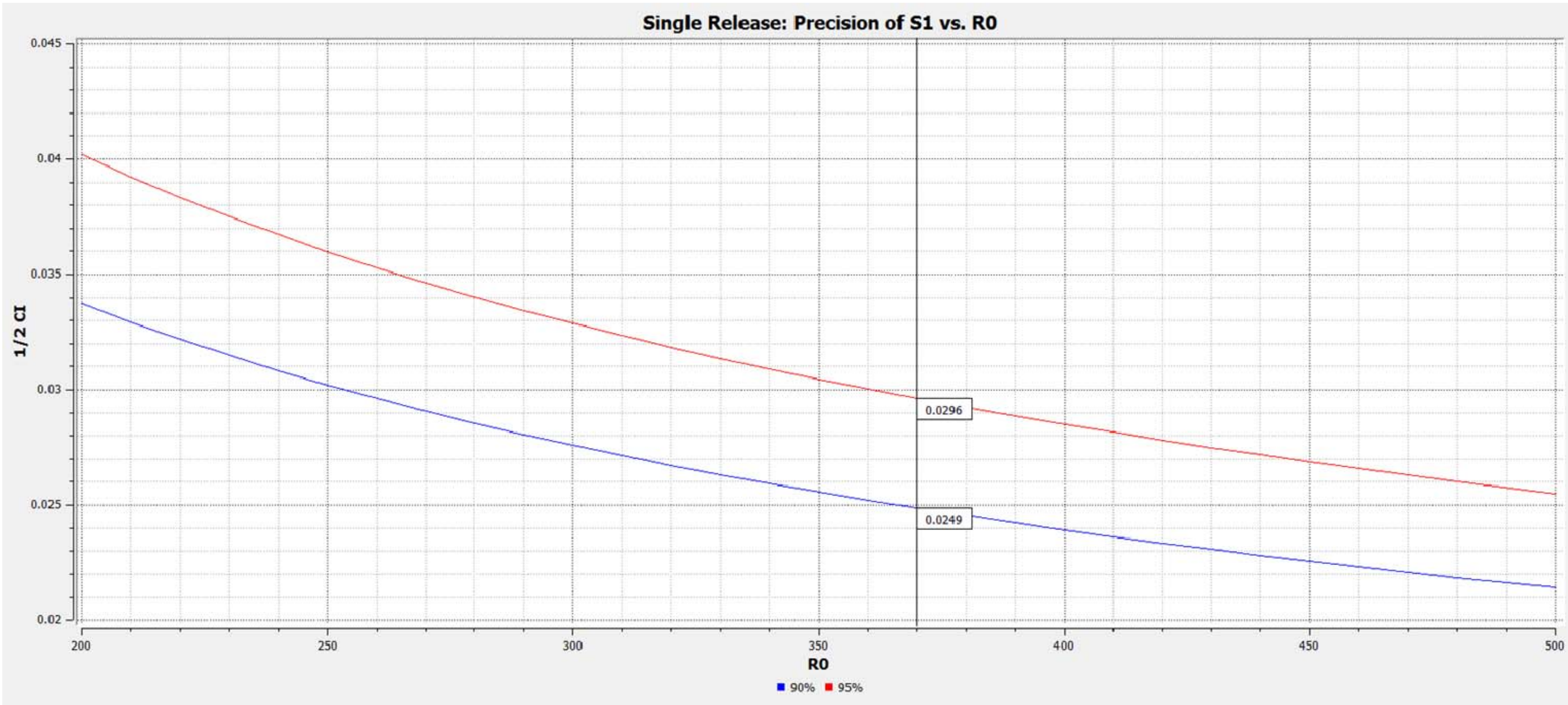
Trumbo, B., Shutters, M., Ahmann, M., Renholds, J. and Nelson, S. (2012). Statistical and Biological Study Design for Evaluation of New Turbine Runners Designed for Safer Fish Passage at Ice Harbor Dam on the Lower Snake River, Washington. U.S, Army Corp of Engineers report dated November, 2012.

Appendix 1.1

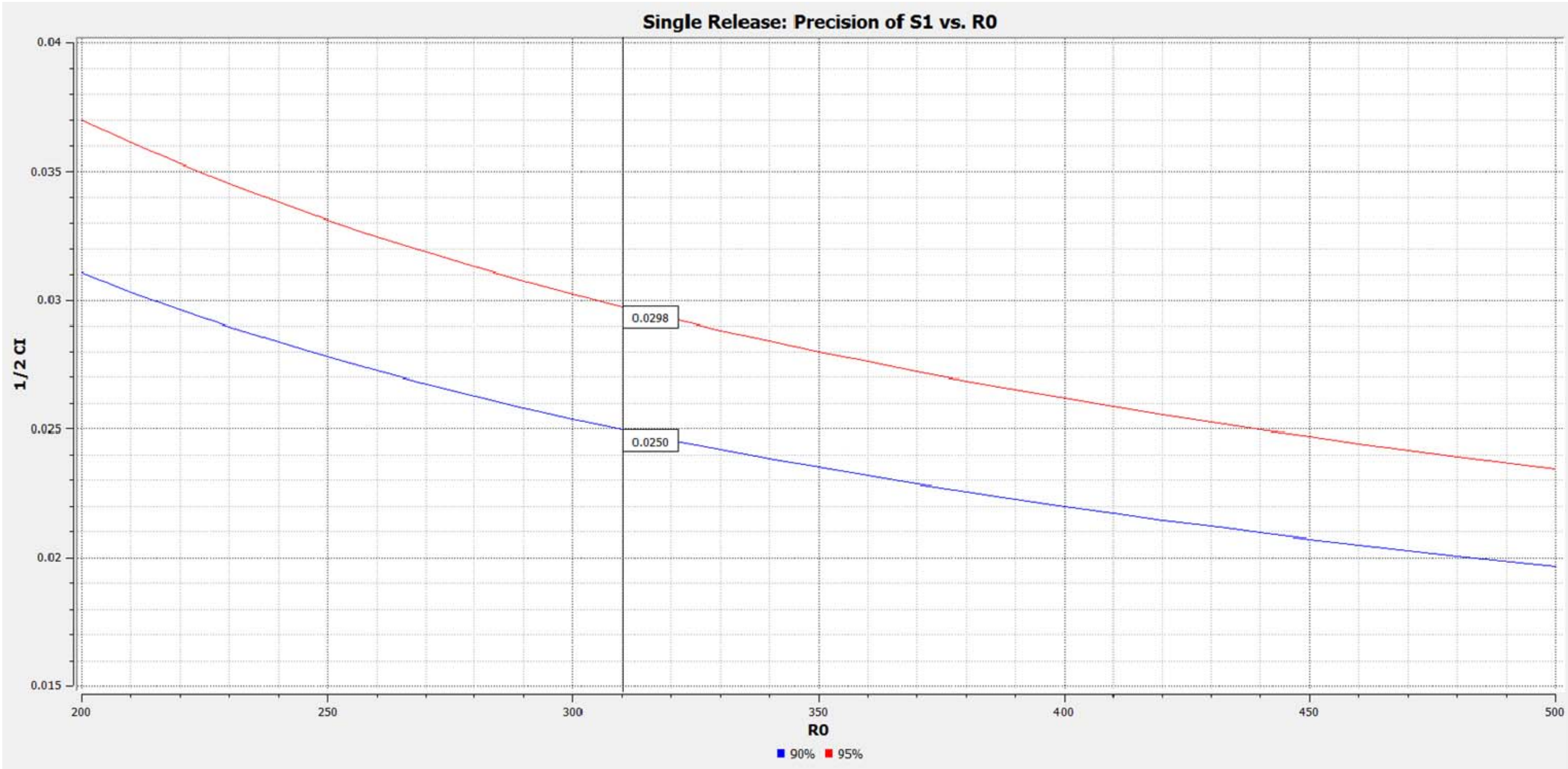
Preliminary SampleSize Single Release-Recapture Design model with ½ 90% and 95% confidence intervals



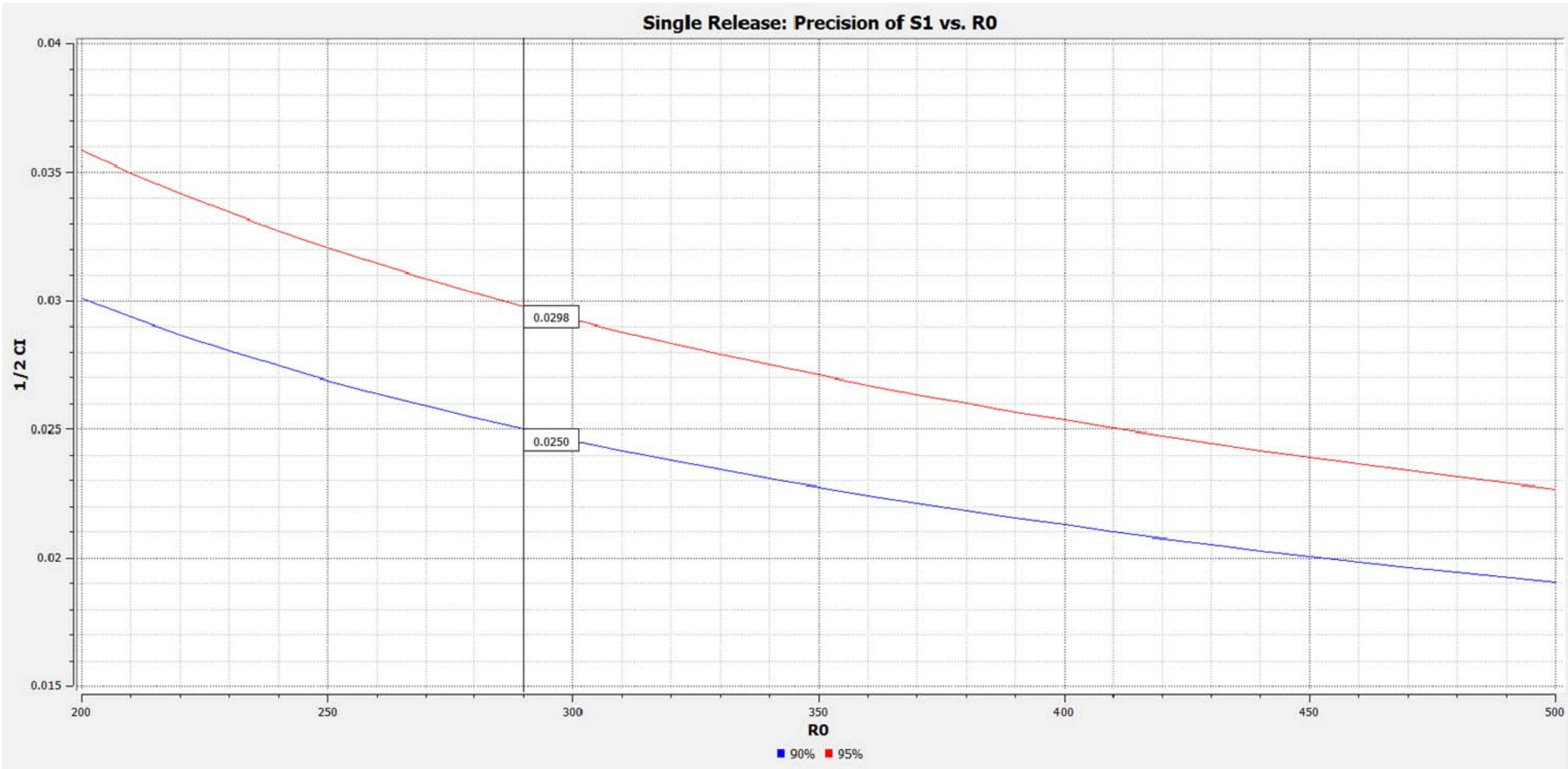
SampleSize Single Release model for <u>subyearling Chinook salmon</u> was run with the default 2 reaches and 1 replicates. “S1” is the BiOp performance standard, Proportion Removed accounts for the average bypass proportion from past studies, and capture Probability was fluctuated among 90, 95, and 98% detection to run the model.



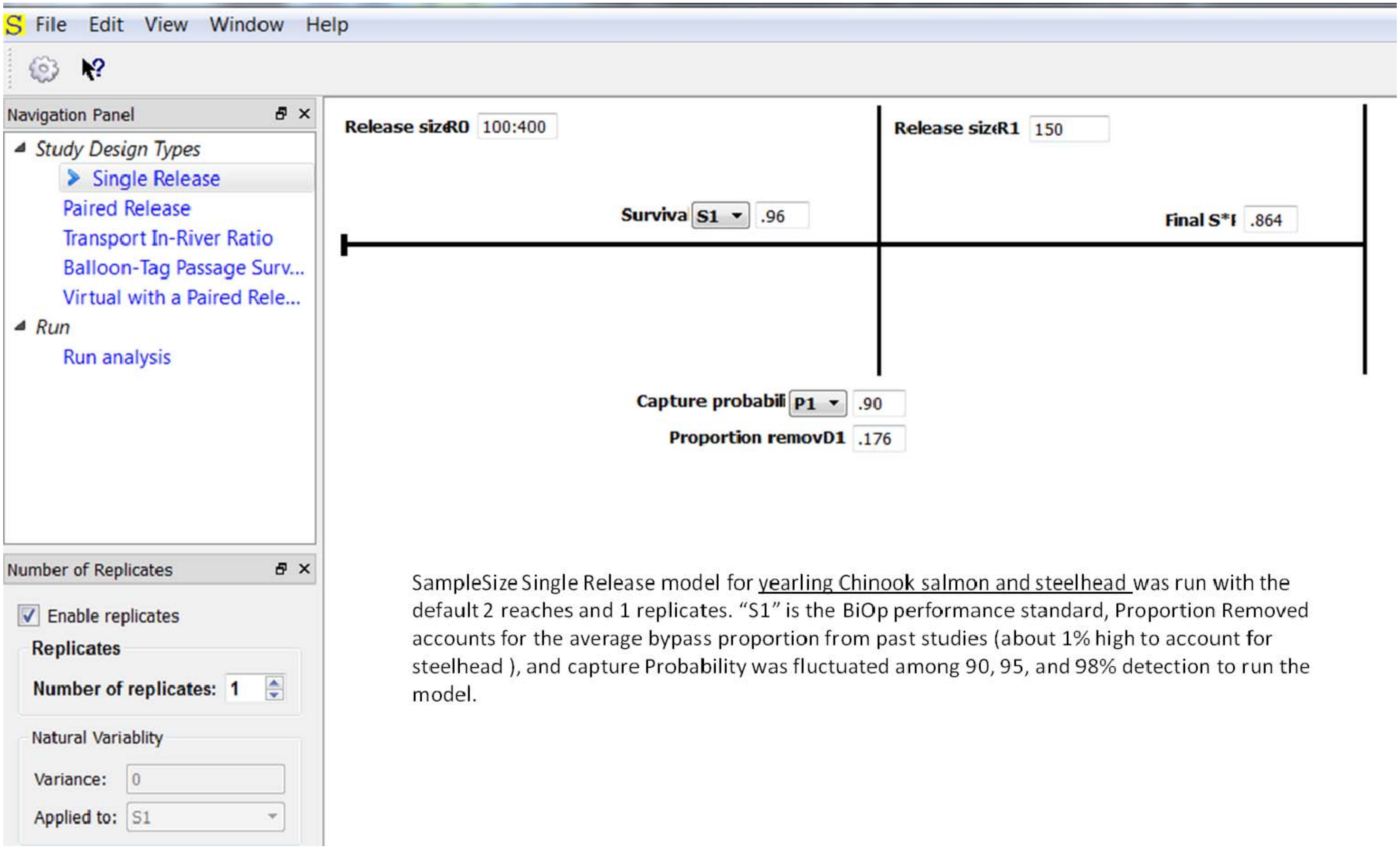
Single Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 90% detection probability.



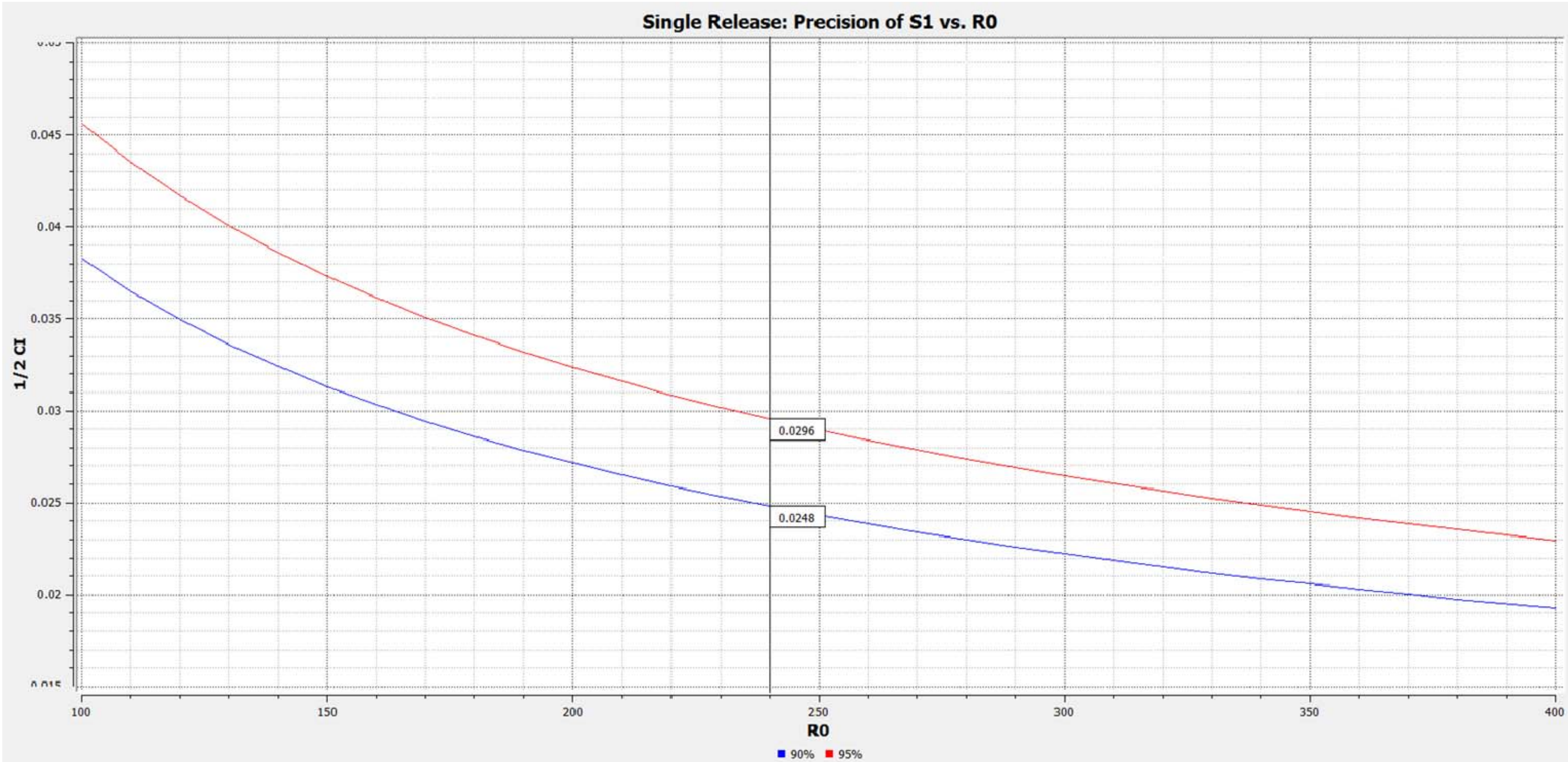
Single Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 95% detection probability.



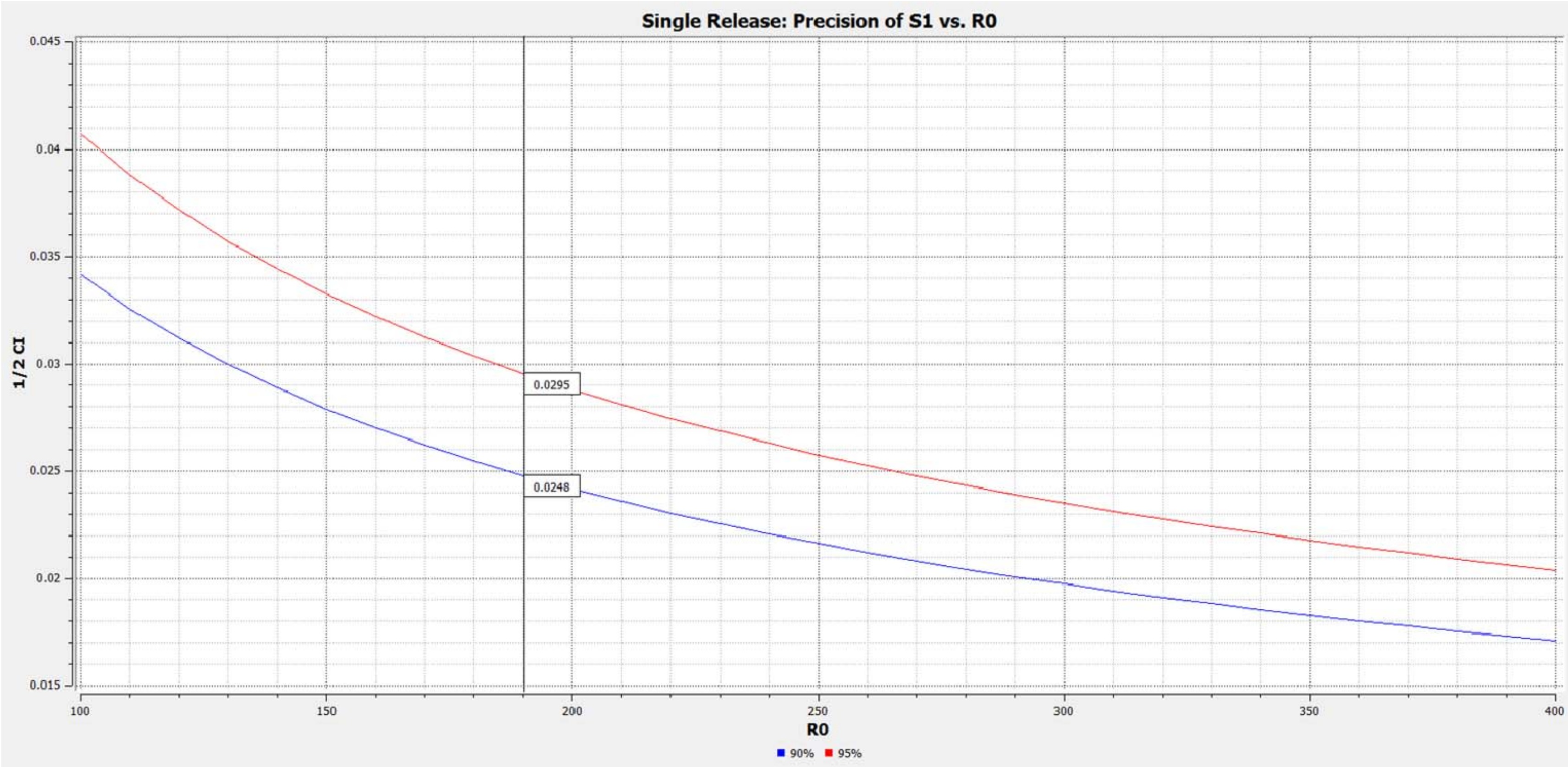
Single Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 98% detection probability.



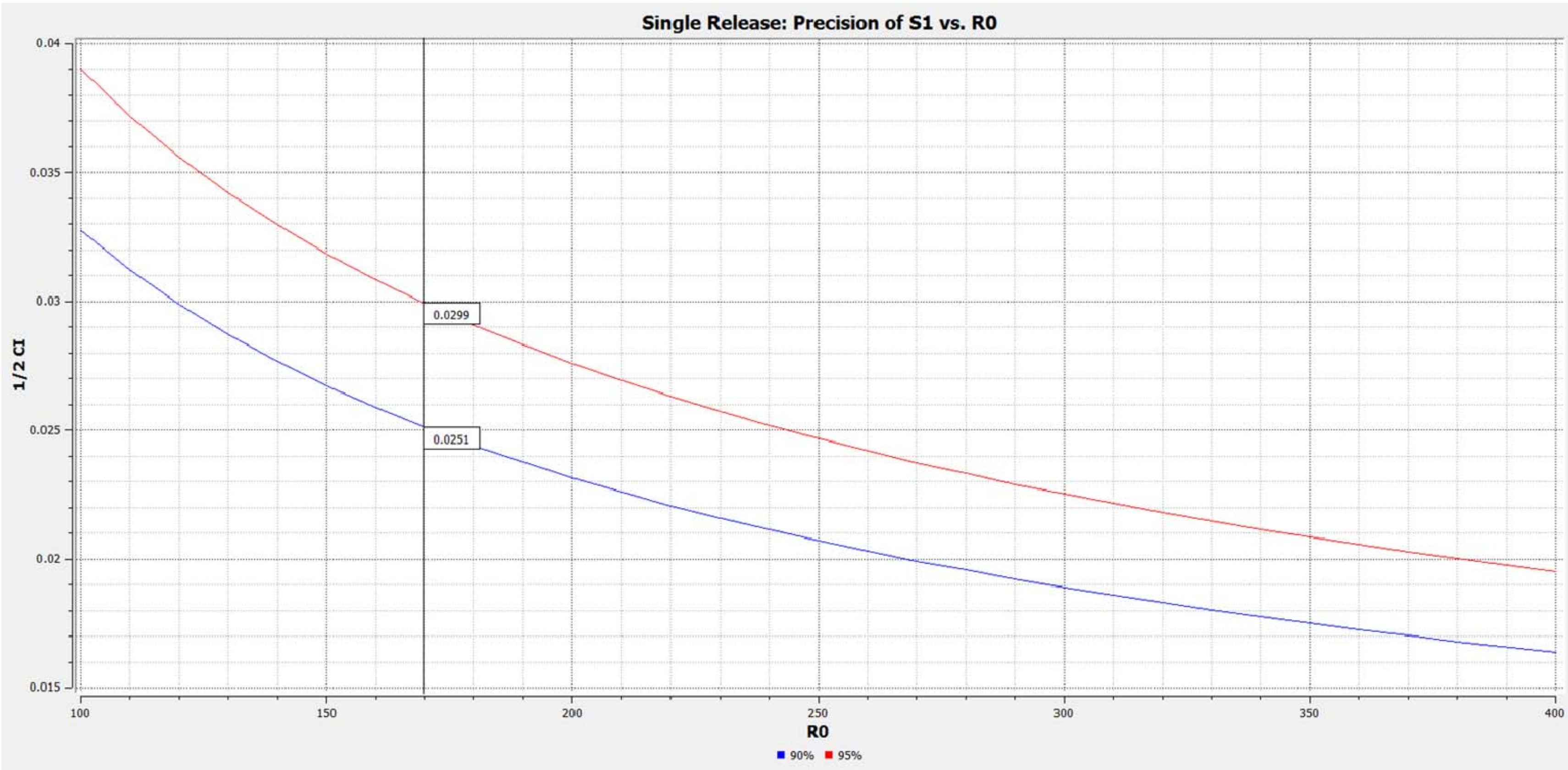
SampleSize Single Release model for yearling Chinook salmon and steelhead was run with the default 2 reaches and 1 replicates. "S1" is the BiOp performance standard, Proportion Removed accounts for the average bypass proportion from past studies (about 1% high to account for steelhead), and capture Probability was fluctuated among 90, 95, and 98% detection to run the model.



Single Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 90% detection probability.



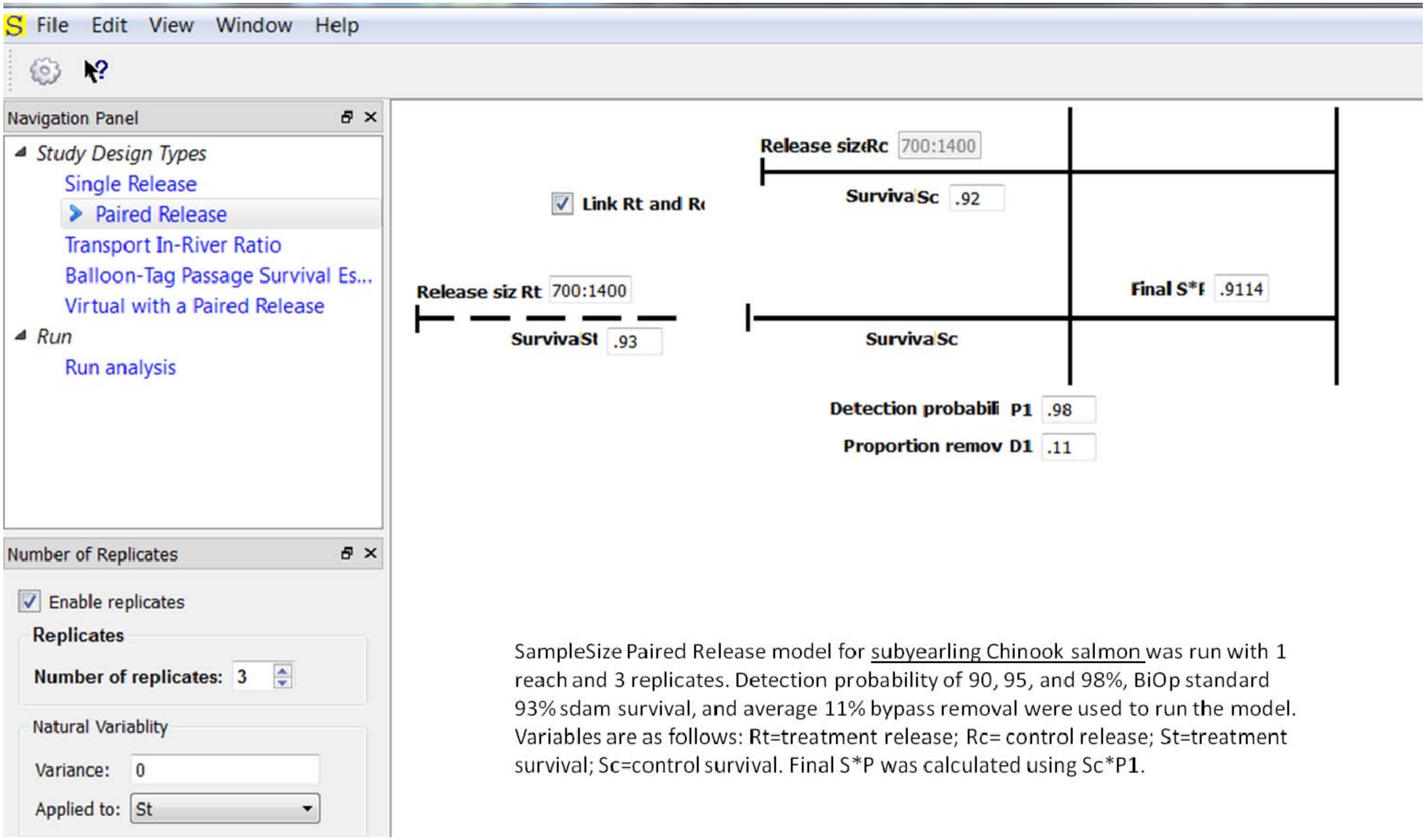
Single Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 95% detection probability.



