Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study
Study Plan Section 8.5

Decision Support System Uncertainty

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

R2 Resource Consultants

October 2016

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
AEA	Alaska Energy Authority
cfs	cubic feet per second
DSS	Decision Support System
EC	Existing Conditions
FA	Focus Area
FERC	Federal Energy Regulatory Commission
fps	feet per second
HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Index
IFS	Fish and Aquatics Instream Flow Study 8.5
ILF-1	Intermediate Load Following – Scenario 1
ISR	Initial Study Report
OWFRM	Open-water Flow Routing Model
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project, FERC No. 14241
RSP	Revised Study Plan
SIR	Study Implementation Report
TM	Technical Memorandum
WUA	Weighted Usable Area

1. INTRODUCTION

On December 14, 2012, the Alaska Energy Authority (AEA) filed with the Federal Energy Regulatory Commission (FERC) its Revised Study Plan (RSP), which included 58 individual study plans (AEA 2012). Included within the RSP was the Fish and Aquatics Instream Flow Study 8.5 (IFS), Section 8.5. RSP Section 8.5 focused on establishing an understanding of important biological communities and associated habitats, and of the hydrologic, physical, and chemical processes in the Susitna River that directly influence those resources. RSP Section 8.5 also described the study methods that would be used to evaluate Susitna-Watana Hydroelectric Project, FERC No. 14241 (Project) effects, including study integration.

One goal of the IFS and its component study efforts is to provide quantitative indices of existing aquatic habitats that enable a determination of the effects of alternative Project operational scenarios. As part of this effort, AEA is developing a matrix-based Decision Support System (DSS) to aid in the integration of the various endpoints estimated for different Project scenarios. Discussion of the matrix approach and alternatives to the matrix approach were provided in the Initial Study Report (ISR) (Study 8.5 ISR Part C, Section 7.8 [AEA 2014a]) June 3, 2014, along with a brief presentation of five proposed evaluation metrics and options for uncertainty analysis.

Based on comments from licensing participants, it is likely that uncertainty in model results is a topic that will continue to be discussed as the licensing process continues. Further, AEA stated in the ISR that it is "considering the feasibility of and methods for incorporating several key uncertainties associated with each riverine resource analysis" (AEA 2014a). During both the April 15-17, 2014 Proof of Concept meeting, and the October 17, 2014 and March 2016 ISR meetings, licensing participants expressed interest in the DSS process, and encouraged further development of the study integration components of the Project sooner in the Project timeline (AEA 2014b; AEA 2014c). However, it will not be practical to assess all types of uncertainty in all models used to predict impacts of the Project. For example, some models take many days to run on single scenarios, precluding considerations of uncertainty or sensitivity. The model integration process is currently determining whether estimates for proposed comparison metrics are possible at the required spatial scales, based on multiple interacting models built on different platforms for different purposes. Methods for estimating key uncertainties for each model have not yet been developed.

This Technical Memorandum (TM) (a supplement to Study 8.5 *2014-2015 Study Implementation Report* (November 9, 2015) and filed with FERC as Attachment 6 to *Response of the Alaska Energy Authority to Comments on the Initial Study Report*) provides an example of the estimation of several evaluation metrics with consideration of uncertainty in output from a *single* model. Licensing participants have questioned how uncertainty would be addressed as part of the Project impact assessment process. This TM illustrates how the issues of uncertainty can be addressed as part of the DSS process being advanced by AEA. The example metrics considered are the Weighted Usable Area (WUA) metrics for juvenile Coho Salmon (*Oncorhynchus kisutch*) in Focus Area (FA) FA-128 (Slough 8A). The estimates are based on habitat results from two example operational scenarios using Coho Salmon juvenile Habitat Suitability Criteria (HSC) models described in the Study Implementation Report (Study 8.5 SIR, Appendix D [R2 2015a]).

2. STUDY OBJECTIVES

Individual study objectives were established in RSP Section 8.5.1.2 (AEA 2012). Specific IFS (Study 8.5) Study Plan objectives for this study are to: develop a DSS-type framework to compare output metrics estimated for several aquatic habitat models. For example, these output metrics may include measurements of:

- Seasonal juvenile and adult fish rearing habitat;
- Habitat connectivity;
- Spawning and egg incubation habitat;
- Ramping rates; and
- Distribution and abundance of benthic macroinvertebrates.

The following five draft key evaluation metrics were discussed during the IFS Riverine Modelers Technical Team meeting on November 13-15, 2014 (AEA 2013; R2 2013) and proposed in Study 8.5 ISR for anadromous fish habitat:

1. WUA of habitat in the Middle and Lower segments of the Susitna River for effective spawning through emergence;
2. WUA in the Middle and Lower river segments for juvenile rearing during open-water and ice cover time periods;
3. Timing/intensity/duration of spring ice breakup;
4. Area of lateral habitats in the Middle and Lower river segments that support juvenile outmigration; and
5. Area of lateral habitats in the Middle and Lower river segments accessible during adult migration (access into lateral spawning habitats, including mainstem river passage within and through Devils Canyon).

As noted above, the issue of addressing uncertainties associated with model outputs has been a continuing theme in the discussions with the agencies. The effort described here is meant to demonstrate to FERC and licensing participants how the issue of uncertainty can be addressed as part of the DSS process being advanced by AEA. Specifically, an example of the estimation of several WUA metrics in the decision support matrix with consideration of uncertainty in the HSC step has been developed. The example is based on habitat results from limited example flow scenarios for FA-128 (Slough 8A) (e.g., as used in the Proof of Concept) and final draft Coho Salmon juvenile HSC.

3. BACKGROUND AND METHODS

Generally, instream flow studies do not include an explicit analysis of uncertainty. Rather, temporal variability is considered in the analysis by including the range of hydrologic conditions or the entire available flow record (e.g., from the previous 50 years), and spatial variability is considered by the selection of study sites to represent reaches. Because the choice among operational scenarios is based on a relative comparison of evaluation metrics for a set of different flow conditions, it is generally assumed that uncertainty would impact the results for each scenario in a similar way. In this case, uncertainty would not impact the ultimate decision. Although this is likely often true, it may not be true in all cases. Therefore, a more explicit consideration of uncertainty may be warranted, an example of which for selected WUA HSC metrics is presented in this TM.

Overall, the majority of Project evaluation metrics will likely be based on a hierarchical combination of inputs from multiple riverine resource studies. The selection and calibration of this information will be based on assumptions and uncertainties that are specific to each resource discipline. Lack of perfect knowledge for some parameters or assumptions may ultimately have little or no impact on evaluation metrics and effects analyses, while other information gaps could have large impacts. Based on the complexities of multiple models being used in sequence to estimate evaluation metrics and the time and effort needed to perform model runs under alternate scenarios, it is not reasonable to incorporate all model uncertainties into the Project DSS. However, AEA is considering the feasibility of incorporating a limited number of key uncertainties associated with each riverine resource analysis.

The example data used in this report are based on river flows for May 28, 1985 through October 28, 1985, the open-water period for the moderate flow year as identified in Study 8.5 ISR Part C, Appendix J (R2 2014). Specific activities used in the development of this uncertainty example include: 1) estimating flow at the upstream and downstream ends of FA-128 (Slough 8A) for the open-water period in 1985 under existing (natural) conditions (EC), and under the Intermediate Load Following - Scenario 1 (ILF-1); 2) simulating a set of alternative HSC curves (n=1,000) based on uncertainty in the site-specific habitat preference relationship for juvenile Coho Salmon; 3) estimating WUA in FA-128 (Slough 8A) for Coho Salmon juveniles during the 1985 open-water period for the simulated HSC curves for EC and ILF-1 flow estimates; and 4) reviewing the potential impact of uncertainty on decisions based on three selected summary statistics for WUA.