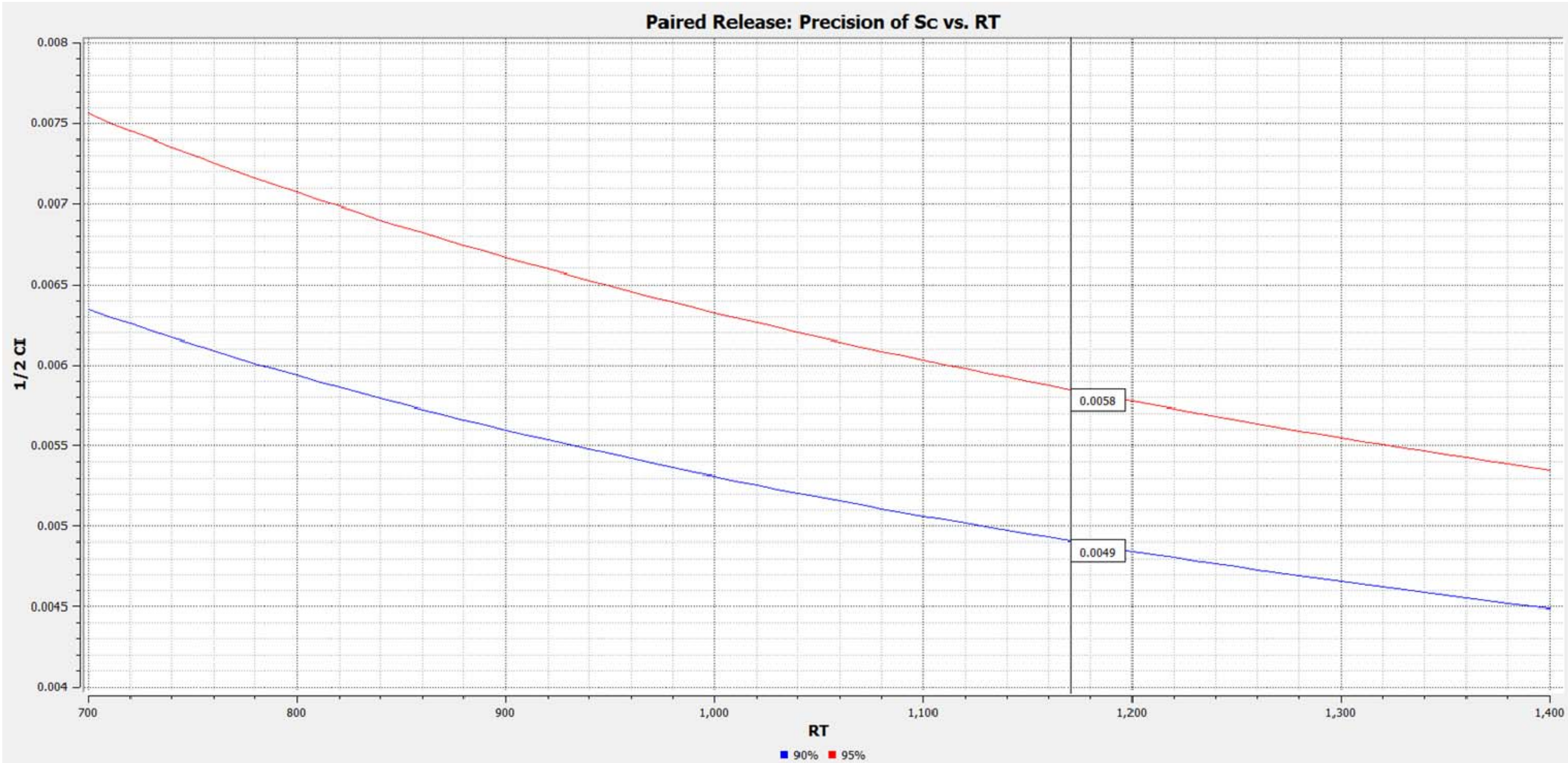
Single Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 98% detection probability.

Appendix 1.2

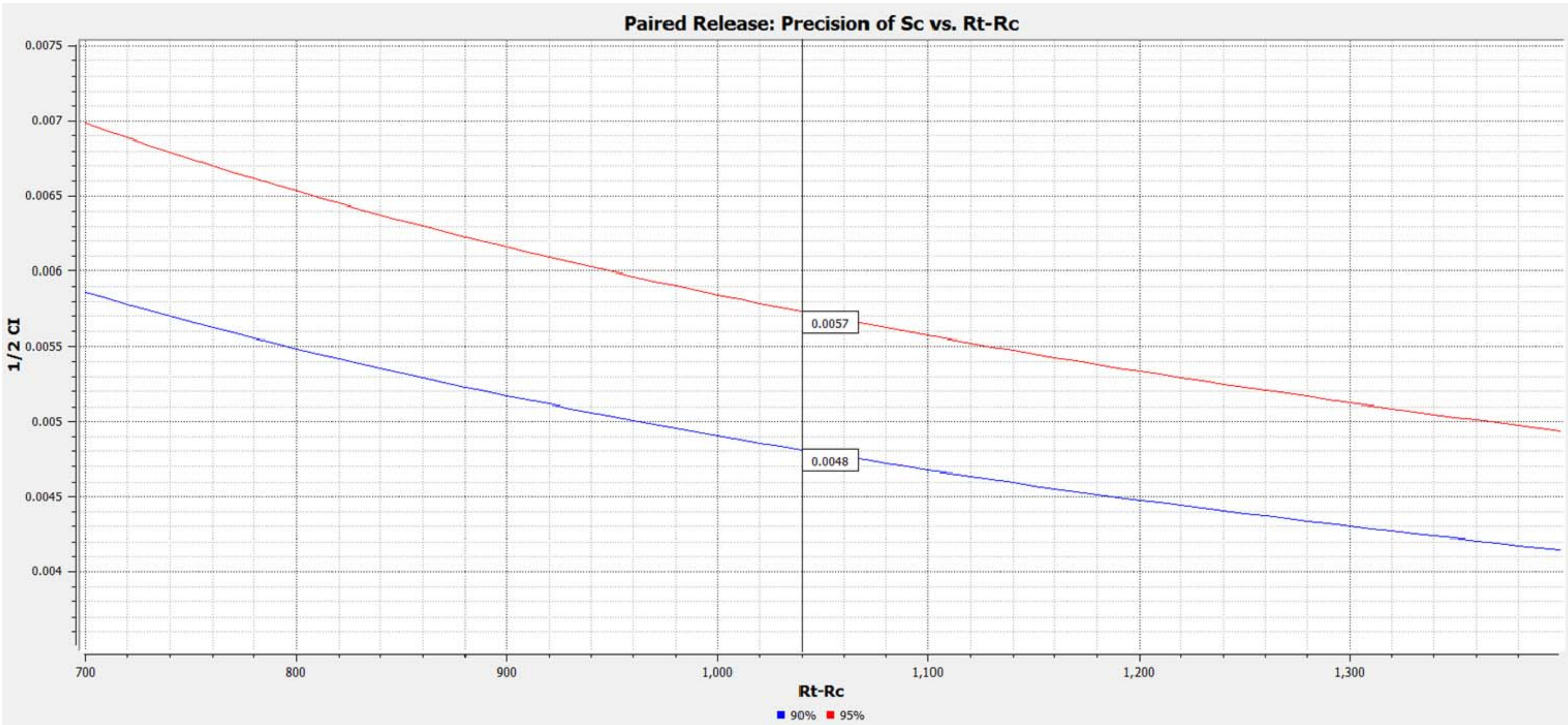
Preliminary SampleSize Paired Release-Recapture Design model with ½ 90% and 95% confidence intervals



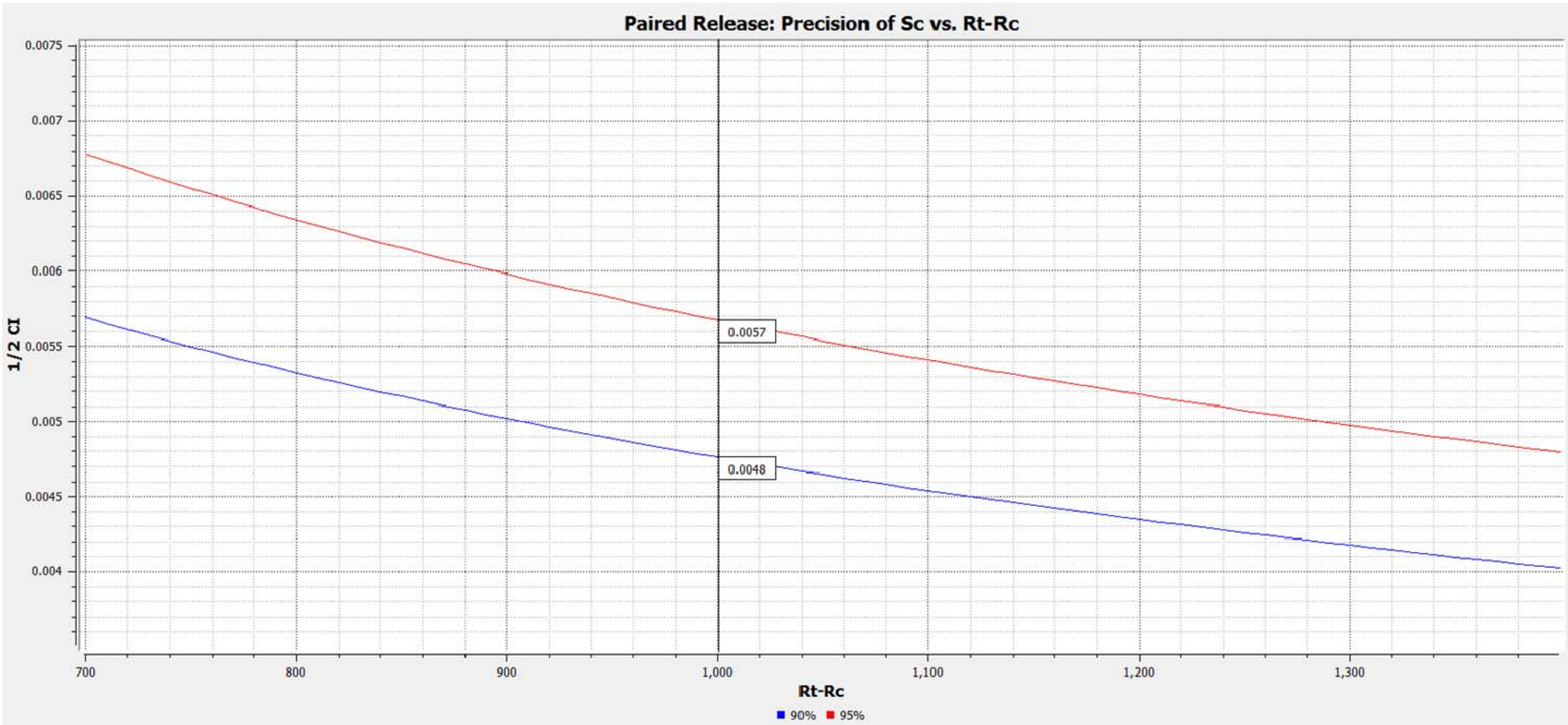
SampleSize Paired Release model for <u>subyearling Chinook salmon</u> was run with 1 reach and 3 replicates. Detection probability of 90, 95, and 98%, BiOp standard 93% sdam survival, and average 11% bypass removal were used to run the model. Variables are as follows: Rt=treatment release; Rc= control release; St=treatment survival; Sc=control survival. Final S*P was calculated using Sc*P1.



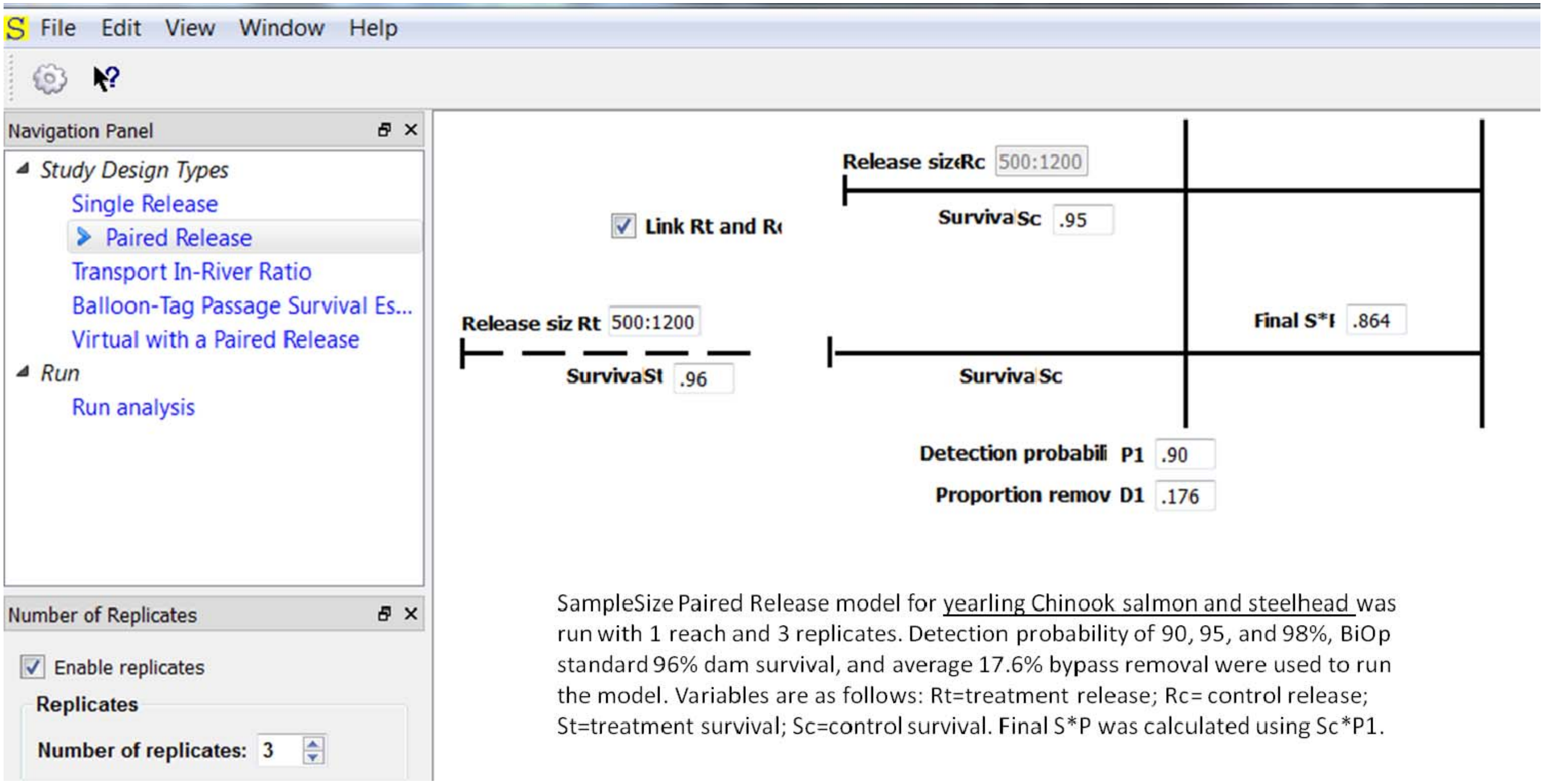
Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 90% detection probability.



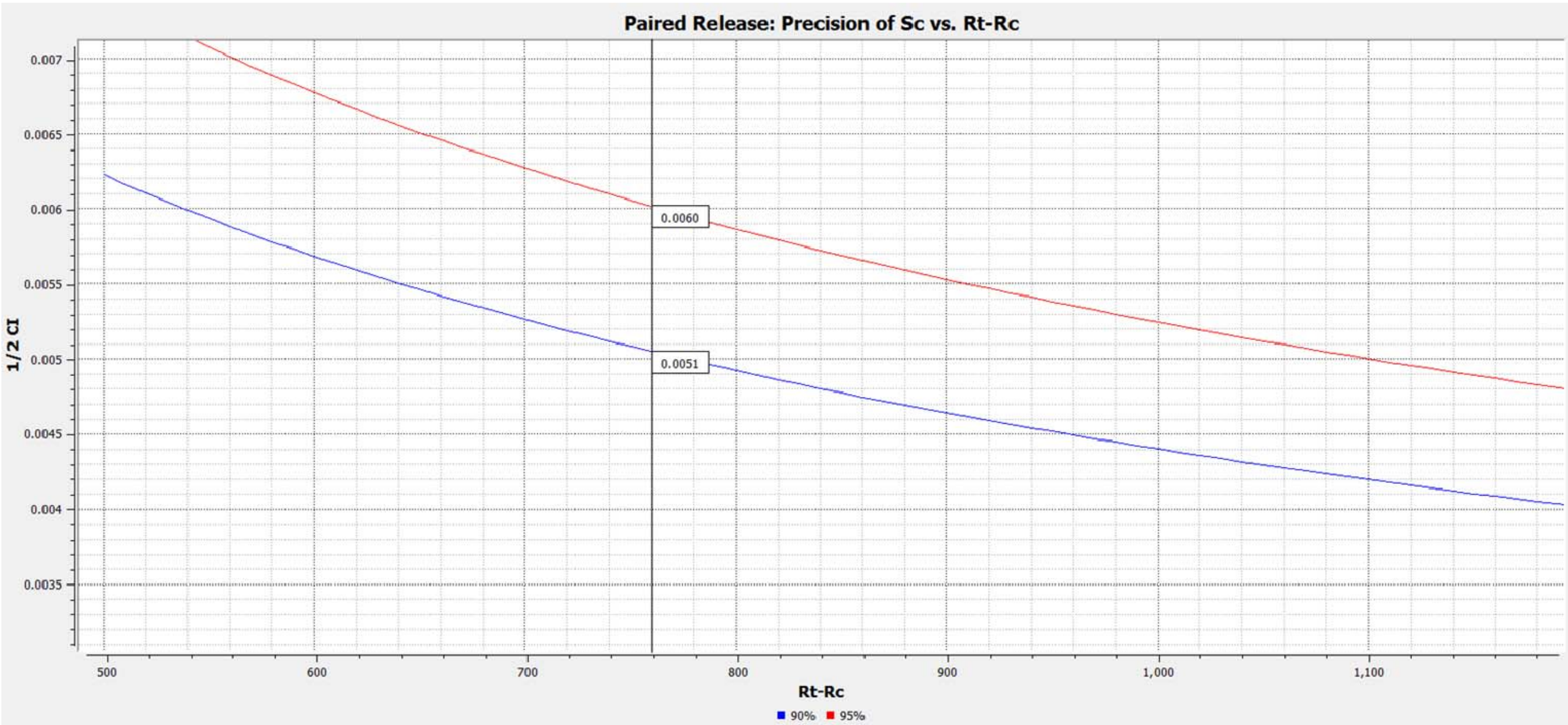
Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 95% detection probability.



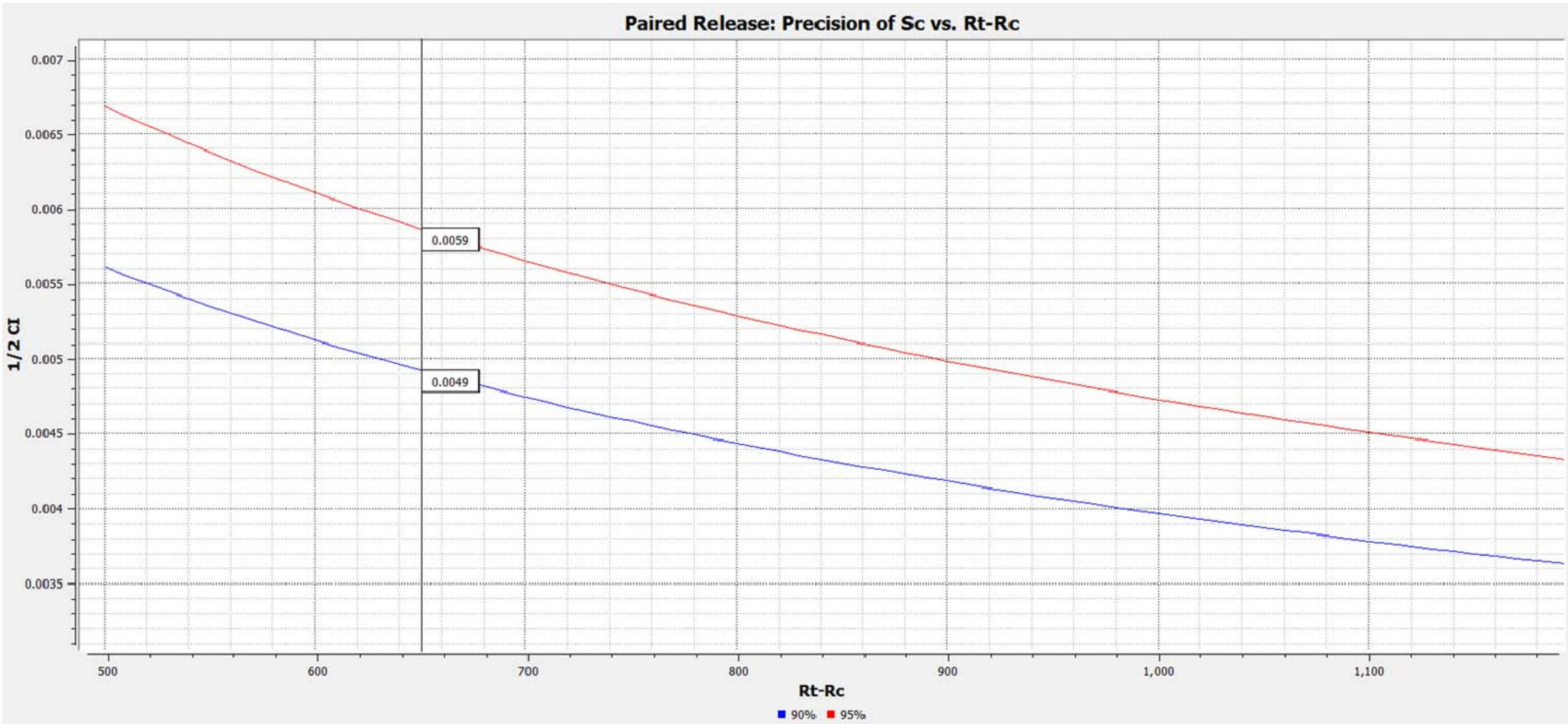
Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 98% detection probability.



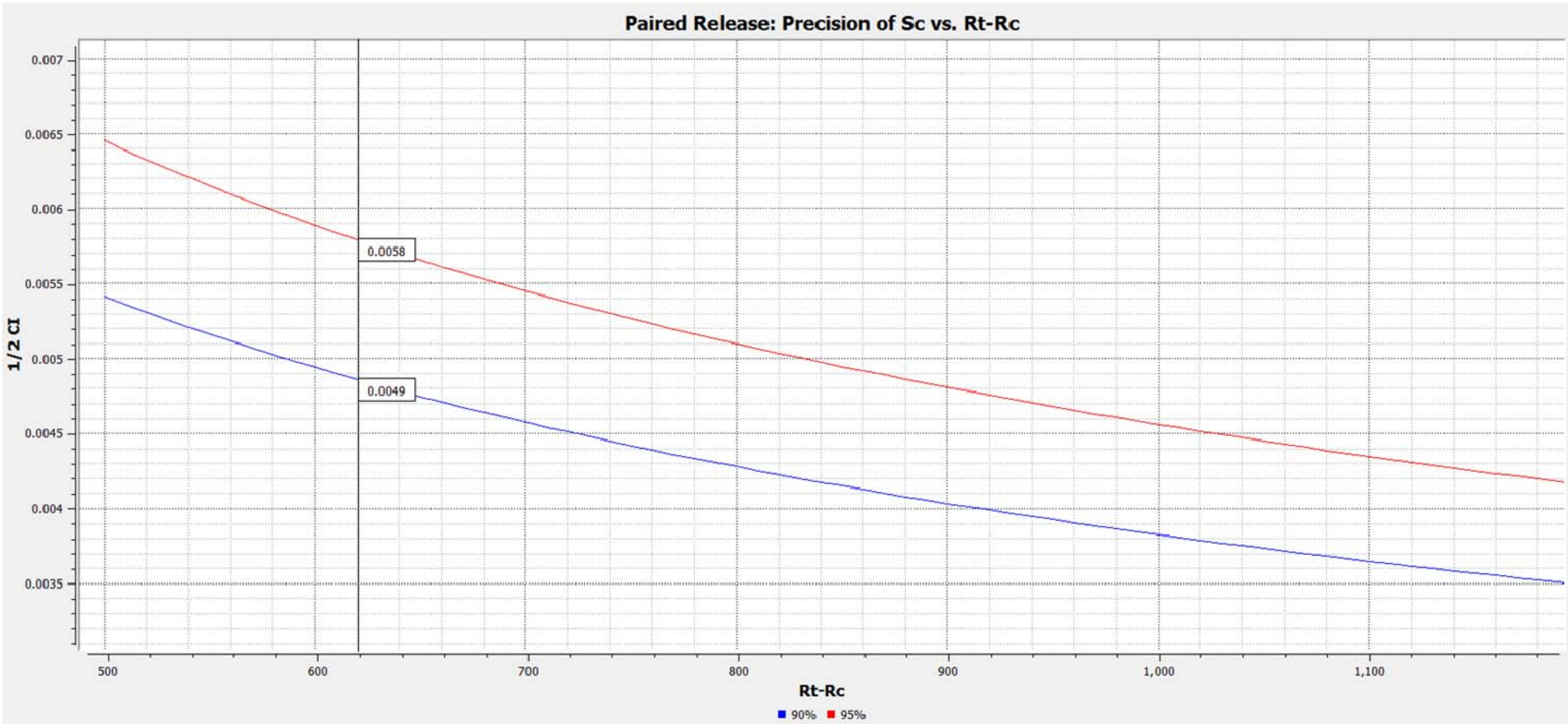
SampleSize Paired Release model for <u>yearling Chinook salmon and steelhead</u> was run with 1 reach and 3 replicates. Detection probability of 90, 95, and 98%, BiOp standard 96% dam survival, and average 17.6% bypass removal were used to run the model. Variables are as follows: Rt=treatment release; Rc= control release; St=treatment survival; Sc=control survival. Final S*P was calculated using Sc*P1.



Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 90% detection probability.



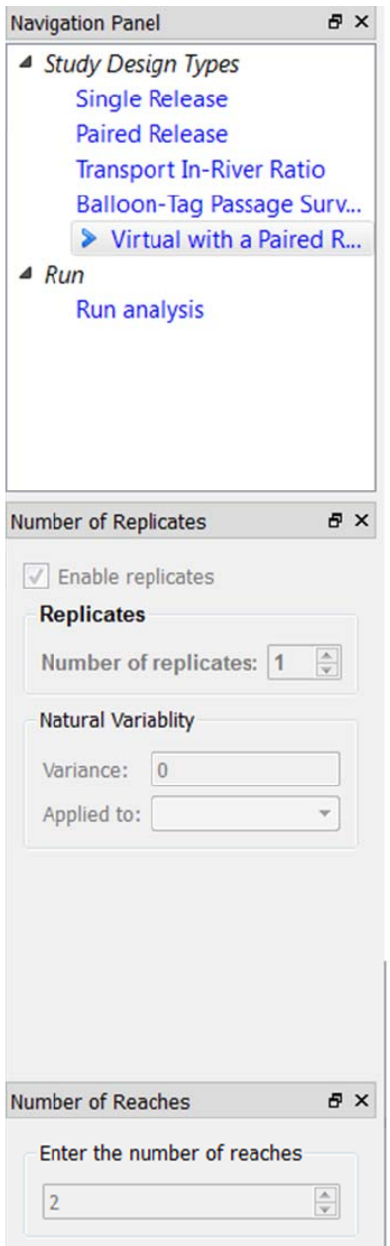
Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 95% detection probability.

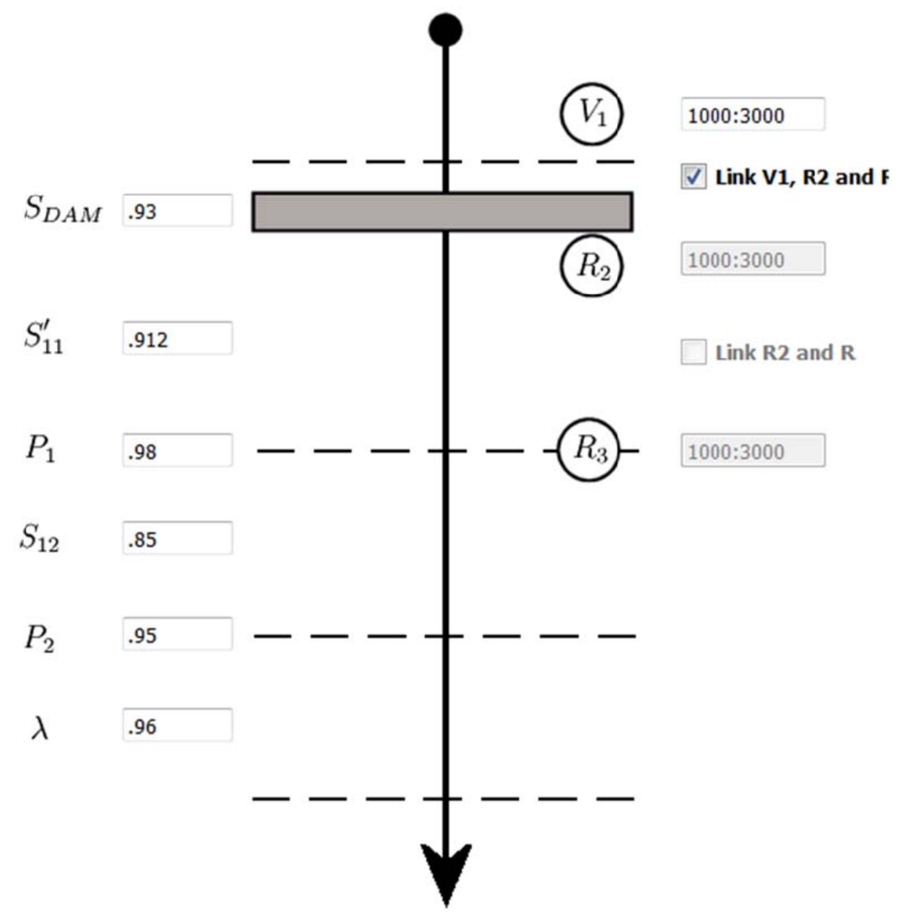


Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 98% detection probability.

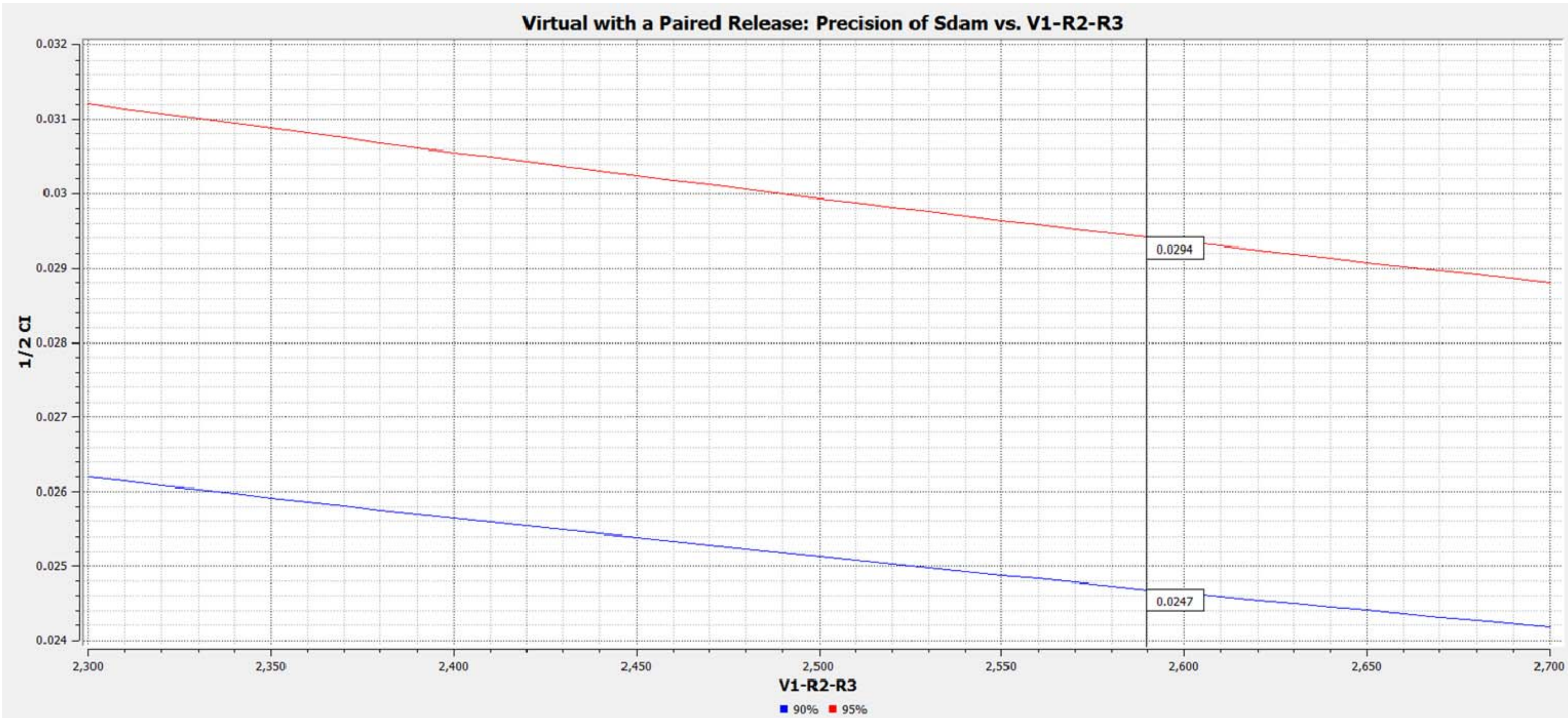
Appendix 1.3

Preliminary SampleSize Virtual with Paired Release-Recapture Design model with ½ 90% and 95% confidence intervals

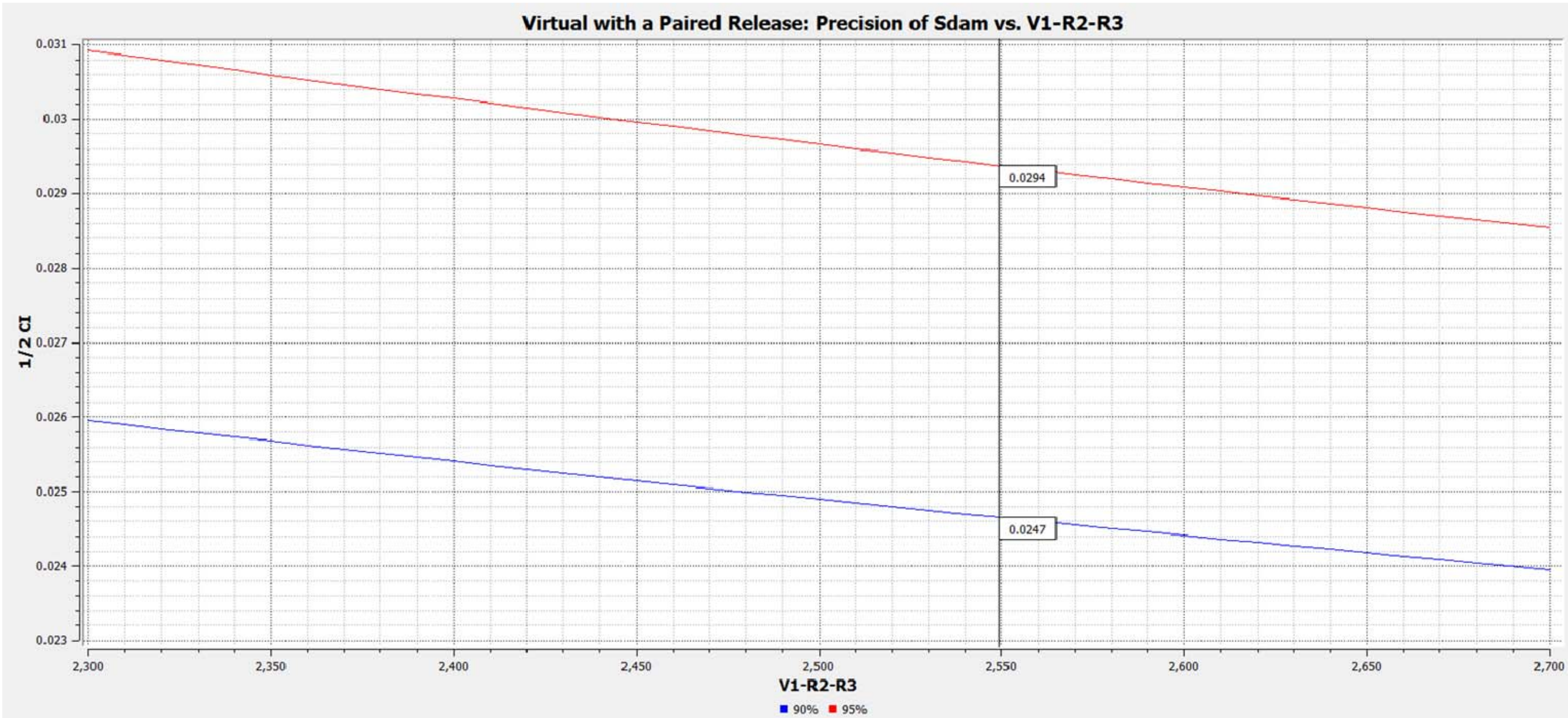




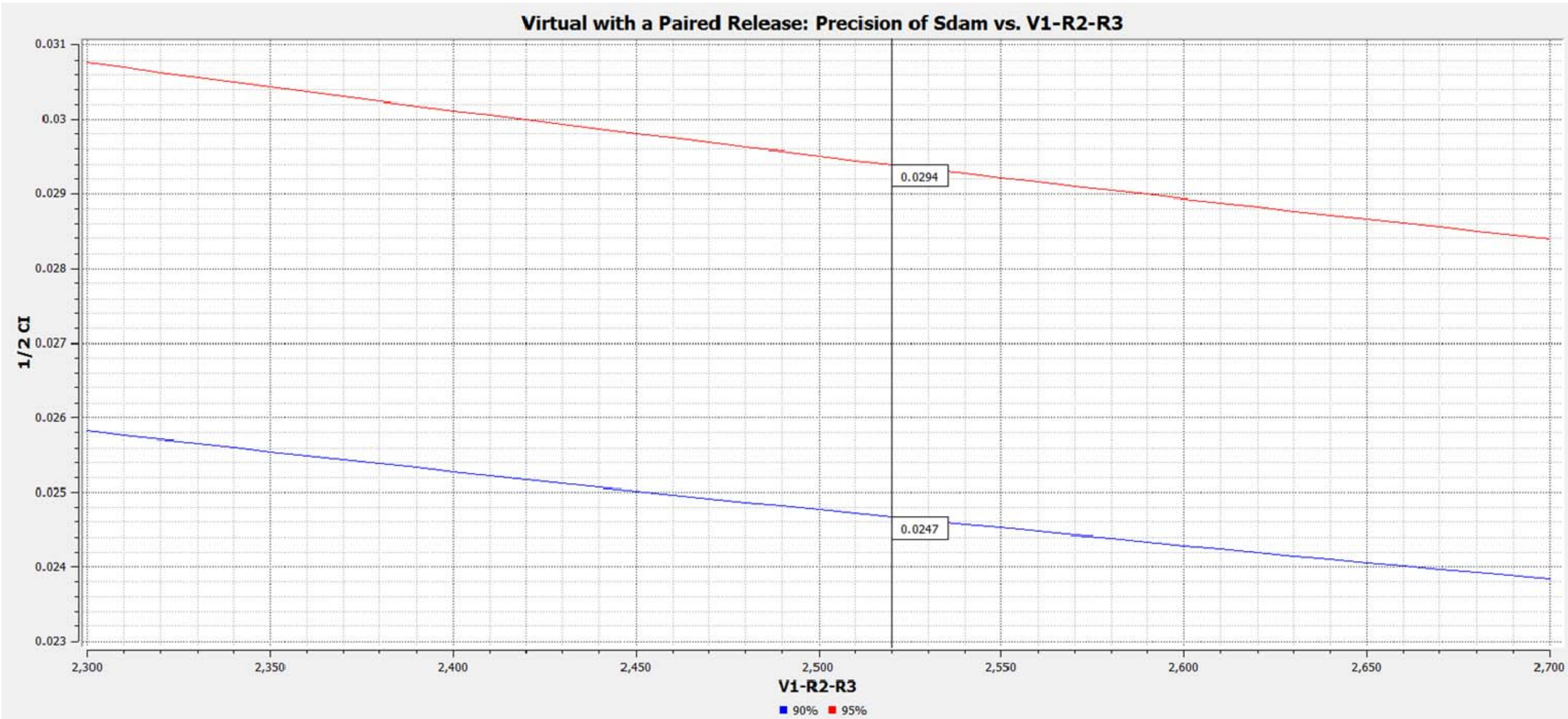
SampleSize Virtual with Paired Release model for <u>subyearling Chinook salmon</u>. Reaches and replicates do not apply to the model. V1 is the virtual release group; Sdam is the subyearling Chinook salmon dam survival estimate set at 93% for the performance standard. Survival "S11" and "S12" is from Skalski (2011), "P2" and Lambda were held constant at 95 and 96%, respectively, as the lowest probabilities likely (Skalski 2011). Detection probability (P1) was modeled among 90, 95, and 98%.



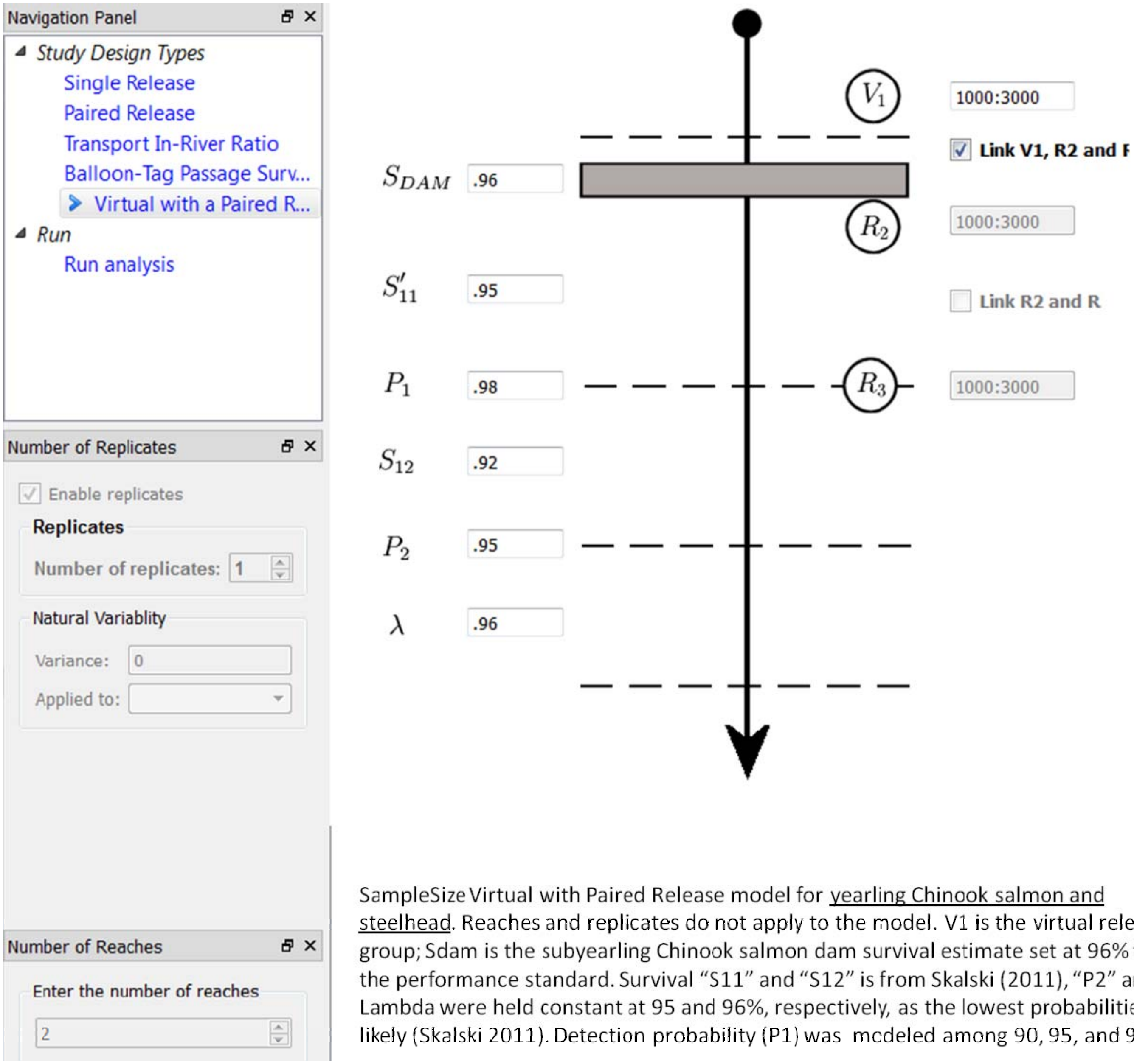
Virtual with Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 90% detection probability.



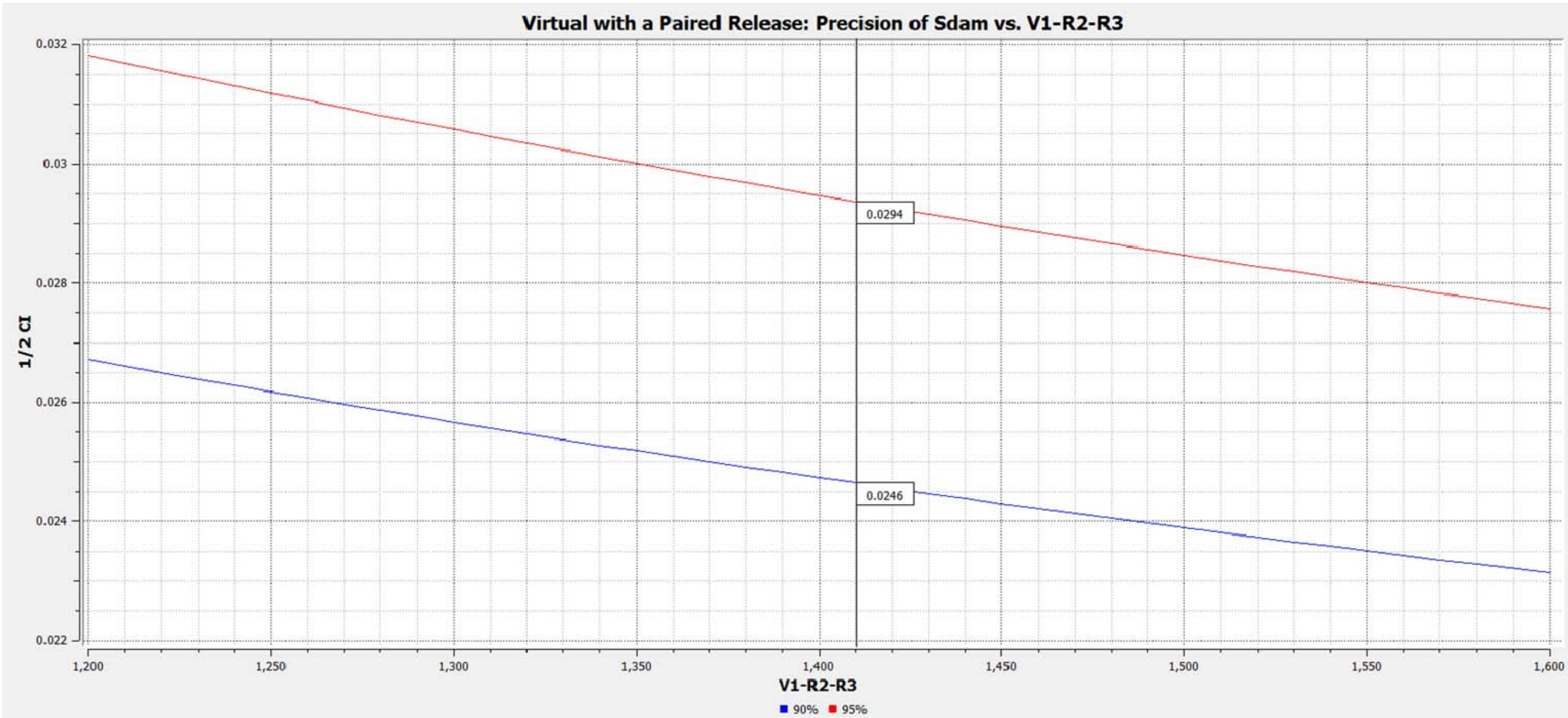
Virtual with Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 95% detection probability.



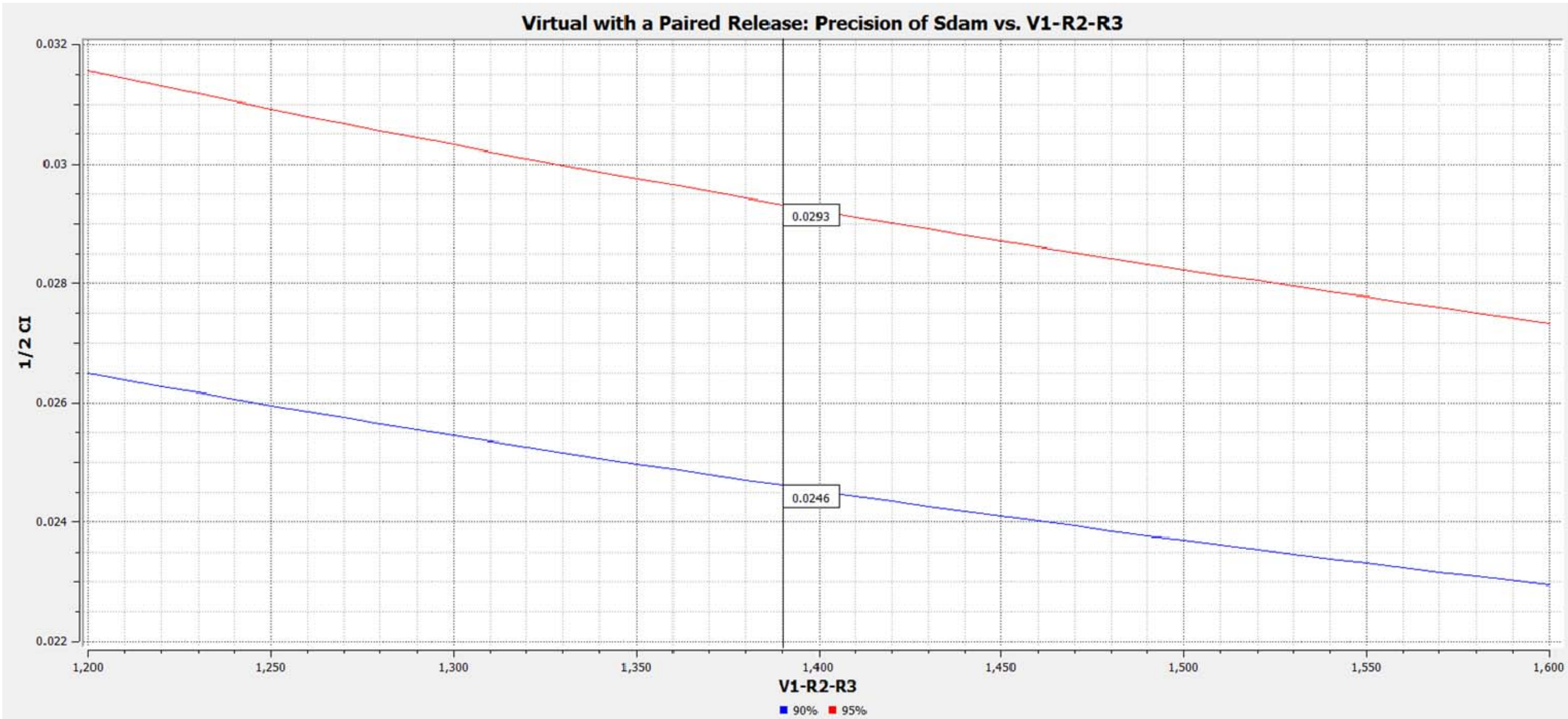
Virtual with Paired Release sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 98% detection probability.



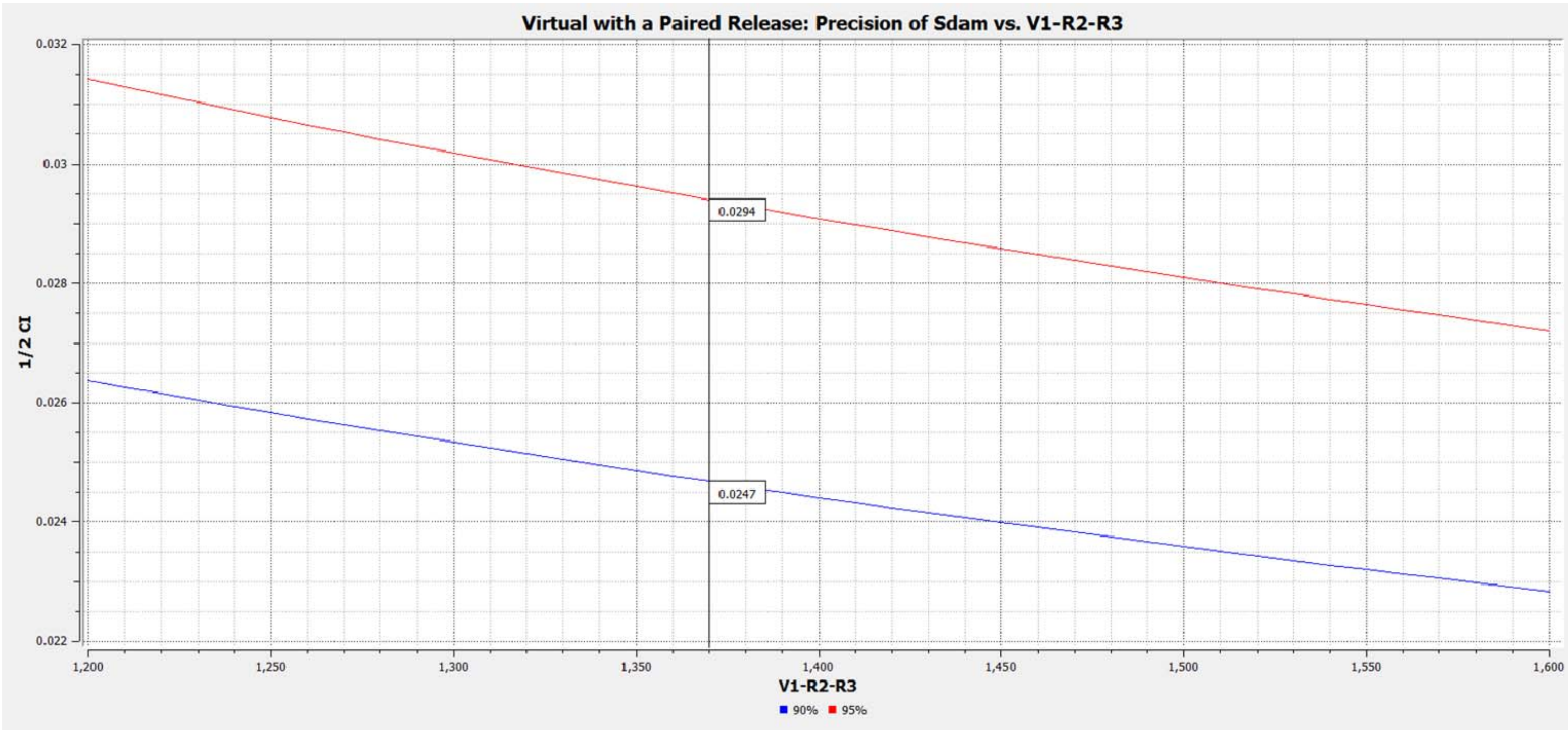
SampleSize Virtual with Paired Release model for <u>yearling Chinook salmon and steelhead</u>. Reaches and replicates do not apply to the model. V1 is the virtual release group; Sdam is the subyearling Chinook salmon dam survival estimate set at 96% for the performance standard. Survival "S11" and "S12" is from Skalski (2011), "P2" and Lambda were held constant at 95 and 96%, respectively, as the lowest probabilities likely (Skalski 2011). Detection probability (P1) was modeled among 90, 95, and 98%.



Virtual with Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 90% detection probability.



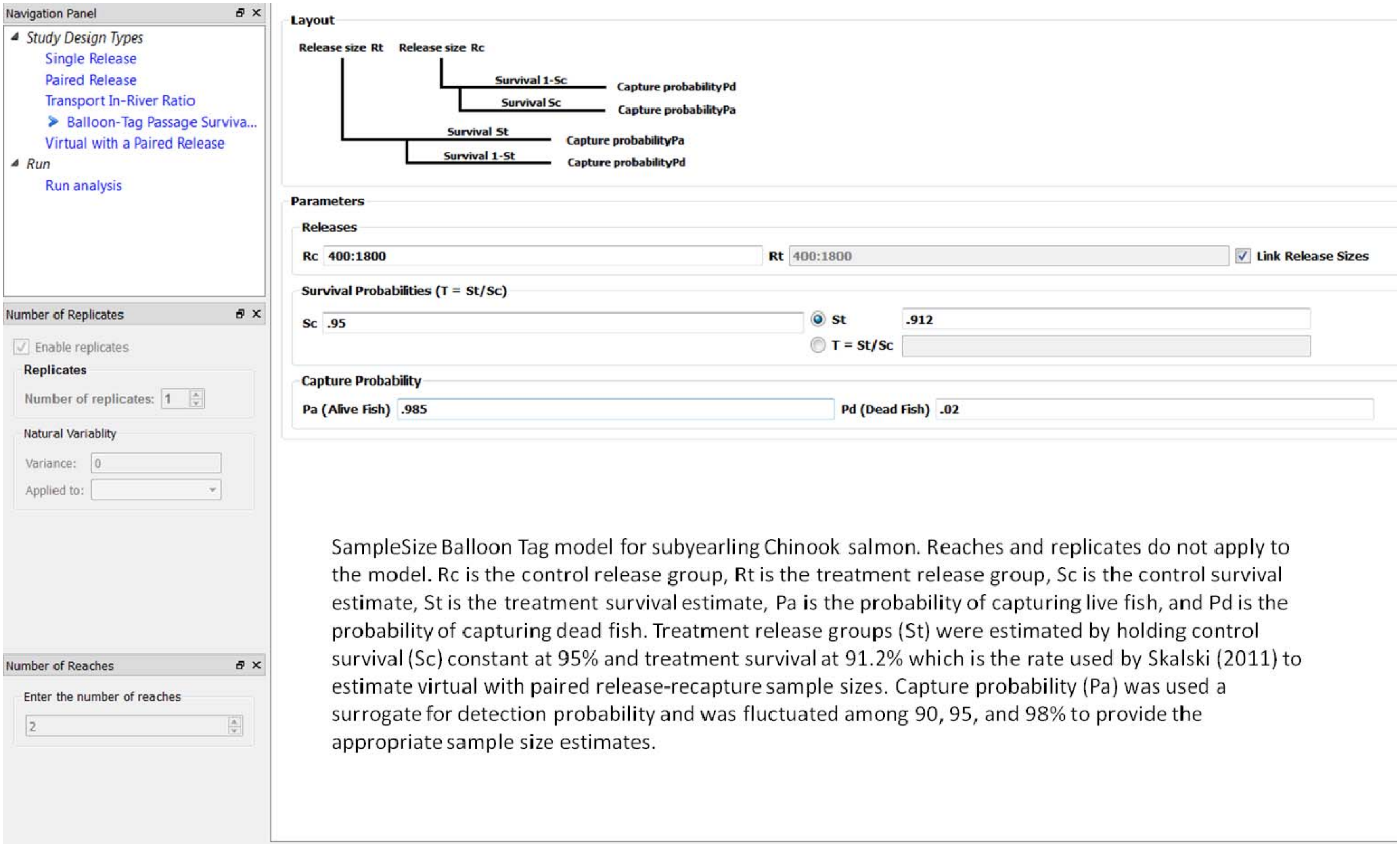
Virtual with Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 95% detection probability.



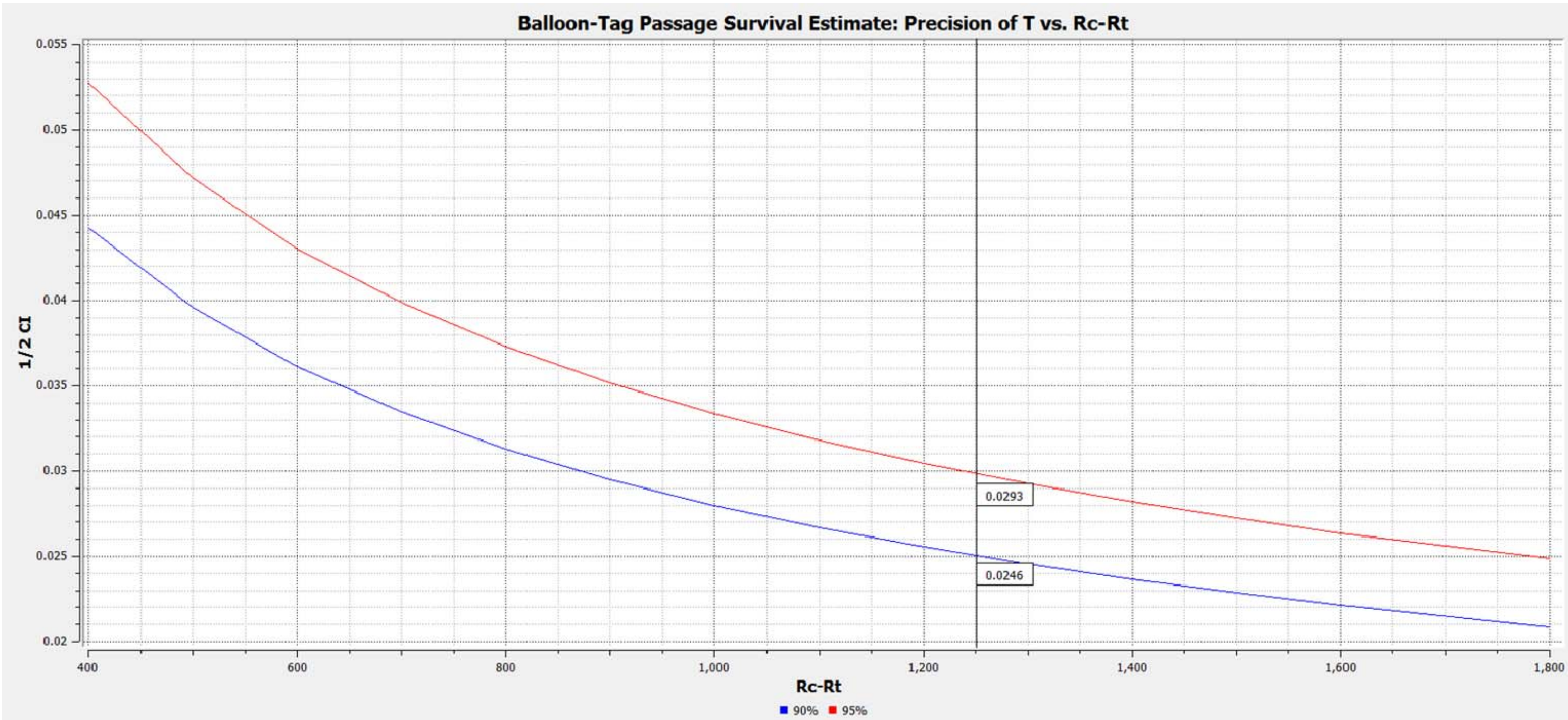
Virtual with Paired Release sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 98% detection probability.