3.1. Estimating Flow for FA-128 (Slough 8A)

The 1-D Open-water Flow Routing Model (OWFRM; Study 8.5 SIR, Appendix B [R2 2015b]) was used to simulate stage and flow at the upstream and downstream ends of FA-128 (Slough 8A) for EC and ILF-1 operational scenarios. The ILF-1 scenario is described in the Engineering Feasibility Report (MWH 2014). Because it is computationally difficult to run multiple alternate operational scenarios over the entire period of record, and difficult to evaluate, representative years have been selected to use for comparing operational scenarios for the Project: 1981 (wet/warm), 1985 (moderate), and 1976 (dry/cold) (Study 8.5 SIR, Appendix B [R2 2015b]). For this example analysis, the moderate year, 1985, was selected. The reservoir/generation operations model provided hourly flow releases at the dam for each operational scenario, and the OWFRM was used to route flows downstream for the open-water period, incorporating accretion, attenuation, and celerity. The output from the OWFRM was provided at seven cross-sectional profiles within FA-128 (Slough 8A) between Project River Mile (PRM) 128.1 and PRM 129.7. Because this Focus Area is less than two miles long, with little change in flow within the reach, the average value of the upstream and downstream transect profile flows was used to estimate habitat conditions for the study site at any given time.

3.2. Simulating Alternative Habitat Suitability Criteria Models

The draft final HSC model for juvenile Coho Salmon was presented in the Study 8.5 SIR, Appendix D (R2 2015a). This estimated habitat preference relationship was based on site-specific utilization and availability data collected in 2013 and 2014 throughout the Susitna River. The selected model is a logistic mixed effects model with random effects for sampling events (location and time), and explicitly included two predictor variables: water depth and the presence/absence of cover. Other habitat variables may be included as index factors with defined suitable ranges in the final HSC analysis. For this example, we include considerations for maximum suitable velocity and distance from the water's edge, as described below.

The HSC model for juvenile Coho Salmon is:

$$\log\widehat{\left(\frac{p}{1-p}\right)} = C_k + 1.17 * depth - 0.228 * depth^2,$$

where:

p is the relative probability of juvenile Coho Salmon presence, and

k indexes two intercept values for presence/absence of non-boulder cover types:

$C_0 = -3.37$ (non-boulder cover absent)

$C_1 = -2.72$ (non-boulder cover present).

The model is displayed in Figure 3.2-1. The standard errors for the coefficients in the above model are shown in Table 3.2-1. The R (version 3.1.1, R Core Team 2014) function *sim* (Gelman and Hill 2006) from the *arm* package (Gelman and Su 2014) was used to generate 1,000 simulations from the joint distribution of coefficients from the mixed effects model described above. These simulations assume normal distribution of the model coefficients.

3.3. Estimating Weighted Usable Area Based on Habitat for FA-128 (Slough 8A)

The *FA-128 (Slough 8A) Hydraulic Modeling Proof of Concept* report (Tetra Tech 2014) demonstrated the integration of hydraulic modeling with habitat analyses. As part of this effort, a 2-D grid of habitat cells was created, and estimates of cell area, water depth, and mean column velocity were estimated for nine flow levels in FA-128 (Slough 8A): 2000, 4000, 6000, 8000, 12000, 16000, 22000, 30000, and 50000 cubic feet per second (cfs). Cover in individual cells was available from the Surficial Substrate and Cover Characterization Study (Study 8.5 SIR, Appendix E [R2 2015c]).

The draft final juvenile Coho Salmon HSC model was used to provide relative ranking of habitat preference for each cell in the 2-D habitat model in FA-128 (Slough 8A), based on depth and cover in the cell under each available flow condition. After estimating the relative preference for each cell based on the HSC model (original model and each simulation), the relative preference was changed to zero for depths ≤ 0.3 feet and mean column velocities ≥ 3 feet per second (fps). For water depths > 4.4 feet, the relative preference was fixed at the result for 4.4 feet (i.e., depth was non-limiting). Because HSC sampling could not be conducted under all field conditions, sampling was generally limited to 50 feet from the water's edge. To avoid extrapolation to unknown conditions, cells in FA-128 (Slough 8A) with centroid location greater than 50 feet from the water's edge at a given flow were assigned a WUA of zero under all flow conditions. This decision applies only to the example analysis for this report, and should not be considered a final decision for the Project. Note that the final WUA estimates for the Project may also include Habitat Suitability Indices (HSI) thresholds for water temperature, dissolved oxygen, and pH, but these criteria were not included in this example analysis.

For each flow condition, the WUA was estimated for each cell in FA-128 (Slough 8A) by multiplying the approximate cell area times the adjusted relative preference based on the HSC model (or simulated HSC model for uncertainty analysis). The total WUA for FA-128 (Slough 8A) for each flow is then the sum of the WUA of the individual cells. This results in a flow-WUA curve, which is combined with hourly flow under each operational scenario to produce hourly vectors of WUA. The estimated flow for each hour was assigned a WUA using linear interpolation from the flow-WUA relationship developed for the nine available flow points.

From the EC and ILF-1 time series' of WUA for 1985, three WUA summary statistics were selected and evaluated for this example: the average daily minimum WUA, the median daily average WUA, and the median daily range WUA for juvenile Coho Salmon. These statistics were estimated for each simulated HSC model (n=1000), resulting in a distribution of feasible metric results based on uncertainty in the HSC.

4. RESULTS

4.1. Estimating Flow for FA-128 (Slough 8A)

The estimated flow for FA-128 (Slough 8A) during the open-water period in 1985 as used in this example is displayed in Figure 4.1-1, for EC and ILF-1 conditions. The open-water period extends from approximately the end of May through the end of October.

4.2. Simulating Habitat Suitability Criteria Models

The simulated HSC coefficients are displayed in Figure 4.2-1, with vertical blue lines depicting the draft final HSC model coefficients. Simulated models with linear depth coefficients less than or equal to zero and/or quadratic depth coefficients greater than or equal to zero (11 simulations total) were not included in the analysis, as these models would not have had credible ecological interpretation. For example, a positive quadratic depth coefficient would indicate preference for shallow and deep water, with lowest preference at intermediate depths.

4.3. Estimating Weighted Usable Area Based on Habitat for FA-128 (Slough 8A)

The estimated example WUA as a function of flow for FA-128 (Slough 8A) is displayed in Figure 4.3-1 (thick red line), with a subset (50) of the simulated results based on alternative HSC models. For these flow levels and the juvenile Coho Salmon HSC curve, WUA is increasing with flow.

Estimated hourly WUA for the open-water period in 1985 for EC and ILF-1 conditions is displayed in Figure 4.3-2. Because the WUA curve is strictly increasing, the WUA curves closely mimic the flow volume (Figure 4.1-1) in this example.

The simulated distribution of average daily minimum WUA for FA-128 (Slough 8A; 1985) with consideration of uncertainty in the HSC curve is displayed in Figure 4.3-3 for EC and ILF-1 conditions superimposed. Similar plots for the median daily mean and median daily change in WUA are displayed in Figure 4.3-4 and 4.3-5, respectively. The expected values for each metric based on the draft final juvenile Coho Salmon HSC curves are displayed in Table 4.3-1 and are plotted as vertical lines in the histograms.

Because the results for the two scenarios are paired within each simulation, it is useful to look at the uncertainty in or the distribution of the difference between the metrics calculated for the two scenarios (EC - ILF-1) across the simulations. This uncertainty is displayed in histograms in Figure 4.3-6, Figure 4.3-7, and Figure 4.3-8. On each histogram, the 5th and 95th percentiles of the simulated distributions are marked with dashed blue lines. For example, the average daily minimum WUA for EC is 34,000 square feet (90% CI: 23,900, 55,100) greater than the average daily minimum WUA for ILF-1.

5. DISCUSSION AND CONCLUSIONS

This analysis provides an example of how uncertainty in one component of the IFS can be included in a comparison of operational scenarios in the DSS. For this example, it is clear that the three WUA summary statistics are lower for the ILF-1 scenario than for the EC scenario, regardless of variability in the HSC model. Without the inclusion of uncertainty, the DSS matrix would provide just the difference between ILF-1 and EC (e.g., 34,000) for average daily minimum WUA (Table 4.3-1). With the uncertainty in the HSC model, uncertainty in the outcome metric can be expressed as a 90% credible interval on the summary statistics, or as a distribution of results showing overlap. The shape of the distributions can provide useful information that is not provided by the credible interval. For example, the graph in Figure 4.3-5 shows that the median daily range in WUA for ILF-1 is less variable than the median daily range for EC. Under EC, there are ranges greater than 13,000 square feet in a single day, whereas the most extreme HSC model predicted a range less than 7,500 square feet for the ILF-1 scenario.

In the final DSS, the comparison of different operational scenarios will likely be made based on differences of multiple operational scenarios from existing conditions. The operational scenario that minimizes the differences across most metrics might then be considered the favored scenario. With multiple scenarios, there may be multiple distributions similar to the plots in

Figures 4.3-6, 4.3-7, and 4.3-8. Graphical comparisons of the entire distribution of potential differences rather than single metrics provides a better context for decision making. These distributions could then be compared to determine how likely it is that one scenario would produce higher daily minimum WUA, for example. The difference among two operational scenarios might be small relative to the range of potential differences, and the distribution of differences may straddle zero, meaning that the operational scenarios do not necessarily differ in the amount of habitat provided. In that case, the decision on which operational scenario is better should be based on other metrics that have distinguishable results.

Because evaluation metrics are generally based on a hierarchical combination of inputs from multiple riverine resource studies, it is expected that simulations like those performed here would be needed to carry uncertainty through all model interactions. Uncertainty is natural to statistical models, but not all of the models are statistical, and some models are too time-intensive to run under extra simulated conditions. It is not reasonable to incorporate all model uncertainties into the Project DSS, but AEA is considering the feasibility of incorporating a limited number of key uncertainties associated with each riverine resource analysis, as shown in this example. The process will require collaboration among all modeling entities, including those outside of the IFS Study 8.5 team. The DSS is in the early stages of development, with multiple activities remaining that need to be completed before final DSS can be developed. These include the following:

- Selection and agreement on all indicator variables;
- Finalization of models and flow of information used to estimate flow and all habitat parameters; and
- Selection and prioritization of key uncertainties to be considered.

6. LITERATURE CITED

Alaska Energy Authority (AEA). 2012. Revised Study Plan. Susitna-Watana Hydroelectric Project, FERC Project No. 14241 Submittal: December 14, 2012. http://www.susitna-watanahydro.org/study-plan.

Alaska Energy Authority (AEA). 2013. Meeting Notes: Riverine Modelers Technical Team meeting on November 13, 14, and 15, 2013. Susitna-Watana Hydroelectric Project, FERC No. P-14241. http://www.susitna-watanahydro.org/wp-content/uploads/2014/02/2013.11.13Modelers_Notes.pdf.

Alaska Energy Authority (AEA). 2014a. Initial Study Report. Susitna-Watana Hydroelectric Project, FERC Project No. 14241 Submittal: June 3, 2014. http://www.susitna-watanahydro.org/type/documents/.

Alaska Energy Authority (AEA). 2014b. Meeting Notes: Riverine Modeling Proof of Concept Technical Team meeting on April 15, 16, and 17, 2014. Susitna-Watana Hydroelectric Project, FERC No. P-14241. http://www.susitna-watanahydro.org/wp-content/uploads/2014/05/2014_04_15-17TT_POC_Notes.pdf.

Alaska Energy Authority (AEA). 2014c. Meeting Transcript: Initial Study Report Meeting on October 17, 2014 (Studies 7.6, 8.5, 8.6, and 11.6). Susitna-Watana Hydroelectric Project, FERC No. P-14241. http://www.susitna-watanahydro.org/wp-content/uploads/2014/11/Oct17_ISR_Meeting_PartA_Transcripts.pdf.

Gelman, A. and J. Hill. 2006. Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge University Press.

Gelman, A. and Y. Su. 2014. arm: Data Analysis Using Regression and Multilevel/Hierarchical Models. R package version 1.7-07. http://CRAN.R-project.org/package=arm.

MWH Americas, Inc. (MWH). 2014. Susitna-Watana Hydroelectric Project Engineering Feasibility Report. Report 14-21-REP v0.0. AEA11-022. December 2014.

R Core Team. 2014. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

R2 Resource Consultants (R2). 2013. Decision Support System Options. PowerPoint Presentation, Riverine Modeling Meetings on November 13-15, 2013. Prepared for Alaska Energy Authority, Anchorage, Alaska. Susitna-Watana Hydroelectric Project, FERC No. P-14241. http://www.susitna-watanahydro.org/wp-content/uploads/2013/11/SuWa-DSS-presentation-20131115.pdf.

R2 Resource Consultants (R2). 2014. Representative Years. Susitna-Watana Hydroelectric Project, FERC No. P-14241 Submittal: June 3, 2014, Initial Study Report, Study 8.5, Part C, Appendix J. Prepared for Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/wp-content/uploads/2014/06/08.5_IFS_ISR_PartC_1_of_2.pdf.

R2 Resource Consultants (R2). 2015a. Habitat Suitability Criteria Development. Susitna-Watana Hydroelectric Project, FERC No. P-14241 Submittal: November 9, 2015, 2014-2015 Study Implementation Report, Study 8.5, Appendix D. Prepared for Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/wp-content/uploads/2015/11/08.5_IFS_SIR_App_D_HSC.pdf.

R2 Resource Consultants (R2). 2015b. Open-water Hydrology Data Collection and Open-water Flow Routing Model (Version 2.8). Susitna-Watana Hydroelectric Project, FERC No. P-14241 Submittal: November 9, 2015, 2014-2015 Study Implementation Report, Study 8.5, Appendix B. Prepared for Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/wp-content/uploads/2015/11/08.5_IFS_SIR_App_B_OWFRM-Hydrology.pdf.

R2 Resource Consultants (R2). 2015c. Fish Habitat Modeling Data: Surficial Substrate and Cover Characterization and Salmon Spawning Observations by Focus Area. Susitna-Watana Hydroelectric Project, FERC No. P-14241 Submittal: November 9, 2015, 2014-2015 Study Implementation Report, Study 8.5, Appendix E. Prepared for Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/wp-content/uploads/2015/11/08.5_IFS_SIR_App_E_FishHabitatModelingData_1_of_2.pdf and http://www.susitna-watanahydro.org/wp-content/uploads/2015/11/08.5_IFS_SIR_App_E_FishHabitatModelingData_2_of_2.pdf.

Tetra Tech. 2014. Updated Fluvial Geomorphology Modeling Approach. Attachment A: FA-128 (Slough 8A) Hydraulic Modeling for Proof of Concept. Susitna-Watana Hydroelectric Project, FERC No. P-14241 Submittal May 27, 2014 Technical Memorandum. Prepared for Alaska Energy Authority, Anchorage, Alaska. http://www.susitna-watanahydro.org/wp-content/uploads/2014/05/06.6_GEOMOD_UpdatedFGM_ModelingApproach_TM_Attachment-A.pdf.

7. TABLES

Table 3.2-1. Coefficients for the juvenile Coho Salmon Habitat Suitability Criteria (HSC) model with standard errors.

	Estimate	Std. Error
No Cover (intercept)	-3.37	0.369
Cover (intercept)	-2.72	0.404
Depth (Linear)	1.17	0.412
Depth (Quadratic)	-0.228	.0992

Table 4.3-1. Expected value of three juvenile Coho Salmon Weighted Usable Area (WUA) metrics for Existing Conditions (EC) and Intermediate Load Following – Scenario 1 (ILF-1) conditions applied to FA-128 (Slough 8A) in the open-water period of 1985.