Appendix 1.4

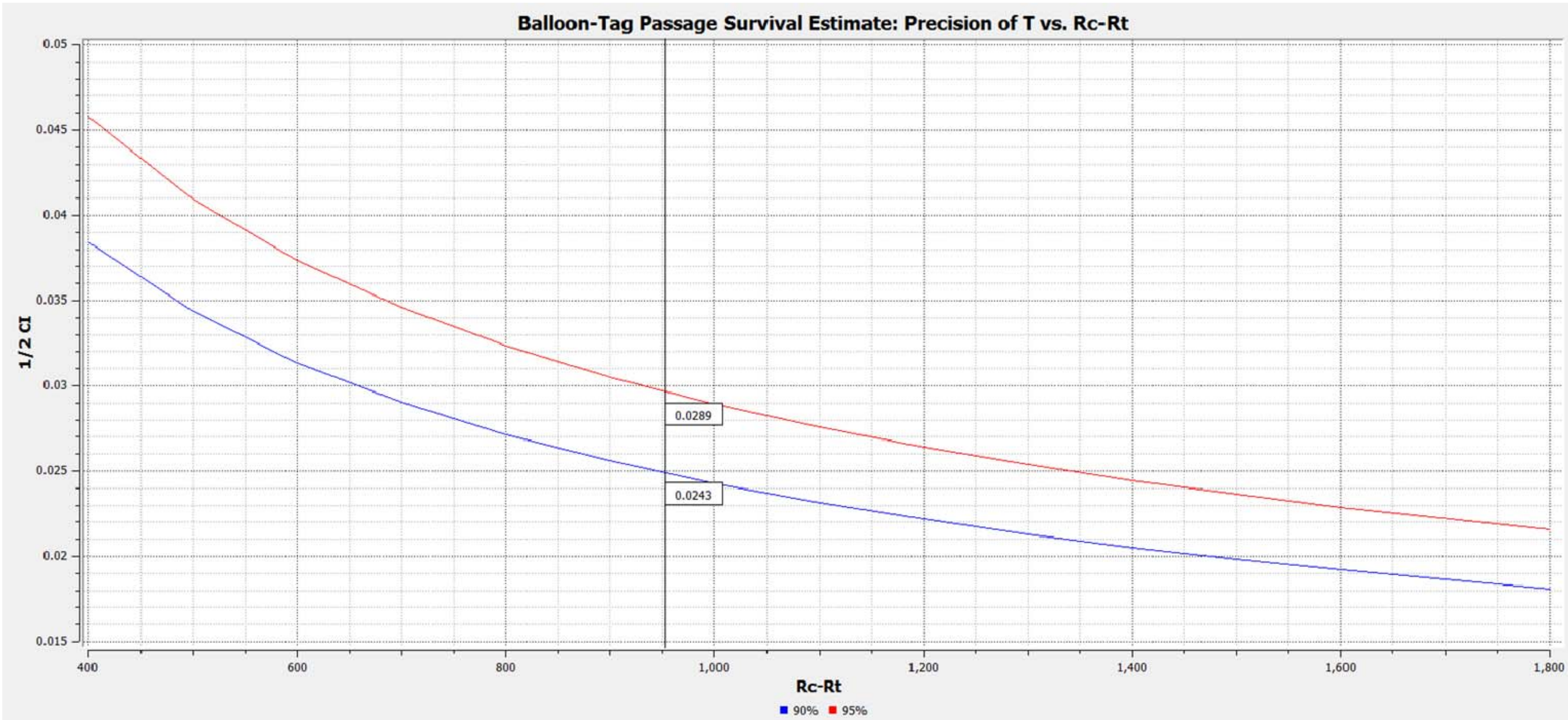
Preliminary SampleSize Balloon Tag model with ½ 90% and 95% confidence intervals



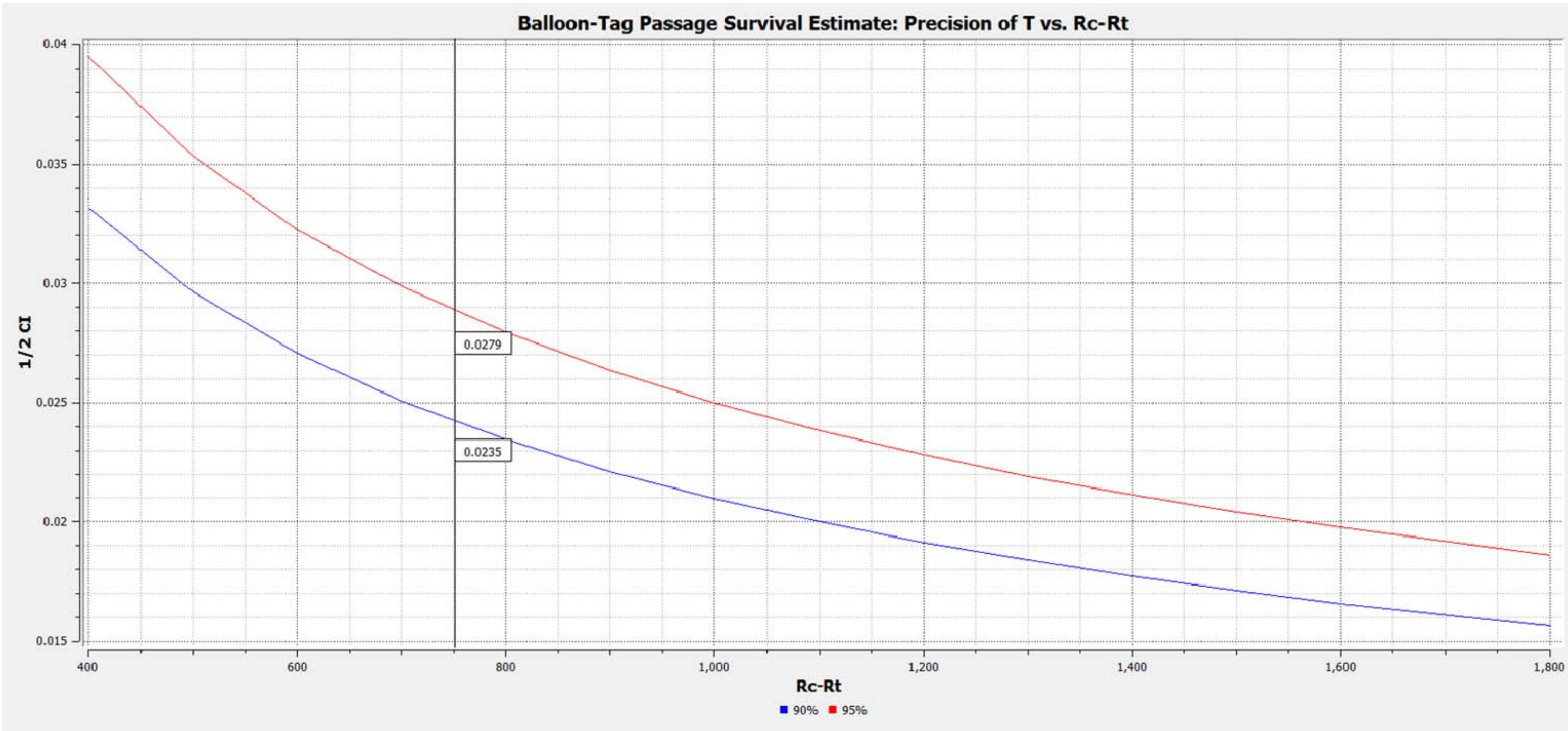
SampleSize Balloon Tag model for subyearling Chinook salmon. Reaches and replicates do not apply to the model. Rc is the control release group, Rt is the treatment release group, Sc is the control survival estimate, St is the treatment survival estimate, Pa is the probability of capturing live fish, and Pd is the probability of capturing dead fish. Treatment release groups (St) were estimated by holding control survival (Sc) constant at 95% and treatment survival at 91.2% which is the rate used by Skalski (2011) to estimate virtual with paired release-recapture sample sizes. Capture probability (Pa) was used a surrogate for detection probability and was fluctuated among 90, 95, and 98% to provide the appropriate sample size estimates.



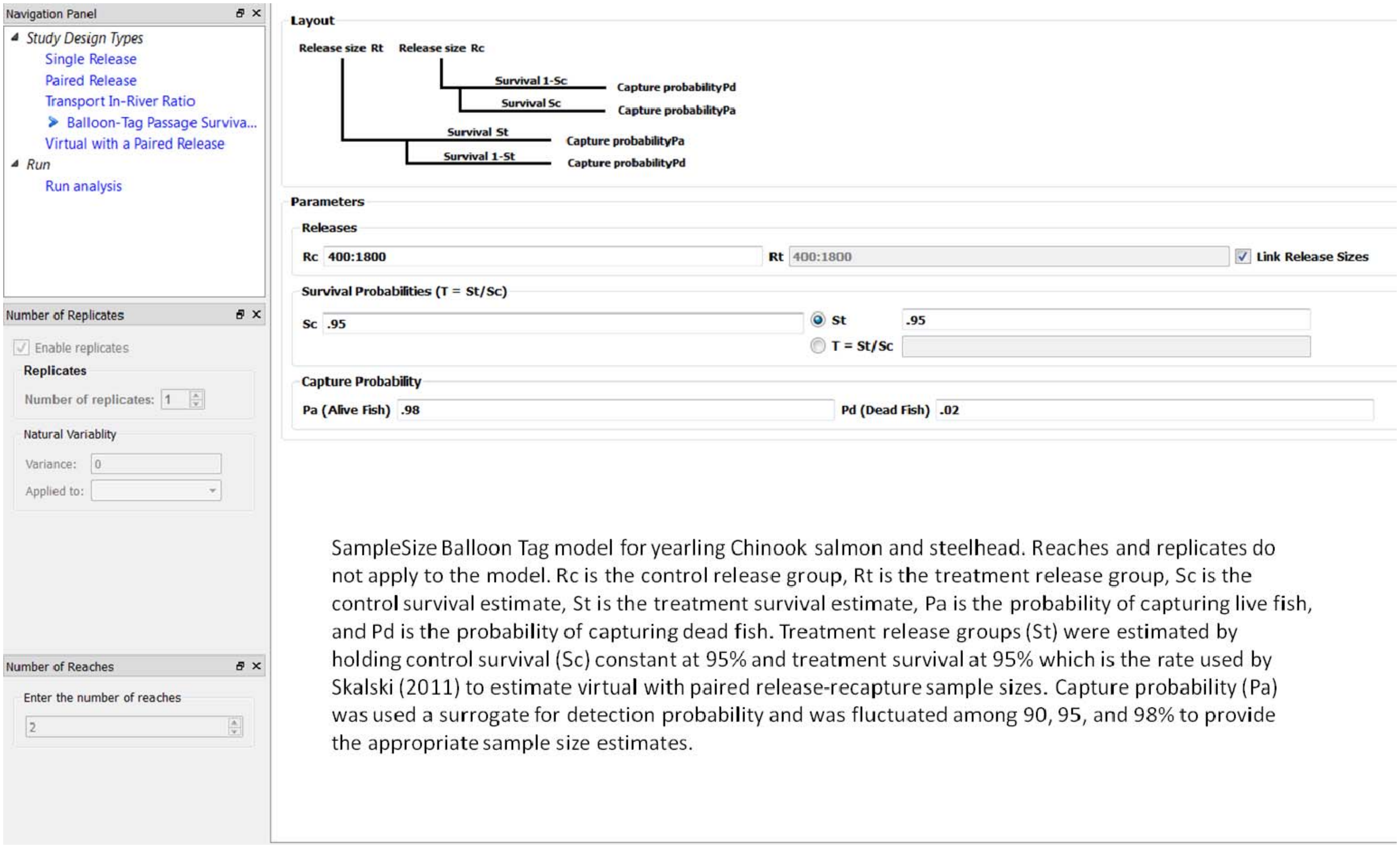
Balloon tag sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 90% live tailrace recapture probability.



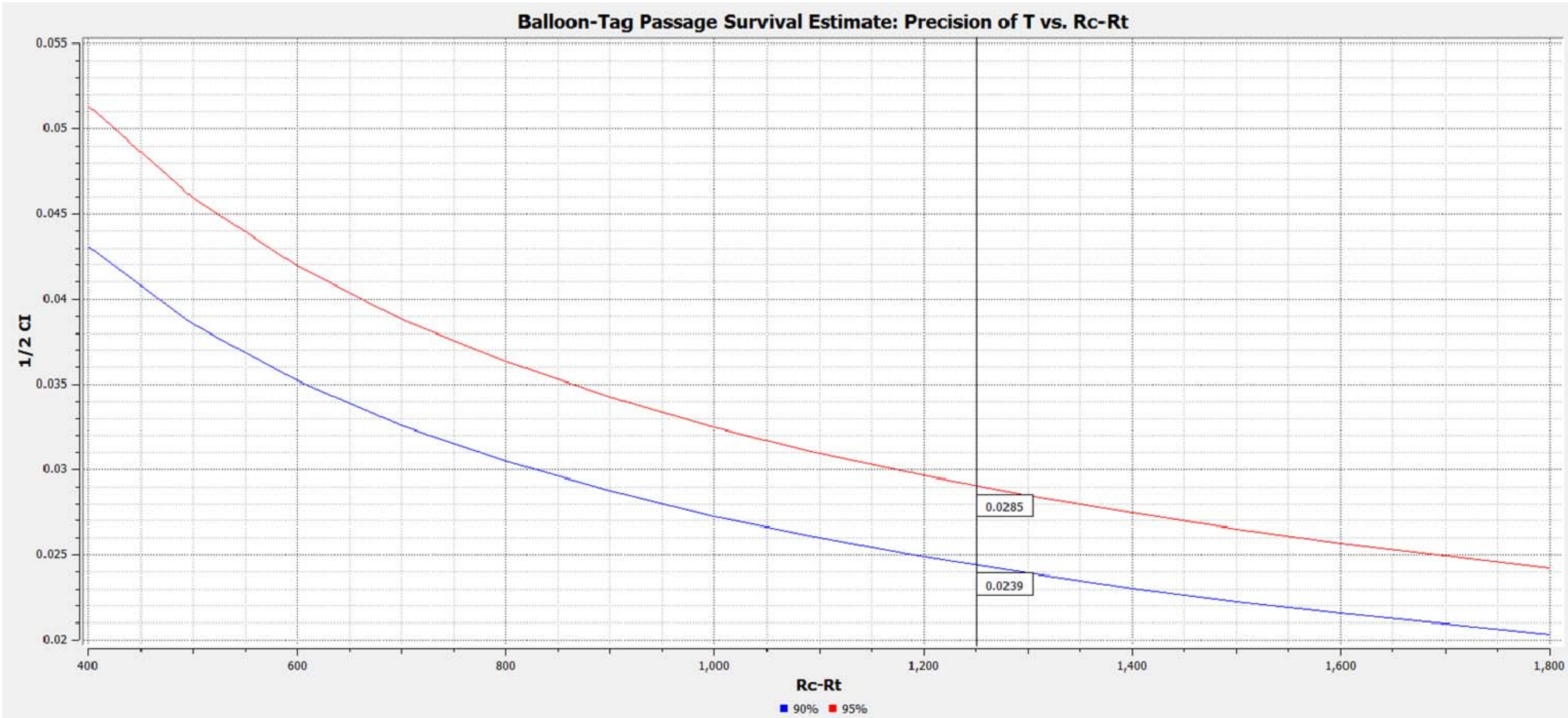
Balloon tag sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 95% live tailrace recapture probability.



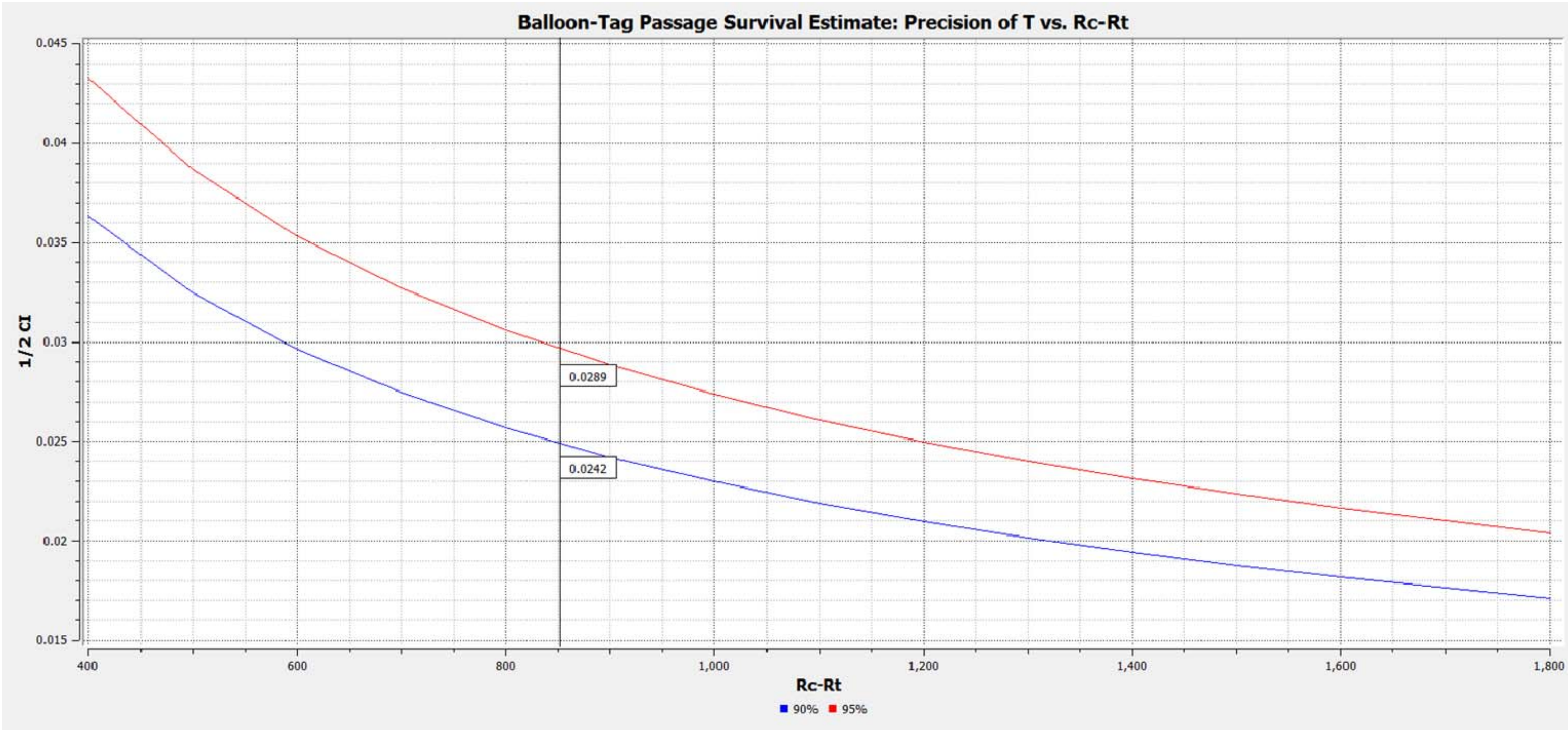
Balloon tag sample size estimate ½ Confidence intervals for subyearling Chinook salmon with 98% live tailrace recapture probability.



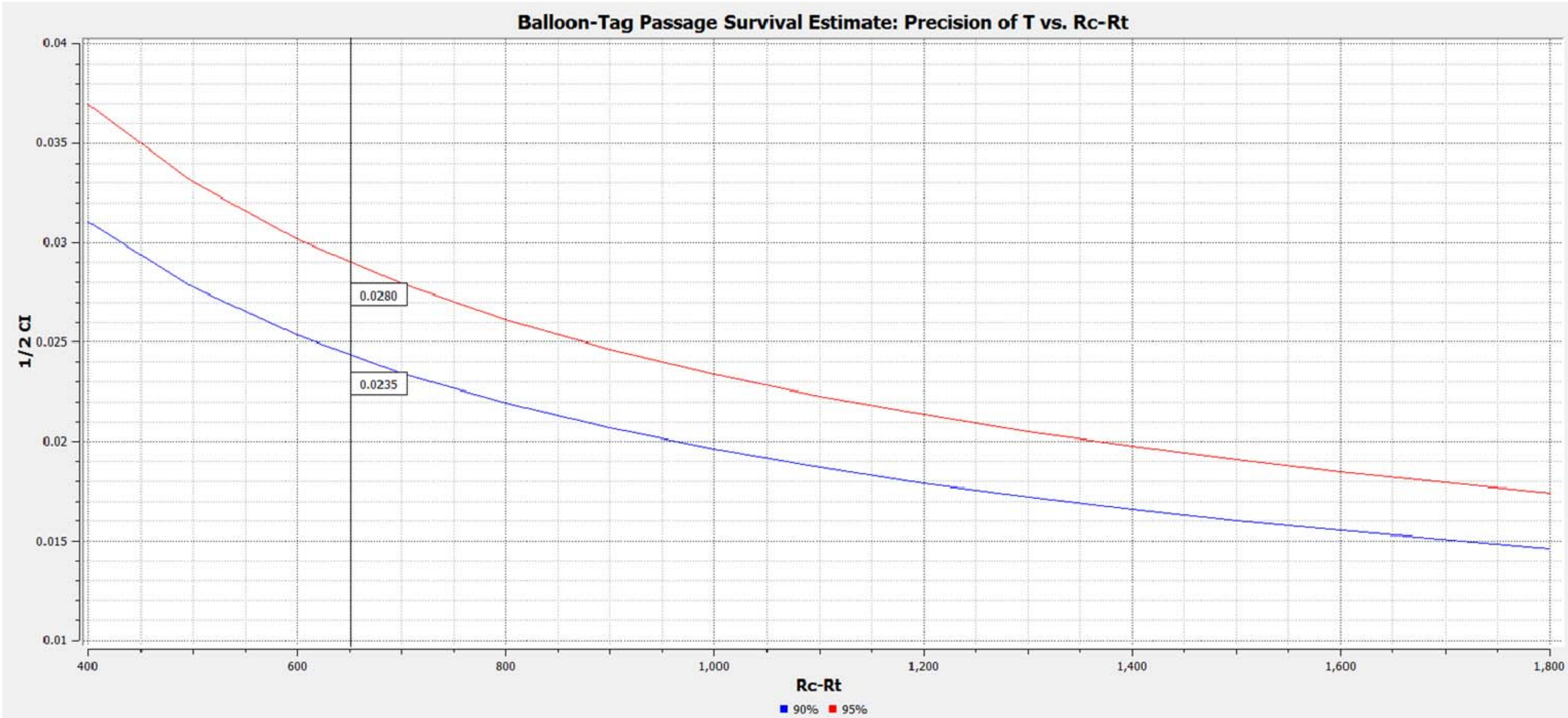
SampleSize Balloon Tag model for yearling Chinook salmon and steelhead. Reaches and replicates do not apply to the model. Rc is the control release group, Rt is the treatment release group, Sc is the control survival estimate, St is the treatment survival estimate, Pa is the probability of capturing live fish, and Pd is the probability of capturing dead fish. Treatment release groups (St) were estimated by holding control survival (Sc) constant at 95% and treatment survival at 95% which is the rate used by Skalski (2011) to estimate virtual with paired release-recapture sample sizes. Capture probability (Pa) was used a surrogate for detection probability and was fluctuated among 90, 95, and 98% to provide the appropriate sample size estimates.



Balloon tag sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 90% live tailrace recapture probability.



Balloon tag sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 95% live tailrace recapture probability.



Balloon tag sample size estimate ½ Confidence intervals for yearling Chinook salmon and steelhead with 98% live tailrace recapture probability.

Appendix 2.0

Statistical Plan for the Ice Harbor Acoustic Tag Investigations of Dam Passage Survival and Associated Metrics (Skalski 2011)

Statistical Plan for the Ice Harbor Acoustic-Tag Investigations of Dam Passage Survival and Associated Metrics

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22 August 2011

Table of Contents

Table of Tables

Table of Figures

1.0 Introduction

This statistical design and analysis plan presents a proposed acoustic-tag, release-recapture study for measuring performance at Ice Harbor Dam as specified in the 2008 Federal Columbia River Power System Biological Opinion (FCRPS) Biological Opinion (BiOp) and the 2008 Columbia River Fish Accords. In particular, five performance measures to be evaluated include the following:

1. Dam passage survival. Defined as survival from the upstream face of the dam to a standardized reference point in the tailrace. Performance[1] should be ≥96% survival for spring stocks (i.e., yearling Chinook salmon and steelhead) and ≥93% survival for summer stocks (i.e., subyearling Chinook salmon). Survival should be estimated with a standard error (SE) ≤1.5%.
2. Spill passage efficiency. Defined as the fraction of fish going through the dam via the spillway and surface flow outlets.
3. Forebay residence time. Defined as the average (median) time smolts take to travel the last 100 m upstream of the dam before passing into the dam (i.e., 100-m mark to dam face).
4. Tailrace egress time. Defined as the average (median) time smolts take to travel from the dam to the downstream tailrace boundary (e.g., boat restricted zone [BRZ]).
5. BRZ_F-to-BRZ_T survival. Defined as survival from the BRZ in the forebay to the BRZ in the tailrace of the dam.

The first performance measure is specified in the 2008 BiOp; the last four performance measures, along with dam passage survival, are specified in the 2008 Columbia Basin Fish Accords.

From a statistical design perspective, the most challenging of the objectives will be to estimate dam passage survival and BRZ_F-to-BRZ_T survival. Traditional single-release (Skalski et al. 1998) and paired-release (Burnham et al. 1987) designs are incapable of estimating dam passage survival and providing unbiased estimates. More sophisticated release-recapture designs will be necessary to estimate dam passage survival. For this reason, the study plan will first focus on this objective. Only minor additions to the design will be needed to accomplish the other objectives.

2.0 Release-Recapture Design

Isolating dam passage survival from other components of smolt outmigration requires special release and detection strategies. The concepts behind the proposed release-recapture design to estimate dam passage survival are presented first. The approaches to estimating the accord measures will follow.

2.1 Dam Passage Survival

2.1.1 Overview

Over the last 15 years of statistically based smolt survival studies (Skalski et al. 1998; Bickford and Skalski 2000; Skalski et al. 2009), we have learned much regarding the estimation of dam passage survival. Among these lessons include the following:

> Lesson 1. Smolts released in the immediate vicinity of the forebay do not pass through a dam in the same spatial distribution as run-of-river fish.

The implication is that tagged groups must be released far enough upriver for smolts to be nominally distributed by the time they reach the dam. Therefore, an upstream release group must be used to construct a virtual release group of fish known to have arrived at the dam face in a nominal manner.

> Lesson 2. Paired upstream–downstream releases are needed to isolate survival to a specific reach or river section.

> Lesson 3. In performing paired releases, fish used in the upstream and downstream release groups need to be similar in all aspects including origin and handling experience.

The implementation of Lessons 2 and 3 include not pairing fresh fish releases with virtual fish releases. Releases of like kind must be used together in order that post-release handling effects are similarly expressed in both upstream and downstream release groups. Furthermore, downstream detection sites must be located sufficiently downriver to allow such handling effects to be expressed equally among release groups.

> Lesson 4. A hydrophone array placed too close to the dam tailrace may detect fish that died during dam passage.

These false-positive detections of dead-tagged fish will overestimate dam passage survival. The first detection array below a dam must therefore be sufficiently far enough below the dam that dead tagged fish would be filtered out of the system before being detected.

Taking these lessons into account, a combination of virtual and paired releases has been used to isolate and estimate dam passage survival in the Lower Columbia River beginning in 2010 (Figure 1). Using a three-dimensional (3D) hydrophone array at the upstream face of the dam, a virtual release will be composed of fish known to have survived to the dam (i.e., Figure 1, V_1). This release group will be used to estimate survival from the upstream face of the dam to a downstream hydrophone array (Figure 1, S_1), sufficiently far enough below the dam to address concerns about detecting fish that may have died while passing through the dam (i.e., eliminating false-positive detections). However, this reach includes more of the river than the requisite dam-to-tailrace of interest.