Operational Scenario		Average Daily Minimum WUA	Median Daily Mean	Median Daily Change (Max-Min)
Existing Condition	Estimate	182000	196000	4580
	90% Credible Interval	(140000,251000)	(149000,268000)	(2390,9310)
ILF1	Estimate	148000	141000	2670
	90% Credible Interval	(114000,199000)	(108000,190000)	(1870,4940)
Difference (EC – ILF1)	Estimate	34000	55000	1910
	90% Credible Interval	(23900,55100)	(38700,80400)	(69.2,4750)

8. FIGURES

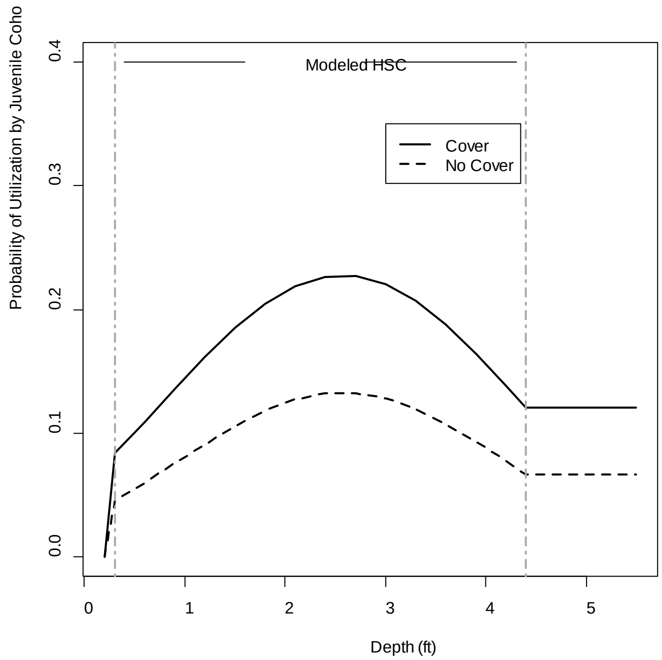

Figure 3.2-1. Coho Salmon juvenile HSC as a function of depth with and without non-boulder cover.

Note: Estimated preference for depths outside observed range of utilization is set based on theoretical thresholds (depth < 0.3 feet: linear decrease to 0 suitability at 0.2 ft; depth > 4.4 feet: non-limiting - fixed at the highest modeled value).

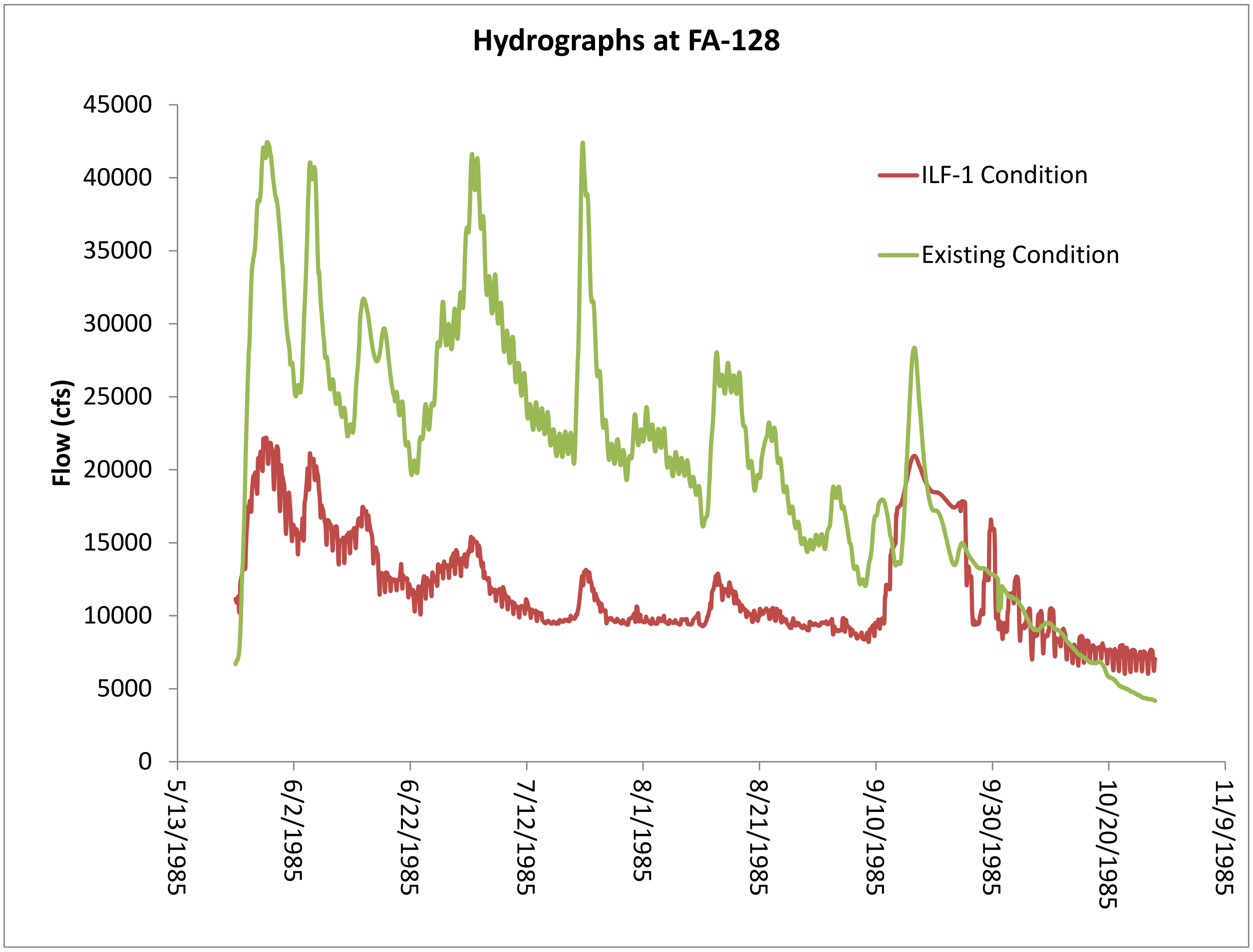

Figure 4.1-1. Example hourly estimated flow for FA-128 (Slough 8A) during the open-water period of 1985 (moderate flow year).

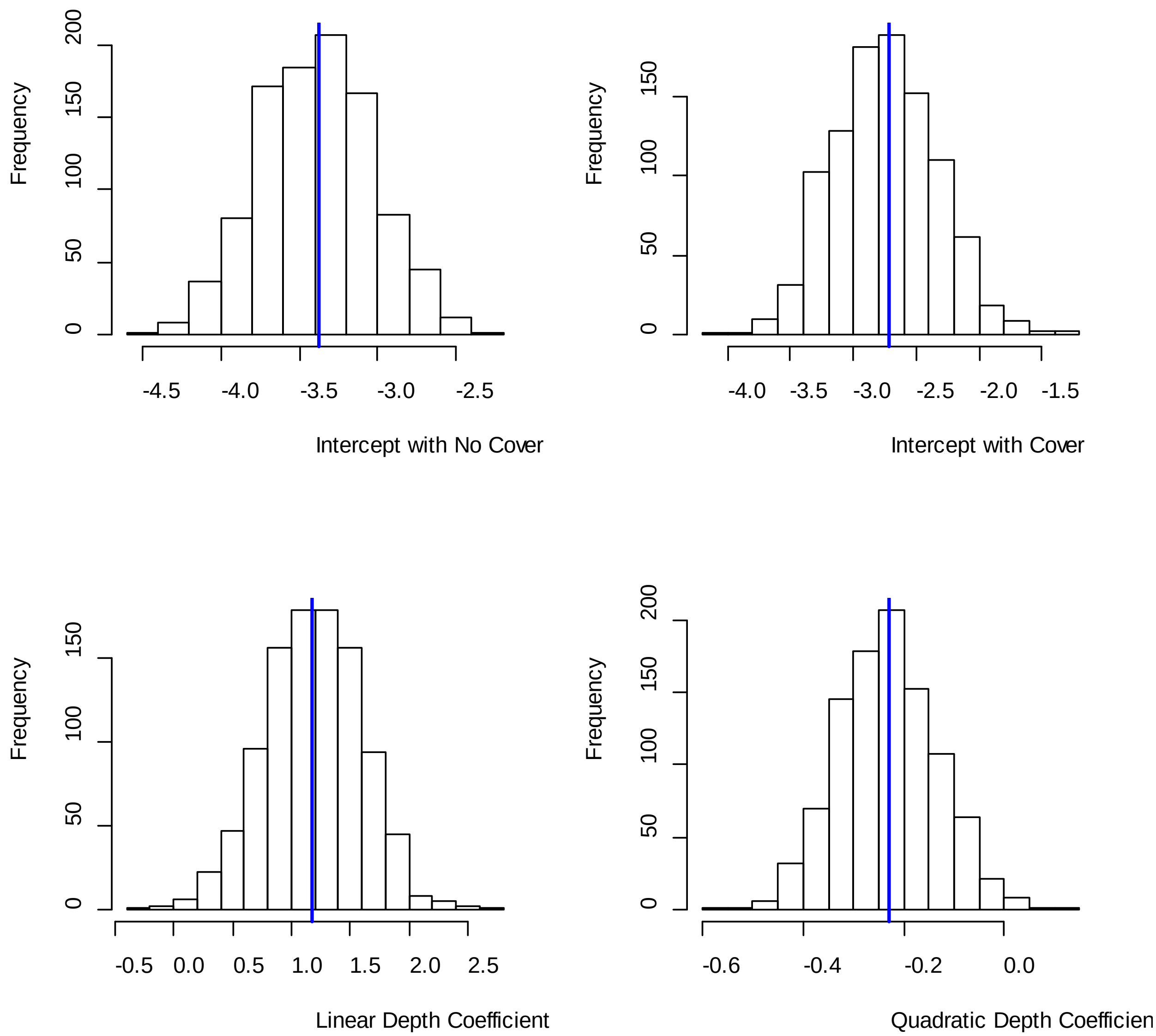

Figure 4.2-1. Distributions of simulated Habitat Suitability Criteria (HSC) model coefficients. For depth, simulations with linear coefficients ≤ 0 and/or quadratic coefficients ≥ 0 were not included in the final results.

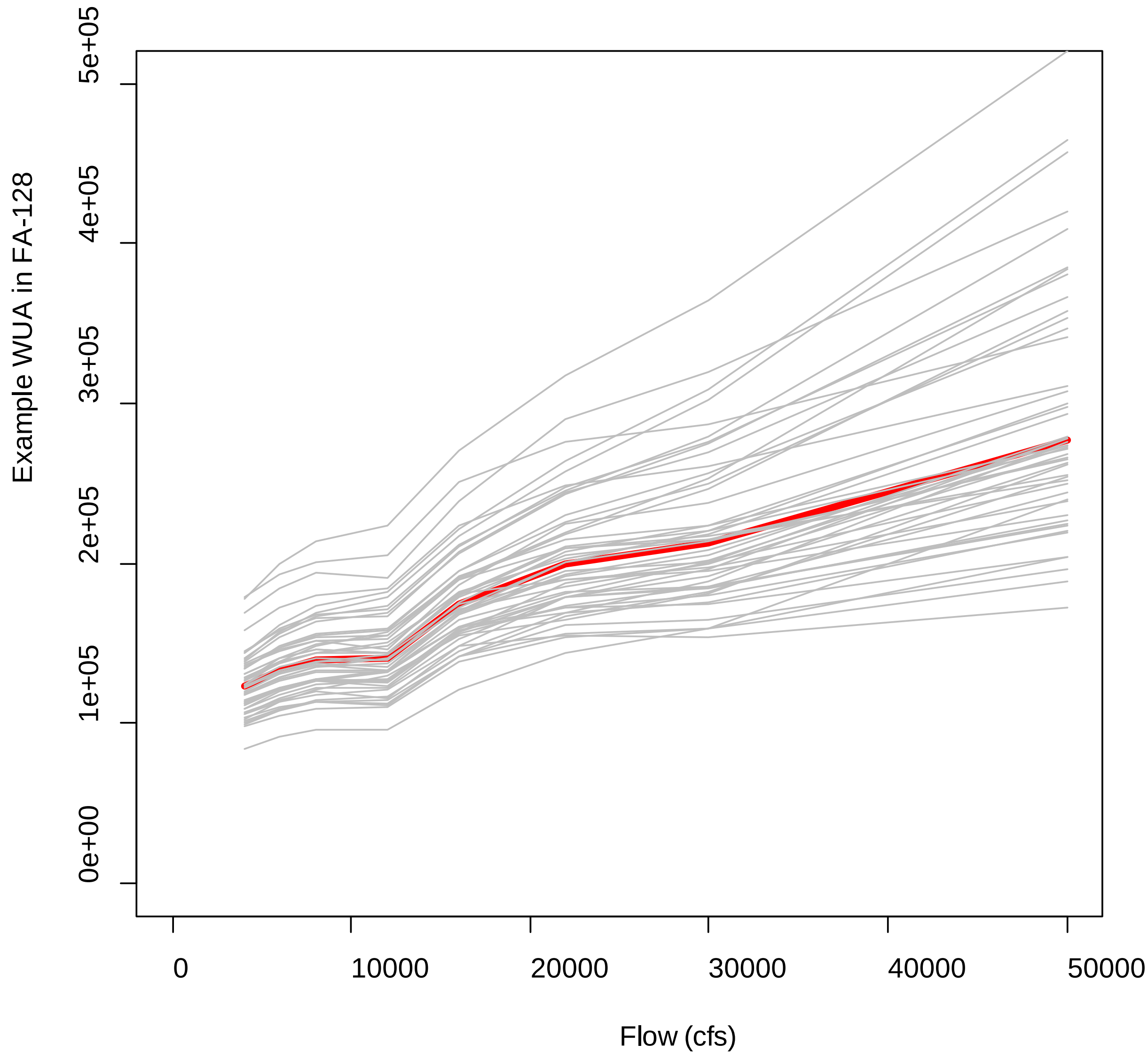

Figure 4.3-1. Example juvenile Coho Salmon Weighted Usable Area (WUA; square feet) as a function of flow at FA-128 (Slough 8A).

Note: Red line is WUA based on site-specific draft final Habitat Suitability Criteria (HSC) curve. Black lines are 50 simulated WUA relationships based on 50 alternative models (out of 1,000 total simulations).

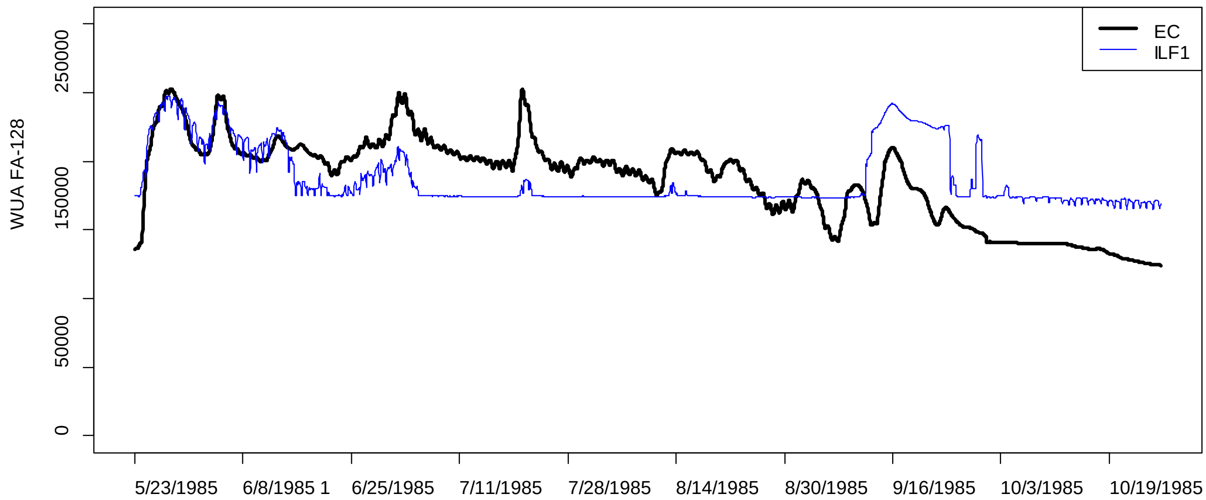

Figure 4.3-2. Example estimated hourly Weighted Usable Area (WUA; square feet) for juvenile Coho Salmon during the open-water period in 1985 in FA-128 (Slough 8A) for Existing Condition (EC) scenario and Intermediate Load Following – Scenario 1 (ILF-1).