In order to estimate the mortality associated with the river reach between the tailrace and the first detection array downstream of the dam, a paired release of fresh fish will be performed (Figure 1, R_2 and R_3). Paired release-recapture methods will be used to estimate survival in this segment of the river. Consequently, dam passage survival will be estimated as the quotient of the overall reach survival estimate (S_1) divided by the survival estimate from the paired release (i.e., S_2/S_3) where

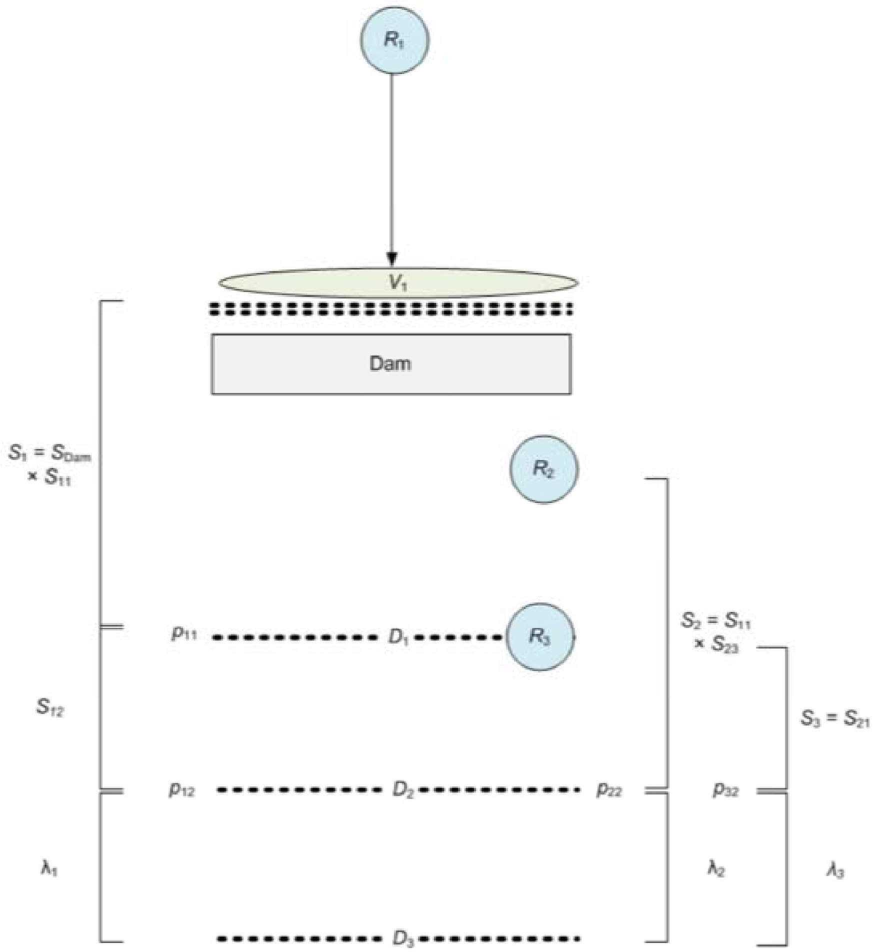
$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1}{\left(\frac{\hat{S}_2}{\hat{S}_3}\right)} = \frac{\hat{S}_1\hat{S}_3}{\hat{S}_2}. \tag{1}$$

The variance of $\hat{S}_{\text{Dam}}$ can be expressed by the quantity

$$\begin{aligned}\operatorname{Var}\left(\hat{S}_{\text{Dam}}\right) = &\left(\frac{1}{S_2^2} + \frac{\operatorname{Var}\left(\hat{S}_2\right)}{S_2^4}\right)\left[S_1^2 \operatorname{Var}\left(\hat{S}_3\right) + S_3^2 \operatorname{Var}\left(\hat{S}_1\right) + \operatorname{Var}\left(\hat{S}_1\right)\cdot \operatorname{Var}\left(\hat{S}_3\right)\right]\\ &+ \frac{\left(S_1 S_3\right)^2}{S_2^4}\cdot \operatorname{Var}\left(\hat{S}_2\right)\end{aligned} \tag{2}$$

and estimated by the quantity

$$\begin{aligned}\widehat{\operatorname{Var}}\left(\hat{S}_{\text{Dam}}\right) = &\left(\frac{1}{\hat{S}_2^2} - \frac{\widehat{\operatorname{Var}}\left(\hat{S}_2\right)}{\hat{S}_2^4}\right)\left[\hat{S}_1^2 \widehat{\operatorname{Var}}\left(\hat{S}_3\right) + \hat{S}_3^2 \widehat{\operatorname{Var}}\left(\hat{S}_1\right) - \widehat{\operatorname{Var}}\left(\hat{S}_1\right)\cdot \widehat{\operatorname{Var}}\left(\hat{S}_3\right)\right]\\ &+ \frac{\left(\hat{S}_1 \hat{S}_3\right)^2}{\hat{S}_2^4}\cdot \operatorname{Var}\left(\hat{S}_2\right).\end{aligned} \tag{3}$$



Dam survival estimate: $\hat{S}_{\text{Dam}} = \dfrac{\hat{S}_1}{\left(\dfrac{\hat{S}_2}{\hat{S}_3}\right)} = \dfrac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2}$

Figure 1. Schematic of the minimum design configuration to estimate dam passage survival based on a virtual release (i.e., V_1), a paired release (R_2 and R_3), and three downriver hydrophone arrays (••••••••). At the dam face, a 3D hydrophone array is used to construct the virtual release of fish known to have arrived at the dam. Downstream detection sites are denoted D_1, D_2, and D_3.

A joint likelihood model can be constructed to estimate S_{Dam} and its variance directly by reparameterizing S_1 as a function of dam passage survival and extra-reach survival. The joint likelihood model can be generalized to multiple downstream detection locations. Model selection criteria such as AIC (Akaike information criterion) and likelihood ratio tests (LRTs) will be used to identify the best parsimonious model for describing the capture data and parameter estimates.

This virtual/paired release-recapture design was successfully implemented during spring and summer survival studies at The Dalles Dam in 2010 (Skalski et al. 2010a; b) and expanded to include studies at John Day, The Dalles, and Bonneville dams in 2011.

2.1.2 Model Assumptions

From past lessons (see Section 2.1.1) and the requirement to isolate and estimate dam passage survival, the virtual/paired-release design was chosen to best avoid major pitfalls of earlier attempts at estimating dam passage survival. Simple single release or paired-release designs alone are inadequate to isolate and validly estimate dam passage survival. Those simpler release-recapture designs violate one or more critical assumptions. However, when used together, they provide the necessary design elements to avoid major pitfalls in isolating the estimation of dam passage survival. The assumptions of the virtual/paired-release design are similar to the combined assumptions of those of the single-release design (Skalski et al. 1998) and the paired-release design (Burnham et al. 1987). The assumptions of the virtual/paired-release model are the following:

- A1. Individuals marked for the study are a representative sample from the population of inference.
- A2. All sampling events are "instantaneous." That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.
- A3. The fate of each tagged individual is independent of the fate of all others.
- A4. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.
- A5. All tagged individuals alive at a sampling location have the same probability of being detected on that event.
- A6. All tags are correctly identified and the status of smolt (i.e., alive or dead), correctly assessed.
- A7. Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segment.
- A8. Releases V_1, R_1, and R_2 experience the same survival probabilities in the lower river segments they share in common.

A9. The virtual release group is constructed of tagged fish known to have passed through the dam.

A10. All fish arriving at the dam have an equal probability of inclusion in the virtual release group, independent of passage route through the dam.

The first assumption (A1) concerns making inferences from the sample to the target population. It was for this reason, a virtual release (V_1, Figure 1) of fish known to have arrived at the face of the dam will be used in estimating dam passage survival. By allowing the tagged fish to distribute themselves as other run-of-river fish before arriving at the dam, a representative sample of fish passage distribution through the dam can be achieved. Competing designs that release fish directly in the forebay will not produce representative dam passage and would violate this assumption. To further the representativeness of the tagged fish, run-of-river fish collected at the juvenile collection facility will be used in the survival studies. The relatively small size of the JSATS micro acoustic-transmitter ($\leq$0.43 g) will also permit a large segment of the smolt population to be tagged. Length, weight, and condition factor distributions of the tagged fish will be compared to distributions for fish routinely monitored at the juvenile collection facility. As acoustic-tag sizes decrease with future advancements, the minimum fish size will decrease and the representativeness of the tagged fish will further increase.

The second assumption (A2) specifies that mortality is negligible in the immediate vicinity of the sampling stations, so that the estimated mortality is related to the river reaches in question and not the sampling event. In the case of outmigrating smolts, the time they spend in the vicinity of detection equipment is brief and short relative to the size of the river reaches in question. One place where this assumption could be violated is in the construction of the virtual release group (V_1, Figure 1). If predation occurs between fish identification and inclusion in the V_1, estimates of dam passage survival would be negatively biased.

The assumption of independence (A3) implies that the survival or death of one smolt has no effect on the fates of others. In the larger river system with tens of thousands of smolts, this is likely true. Furthermore, this assumption is common to all tag analyses with little or no evidence collected to suggest it is not generally true. Nevertheless, violations of assumption (A3) have little effect on the point estimate but might bias the variance estimate with precision being less than calculated.

Assumption (A4) specifies that a smolt's prior detection history has no effect on subsequent survival. This could be violated if smolts were physically recaptured or, as in the case of PIT-tagged fish, detections occur for only bypassed fish. The lack of handling following initial release of acoustic-tagged smolts minimizes the risk that subsequent detections influence survival. This assumption is tested using Burnham et al. (1987) tests T2 and T3, which are routinely nonsignificant in acoustic-tag studies. Assumption (A5) is satisfied by placing hydrophone arrays across the breadth of the river so that all fish, regardless of location, have the same probability of detection.

Assumption (A6) implies that the smolts do not lose their tags and are subsequently misidentified as dead or not captured, nor are dead fish falsely recorded as alive at detection locations. Dead tagged fish drifting downstream after dam passage could result in false positive detections and upwardly bias survival estimates. This is the reason why the first detection array below the dam (Figure 1) is placed considerably downriver in order to avoid such false positive detections. Releases of dead tagged fish at the dams will be used to confirm the absence of false positive detections due to fish dying during dam passage but being detected downriver. Further, if dead fish are detected at the first detection array downstream of the dam, deployment of multiple additional arrays will allow flexibility to select arrays farther downstream to ensure this assumption is not violated.

Tag loss and tag failure would also violate Assumption (A6). The possibility of acoustic-tag failure will depend on travel time relative to battery life. A systematic sample of the tags used in the survival studies will be collected. This representative sample of tags will be tested and failure times recorded in order to estimate a tag-life curve. A sample size of ≥ 50 tags will be collected and used in the tag-life studies. If separate tag lots are used in the spring and summer studies, separate tag-life studies will be required.

Assumption (A7) implies there is no synergistic relationship between survival processes in the two river segments of the first reach. In other words, smolts that survive dam passage are no more or less susceptible to mortality downriver than smolts released downriver (i.e., R_2 and R_3). This is the reason the virtual-release groups are not simply paired with tailrace release groups. Such a paired design would match inriver tag groups with a new release. While the fish in the virtual-release group would have time to express any post-release handling mortality, the fresh release group would not. The resulting discrepancy could bias estimates of dam passage survival upward. Instead, the virtual/paired-release design matches fresh releases (R_2 and R_3; Figure 1) in order for handling effects to be cancelled before adjusting the reach survival of the virtual-release group. In addition, all three release groups (i.e., V_1, R_2, and R_3; Figure 1) will pass through the two downstream reaches formed by the three below-dam hydrophone arrays. Comparison of the survival estimates through these reaches for the three release groups can therefore be used to help assess the validity of assumption (A7).

Assumption (A8) is satisfied by the inriver mixing of the release groups and can further be satisfied if the survival processes prove stable over the course of the study. Release times for the release groups will be intentionally staggered during the survival study to help facilitate the inriver mixing. Arrival times will later be examined to determine the degree of temporal mixing of release groups.

Assumptions (A9) and (A10) refer to constructing a representative sample of fish that pass through the dam. By placing the hydrophone arrays used in constructing the virtual-release groups directly at the dam face, the prospects that only live fish are included is improved. Should identified fish for the virtual release die due to predation prior to dam passage, the estimates of dam passage survival will be negatively biased. Detection rates of the forebay array need to be uniform across the dam face to insure fish passage is representatively sampled with respect to all passage routes. A double-detection array in the forebay increases detection probabilities close to 1.0 and will be used to test for homogeneous detection rates.

2.1.3 Survival Estimate

Maximum likelihood estimation will be used to estimate dam passage survival and BRZ_F-to-BRZ_T survival based on the virtual/paired-release design. The capture histories from all the replicate releases, both day and night, will be pooled for the survival analysis. This single dam passage survival estimate for the season will be compared to the BiOp performance standards. Corrections for tag-life failure will be performed as needed to obtain bias-corrected survival estimates. Tag analyses will be performed using Program ATLAS (Active Tag-Life-Adjusted Survival), which incorporates tag-life data into the analysis of release-recapture data. The software is publicly available at: http://www.cbr.washington.edu/paramest/atlas/.

The most basic model for a virtual/paired release-recapture is depicted in Figure 1. It has a minimum of three downstream detection sites needed for estimation purposes. For the virtual release (V_1), there are three downstream detection sites and $2^3 = 8$ possible capture histories. For releases R_2 and R_3, there are two downstream detection sites and $2^2 = 4$ possible capture histories. In order to directly estimate the dam passage survival parameter (S_{Dam}), the survival parameters need to be redefined as illustrated in Figure 1.

The eight capture histories (i.e., 0 denotes escape and 1, capture) associated with release V_1 and the probabilities of occurrence as follows:

History	Probability
111	$S_{\text{Dam}} S_{11} p_{11} S_{12} p_{12} \lambda_1 L_{13}$
011	$S_{\text{Dam}} S_{11} (1-p_{11}) S_{12} p_{12} \lambda_1 L_{13}$
101	$S_{\text{Dam}} S_{11} p_{11} S_{12} (1-p_{12}) \lambda_1 L_{13}$
001	$S_{\text{Dam}} S_{11} (1-p_{11}) S_{12} (1-p_{12}) \lambda_1 L_{13}$
110	$S_{\text{Dam}} S_{11} p_{11} S_{12} p_{12} (L_{12} - L_{13}\lambda_1)$
010	$S_{\text{Dam}} S_{11} (1-p_{11}) S_{12} p_{12} (L_{12} - L_{13}\lambda_1)$
100	$(1-S_{\text{Dam}} S_{11}) + S_{\text{Dam}} S_{11} \left[(1-L_{11}) + (1-p_{11}) \left(L_{11} - S_{12} L_{12} + S_{21} (1-p_{12}) (L_{12} - \lambda_1 L_{13}) \right) \right]$
000	$1 - \sum \text{others}$

The four capture histories associated with release R_2 and the probabilities of occurrence are as follows:

History	Probability
11	$S_{11}S_{21}p_{22}\lambda_2 L_{23}$
01	$S_{11}S_{21}(1-p_{22})\lambda_2 L_{23}$
10	$S_{11}S_{21}p_{22}(L_{22}-L_{23}\lambda_2)$
00	$(1-S_{11}S_{21})+S_{11}S_{21}\left[(1-L_{22})+L_{22}(1-p_{22})-L_{23}(1-p_{22})\lambda_2\right]$

The four capture histories associated with release R_3 and the probabilities of occurrence are as follows:

History	Probability
11	$S_{21}p_{32}\lambda_3 L_{33}$
01	$S_{21}(1-p_{32})\lambda_3 L_{33}$
10	$S_{21}p_{32}(L_{32}-L_{33}\lambda_3)$
00	$(1-S_{21})+S_{21}\left[(1-L_{32})+L_{32}(1-p_{32})-L_{33}(1-p_{32})\lambda_3\right]$

The parameters L_{ij} are the probabilities of an acoustic tag being active for release i at detection site j estimated from the tag-life study (see Section 2.3). The joint likelihood model for the virtual/paired-release design can then be written as follows:

$$L=\binom{V_1}{\underset{\sim}{l}}\prod_{j=1}^{8}P_{1j}^{l_{1j}}\cdot\binom{R_2}{\underset{\sim}{m}}\prod_{j=1}^{4}P_{2j}^{m_{2j}}\binom{R_3}{\underset{\sim}{n}}\prod_{j=1}^{4}P_{3j}^{n_{3j}} \tag{4}$$

where P_{ij} = probability of occurrence for the jth capture history for the ith release group,

l_{1j} = number of fish with capture history j for the first release group (V_1),

m_{2j} = number of fish with capture history j for the second release group (R_2),

n_{3j} = number of fish with capture history j for the third release group (R_3).

Model parsimony may be obtained by equating $p_{12}=p_{22}=p_{32}$ and/or $\lambda_1=\lambda_2=\lambda_3$ if supported by the capture data. Survival probabilities S_{12} and S_{21}, while over the same reach, will not be equated because of possible differences in survival between in-river and freshly released fish.

One advantage of the virtual/paired-release design is that fish from all upstream releases are potentially available to help form the virtual release at the dam face. This means sample sizes for V_1 (Figure 1) could increase beyond those initially estimated for a single dam study.

However, fish from different release locations will have spent different times in river with different probabilities of tag failure. In these circumstances, the joint likelihood model (4) will be expanded to include the multiple upstream releases contributing to the V_1 group. These releases will have different tag-life corrections but share common downstream detection probabilities and reach survivals through the study area. Program ATLAS can be used to test these assumptions and equate parameters if homogeneity has been demonstrated. Correction for tag failure will follow the methods in Townsend et al. (2006) extended to multiple release groups.

Asymptotic 95% confidence intervals for dam passage survival will be calculated as

$$\hat{S}_{\text{Dam}} \pm 1.96\sqrt{\widehat{\text{Var}}\left(\hat{S}_{\text{Dam}}\right)}. \tag{5}$$

2.1.4 Tests of Assumptions

Burnham et al. (1987) Tests. Tests 2 and 3 of Burnham et al. (1987) can be used to assess whether upstream detection has an effect on downstream survival. These tests are most appropriate when fish are physically recaptured or segregated during capture as in the case with PIT-tagged fish going through the juvenile bypass system. However, acoustic-tag studies do not use physical recaptures to detect fish. Consequently, active-tag studies rarely, if ever, result in significant tests T2 and T3 beyond expected α levels of occurrence. Furthermore, the very high to nearly complete detection probabilities result in data often too sparse to analyze using Burnham tests 2 and 3. For this reason, they are not scheduled to be used.

Tests of Mixing. Chi-square tests of homogeneity can be used to test whether release groups V_1, R_2, and R_3 are mixed upon arrival at downriver detection sites. A contingency table test of homogeneous arrivals over time can be constructed of the form

Day of Detection	V_1	R_1	R_3
1			
2			
3			
⋮			
⋮			
D			

Typically, such chi-square tests are very sensitive to departures from homogeneous arrival distributions and are most often significant, even in the best of circumstances. Graphs of cumulative arrival distributions are therefore more useful in detecting systematic and meaningful departures from mixing.

Test of Tagger Effects. The effects of tagging and handling smolts by different taggers may not be manifested until sometime after release. To avoid biasing studies, tagging efforts by the tagging crews must be homogeneous across release groups used in the virtual/paired-release studies. Two different analyses may be used to help assure differential post-release handling mortality is not affecting study results.

First, analyses will be performed to evaluate whether the proportions of fish tagged by different taggers are similar across release groups. Chi-square R × C contingency table tests can be used to test for significant departures from homogeneity. Second, single release-recapture models can be run on the fish from different taggers to determine whether reach survivals may be affected.

An F-test can be used to test for homogeneous survival of the form

$$F_{k-1,\infty} = \frac{s_{\hat{S}_i}^2}{\left[\frac{\sum_{i=1}^{k} \widehat{\mathrm{Var}}\left(\hat{S}_i \middle| S_i\right)}{k}\right]} \tag{6}$$

where

$$s_{\hat{S}_i}^2 = \frac{\sum_{i=1}^{k}\left(\hat{S}_i - \bar{\hat{S}}\right)^2}{(k-1)},$$

k = number of replicate survival estimates,

$\widehat{\mathrm{Var}}\left(\hat{S}_i \middle| S_i\right)$ = estimated sampling variance for the ith estimate of survival $(i = 1, \ldots, k)$.

Reduced survival estimates compared to other taggers over multiple reaches and/or multiple release groups would indicate tagger effects. Should tagger effects be found to exist at a level that could lead to a biased result, all fish tagged by poor taggers will be eliminated from the survival analysis to avoid bias.

Test of Tag Lot Effects. The thousands of tags used in these survival studies will not necessarily be produced in a single manufacturing lot. Although QA/QC steps during manufacturing are meant to maintain strict standards, there is always the possibility of tag quality and operational performance differences between tag lots. These differences could bias the survival estimates in varying ways depending on how the tags are distributed between release groups. In order to avoid such problems, all tag lots used in the study will be made available before the study commences in order to evenly mix lots between release groups over time and locations. This mixing will also help assure the tags drawn for the tag-life study are representative of the population of tags used in the investigations. Separate tag lots will be used for the spring and summer studies, along with separate tag-life investigations. Reach survivals will be compared between tag lots using the F-test of homogeneity [Equation (6)] or LRTs. Should malfunctioning tag lots be identified, they will be excluded from the survival estimation.

Testing for Tag Effects. Handling and tagging can affect fish regardless of the type of tags being used. Surgical protocols and miniaturization of tags have as their goals to minimize such effects. Nevertheless, effects may occur. A release-recapture design, which is robust to tag effects, can help to minimize remaining problems. For example, paired designs are more robust to tag effects than single release-recapture models when estimating reach survival. It is commonly assumed that first-order tag effects cancel when the ratio of survival estimates is used to calculate reach survival.

In the virtual/paired-release design, tag effects can enter the model through either the virtual release (V_1) or the paired releases (R_2 and R_3). Any post-release tag effects will depress the reach survival estimates derived from the virtual releases, which will, in turn, negatively bias estimates of dam passage survival. Careful attention to tagging and handling protocols will be necessary to help minimize or eliminate such biases. Virtual releases may be composed of fish from multiple upriver release locations with varying times inriver. Reach survivals will be compared between fish from different release locations for any indications of time-dependent tag effects (Table 1). An F-test of homogeneous survival [Equation (6)] will be used to compare reach survivals on a row-by-row basis in Table 1. Should heterogeneity be detected as a function of time inriver, those release groups will be eliminated when forming a virtual release.

The paired releases R_2 and R_3 below the dam may also experience tag and handling effects. However, the release times will be only hours apart, such that any effects should be very similar between upstream (R_2) and downstream (R_3) releases. Nevertheless, the reach survivals can be compared as the fish move through the multiple downstream arrays on their way to the ocean to determine where and when tag effects have been equally expressed. Likelihood ratio tests of homogeneous survival will be used to assess whether the planned secondary and tertiary arrays for the survival analyses are sufficiently farther downriver for tag effects to have been equally expressed. If not, the tests of homogeneity will be used to select other downstream arrays where the model assumptions have been met. The array selection will be based on the first reach where survivals become homogeneous.

Table 1. Example of replicate estimates of reach survival (S_{1i}) from multiple tag groups used in constructing the virtual releases (V_1). F-test of homogeneous survival performed on a row-by-row basis used to identify any latent effects of tagging.

	Release				
Reach	1	2	...	k	F-test
1	$\hat{S}_{11}$	$\hat{S}_{12}$	$\cdots$	$\hat{S}_{1k}$	$F_{k-1,\infty}$
2	$\hat{S}_{21}$	$\hat{S}_{22}$	...	$\hat{S}_{2k}$	$F_{k-1,\infty}$
3	$\hat{S}_{31}$	$\hat{S}_{32}$	...	$\hat{S}_{3k}$	$F_{k-1,\infty}$
$\vdots$	$\vdots$	$\vdots$		$\vdots$	$\vdots$
m	$\hat{S}_{m1}$	$\hat{S}_{m2}$		$\hat{S}_{mk}$	$F_{k-1,\infty}$

2.2 Fish Accord Performance Measures

The design configuration depicted in Figure 1 illustrates the design elements needed to estimate dam passage survival. This configuration must be augmented, however, to permit estimation of the other performance measures (Figure 2). Added to the basic design will be hydrophone arrays at the forebay and tailrace BRZs. In addition, more hydrophones will be located in the forebay to permit 3D tracking of smolts in the immediate vicinity of the dam (i.e., ≤ 100 m upstream).

2.2.1 Spill Passage Efficiency (SPE)

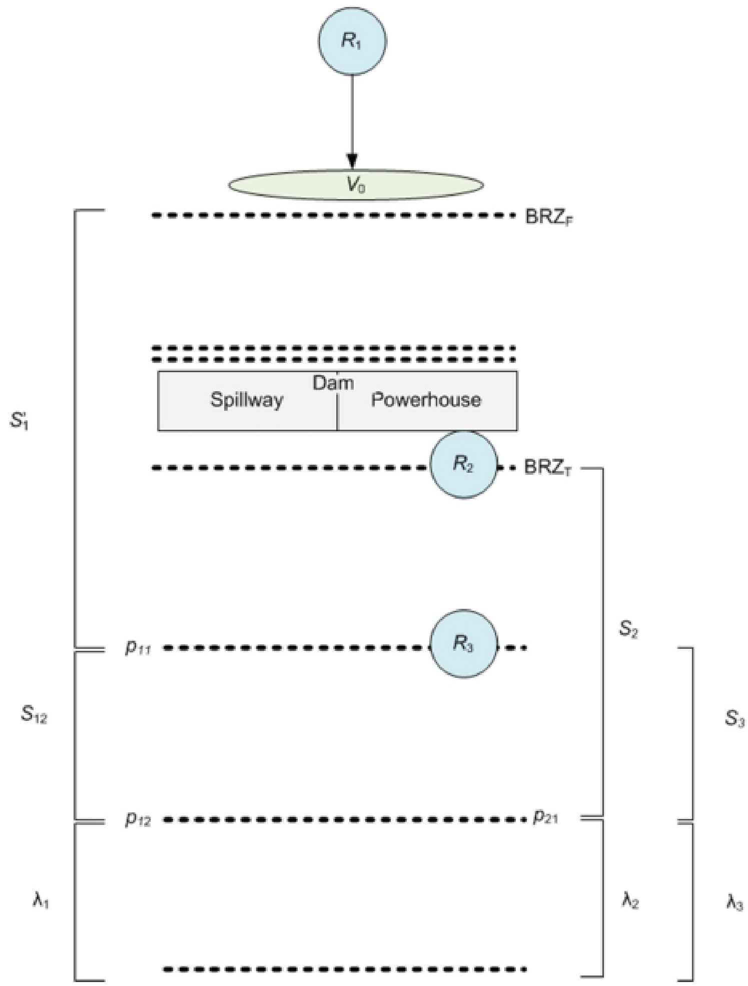
Using fish known to have passed through specific routes (e.g., spillway, powerhouse, sluiceway, etc.), estimates of route-specific passage proportions can be calculated using the data from the double forebay arrays in front of the dam. The double detection data will be used to estimate the absolute abundance (N) of tagged smolt passage through the various routes. Define for any particular passage route the following variables:

n_{10} = number of tagged smolts detected at the first array but not the second,

n_{01} = number of tagged smolts detected at the second array but not the first,

n_{11} = number of tagged smolts detected at both the first and second arrays.

From these counts of smolt with various route-specific detections histories, absolute passage abundance $(\hat{N})$ of tagged smolts will be estimated as



BRZ_F-to-BRZ_T survival estimate: $\hat{S}_{B-B} = \dfrac{\hat{S}_1'}{\left(\dfrac{\hat{S}_2}{\hat{S}_3}\right)} = \dfrac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2}$

Figure 2. The minimum design configuration to estimate forebay BRZ (boat restricted zone)-to-tailrace BRZ survival, forebay delay, tailrace egress, and spill passage efficiency.

$$\hat{N} = \frac{(n_{10} + n_{11} + 1)(n_{01} + n_{11} + 1)}{(n_{11} + 1)} - 1$$

or

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(n_{11} + 1)} - 1 \tag{7}$$

where $n_1 = n_{10} + n_{11}$ and $n_2 = n_{01} + n_{11}$ with associated variance estimate (Seber 1982:60)

$$\widehat{\mathrm{Var}}\left(\hat{N}\right) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - n_{11})(n_2 - n_{11})}{(n_{11} + 1)^2 (n_{11} + 2)}. \tag{8}$$

The estimated probability of detection (p_1) in the first array is calculated as

$$\hat{p}_1 = \frac{n_{11}}{n_2},$$

and the probability of detection (p_2) at the second array as

$$\hat{p}_2 = \frac{n_{11}}{n_1}.$$

The overall probability of a smolt being detected in the double array system is estimated as

$$\hat{P} = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2) = \frac{n_{11}(n_1 + n_2 - n_{11})}{n_1 n_2}.$$

Passage abundance will be estimated for each route at the dam.

Consider a project with k different passage routes, including a spillway. The spill passage efficiency would be estimated as

$$\widehat{\mathrm{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \sum_{i=2}^{k} \hat{N}_i}. \tag{9}$$

Using the delta method (Seber 1982:7-9), the variance of $\widehat{\mathrm{SPE}}$ can be approximated by

$$\mathrm{Var}\left(\widehat{\mathrm{SPE}}\right) = \widehat{\mathrm{SPE}}^2 \left(1 - \widehat{\mathrm{SPE}}\right)^2 \left[\frac{\mathrm{Var}\left(\hat{N}_{SP}\right)}{\hat{N}_{SP}^2} + \frac{\sum_{i=2}^{k} \mathrm{Var}\left(\hat{N}_i\right)}{\left(\sum_{i=2}^{k} \hat{N}_i\right)^2} \right], \tag{10}$$

where $\hat{N}_{SP}$ = estimated abundance of tagged fish through the spillway.

According to the 2008 Columbia Basin Fish Accords, SPE includes fish passage through surface flow outlets. The SPE calculations will be adjusted accordingly, depending on site- and year-specific conditions.

2.2.2 Forebay Residence Time

Using the double hydrophone array upstream of the dam and additional hydrophones placed in the forebay, acoustic-tagged fish will be tracked in three dimensions within 100 m of the dam face. Their excursion times within the 100-m zone will be used to estimate average (and median) time in the forebay, or forebay residence time.

2.2.3 Tailrace Egress

The double array at the face of the dam and the hydrophone array at the tailrace BRZ will be used jointly to estimate tailrace egress time. Times of passage will be calculated from the last time a tagged smolt is detected at the dam face to the time of passage at the tailrace BRZ. Mean and median tailrace egress times will be calculated for all smolts with joint detections at the upstream and downstream arrays.

2.2.4 BRZ_F-to-BRZ_T Survival

The approach to estimating BRZ_F-to-BRZ_T survival will be exactly analogous to that used to estimate dam passage survival. Instead of using a virtual release group constructed of fish known to have arrived at the dam face, a virtual release group will be constructed of fish known to have arrived at the forebay BRZ hydrophone array. The two tailrace release groups will be the same ones used in estimating dam passage survival. Because of the similarity between estimation approaches for dam passage survival and BRZ_F-to-BRZ_T survival, the statistical model will not be redescribed.

2.3 Tag-Life Study

In order to produce the tag-life-adjusted survival estimates, an independent tag-life assessment study must be conducted concurrent with the compliance testing studies. Typically, this will mean at a minimum separate tag-life studies for each of the spring and summer compliance test periods. If yearling Chinook salmon and steelhead are sharing the same tag lot(s), a single tag-life study may be adequate for both species. A minimum of 50 tags should be systematically sampled directly from the tags used in the studies. If multiple tag lots will be used during the course of either the spring or summer investigations, it might be necessary to conduct separate tag-life studies for each lot. The decision to test separate tag lots may depend on the variability and the production history of the tag vendor. At a minimum, the various tag lots need to be represented proportionately to their use in the tagging study. In expectation, this should occur if the tags are systematically withdrawn during the tagging process for purposes of the tag-life study.

Program ATLAS will be used to model the tag-life survivorship of the acoustic tags using either a Weibull model (2 or 3 parameters) or the vitality model of Li and Anderson (2009) (3 or 4 parameters), whichever is most appropriate. The fitted curve will be used to estimate the probability an acoustic tag is active upon arriving at a detection site (see Section 2.1.3).

3.0 Sample Size Calculations

A requirement of the acoustic-tag compliance studies is to estimate dam passage survival with a precision of ± 0.03. In general, the absolute error in estimation should be less than ε, $(1-\alpha)$ 100% of the time, where

$$P\left(\left|\hat{S}-S\right|<\varepsilon\right)\geq 1-\alpha \tag{11}$$

Precision, as defined above and in the statistical literature (Cochran 1977:75-76,77-78; Williams 1978:219; Snedecor and Cochran 1989:58; Thompson 1992:31-32; Levy and Lemeshow 1999:70-74; Williams et al. 2002:64), is then translated to

$$\varepsilon = Z_{1-\frac{\alpha}{2}}\,\mathrm{SE}\left(\hat{S}\right).$$

In terms of BiOp specifications,

$$0.03 = 1.96\,\mathrm{SE}\left(\hat{S}\right),$$

and leading to $\mathrm{SE}\left(\hat{S}\right) = 0.0153$, say, a standard error of 0.015. The resultant 95% confidence intervals for dam passage should have a half-width ≤ 0.03.