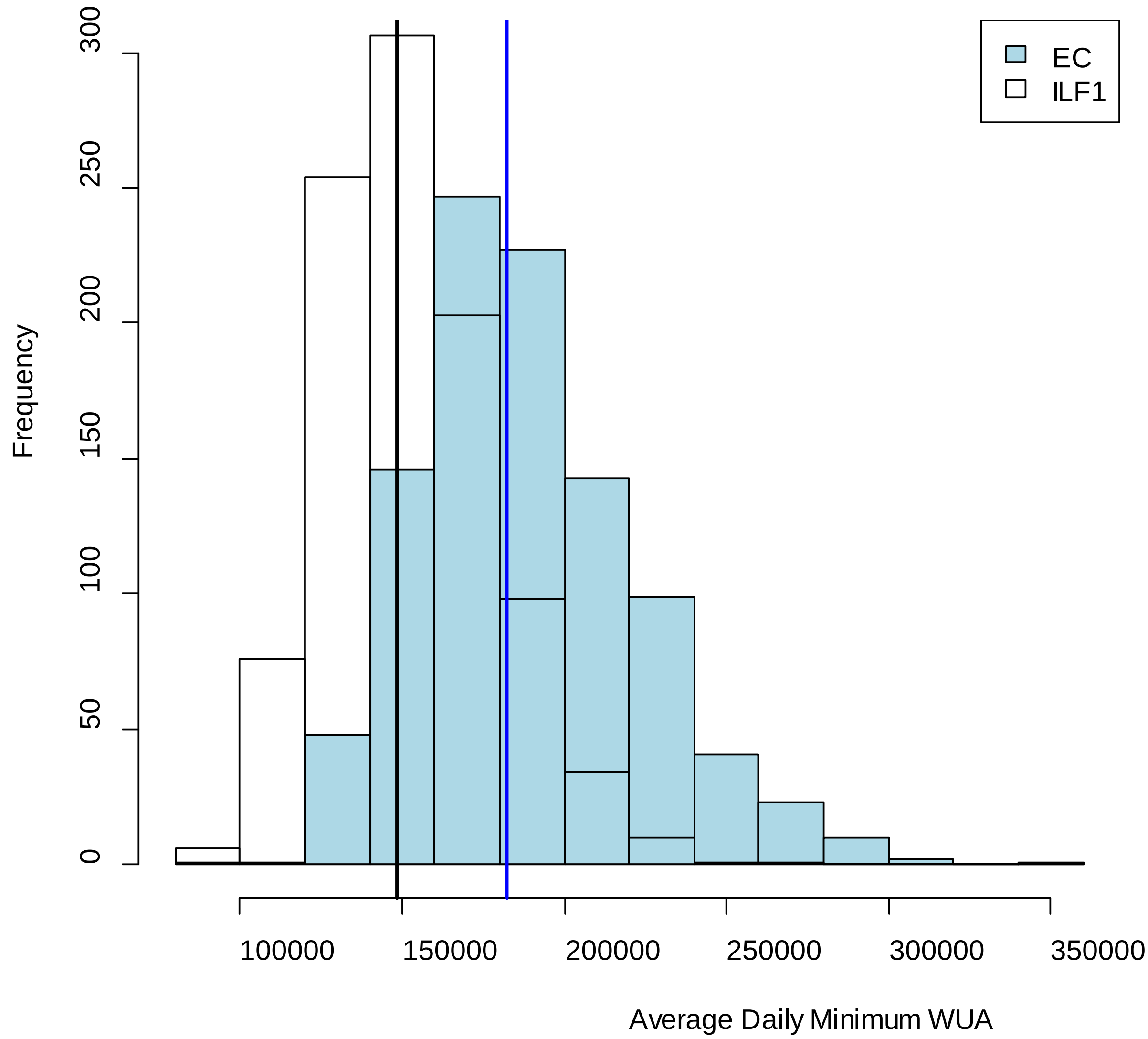

Figure 4.3-3. Histograms showing the average daily minimum Weighted Usable Area (WUA; square feet) for open water period of 1985 under two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical lines show the estimate based on the best-fit HSC model for each scenario (blue = Existing Condition [EC], black = Intermediate Load Following – Scenario 1 [ILF-1]).

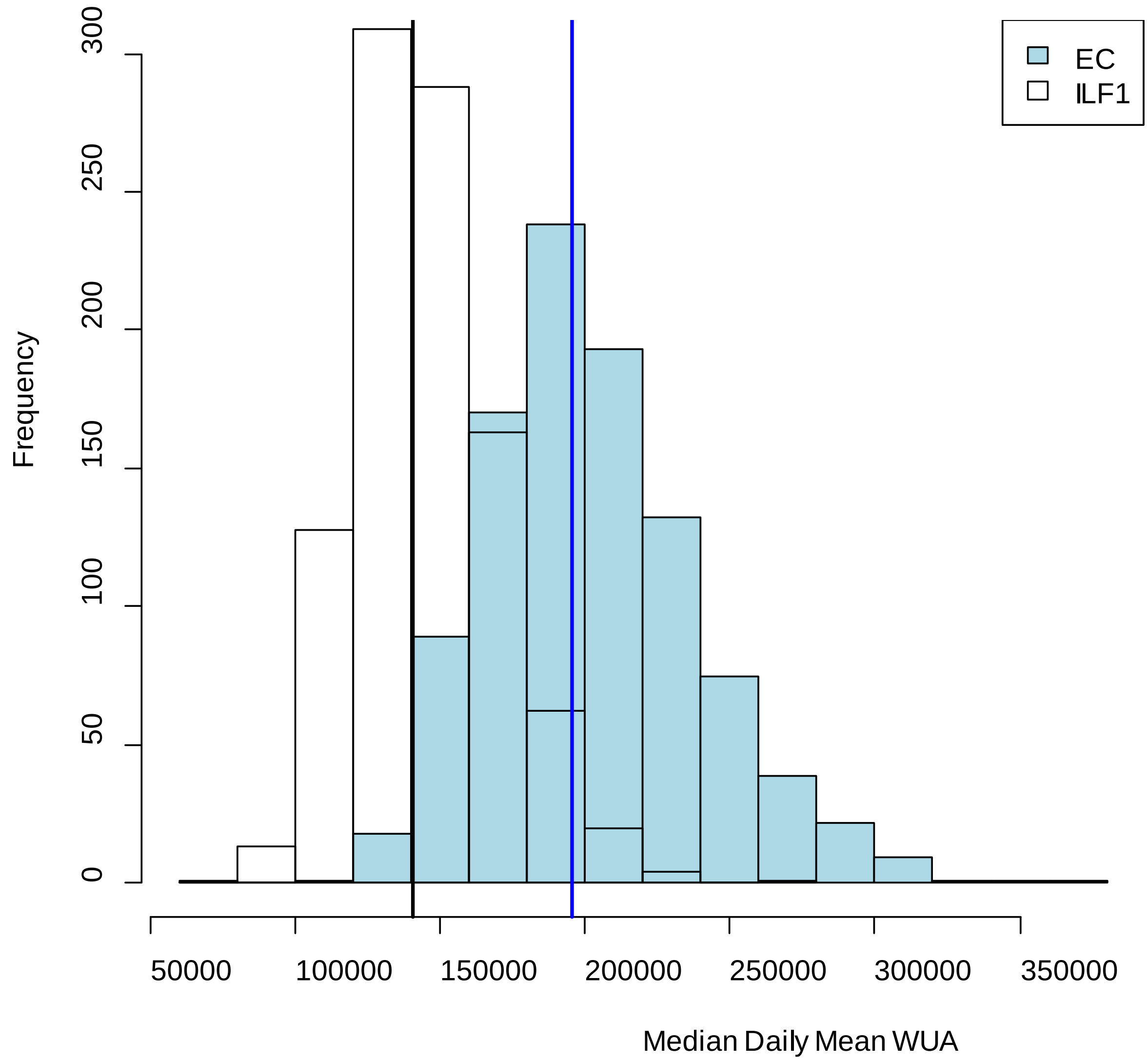

Figure 4.3-4. Histograms showing the median daily mean Weighted Usable Area (WUA; square feet) in 1985 under two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical lines show the estimate based on the best-fit HSC model for each scenario (blue = Existing Condition [EC], black = Intermediate Load Following – Scenario 1 [ILF-1]).

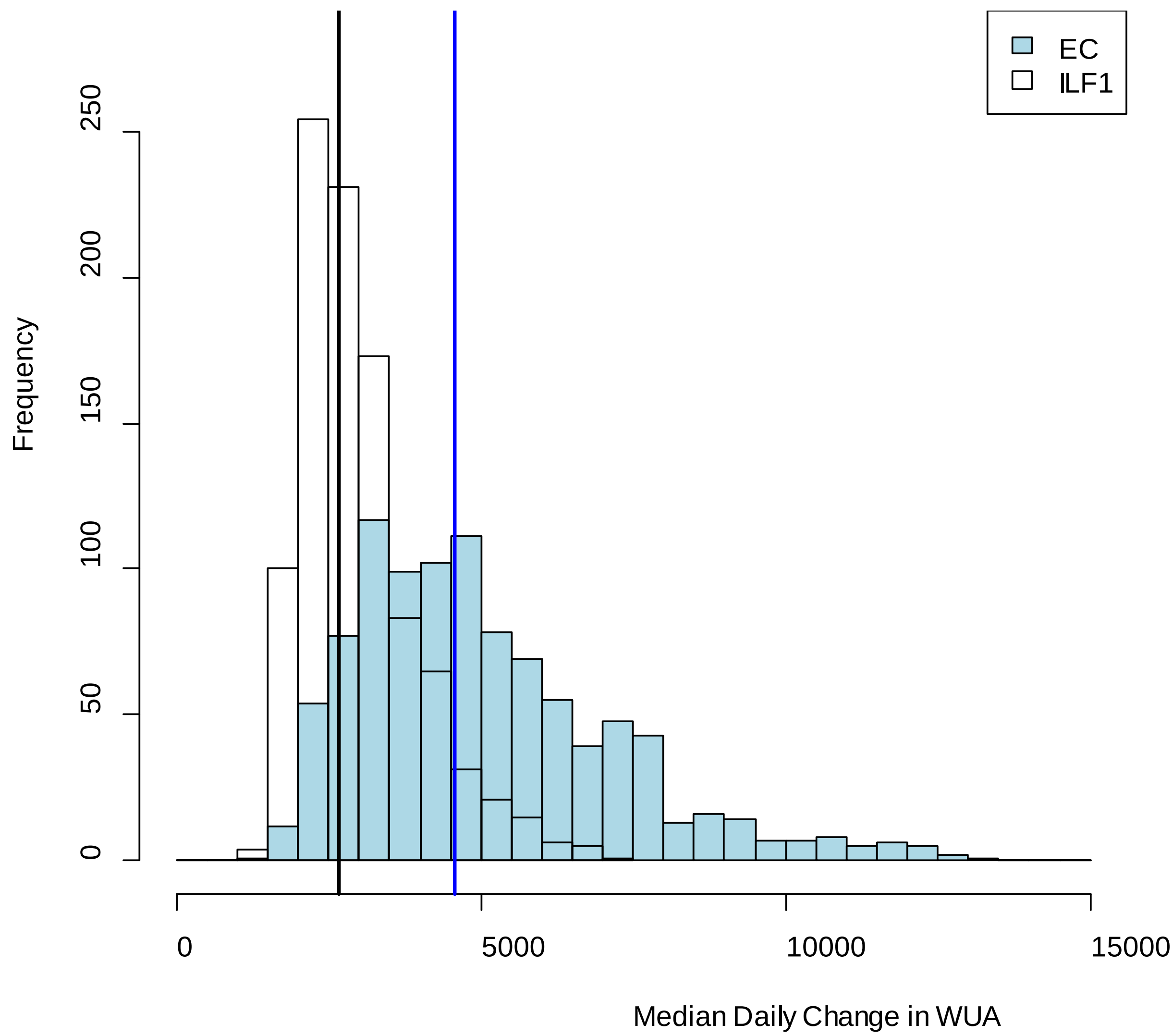

Figure 4.3-5. Histograms showing the median daily change (max-min) in Weighted Usable Area (WUA; square feet) in 1985 under two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical lines show the estimate based on the best-fit HSC model for each scenario (blue = Existing Condition [EC], black = Intermediate Load Following – Scenario 1 [ILF-1]).

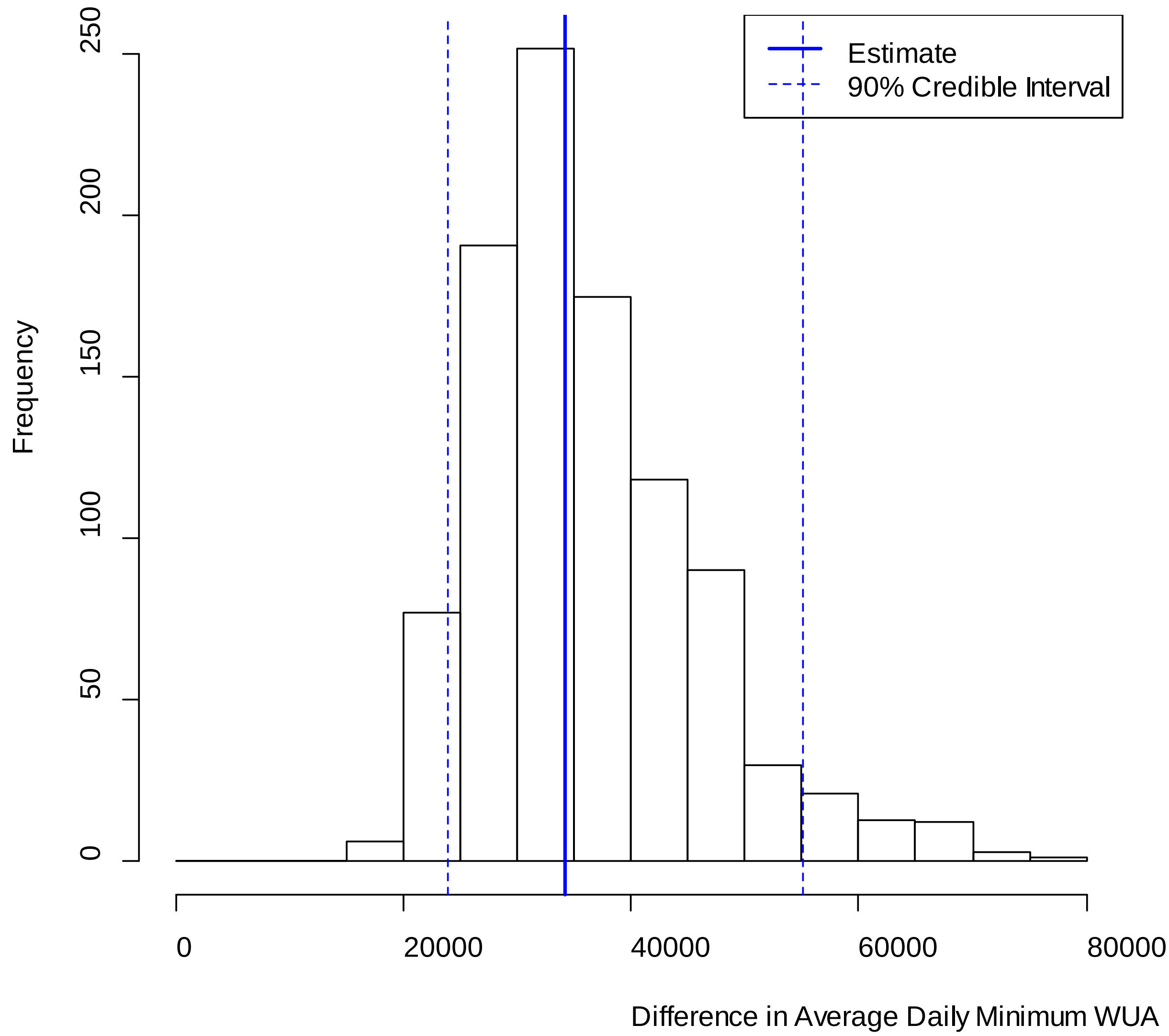

Figure 4.3-6. Histogram showing the difference in average daily minimum Weighted Usable Area (WUA; square feet) for 1985 between two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical line shows the estimated difference based on the best-fit HSC model; dotted line show 95% credible interval from the simulations.