Sample size calculations focused on the release sizes R_1, R_2, and R_3 (Figure 1) needed to obtain a SE ≤ 0.015. In performing the sample size calculations, the minimum detection configuration of three downstream arrays was assumed as depicted in Figure 1. Calculations were based on estimates of the survival and detection probabilities likely to be encountered during a study. These estimates were either based on historical values observed from other acoustic-tag studies or best guesses based on professional experience. In some instances, best and worst case estimates of input parameters were used to bracket uncertainty. For Ice Harbor Dam, the survival and detection parameter values used in the sample size calculations are summarized in Figure 3 and Figure 4 for spring and summer studies, respectively.

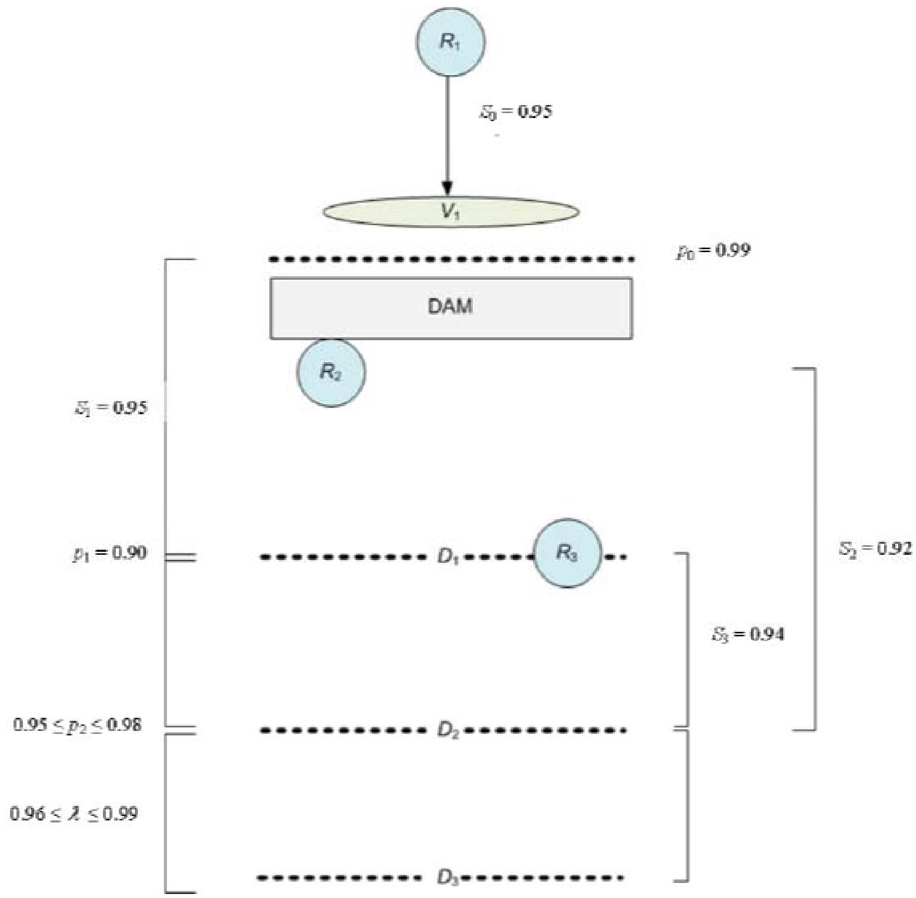


Figure 3. Range in survival (S) and detection (p) probabilities used in the sample size calculations for yearling Chinook salmon and steelhead smolts at Ice Harbor Dam.

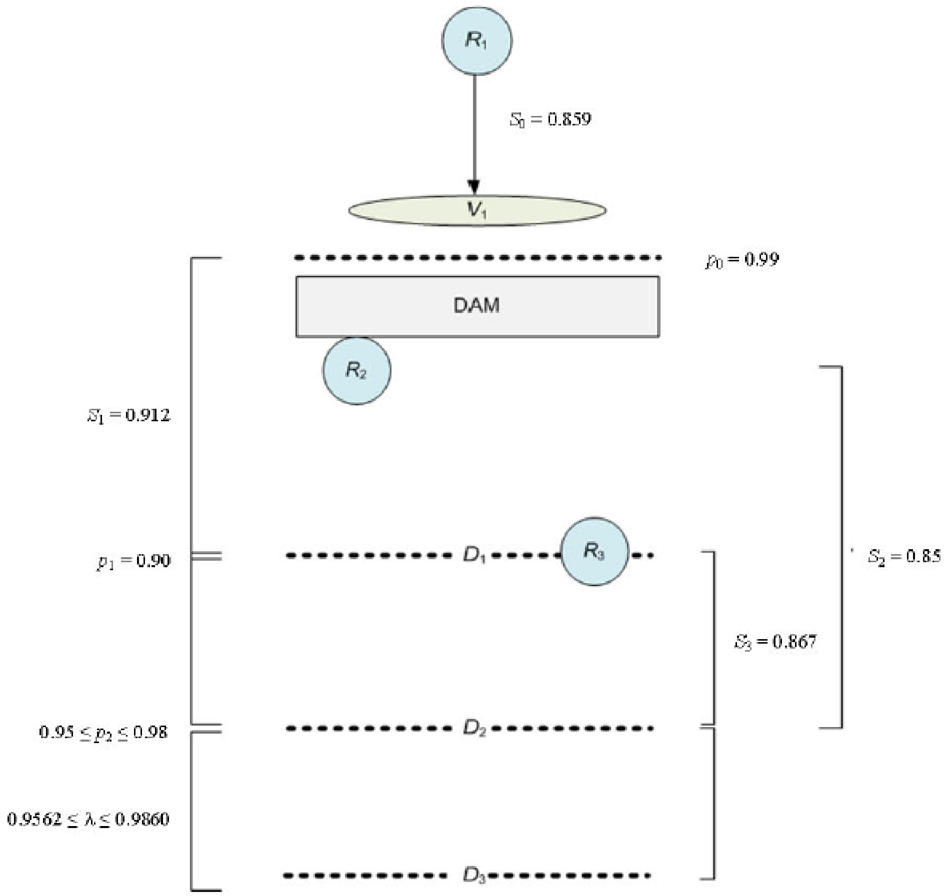


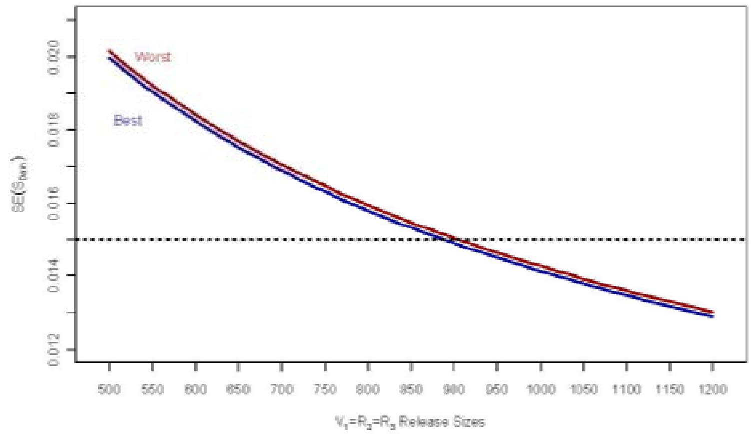
Figure 4. Range in survival (S) and detection (p) probabilities used in the sample size calculations for subyearling Chinook salmon smolts at Ice Harbor Dam.

Using Program SampleSize (http://www.cbr.washington.edu/paramest/samplesize), the anticipated size of the SE for the estimate of dam passage survival was calculated over a range of release sizes $V_1 = R_2 = R_3$ for survival and detection probabilities reported in Figure 3 for yearling Chinook salmon and steelhead and Figure 4 for subyearling Chinook salmon. It was assumed yearling Chinook salmon and steelhead would have comparable survival and detection probabilities. Sample size curves of SE vs. release size under best and worst case scenarios are presented in Figure 5 for spring and summer test species.

Recommended release sizes (i.e., R_1, R_2, and R_3) were based on averaging best and worst case sample sizes needed to obtain an SE = 0.015, then inflating that value by 25% (e.g., 1.25 multiplier) to account for unanticipated events, poor luck, and incorrect inputs to the sample size calculations. For Ice Harbor Dam during spring, this meant $R_2 = R_3 = 1120$ and $R_1 = 1120/(0.95*0.99) = 1192$. To determine the release size R_1, the calculated value for V_1 must be adjusted for the probability of a fish from R_1 being used in the construction of the virtual release group V_1.

Hence, total number of acoustic-tagged fish needed for a Ice Harbor spring compliance tests is 3432 (= 1120 + 1120 + 1192) for each of the yearling Chinook salmon and steelhead stocks (Table 2). For the summer subyearling Chinook salmon study, a total of 6851 tags are projected (Table 2). Therefore, a three-species set of tests at Ice Harbor Dam would require a total of 13,715 (=3432 + 3432 + 6851) fish in any one year.

a. Yearling Chinook salmon and steelhead



b. Subyearling Chinook salmon

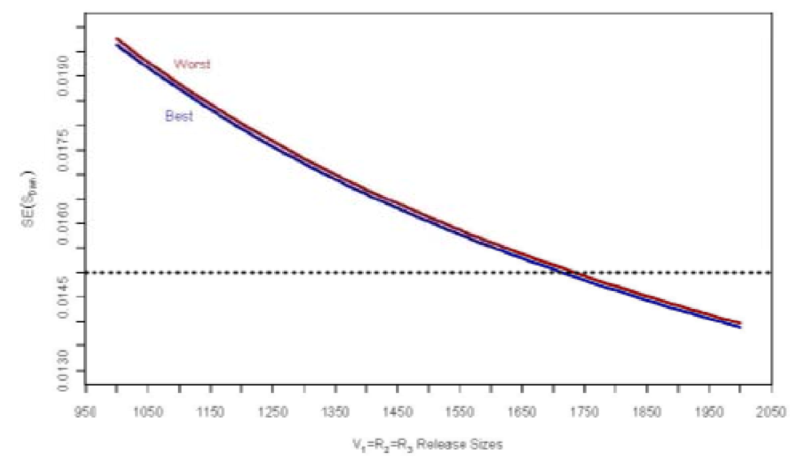


Figure 5. Sample size curves for releases $V_1 = R_2 = R_3$ vs. anticipated standard error (SE) for the estimate of dam passage survival at Ice Harbor Dam for (a) yearling Chinook salmon and steelhead and (b) subyearling Chinook salmon smolts. The best and worst case scenarios are based on the anticipated range in survival and detection probabilities depicted in Figure 3 and Figure 4, respectively.

Table 2. Calculated sample sizes for releases R_1, R_2, and R_3 (Figure 1) based on best and worst case scenarios of survival and detection probabilities (Figure 3, Figure 4) for compliance testing at Ice Harbor Dam to achieve a standard error ≤ 0.015 by fish stock. Recommended values based on 1.25 × [(Best and worst case)/2].

Stock	Release	Best Case	Worst Case	Recommended
Yearling Chinook Salmon, Steelhead	R_1	945	962	1,192
	R_2, R_3 each	888	904	1,120
			Test Total	3,432
Subyearling Chinook Salmon	R_1	2,017	2,041	2,537
	R_2, R_3 each	1,715	1,735	2,157
			Test Total	6,851
			Three Species Total	13,715

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Appendix 3.0

Methods for surgically implanting and attaching JSATS tags for biological studies (Axel et al. 2011)

Surgical Protocols for Implanting JSATS Transmitters into Juvenile Salmonids for Studies Conducted for the U.S. Army Corps of Engineers

Version 1.0

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Table of Contents

1. Introduction

Biotelemetry has become a standard tool in the Columbia River to assess behavior and survival of downstream migrating anadromous salmonids. Use of passive integrated transponder (PIT) tags as well as radio telemetry (RT) has been common in the Columbia Basin (see Skalski et al. 1998; Bickford and Skalski 2000; Hockersmith et al. 2003). Technological advances have improved the capacity and reliability of these methods, but each has inherent limitations. For example, radio signals used for aquatic telemetry (e.g. 30 to 300 MHz range) are attenuated proportionally with water depth, making signals difficult to detect if fish are relatively deep (>15 to 20 ft). In salt water, radio signals are attenuated at an even greater rate because of the associated conductivity. Radio telemetry transmitters also typically incorporate an external antenna which may affect swimming behavior and long term survival of small fish. Alternatively, acoustic signals (30 to 500 Hz) travel well through fresh and saltwater, their transmitters do not require an external antenna, and this technology provides the potential for three-dimensional positioning. In an effort to create an effective and affordable salmon research tool, the U.S. Army Corps of Engineers (USACE) has developed an acoustic telemetry system for use with juvenile salmon evaluations within the Federal Columbia River Power System (FCRPS). The juvenile salmon acoustic telemetry system (JSATS) is being used in many parts of the FCRPS system for juvenile salmon evaluations and shows promise for use with other species and life stages. As use of JSATS expands, efforts to coordinate and standardize methods among research groups will be critical to maintain the quality and comparability of data that are collected. Subsequently, there is a need to develop surgical procedures for the intraperitoneal implantation of transmitters in fish while maintaining welfare status and ensuring that tagged fish are representative of untagged conspecifics.

To provide oversight of these protocols a Surgical Protocol Steering Committee has been formed consisting of research scientists from within the Columbia River Basin. The protocols described in this document are intended to provide strict guidelines as to how research fish utilized in Andromous Fish Evaluation Program (AFEP) funded passage and survival studies should be handled throughout the collection, tagging, and holding process prior to release. Surgical protocols documented here were established based on a thorough review of the scientific literature, current research, group discussions among experts in the field of biotelemetry and fish physiology and a consensus of the Steering Committee. As such, protocols that require the use of specified materials or techniques are not subject to change without discussion and consent of the Steering Committee prior to the start of the research field season. Anticipated or planned deviations from these protocols should be presented to the Surgical Protocol Steering Committee at least 90 days in advance of the research field season. Information pertaining to changes should be prepared and presented to the committee allowing for time to review and discuss proposed changes. Based on the discussion and decision of the Steering Committee, a waiver for deviation from a given protocol may be granted. This deviation shall be clearly documented in the Methods section of the annual research report. All waivers, granted and denied (and reasons for denial) will be documented by the Steering Committee for future reference.

The Surgical Protocol Steering Committee recognizes that unplanned issues and challenges are inherent to all scientific research therefore other protocols were established to allow for flexibility on the part of individual researchers. These protocols are intended to function more as guidelines however every effort should be made to follow protocols where practical. When possible a project lead should attempt to get a waiver from the Steering Committee by emailing its members prior to making any changes. In the event that this is not possible the USACE point of contact, Steering Committee members, and other affected researchers should be notified as soon as practical. All deviations from these protocols shall be documented and reported in the Methods section of the annual research report.

Similar documents that standardize other aspects of JSATS research (i.e. receiver deployment, data structure and processing methods, etc.) are in development. These are intended to be living documents. We anticipate that this document will be regularly updated as improvements to surgical techniques are developed, more data become available on current techniques, or logistical challenges associated with execution of these protocols are encountered. The scientific literature review and the most recent version of this document can be found under the AFEP Final Report/FCRPS section at

http://www.nwp.usace.army.mil/environment/home.asp

2. Pre-surgical Handling

Fish collection

In most cases juvenile salmonids *Oncorhynchus spp*. to be used for biotelemetry studies will be collected from juvenile fish facilities at USACE operated hydroelectric dams on the Columbia and Snake rivers. Dams with fish collection capabilities include Bonneville, John Day, McNary, Ice Harbor, Lower Monumental, Little Goose and Lower Granite dams. Fish may also be tagged at regional hatcheries when large numbers of study animals are needed in a short period of time or when potential impacts to wild fish need to be minimized.

While current ESA permitting requires that fish be held at dams for no more than 48 hrs by the COE before being released or transported, it is possible for fish to hold behind screens or in gatewells for extended amounts of time before arriving at juvenile facilities (Beeman and Maule 2001; Axel et al. 2002)[1,2]. Researchers should be aware of these potential delays when fish are being processed for telemetry programs.

Pre-surgical holding

The pre-surgery holding time starts once the group of fish to be tagged has been collected and the fish are considered in the possession of the researcher. Researchers should plan tagging operations so that the pre-surgery holding time is about 24 hr, plus or minus 6 hr (18 to 30 hr). Twenty-four hrs is believed sufficient to allow physiological recovery from the collection and sorting process and to allow for gut evacuation and for standard dynamic action to at least partially subside, but not too long so as to incur additional holding stress (Oldenburg et al. *In press*). Researchers should be aware that collection time prior to the start of pre-surgery holding can be up to 48 hrs, depending on fish abundance, and should plan accordingly to tag fish as quickly as possible. If fish are collected at a hatchery or other location where they are typically fed, food should be withheld for 24 h prior to tagging.

[1] Axel et al. (2002) reported median residence times in gatewells at McNary Dam for subyearling Chinook salmon smolts at McNary Dam were 2.6 to 8.6 hrs, median collection channel travel times were 4.5 to 10.5 minutes, and that time in gatewells represented 90 to 98% of time to transit the bypass system.
[2] Beeman and Maule (2001) reported median residence times in gatewells were 8.9 hr for Chinook salmon and 3.2 hr for steelhead, making up 83% and 96% of total transit times.

A tagging session can take from <1h to 12 hrs, from first to last fish, depending on the number of fish to be tagged and the structure and size of the tagging crew. Total surgery time begins (and pre-surgical holding ends) when the first fish is anesthetized for tagging. Post-surgical holding should generally be 24 hrs with an allowable range of 18 to 36 hrs. The post-surgical time begins (surgery time ends) when the last fish has been tagged and has been placed into the recovery container. ***Researchers should target total holding time, from researchers taking possession of fish to release (or loading onto a barge for transport studies) of around 72 hrs.***[3] Researchers should document total pre-surgical hold time, overall surgical time (from first fish in the knock-down anesthetic to the last fish placed into recovery container) and post-surgery holding times for each tagging group.

Note, surgical time for each fish is individually tracked (see below) and is a separate time measure than the total surgery period described here.

Exemptions from these protocols may be sought from the Steering Committee if a study design requires large release groups, or if fish abundances are low, such that more than one day of tagging is required to be pooled into one release group, requiring that some fish may have total holding time greater than 72 hrs. See above for description on how to obtain waivers from these protocols.

Holding conditions

Factors such as holding conditions, containers used, and distance of holding containers from tagging facility/trailer will vary by project. Typically, fish are transferred from the holding area to tanks at the collection location, then moved from these tanks to an anesthetic container. Researchers shall strive to reduce the number of times that fish are transferred and handled using equipment and methods that maximize water-to-water transfer. Environmental conditions should be as optimal as possible to reduce stress and maintain fish health prior to, during, and following surgery; these include:

- The water source for holding fish shall be river water where possible or well water if tagging/holding fish at a hatchery; treated water (i.e. tap water) shall never be used to hold fish.
- Dissolved oxygen shall be maintained at 80-110% saturation in continuous flow-through tanks (ideally) or by adding oxygen from an aeration system or via oxygen tanks through air stones in static tanks.
- Total dissolved gas levels shall be maintained below 105%. De-gassing columns can be used as needed to reduce gas levels.
- Water temperature deviations shall be less than 2°C from ambient.
- Maximum water temperature limits for handling and tagging operations are generally set by USACE and NOAA Fisheries in the Fish Passage Plan[4] and collection/scientific permits.
- Fish shall be held in dark and covered tanks when possible (provide shading at minimum) and only dark containers (i.e. buckets) should be used.
- Holding densities should be less than 50g/L for all container types.

Researchers shall monitor and record water temperatures at regular intervals (i.e. Hobo temperature loggers recording at least hourly) and dissolved oxygen periodically, and appropriate steps

[3] Congleton and Wagner (2006) demonstrated that blood chemistry indicators of fish nutritional state (plasma proteins, lipids, ALP, etc.) significantly declined in Chinook salmon smolts after 7 to 14 days of fasting. After 3 days of fasting (hatchery Chinook salmon only) blood-chemistry variables were measurably lower (e.g. 3.65 vs. 3.35 g/dl plasma protein) for fasted fish, but no comparison was statistically significant.
[4] See: http://www.nwd-wc.usace.army.mil/tmt/documents/fpp/2008/index.html

shall be taken prior to reaching threshold levels. Precautions should be made by researchers to monitor water conditions appropriate to risks. For example, pumped water supplies may be more prone to interruption than gravity feed and should involve closer monitoring. Monitoring water quality overnight shall be considered if it is determined that the water supply is not reliable. Researchers shall document water quality conditions in their report if temperature or dissolved oxygen falls outside acceptable ranges as described above so this information can be taken into consideration when data are used later.

3. Surgical technique and materials

Fish collection and pre-sorting

Fish used for studies are usually collected at juvenile bypass facilities by non-research personnel and possibly research project designated assistants. It is important that study fish be representative of the untagged population. Selection of fish at this stage by non-researchers should be based solely on species and age/size group required for the study to avoid the chance that fish may be high-graded prior to coming into possession of research teams. Extra fish should be collected to insure that the researcher has the required number of fish needed in case some fish are rejected during the sorting/tagging process.

Fish sorting

Once researchers take possession of fish, the period of holding begins. Total time from this point until tagged fish are release should not exceed 72 hrs (see above). Fish shall be inspected prior to surgery and shall be excluded from the study group if one of the following conditions exists;

- Health or condition of the fish is poor to the point that short-term survival is questionable. These conditions include;
  - Greater than 20% descaling
  - Significant injury (open wound, significant deformity, bleeding)
  - Missing or mostly missing opercles.
  - Fungus
  - Moribund from existing disease (such as bacterial kidney disease or gas bubble trauma)
- Fish that are already tagged other than coded-wire-tag (CWT).
- Fish that are too small-- *< **95 mm fork length.***

The total numbers and percent of fish rejected and reason for rejection for the study shall be documented in report appendices. The goal is 1% or lower rate of rejection over the course of a study. This goal does not include surplus fish collected above those needed for tagging. A rejection rate or holding mortality approaching or exceeding 1% for 2-5 d should be an indication of a chronic problem and researchers should discuss with appropriate USACE personnel on whether tagging should proceed.

Anesthetizing fish

MS-222 (tricaine methanesulfonate) is the anesthetic selected for tagging juvenile salmon. All precautions for use as noted in material safety data sheets (MSDS) shall be followed by researchers, in particular, when handling the drug in its crystalline powder form.

- Powdered MS-222 should be stored in a secure location (i.e. to limit potential exposure during day-to-day operations) and refrigeration is recommended.
- It is recommended that researchers make a stock solution[5] in amounts that can be used within one week (i.e. make fresh weekly).
- Stock solution should be stored in dark bottles since the chemical degrades in sunlight.

Recommended dosage for knock-down anesthesia is 60-80 mg/L. Researchers should adjust dosage as needed to ensure fish lose equilibrium (stage 4 anesthesia; Summerfelt and Smith 1990) within 2 to 3 minutes after being placed into the knock-down solution. Fish should be kept in anesthesia for an additional 30 to 60 seconds to assure they are sufficiently sedated for surgery.

MS-222 anesthesia solutions should be buffered with sodium bicarbonate. Typically researchers use a stock solution[5] with buffer added to anesthesia container just prior to use[6]. It is best if this buffer is stored in same location as stock anesthesia.

A mucus protecting water conditioner (e.g. 'Stress Coat', 'Poly Aqua') should be used in knock-down and, if necessary, recovery containers (and used to coat all surfaces fish may come in contact, see below) according to manufactures directions.

Water quality (temperature and D.O.) should be same as for holding requirements. Anesthesia water should be changed before the temperature exceeds ± 2°C from ambient water temperature and dissolved oxygen levels should be at 80-110% of saturation at all times.

All fish transfers shall be water-to-water using sanctuary nets (or in small containers) so fish are always submerged.

Digital timers should be used to help track the time that individual/batches of fish are anesthetized.

Any fish inadvertently exposed to knock-down anesthesia for 10 minutes or more (includes total time in anesthesia, including time to weigh and measure fish prior to transfer to surgical cradle) should be censored from the study, allowed to recover and released.

Surgeries

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[5] Example; 100 g MS222 powder to 1 L of water. 8 ml of stock solution in 10 L water = 80 mg/L concentration. Use same recipe for buffer (100 g in 1 L water) and add equal amount as MS222 stock solution used.

[6] Mixing MS222 and buffer stock solutions prior to use will cause precipitate to form.

Fish shall be held ventral side up in a rubber or foam cradle and kept moist with water and water conditioner. During surgery, a maintenance dose of anesthesia between 16-40 mg/L should be delivered to the fish through a soft tube placed in the fish's mouth. Each surgeon shallhave access to 2 sources of water: fresh water and water dosed with 40mg/L MS-222. The two water sources should be fitted with valves that feed into hoses. The two hoses should converge and attach to the tube placed in the fish's mouth. The surgeon can determine the mixture of anesthesia and freshwater throughout the duration of the surgery by adjusting the valves for the two water containers. The water supplied to the fish during surgery shall be oxygen saturated and the temperature should be within ±2°C of ambient.

The posterior aspect of the incision shall be 3 to 5 mm anterior to the pelvic girdle. The incision should be made on the linea alba and shall be no longer than is necessary to easily insert the tag, ~6-8 mm. The incision location and size are critical. An incision placed too far posterior risks injury to the pelvic girdle. Conversely, placing the incision too far forward and/or making the incision too long risks injury to internal organs. Training on this procedure will need to be closely monitored.

Following insertion of the transmitter and PIT tag (if used), the incision is closed using two simple interrupted stitches using 5-0 monofilament (e.g. Ethicon Monocryl) suture material with attached needle (tapered or reverse cutting). Stitches shall be secured using a knot consisting of four single-wrap throws in alternating directions.

Fish shall be placed into a recovery container immediately following suturing and observed until they have recovered equilibrium. Fish that have not recovered equilibrium (as noted at the last point they can be observed prior to release) shall be rejected. It is recommended that the recovery vessel also serve as the release container to reduce extra handling. The density of tagged fish in any holding container shall not exceed 50 g/L.

Atypical events during surgery shall be documented and recorded in report appendices.

4. Procedures for sterilization and disinfection

All surgical equipment shall be sterilized in an autoclave at least daily and between tagging sessions as often as possible (some supplies will come sterilized from manufacturer).

All surgical equipment, including sutures and needles, shall be disinfected by soaking in Chlorhexadine or 70% ethanol (30% distilled water) for a minimum of 10 minutes, and then rinsed with distilled water between surgeries. Sufficient number of instruments should be available per surgeon to allow each set of tools to soak for at least 10 minutes. The disinfectant baths need to be changed regularly as organic debris (scales, mucus, blood) dramatically reduces the effectiveness of disinfectants. A toothbrush or other small brush should be used to remove organic debris from instruments prior to disinfection to maximize effectiveness.

Transmitters shall be soaked in Chlorhexadine or 70% ethanol (30% distilled water) and rinsed with distilled water prior to implantation. Typically, transmitters are disinfected the night or morning prior to tagging, and rinsed prior to being implanted. It is recommended that disinfected forceps or gloved hands be used to handle transmitters to minimize exposure prior to implantation.

Surgeons and all researchers handling fish shall wear surgical gloves while tagging.

The surgical table, cradles, buckets, and all other pieces of equipment and surfaces that come in contact with fish shall be disinfected regularly using Virkon Aquatic. All items or surfaces should be exposed for 10 minutes and then rinsed with clean water (non-river where available). Where appropriate, Virkon should be neutralized prior to disposal. It is recommended that this procedure be used during the day when time allows (e.g. during lunch break).

Products mentioned here are those recommended for disinfection but local permitting/requirements may limit use of certain chemicals. Researchers should check with local POCs to determine what chemicals and disposal methods are acceptable prior to the study.

Antibiotics shall not be used.

5. Post-surgery holding

Post-surgery holding shall generally be 24 hrs with an allowable range of 18 to 36 hrs. This time frame allows fish to recover from the physiological stresses of surgery[7]. This time period will begin once the last fish has been tagged and will end when the fish have been released to the river or transportation barge. Researchers shall target total holding time, from collection to release, of around 72 hrs. Holding conditions shall be as described for the pre-surgery period, (see above) except fish are often held in individual buckets within holding tanks.

6. Transportation and release of tagged fish.

Transport and release methods will vary with the location and study goals. Once fish have recovered from anesthesia associated with surgery, researchers shall attempt to avoid any additional handling. The dissolved oxygen levels in transport containers shall be maintained at 80-110% saturation and shall be less than 2°C differential from river water at point of release. If the container temperature varies by more than 2˚C from that of receiving waters, the container water shall be tempered to a level within 2˚C by gradually exchanging water between holding container and receiving water so that temperature does not change faster than 1˚C in 15 minutes. During poor weather conditions, releasing surgically implanted fish shall be conducted in a manner safe to the researchers and the tagged fish.

7. Surgery training

A number of laboratory studies conducted in recent years have shown that taggers with feedback training perform better than taggers that have not had the same level of training (e.g. Deters et al 2010). For studies utilizing surgical implantation of transmitters this can result in negatively biased results and/or failure to determine actual differences between treatments. To minimize these effects the Surgical Tagging Protocol Steering Committee developed the following protocols for surgeon training.

Training Protocols

[7] For example, MS-222 typically is no longer detectable in the system at 24 hrs post-exposure Committee for Veterinary Medicinal Products. 1999. Tricaine Misilate Summary Report. The European Agency for the Evaluation of Medicinal Products.

The following components of surgeon training are mandatory for USACE funded projects where surgical implantation of acoustic transmitters is utilized. These are minimum requirements.

1. All trainees must tag a minimum of 75 live fish.
    a. All fish must be implanted in a single day. (NOTE: if a study design calls for tagging fewer than 50 fish per tag day trainees may tag the 75 fish over two days)
    b. All 75 tagged fish shall be held for a minimum of 14 days post tagging to evaluate survival and tag retention.

2. The last 20 fish tagged by each tagger shall be held separately from the other fish and used for evaluation of suture retention and incision healing. (NOTE: if tagging is conducted over 2 days, the last 10 fish from each day shall make up this group)
    a. Images of each fish incision shall be taken for the 20-fish group on day 0, 7, and 14.
    b. Images shall be made available to surgeons to provide feedback on surgery performance.
    c. Images of fish implanted by the trainer will be included for every group of trainees.

3. Fish used for training shall be of the species being studied. The size distribution of fish used for training shall also be representative of the fish planned for study. It is recommended that fish used for training are in the lower end of the expected size distribution for study fish. In the event that multiple species are being targeted for study surgeons should be trained on the smaller of the two species. For example, if planning to tag Chinook and steelhead, training should be done on Chinook.

4. All surgeons must be re-evaluated every year and retrained if there is a modification to surgical protocols.
    a. For previously trained surgeons this will include only implanting and evaluating at least 20 live fish
    b. If the previously trained surgeon fails this evaluation, they would be subjected to full surgery retraining.

5. A record of results including images from days 0, 7, and 14 shall be maintained for each research project and made available to the USACE upon request.

Evaluation Criteria

Since fish health can be an issue during training, the performance of all trainees will be examined in relation to the trainer. Surgeon grading will be based upon images taken directly after surgery, and 7 and 14 d after surgery. If any of the following conditions are present at a rate empirically higher than the trainer, the trainee will need to have further training and be retested:

1. Mortality
2. Tag expulsion
3. Lack of suture functionality prior to day 14
    a. The suture has pulled through one side of the incision
    b. The suture is untied and is not holding the incision closed
    c. The suture is not present
4. Major tissue trauma is present (an example is shown in figure 11)

Suggested Training Outline

The following is a suggested outline for a training module (Brown et al. 2010; T. Liedtke and J. Beeman USGS, *pers. com.*). It is suggested that the following topics be included in a training program, however, format or use of the outline is placed at the discretion of the agency and project leaders.

Learning Objectives

At the end of the training period, it is suggested that the trainee should:

- Recognize and understand the importance of conducting surgery in a manner that put the fish on a trajectory to survive with negligible sublethal impairments.
- Develop an understanding of anesthesia and recovery of fish.
- Understand basic information about fish biology and surgical techniques (including principles of sterilization) needed to properly handle and care for fish during surgery.
- Exhibit proficiency in fish surgical procedures, including the handling and use of tools and completion of all phases of the surgical procedure.
- Understand body positioning and posture needed to reduce surgical fatigue and reduce chances of surgeon injury or exhaustion.
- Recognize the types and level of practice needed to maintain skills and be willing to subject themselves to testing (surgical evaluation).

1. Introduction

    a. Importance of training program – In general, trainers need to emphasize the importance of following protocols, taking care of the study animals and conducting good science so information collected provides the greatest benefit for all interested groups. Positive attitude by researchers may significantly affect (improve) quality of data that is produced. Topics that may be included are:
        i. Care of animals
        ii. Conducting good science
        iii. Producing comparable and reliable information
    b. Your research project
        i. Background
        ii. Goal
        iii. Objectives
        iv. Study plan, etc.
    c. Project personnel introductions--experience, background, roles
    d. Go over training manual/materials
        i. Include a CD/DVD with photographs, video of procedure when possible.
        ii. Describe training outcomes and evaluation criteria (see below).

2. More background information
    a. Basics
        i. Fish biology/physiology facts (e.g. how fish breath)
        ii. Key points of fish handling (e.g. stress kills)
        iii. Fish identification
    b. Surgical tagging procedure (PowerPoint slides and/or video)

c. Importance of using protocols for sterile and clean work environments

3. Equipment Familiarization
    a. Blades, catheters, suture, gravity feeds, etc.
4. Suture demo/training.
    a. Practice suturing on a non-fish model such as a piece of foam or a banana until proficient in technique and able to suture quickly
        i. Discuss body position (the surgeon must be comfortable)
        ii. Discuss technique
    b. Suture dead fish until proficient with the technique able to suture quickly.
        i. Discuss incision location, length, depth and tag placement
    c. Conduct dissections to inspect tag and suture placement
    d. Repeat on dead fish until surgery times are 4-5 (maybe this should be 2-4 min which is more representative of actual tagging times) minutes per fish
    e. The trainer should provide detailed personal instruction to trainees to aid in time saving measures and to improve suturing technique.

5. MS-222 Training
    a. Preparing solutions, buffering, dosing buckets, maintenance buckets
    b. Water temperature and dissolved oxygen monitoring
    c. Fish behavior and fish handling guidelines
    d. Netting
    e. Fish recovery
    f. Timing of procedures

6. Data recording
    a. Datasheets
    b. Computer programs
    c. Storing and archiving

The surgeon should practice verbalizing observations/data to the data recorder while performing surgeries.

Appendix A: Examples of good and poor surgery technique

Examples of good suturing technique

Figure 1. Good closure with two 2x2x2x2 sutures. Nice small incision but with slight overlapping (this can be very hard to avoid on subyearling fish or fish with very little muscle tissue). Sutures are in a compact ball even on days 7 and 14, indicating they were tied correctly. The tissue bites were adequate to hold the wound closed without tearing too soon. By day 14, the sutures are starting to migrate/tear toward the incision, but they are still keeping the tissue edges apposed.

Figure 2. Good closure with two 2x2x2x2 sutures. The knots are in a compact ball. The tissue edges are apposed correctly on day 0 which will lead to faster healing. Since the tissue bites were substantial and the knots were tied correctly (notice the compact "ball" of suture), the sutures continue to provide good apposition. By day 14, the sutures are starting to tear or be expelled out of the skin. This is good timing because the incision is starting to close up at this time as well.

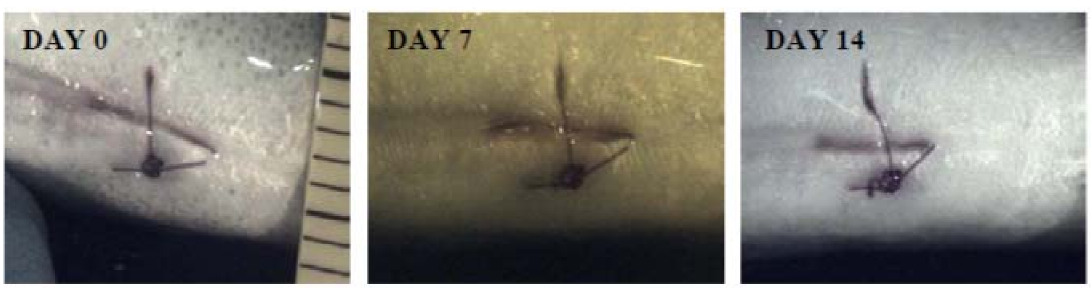

Figure 3. Another example of good closure with a single 1x1x1x1 suture.

Examples of poor suturing technique

1. **Poor knot construction** (Figures 4, 5, and 6). Incorrectly tied sutures can result in knots coming untied which may lead to gaping incisions and possible tag loss. Occasionally, the sutures remain intact, but the suture "ball" is so large that it can cause excessive irritation to the fish's skin which could lead to necrosis and tag loss. It can be difficult to identify incorrectly tied sutures immediately after surgery. That is why it is important to examine fish several days/weeks later after the fish has had a chance to engage in active swimming. Correctly tied sutures should look like a tight ball of suture with very few gaps. Incorrectly tied sutures appear as a high stack (Figure 11) or have large gaps within the "ball" (left suture Figure 6).

Figure 4. Poor knot construction can cause increased irritation (redness, ulceration of the skin) due to the larger surface area of the suture. Large gaps in the suture knots indicate incorrectly tied sutures.

Figure 5. This is a poorly-constructed single 2x2x2x2 suture. Since the suture is still functional (just barely) on day 7, this would not count as a lost suture.

Figure 6. Inadequate suture bite can lead to loss of sutures. Note: this would not count as a lost suture since the suture is still functional on day 7. These are also examples of poorly-constructed knots. The consecutive throws should "lock" down on one another, not stack up high; these appear to be "granny" (slip) knots.

2. **Inadequate bite** (Figure 6). When surgeons insert the suture needle through the body wall too close to the incision, the suture does not bite an adequate amount of skin and the suture is likely to tear through the skin. This leads to a loss of closure on the incision and can lead to a gaping, open incision. Inadequate bites can be hard to gauge in pictures due to overlapping of the tissue edges, 2-D pictures, etc. Therefore, grading will likely be based on tearing, torn through to the incision, or lost sutures.

3. **Too much pressure on sutures** (puckering / tearing; Figures 7, and 8). The application of too much pressure when tying sutures leads to a puckering effect. The edges of the incision are typically not apposed appropriately when puckering occurs. Incision edges are typically apposed at the site of the suture but not apposed along the rest of the incision. This leads to loss of sutures.

Figure 7. Poor apposition coupled with too much tension/puckering can result in wounds opening.

Figure 8. Too much pressure on sutures/puckering (most noticeable on day 7) and poor knot construction lead to ripping sutures and irritation to the tissue.

4. **Poor apposition** (Figures 7 and 8). Misaligned suture entry and exit points and unbalanced or excessive pressure when tying sutures can cause skin overlapping or puckering which results in poor apposition of the two tissue edges. Poor apposition requires increased healing time since similar tissue layers have a greater distance to cover in order to reconnect. Poor apposition alone does not lead to surgeon failure (unless it is consistent), but when coupled with one or more other bad techniques will not be accepted.

5. **Tissue trauma** (Figures 9, 10, 11 and 12). Incorrect usage/force of tools during surgery can lead (whether moderate [Figure 9] or severe [Figure 11]) to poor healing and likely increases the chance of tag expulsion, fungal growth, and abnormal behavior. Some trainees squeeze tools (forceps) too tightly while conducting surgery (Figure 12). This can lead to death of the tissue (necrosis), poor healing, and fungus. Tissue trauma can take extended periods for healing as can be seen by wounds remaining on the fish exhibited in Figure 10, 28 days after surgery.

Figure 9. Moderate tissue trauma (visible over the incision) associated with incision closure on a juvenile salmonid. Tissue puckering is also evident in these pictures.

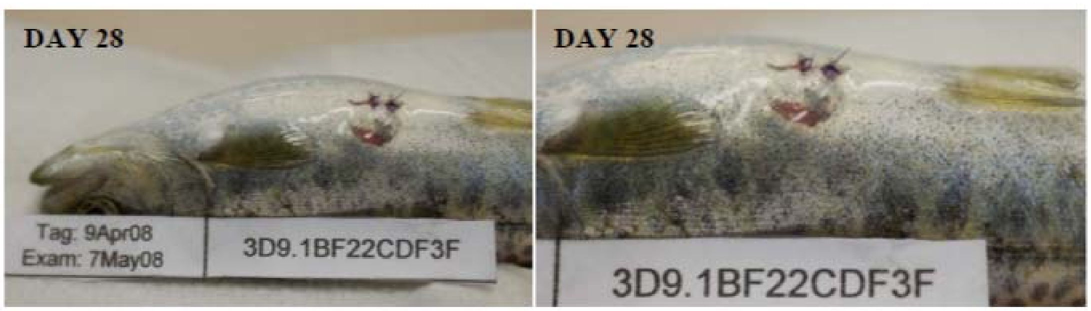

Figure 10. Tissue trauma (visible below the incision) associated with incision closure on a juvenile salmonid. Images were taken 28 d after surgery (Images provide by NOAA Fisheries).

Figure 11. Severe tissue trauma (visible above incision) associated with incision closure on a juvenile salmonid.

Figure 12. Tissue necrosis (visible above the incision) due to too much pressure applied to surgical tools.

6. **Loss of suture** (Figures 13, 14 and 15). Sutures are critical to the retention of transmitters, especially when exposed to the low pressure environments of turbines. Effort is being made to identify techniques that will allow the use of just a single suture to close the incision. This makes the loss of even a single suture unacceptable. However, at some point after the implantation of a transmitter, sutures are naturally expelled. Thus any suture that is non-functional within the first seven days after surgery will be considered unacceptable. Non-functional sutures include missing sutures, untied sutures and sutures that have torn through to the incision (on either side).

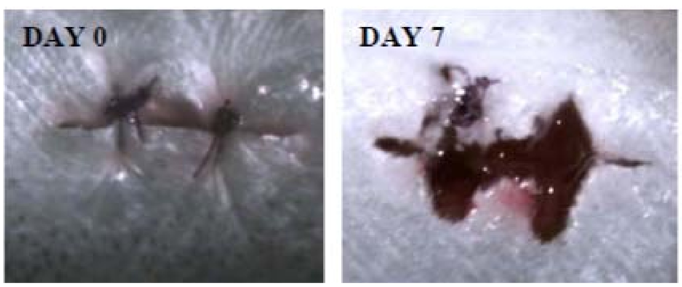

Figure 13. Loss of sutures due to too much pressure being applied when tying suture (i.e. puckering).

Figure 14. Suture loss on day 7 is due to poor knot construction during surgery. Loss of the suture can lead to an open incision and poor healing. In the day 0 image, gaps in the suture ball indicate that this knot was tied incorrectly (look at examples of good suture technique in Figures 14 -17 below; no gaps are visible on day 0). As a result, the knot has come untied and the tag is visible on day 7. We assume loss of the tag would be very likely in a river environment. For this reason, suture loss on day 7 is unacceptable.

Figure 15. Gaping wound as a result of sutures tearing out.

7. **Gaping wounds** (Figures 15 and 16). Non-functional sutures and poor apposition can cause wounds to gape open which could lead to tag loss. There are many other factors that may cause wounds to open such as tissue necrosis and inadequate wound closure during surgery. Therefore, any technique that results in wounds opening greater than 3 mm will be considered failure.

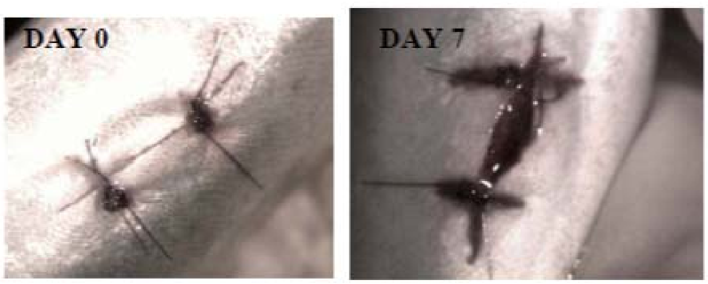

Figure 16. Incisions may begin to open up due to inappropriately-sized incisions and incorrectly spaced sutures. Sutures should be evenly spaced between the ends of the incision with erring on the side of too close to the center rather than too close to the ends.

USACE will work with the research agencies to provide source of fish and dummy transmitters for training sessions.

Instructors should be experts and should be present throughout the training process.

8. Documentation

Due to the nature of fisheries research, unexpected changes to study designs or implementation plans do occur. Therefore flexibility in how work is carried out is sometimes required. Researchers should endeavor to adhere to these protocols and where important deviation occurs the project sponsor should be notified as soon as possible. Further, deviation from these protocols should be documented in the annual research report with an explanation as to what protocol(s) was altered and why. This document should be considered a living document; changes based on sound science will be considered and discussed by the steering committee prior their adoption. This document will be updated as changes to these protocols are made.

9. References

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Appendix 4.0

Balloon Tag Study Statistical Analysis (Normandeau et al. 2008)

TURBINE OPERATIONAL EFFECTS ON SURVIVAL/CONDITION OF YEARLING CHINOOK SALMON, *Oncorhynchus tshawytscha*, AT ICE HARBOR DAM, MARCH 2007

Contract No. DACW68-02-D-0002
Task Order 29

Prepared for

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Normandeau Project Number 18880.050, Task 1

FEBRUARY 2008

3.0 STATISTICAL ANALYSIS

3.1 Data Analysis

Statistical analyses were performed by Drs. John R. Skalski and Richard Townsend, University of Washington, Seattle, Washington. The basic tag-recapture data given in Appendix Tables B-1 and B-2 and malady data given in Appendix Table C form the basis for all of the statistical analyses reported herein. Only the summarized results are presented in the main body of the report. Individual fish release, recapture, and trial data are presented in Appendix Table D. Three different metrics were estimated from these data: (1) direct survival, (2) conditional probability of being malady-free given survival (herein called the Conditional Malady-Free Estimate or CMFE), and (3) the joint probability of survival (48 h) and being malady-free.

Because a goal of the study was to assess interaction which may exist between the three intake slots and the five operational levels, analysis of deviance (ANODEV) was used to compare the 12 turbine passage survival, 12 MFE estimates, and 12 survival and being malady-free estimates. The peak operating level was not included in this analysis because at the Corps' request, only one replicate was completed at that operating level. The ANODEV was used to test the main effects of discharge, the main effects of turbine slot, and their interactions (Table 3-1).

3.1.1 Survival Without Injury

The survival without injury metric was selected as a possible means to find a performance measure for the HI-Z studies that might be comparable with the observed bead strike data from physical turbine models. The bead data are unconditional in nature. In other words, observations are available from all beads regardless of their fates. Mortality data are inferred from the mark-recapture data of HI-Z tag studies. Injury observations are made only from fish in hand. Thus, the physical model and HI-Z tag data are inherently different. The purpose of this report is to provide a metric from the HI-Z tag data that may be comparable to the unconditional bead strike data.

Bead strike data rank strikes from severe to nonexistent. It is assumed some of the bead strike severity rankings include levels comparable to fish death and injury. Therefore, a HI-Z tag metric is sought that incorporates both of these biological responses to turbine passage. The desire is to have a measure that expresses the probability of death or injury. The complement of this measure is the probability that a fish is alive and uninjured after passage through a turbine. Figure 3-1 presents a Venn diagram illustrating these potential fates.

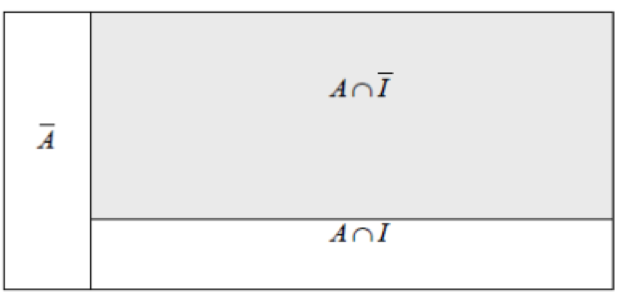


Figure 3-1 Venn diagram illustrating the states of mortality (i.e., not alive, $\bar{A}$), alive (A), and if alive, injured $(A \cap I)$ or not injured $(A \cap \bar{I})$. The metric being measured (i.e., the shaded area) is the probability of a fish being alive and uninjured through a turbine $(A \cap \bar{I})$.

The conduct of the experimental design at Unit 3 at Ice Harbor Dam is summarized in Table 3-1. On any one day, yearling Chinook salmon releases through the three intake slots (i.e., A, B, or C) were conducted at a single operation level. At four operation levels (lower 1%, intermediate, upper 1%, and maximum), releases were replicated on two different days. One set of trials (i.e., Block 1) occurred from 17 March to 21 March 2007; the other set of trials, (i.e., Block 2) occurred from 22 March to 25 March 2007. For the peak operation level, only one day of trials was performed during Block 1 at the request of the U.S. Army Corps of Engineers (ACOE).

Table 3-1 Schematic of the split-plot Ice Harbor turbine Unit 3 passage survival study indicating blocks, whole-plot treatments (operation levels) and split-plot treatments (slots), March 2007.

			Slots		
Block	Date	Operation level	A	B	C
1	March 17	Lower 1%	x	x	x
	March 18	Intermediate	x	x	x
	March 19	Peak	x	x	x
	March 20	Upper 1%	x	x	x
	March 21	Maximum	x	x	x
2	March 22	Lower 1%	x	x	x
	March 23	Intermediate	x	x	x
	March 24	Upper 1%	x	x	x
	March 25	Maximum	x	x	x

As indexed in Section 2.0 (study design) the experiment was a split-plot design with turbine operational levels as whole-plot treatments and intake slots split-plot treatments. Because the peak operation trial was halted at the request of ACOE before the second block of replication, it was omitted from the tests of hypotheses and the analysis of deviance (ANODEV) (Table 3-2). Instead, only point estimates of passage survival and associated standard errors (SE) were computed for that treatment combination.

Table 3-2 Degree-of-freedom table for the split-plot analysis of operation level, whole-plot treatments and slot, split-plot treatments (peak operation level releases omitted), turbine Unit 3, Ice Harbor Dam, March 2007.

Source	DF	F-test
TotalCor	23	
Block	1	
Whole plot (operation)	3	$F_{3,3}$
Error	3	
Split plot (slots)	2	$F_{2,8}$
Operation x slot interaction	6	$F_{6,8}$
Error	8	

3.2 Estimation of Passage Survival

A joint likelihood model was used to estimate both 1 and 48 h passage survival for the two test blocks, four operation levels, three slots, and the common control group. Chi-square tests of homogeneity was used to compare control releases over the course of the study to guide pooling of the release-recapture data. The joint likelihood can be written as

$$L = \binom{R_c}{a_c, d_c} (Sp_a)^{a_c} \left((1-S)p_d\right)^{d_c} \left(1 - Sp_a - (1-S)p_d\right)^{R_c - a_c - d_c}$$

$$\cdot \prod_{i=1}^{2} \prod_{j=1}^{4} \prod_{k=1}^{3} \left[\binom{R_{ijk}}{a_{ijk}, d_{ijk}} (\tau_{ijk} Sp_a)^{a_{ijk}} \left((1-\tau_{ijk}S)p_d\right)^{d_{ijk}} \right.$$

$$\left. \cdot \left(1 - \tau_{ijk} Sp_a - (1-\tau_{ijk}S)p_d\right)^{R_{ijk} - a_{ijk} - d_{ijk}} \right], \tag{1}$$

where

S = survival from tailrace to recovery location for all fish;
p_a = probability an alive fish is recovered;
p_d = probability a dead fish is recovered;
R_c = number of control fish released;
a_c = number of control fish recovered alive;
d_c = number of control fish recovered dead;
R_{ijk} = number of fish released for the ith block $(i = 1, 2)$, jth operation level $(j = 1, \ldots, 4)$, and kth slot $(k = 1, \ldots, 3)$;
a_{ijk} = number of fish recovered alive for the ith block $(i = 1, 2)$, jth operation level $(j = 1, \ldots, 4)$, and kth slot $(k = 1, \ldots, 3)$;
d_{ijk} = number of fish recovered dead for the ith block $(i = 1, 2)$, jth operation level $(j = 1, \ldots, 4)$, and kth slot $(k = 1, \ldots, 3)$.

The maximum likelihood estimates will be calculated based on a numerical maximization/minimization algorithm in R software.

In the case where all control yearling Chinook salmon are recovered alive, Sp_a is set to 1 in likelihood (1), and the joint likelihood can be reduced to

$$L = \prod_{i=1}^{2} \prod_{j=1}^{4} \prod_{k=1}^{3} \left[\binom{R_{ijk}}{a_{ijk}} \tau_{ijk}^{a_{ijk}} \left(1 - \tau_{ijk}\right)^{R_{ijk} - a_{ijk}} \right]. \tag{2}$$

Maximum likelihood estimates are

$$\hat{\tau}_{ijk} = \frac{a_{ijk}}{R_{ijk}} \quad (3)$$

with associated variances

$$\widehat{\mathrm{Var}}\left(\hat{\tau}_{ijk}\right) = \frac{\hat{\tau}_{ijk}\left(1 - \hat{\tau}_{ijk}\right)}{R_{ijk}}. \quad (4)$$

3.3 Estimation of Conditional Probability of Malady-Free, Given Alive at 48 H

The conditional probability a yearling Chinook salmon being malady-free (i.e., no injury, scale loss ≥ 20% per side or loss of equilibrium), given it passed through the turbine alive, i.e.

$$\hat{\Psi} = 1 - \hat{P}\left(I \mid A\right) \quad (5)$$

was also compared among treatments.

3.4 Estimation of Joint Probability of 48 H Survival and Being Malady-Free

In addition to the comparison of 48 h turbine passage survival (τ), the probabilities yearling Chinook salmon passed through the turbine being malady-free and alive were compared among the test conditions. The probability a yearling Chinook salmon passed through the turbine malady-free and alive was estimated by

$$\hat{\theta} = \hat{\tau}\left(1 - \hat{P}\left(I \mid A\right)\right), \quad (6)$$

where $P\left(I \mid A\right)$ = probability of malady, given a fish is alive. The variance of $\hat{\theta}$ is estimated by

$$\widehat{\mathrm{Var}}\left(\hat{\theta}\right) = \left(1 - \hat{P}\left(I \mid A\right)\right)^2 \cdot \widehat{\mathrm{Var}}\left(\hat{\tau}\right) + \hat{\tau}^2 \cdot \widehat{\mathrm{Var}}\left(\hat{P}\left(I \mid A\right)\right) - \widehat{\mathrm{Var}}\left(\hat{\tau}\right) \cdot \widehat{\mathrm{Var}}\left(\hat{P}\left(I \mid A\right)\right), \quad (7)$$

where

$$\widehat{\mathrm{Var}}\left(\hat{P}\left(I \mid A\right)\right) = \frac{\hat{P}\left(I \mid A\right)\left(1 - \hat{P}\left(I \mid A\right)\right)}{k} \quad (8)$$

and where k = number of fish alive at 48 h.

3.5 Tests of Operation Level and Slot Effects

Analysis of deviance (ANODEV) was used to test the effects of operation level (i.e., lower 1%, intermediate, upper 1%, maximum), slot location (A, B, C), and their interaction based on a split-plot design (Table 3-1) using general linear models (GLMs). Based on likelihood (2), a binomial error structure and a logit-link was used to test the effects of operation level, slot location, and their interaction at α = 0.05 (Table 3-2). The single replicate at peak operation was not tested as part of the split-plot design. The ANODEV was used to analyze passage survival, conditional malady-free, and the joint probabilities of survival and malady-free.

Plots of survival profiles and the two malady metrics were constructed across operation levels for each slot location. The best summaries of the response variables were guided by the results of the ANODEV.

Appendix 5.0

Equipment Considerations (McMichael et al. 2011)

Table G.1. Procurements for the Ice Harbor Dam Acoustic-Telemetry Evaluation

Item	Quantity	Cost Each	Total Cost	Vendor	Procurer	Comments
Cables	104		TBD	Ocean	CENWW	spares included
Y-blocks	28		TBD	Innovations	CENWW	spares included
Trolley sleds	39		TBD		CENWW	spares included
Pipes	16		TBD		CENWW	
Cabled-array computers Systems	14		TBD	ATS	CENWW	spares included
Hydrophones	56		TBD	SC	CENWW	spares included
Trolley beacon	10		TBD	ATS	CENWW	spares included
Acoustic tags for study	13,715		TBD	ATS	CENWW	
Acoustic tags for tag-life study	100		TBD	ATS	CENWW	
PIT tags	13,815		TBD		CENWW	
Autonomous receivers	40		TBD	ATS	CENWW	spares included
Acoustic releases	40	2,750.00	110,000.00	InerOceans	CENWW	spares included
Release command unit	1	6,495.00	6,495.00	InerOceans	CENWW	
Handheld GPS	3		TBD		CENWW	already had GPS units
Baffles for hydrophones	56	210.00	11,760.00	TBD	Contractor	spares included
Auto receiver batteries	50	300.00	15,000.00	TEnergy	Contractor	rechargeable batteries; includes $250/battery and $50/charger
Auto receiver anchors	290	75.00	21,750.00	TBD	Contractor	spares included
Anchor buoy leads	330	50.00	16,500.00	West Marine Rigging	Contractor	spares included
Cable trays			20,000.00	Platt Electric Supply	Contractor	
Computers (data processing)	3	5,000.00	15,000.00	B2B	Contractor	
Computer hard drives (internal)	40	300.00	12,000.00	TBD	Contractor	for up to 12 cable array systems
Trailers	4	1,000.00	4,000.00	Pac Mobile	Contractor	monthly rentals
Trailer power needs	4	2,250.00	9,000.00	Shelco electric, Hermiston, OR	Contractor	three 480-V transformer boxes, cables, contractor labor
Boats	3	TBD	TBD	TBD	Contractor	
Boat fuel			3,000.00	TBD	Contractor	

Table G.1. (contd)

Item	Quantity	Cost Each	Total Cost	Vendor	Procurer	Comments
Boat maintenance	2	875.00	1,750.00	TBD	Contractor	for damaged props, motor and trailer servicing, etc.
Life jackets	5	100.00	500.00	West Marine	Contractor	for boats
Tagging trailer	1	50,000.00	50,000.00	TBD	Contractor	mobile tagging trailer, limited tagging space at JFF
Outside holding tanks	2	5,000.00	10,000.00	TBD	Contractor	
Computer rack mounts	5	500.00	2,500.00	TBD	Contractor	
Hard drive cases	20	100.00	2,000.00	TBD	Contractor	
UPS/line conditioners	10	400.00	4,000.00	TBD	Contractor	
Misc. hardware/equipment		Misc	15,000.00	TBD	Contractor	
Circulars with lids	4	600.00	2,400.00	Reiff	Contractor	30-in. × 30-in. circular; 4 tanks needed
Ethanol	10	10.12	101.20	CMS	Contractor	5 gallons - purchase through CMS (Robbie Tidwell)
Sutures	56	175.00	9,800.00	Suture express	Contractor	14,000 fish
UV sterilizers	4	2,984.00	11,936.00	Millipore and Technical Glass Products	Contractor	
buckets square blue	100	TBD	TBD	Quickparts	Contractor	max number of fish per season (7212)/tagging days (35)/fish
Surgery pads	1	300.00	300.00	McMaster-Carr	Contractor	6-ft × 42-in. sheet; 8647K681
Microsharps	234	25.00	5,850.00	BD	Contractor	6 per box $25 per box
Microsharps handles	6	20.00	120.00	BD	Contractor	need two more per surgeon
Forceps	6	64.75	388.50	Fine Science Tools	Contractor	11152-10; need two more per surgeon
Needle holders	6	130.00	780.00	Fine Science Tools	Contractor	12002-14; need two more per surgeon
Tupperware		Misc	90.00	Target	Contractor	
Sanctuary nets	6	112.00	672.00	Aquatic Ecosystems	Contractor	NT101
Gloves	7	200.00	1,400.00	Fisher Scientific	Contractor	19-149-863 or 19-048-132
Sodium bicarbonate	1	63.13	63.13	Aquatic Ecosystems	Contractor	SC12; 40-lb bucket
MS-222	3	450.00	1,350.00	Argent Labs	Contractor	

Table G.1. (contd)

Item	Quantity	Cost Each	Total Cost	Vendor	Procurer	Comments
Refrigerator for MS-222	1	200.00	200.00	Home Depot	Contractor	
Argentyne	3	132.00	396.00	CMS	Contractor	Argent Labs
Chairs	4	200.00	800.00	Bevco	Contractor	
Surgery tables	3	200.00	600.00	Home Depot	Contractor	
Lamps	4	100.00	400.00	Home Depot	Contractor	
PIT-tag reader	1	3,000.00	3,000.00	Biomark	Contractor	Destron Fearing 2001F-ISO kit
Scale	1	300.00	300.00	HOGENTOGLER & Co.	Contractor	
Laptop	1	2,000.00	2,000.00	B2B	Contractor	
Computer	1	4,000.00	4,000.00	B2B	Contractor	
Digitizer board	2	600.00	1,200.00	CSMDirect	Contractor	
Digitizer pens	4	125.00	500.00	CSMDirect	Contractor	
Poly-Aqua	1	36.80	36.80	Aquatic Ecosystems	Contractor	PA64; use DTpetsupplies.com if not available from AqEco
Sharps containers	10	6.68	66.80	Fisher Scientific	Contractor	14-827-63; 3.06 1-gal 14-827-122 5-qt; 14-827-109 1-qt
Oxygen rental	3	1,000.00	3,000.00	Oxarc	Contractor	~$1,000 per month to have 2–3 containers
DO meters	2	1,000.00	2,000.00	Aquatic Ecosystems	Contractor	YSI ProODO meter
pH meters	3	180.00	540.00	Aquatic Ecosystems	Contractor	YSI pH/Temp pen
Temperature loggers	12	123.00	1,476.00	Onset	Contractor	Hobo Water Temp Pro V2
DO/temp monitoring system	1	6,000.00	6,000.00	YSI	Contractor	
Storage trailer	1	2,000.00	2,000.00	PacMobile	Contractor	
Ice machine	1	1,800.00	1,800.00	Ice MachinesPlus	Contractor	for monitoring water temps; Manitowoc QD-0132A
Fireproof safes	1	1,300.00	1,300.00	Sentry Safe	Contractor	for transmitter storage
Keyboards and mice	2	300.00	600.00	Man and Machine	Contractor	2 sets - keyboard and mouse, Waterproof
Submersible pumps	3	100.00	300.00	Home Depot	Contractor	Flotec
Flex hose and fittings		Misc	2,000.00	Central Hose and Fitting, Pasco	Contractor	
Shade screen	4	250.00	1,000.00	Backyardcity.com	Contractor	12-ft × 30-ft sections