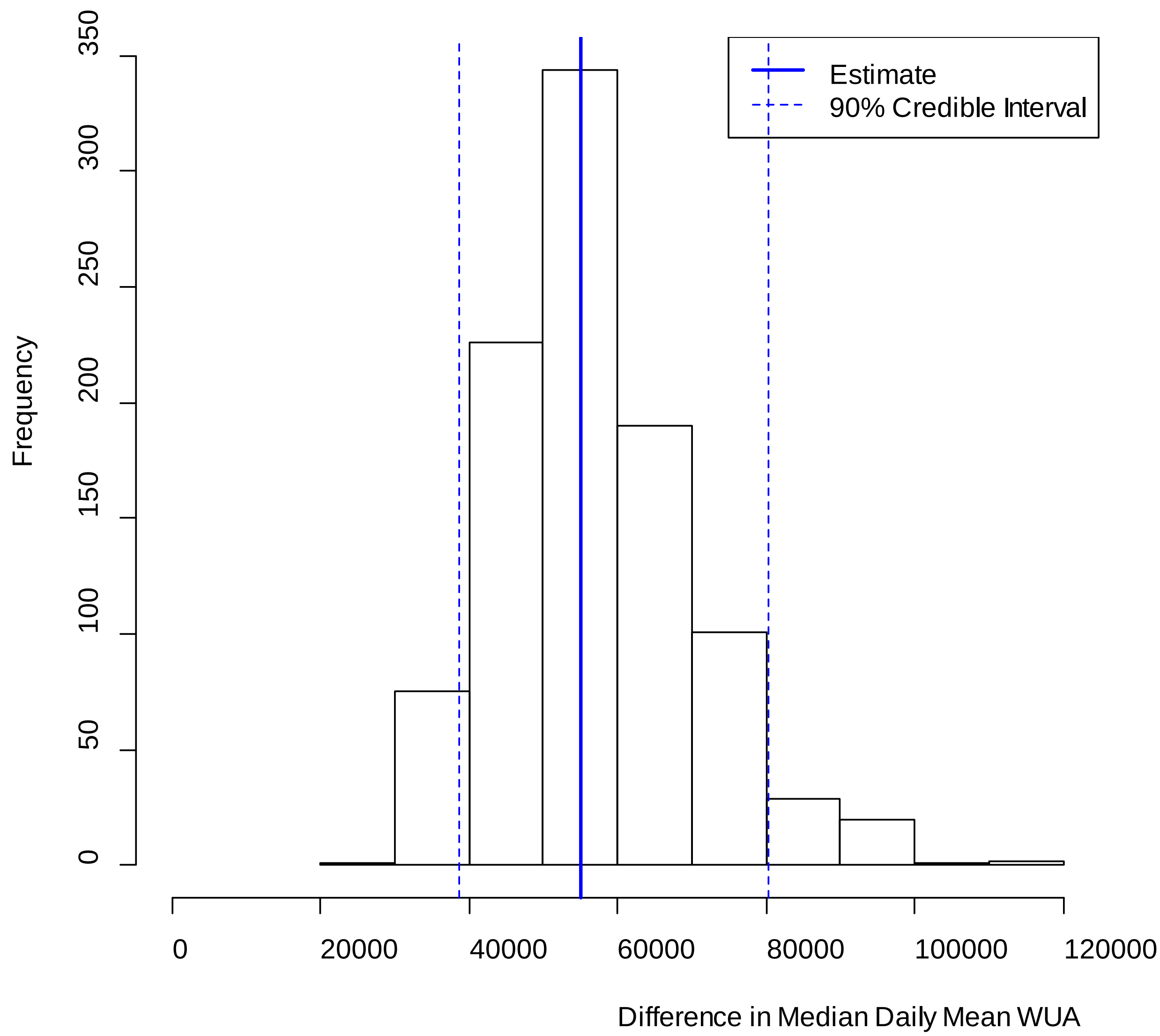

Figure 4.3-7. Histograms showing the difference in median daily average Weighted Usable Area (WUA; square feet) for 1985 between two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical line shows the estimated difference based on the best-fit HSC model; dotted line show 95% credible interval from the simulations.

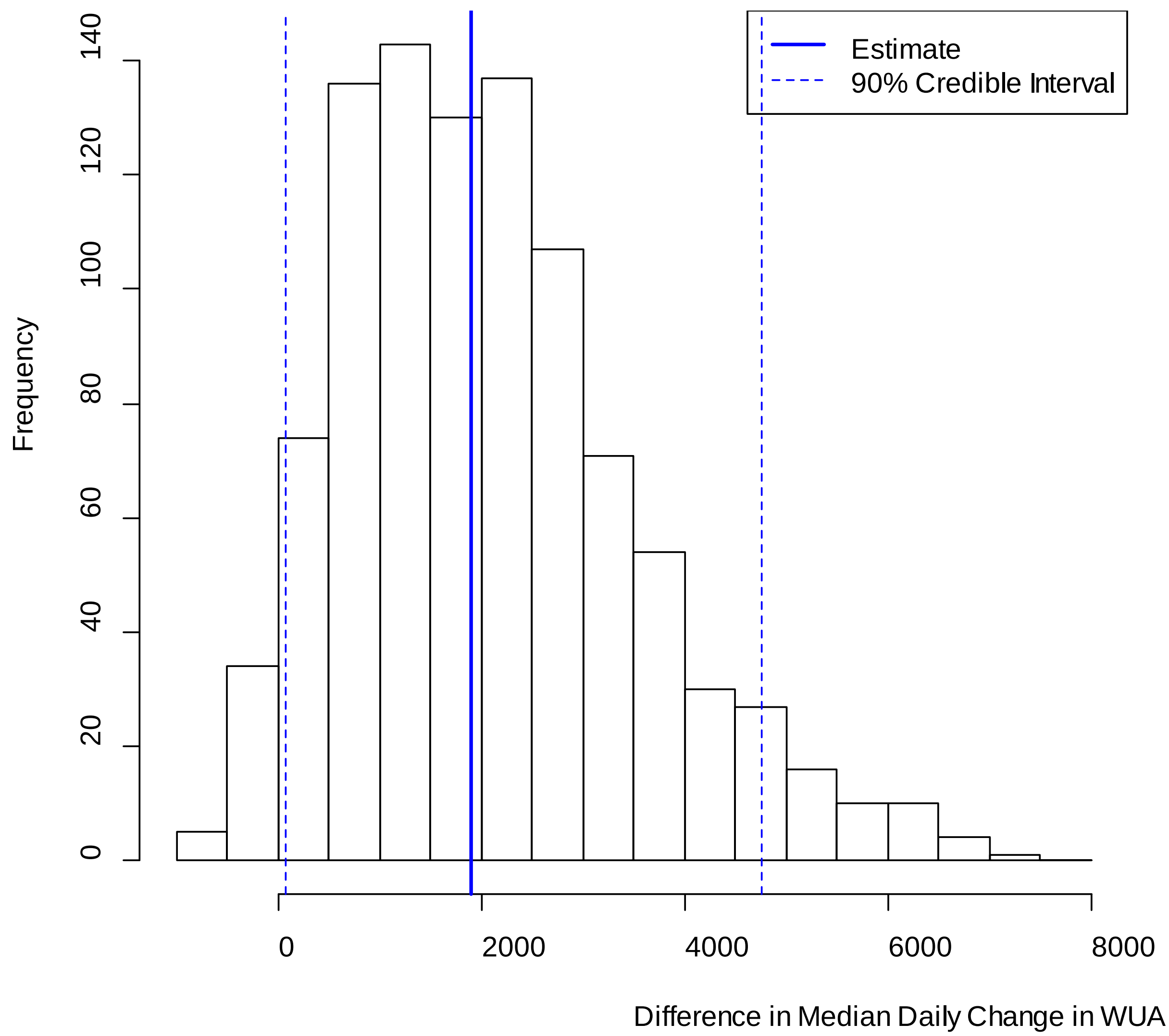

Figure 4.3-8. Histograms showing the difference in median daily change (max-min) in Weighted Usable Area (WUA; square feet) for 1985 between two flow scenarios for 1,000 simulated Habitat Suitability Criteria (HSC) curves based on the observed variance in the habitat preference relationship.

Note: Solid vertical line shows the estimated difference based on the best-fit HSC model; dotted line show 95% credible interval from the simulations.