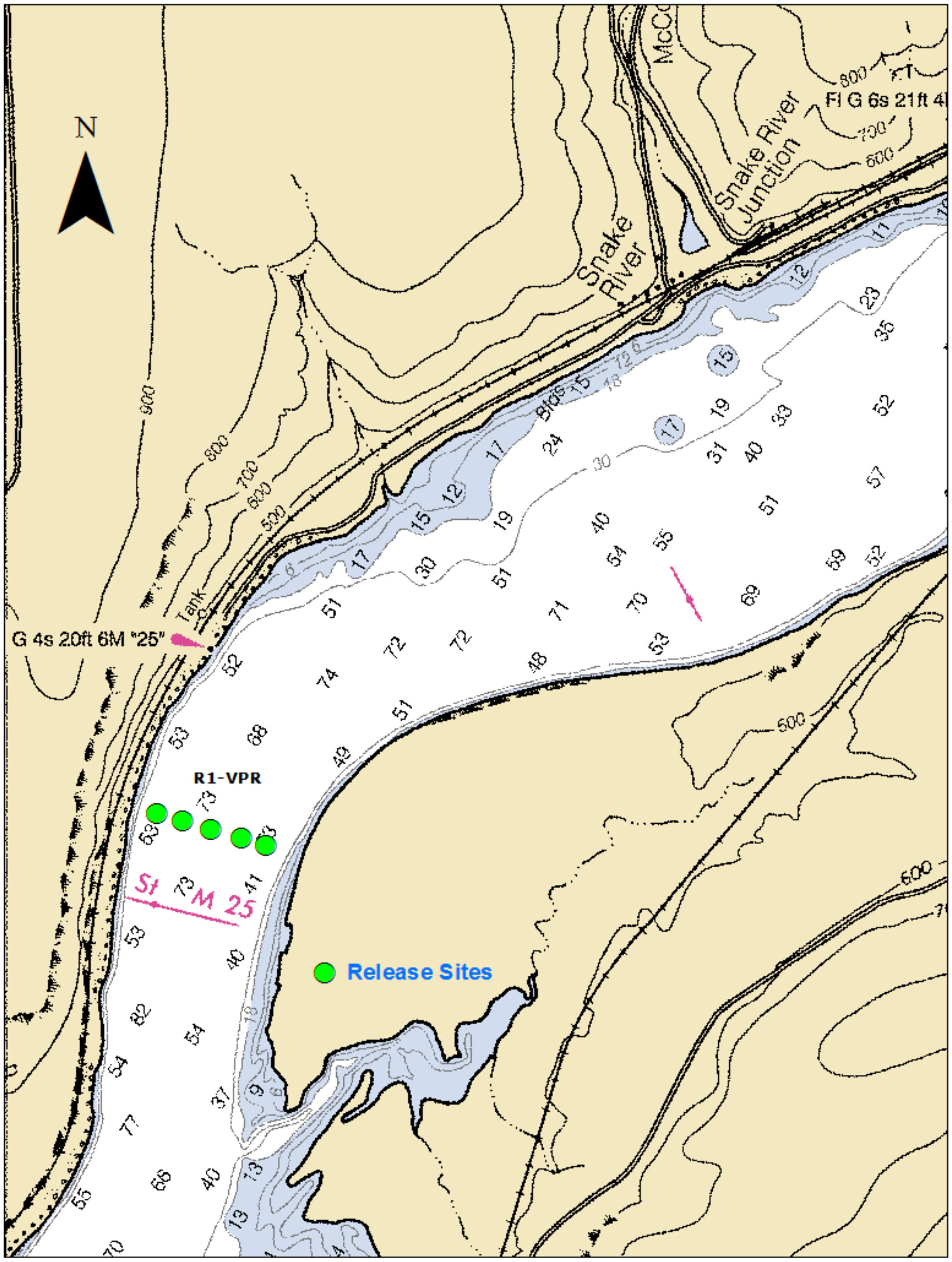
Table G.1. (contd)

Item	Quantity	Cost Each	Total Cost	Vendor	Procurer	Comments
Transport insulated totes	3	800.00	2,400.00	Bonar Totes - IB1545	Contractor	1 for each truck plus 1 extra
O_2 tank brackets	3	325.00	975.00	TDA Ironworks	Contractor	
O_2 manifold	3	100.00	300.00	TBD	Contractor	
O_2 regulator	3	270.00	810.00	Grainger	Contractor	1 per truck plus 1 extra; 5EFZ4
Invertors	3	325.00	975.00	hook into boat batteries	Contractor	1 per truck plus 1 extra; hook into boat batteries
Bubblers	4	40.00	160.00	PetSmart	Contractor	Rena Air 400 or similar
Lights		Misc	250.00	Home Depot	Contractor	headlamps, spot lights
DO meter	6	1,000.00	6,000.00	Aquatic Ecosystems	Contractor	3 meters for each of 2 transport trucks; YSI ProODO meter
Misc tagging equipment			7,500.00	TBD	Contractor	for broken or missing equipment

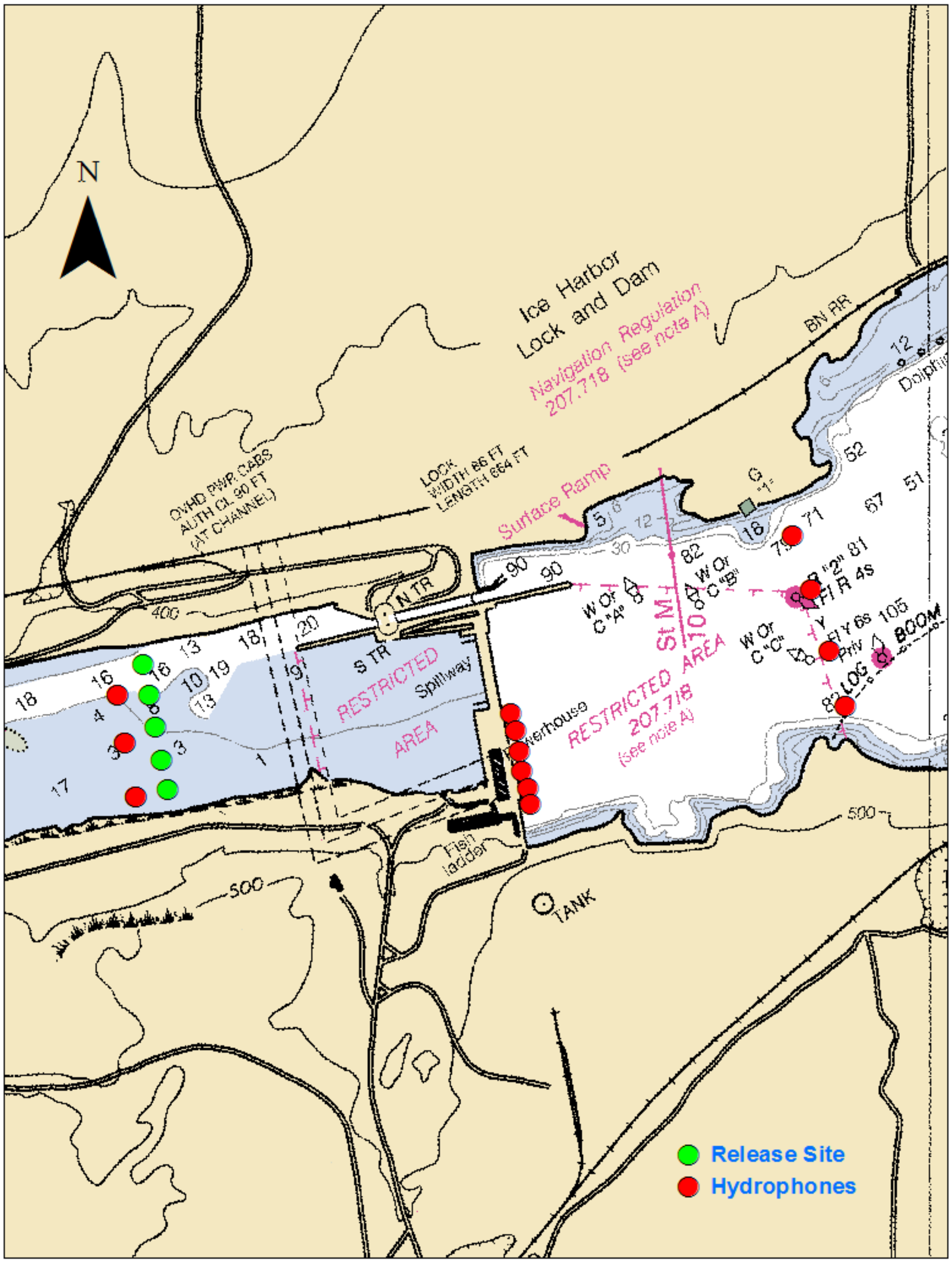
ATS = Advanced Telemetry Systems
TBD = to be determined
CENWW = Corps of Engineers, Walla Walla District
DO = dissolved oxygen
O_2 = oxygen
PIT = passive integrated transponder
SC= Sonic Concepts
TDA = The Dalles Dam
UPS = uninterrupted power supply

Appendix 6.0

Possible Geographic Locations for Fish Releases and Acoustic Detection Arrays McMichael et al. (2011)

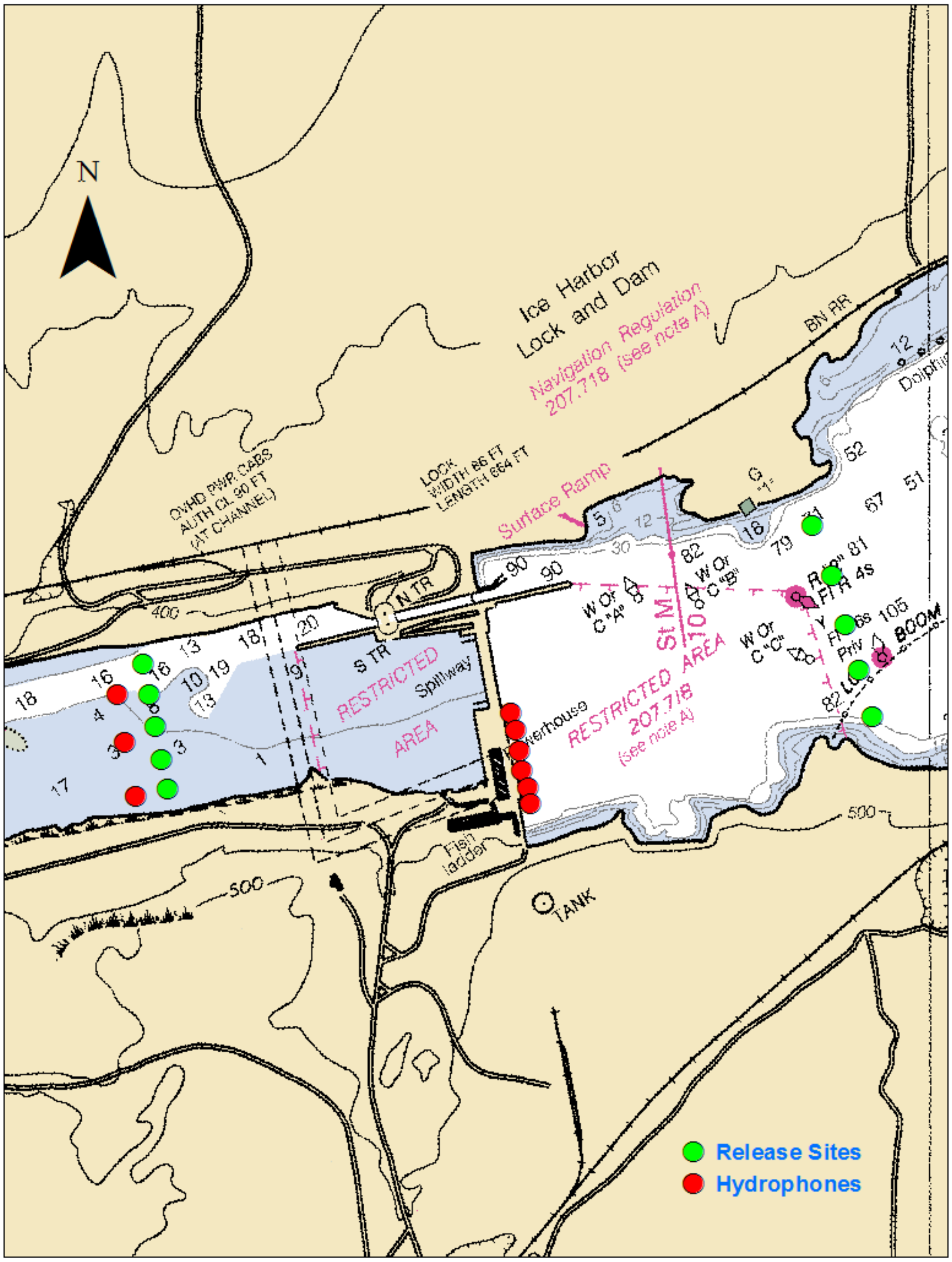


R1 release location about 24km upstream of Ice Harbor Dam and 1km downstream of the Snake River boat ramp for virtual with paired release-recapture (VPR) study design.



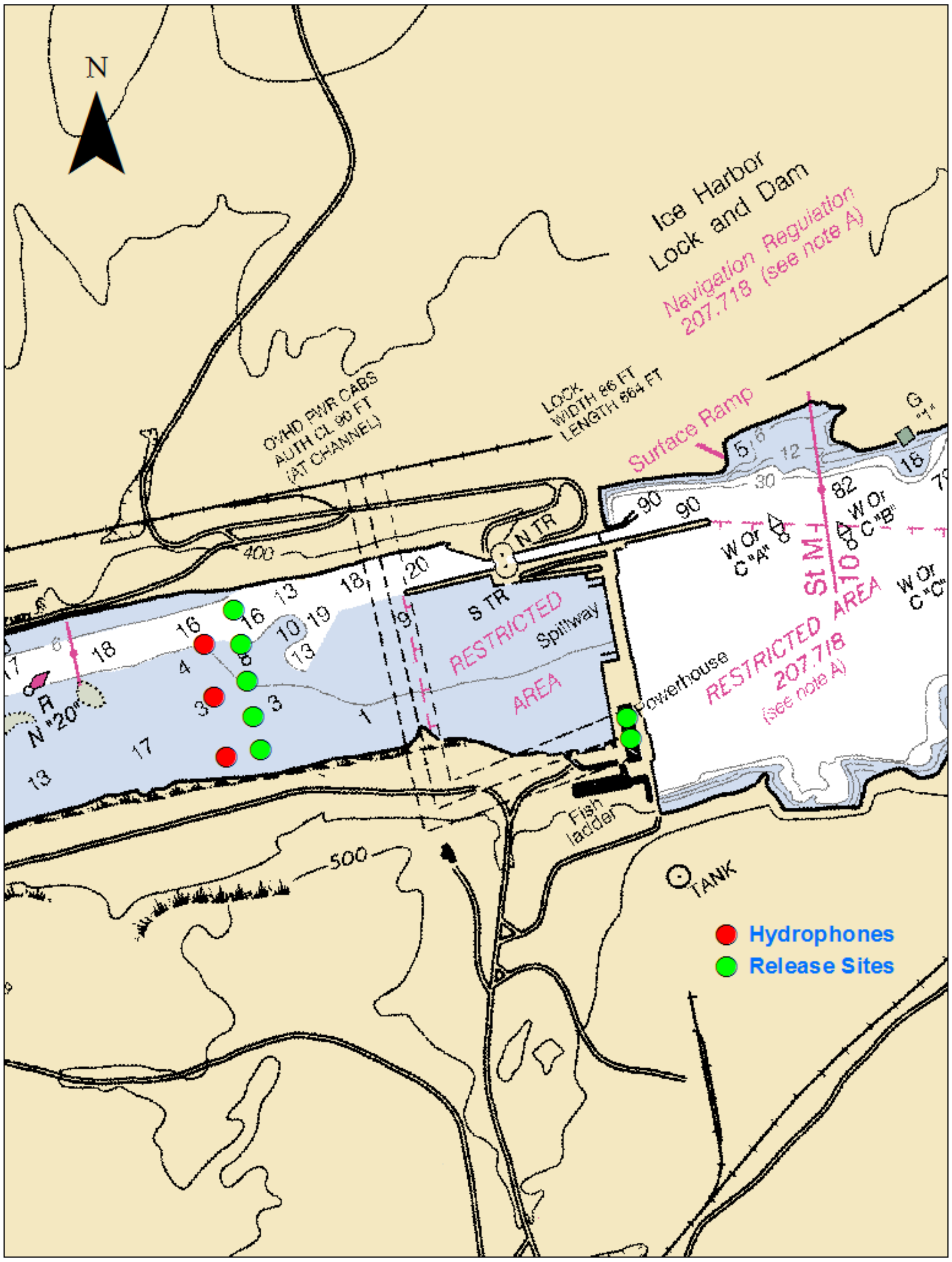
Upstream of dam: BRZ and powerhouse acoustic detection arrays for VPR.

Downstream of dam: R2 release location and egress detection array.

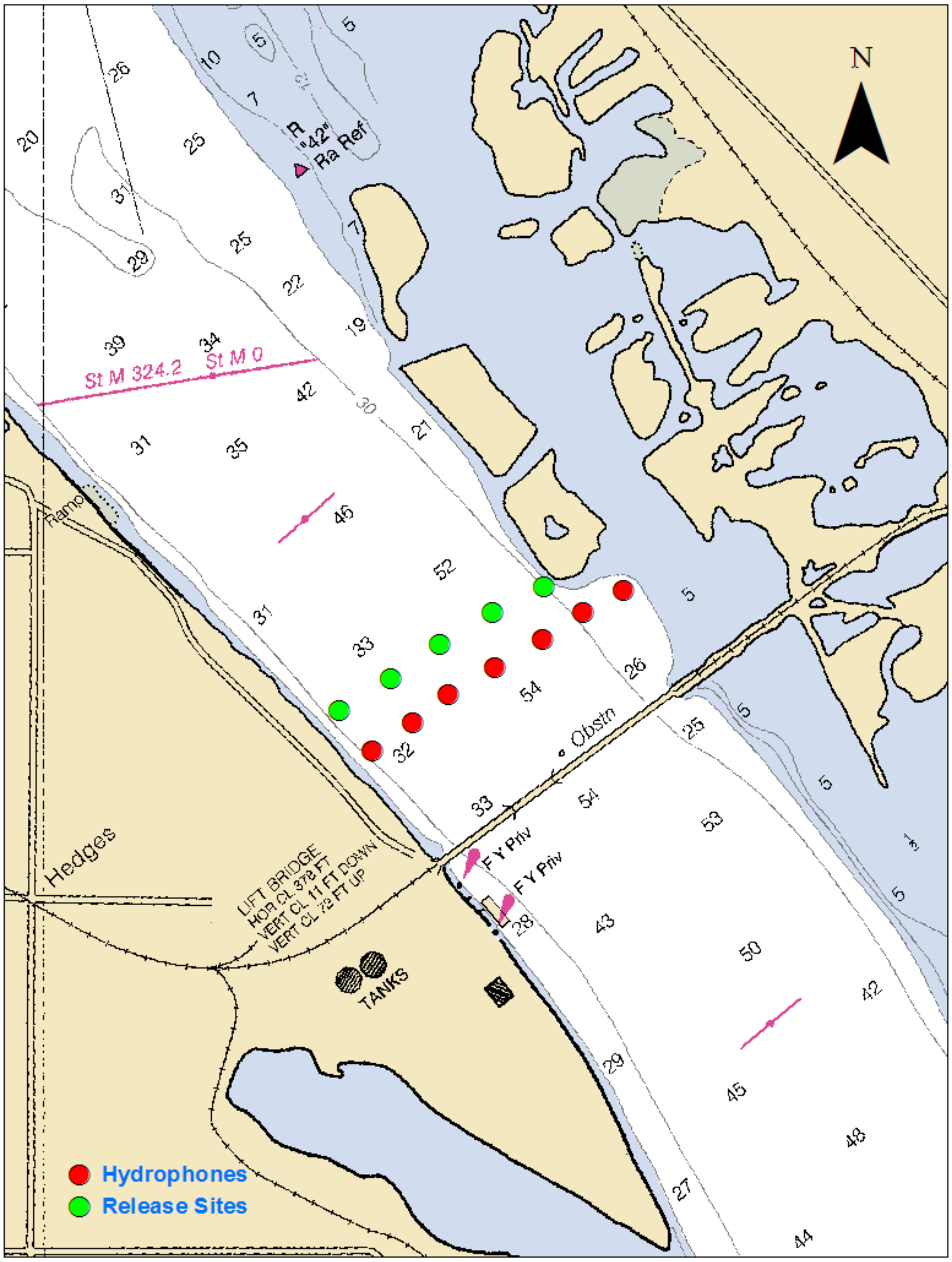


Upstream of dam: R1 release location and powerhouse acoustic detection array for paired release-recapture (PR) study design.

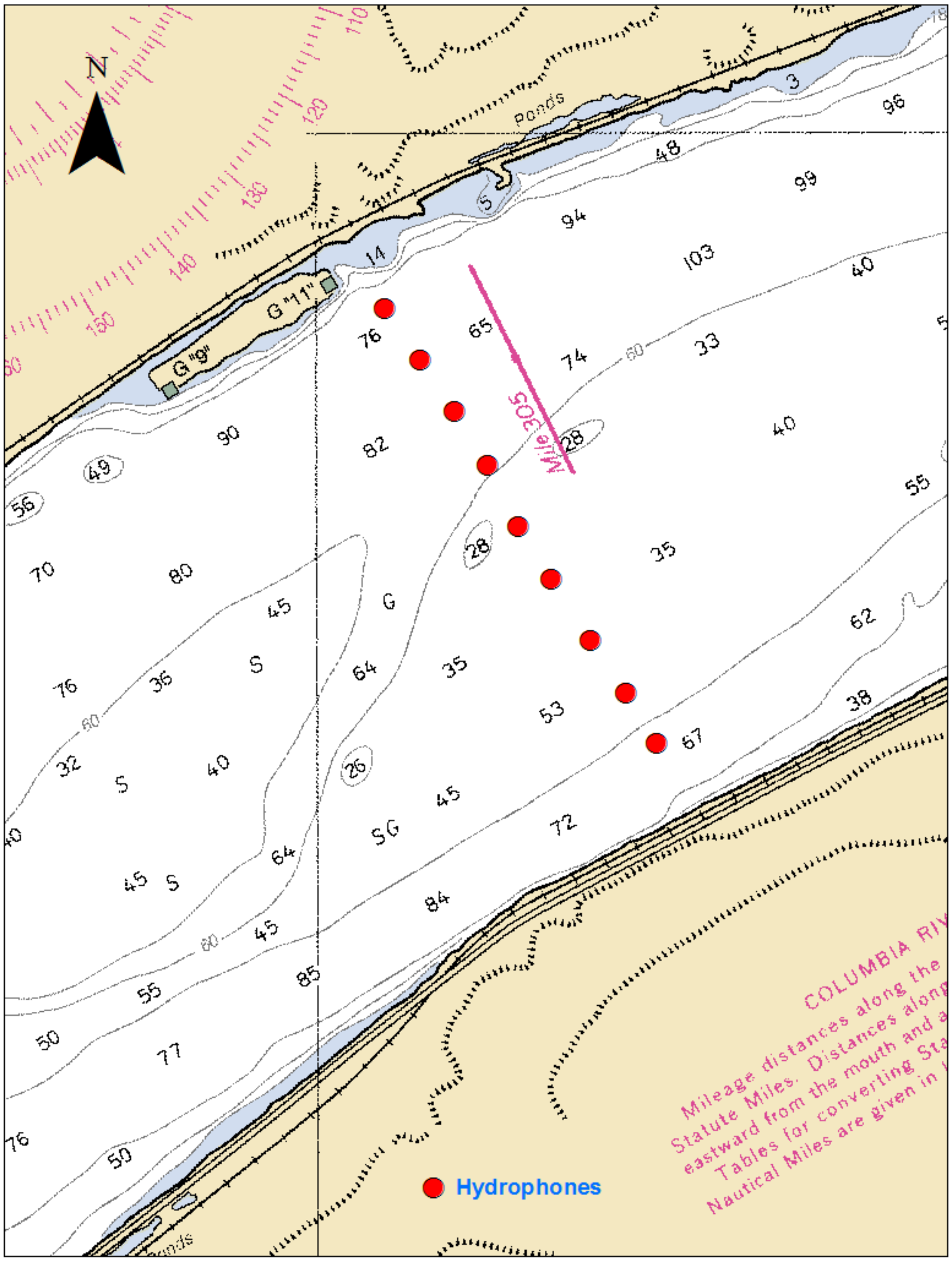
Downstream of dam: R2 release location and egress detection array for PR.



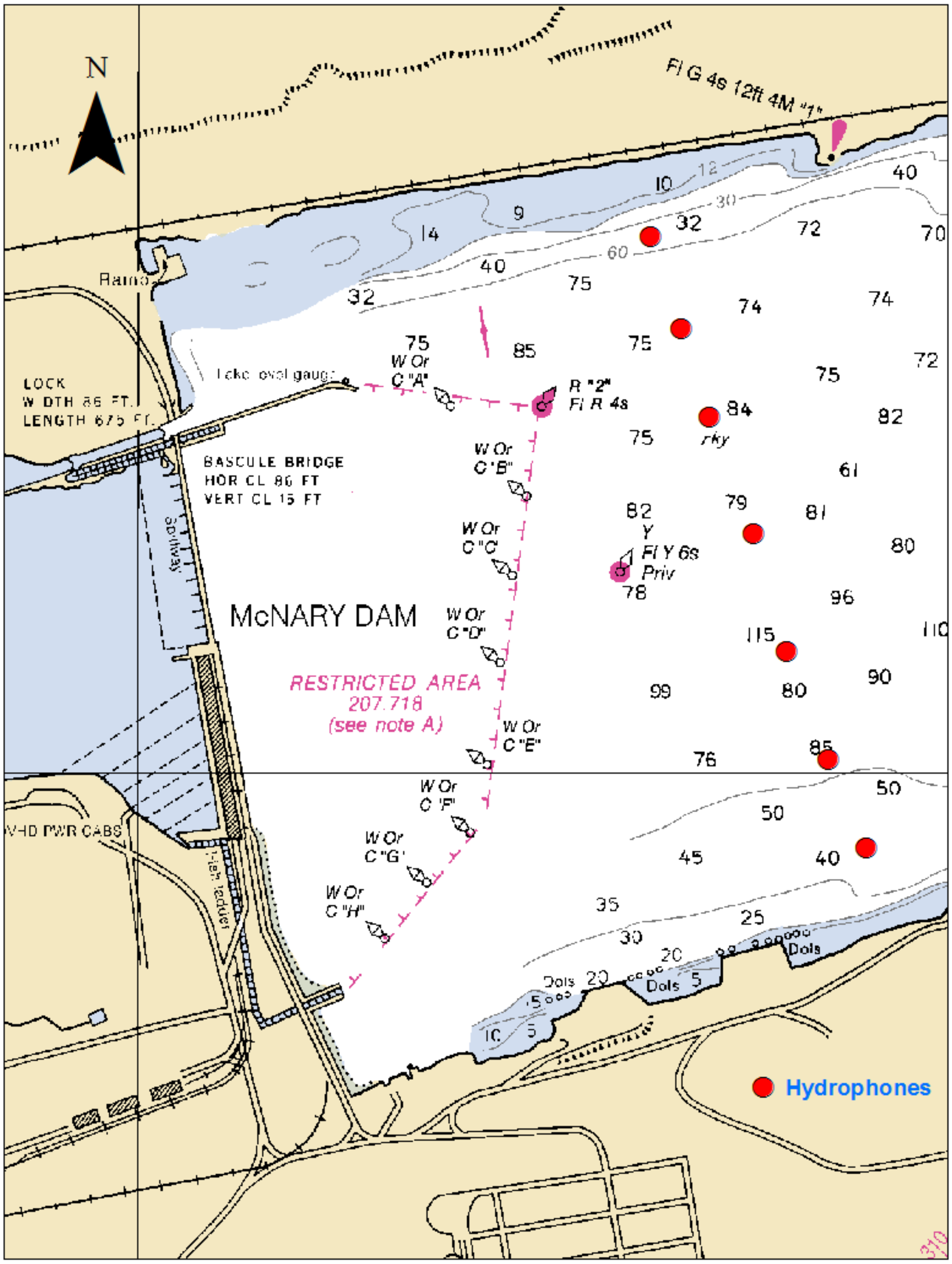
Powerhouse direct release into units 2 and 3 for either a single release-recapture (SR) or PR with control release location and egress detection array in the tailrace.



R3 release location about 3.3km downstream of the Hood Park boat ramp for VPR and PR study designs and first downstream detection array below the Snake River/Columbia River confluence for VPR, PR, and SR.



Second downstream detection array about 21km upstream of McNary Dam for VPR and PR, and possible final detection array for SR.



Final detection array in the forebay at McNary Dam for VPR and PR

Appendix 7.0

Quality Assurance/Quality Control (QA/QC) Plan Outline

EXAMPLE

Quality Assurance/Quality Control Plan:

STUDY TITLE
Contract #
Principle Investigators (names)

Agency/Firm

Introduction:

Quality assurance and quality control (QA/QC), along with surveillance of quality during the project, will be critical to successful study implementation. In addition to standard QA/QC procedures, two of the main categories of QA/QC will be diagnostics and assumption testing. Fulfilling these QA/QC examinations will help ensure that data and results are accurate and defensible. The following actions will satisfy necessary QA/QC measures to provide accurate study results and these actions including surveillance efforts should be detailed throughout the procedures of the study plan.

Pre-field QA/QC

1.0 Study Design

1.1 Development (short detail paragraph)

1.2 Peer-Review (short detail paragraph include government review)

1.3 Finalizing (short detail paragraph including response to government review)

2.0 Equipment calibration

2.1 Details (e. g. hydrophone calibration, radio telemetry receiver calibration)

3.0 Equipment Install

3.1 Details (e. g. hydrophone configuration for 3D acoustic telemetry detection and Yagi antennae configuration to improve location precision)

4.0 Personnel Training

4.1 Details (e. g. acoustic tag surgical procedures)

5.0 Anything else necessary

QA/QC Throughout Data Collection

1.0 QA/QC field methods
    1.1 Details (e. g. equipment use, fish releases, tagging, monitoring, etc)

2.0 Other protocols
    2.1 Details

3.0 Testing Assumptions and preventing violations
    3.1 Details

Post-field QA/QC

1.0 Data
    1.1 Data Collection details

    1.2 Data Processing details

    1.3 Data Analysis details

2.0 Final reporting
    2.1 Consistency, formatting, government review, etc.

Conclusions

References