Susitna-Watana Hydroelectric Project
(FERC No. 14241)

Fish and Aquatics Instream Flow Study
Study Plan Section 8.5

Alternative HSC/HSI Development Methods

Prepared for

Alaska Energy Authority

SUSITNA-WATANA HYDRO

Clean, reliable energy for the next 100 years.

Prepared by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND SCIENTIFIC LABELS

Abbreviation	Definition
AEA	Alaska Energy Authority
APA	Alaska Power Authority
FERC	Federal Energy Regulatory Commission
fps	feet per second
HSC	Habitat Suitability Criteria
HSI	Habitat Suitability Indices
IFS	Fish and Aquatics Instream Flow Study (Study 8.5)
ISR	Initial Study Report
LR	Lower Susitna River Segment, PRM 102.4 to PRM 0
MR	Middle Susitna River Segment, PRM 187.1 to PRM 102.4
PRM	Project River Mile
Project	Susitna-Watana Hydroelectric Project, FERC No. 14241
RM	River Mile or Historic River Mile
RSP	Revised Study Plan
SIR	2014-2015 Study Implementation Report
Study Plan Section 8.5	FERC-approved RSP Section 8.5 (Fish and Aquatics Instream Flow Study [IFS]) (AEA 2012) as modified by FERC's April 1, 2013 Study Plan Determination (FERC 2013), the *Open Water HEC-RAS Flow Routing Model* Technical Memorandum (TM) (R2 et al. 2013), the *Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies – 2013 and 2014* TM (R2 2013a), and the *Adjustments to Middle River Focus Areas* TM (R2 2013b)
TM	Technical Memorandum
TWG	Technical Workgroup

1. INTRODUCTION

On December 14, 2012, 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). The FERC-approved RSP Section 8.5 (Fish and Aquatics Instream Flow Study [IFS]) (AEA 2012) as modified by FERC's April 1, 2013 Study Plan Determination (FERC 2013), the *Open Water HEC-RAS Flow Routing Model* Technical Memorandum (TM) (R2 et al. 2013), the *Selection of Focus Areas and Study Sites in the Middle and Lower Susitna River for Instream Flow and Joint Resource Studies – 2013 and 2014* TM (R2 2013a), and the *Adjustments to Middle River Focus Areas* TM (R2 2013b) is collectively referred to herein as the "Study Plan Section 8.5." Study Plan 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 communities and habitats. Study Plan Section 8.5 also described the study methods that would be used to evaluate Susitna-Watana Hydroelectric Project, FERC No. 14241 (Project) effects, including the selection of study sites, collection of field data, data analysis, and modeling.

The goal of the IFS and its component study efforts was 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 and represented in Objective 4 of the IFS Study Plan (RSP Section 8.5.4.5) (AEA 2012), AEA is developing site-specific Habitat Suitability Criteria (HSC) and Habitat Suitability Indices (HSI) for various species and life stages of fish for biologically relevant time periods.

These criteria are to include observed physical phenomena that may be a factor in fish preference (e.g., depth, velocity, substrate, embeddedness, proximity to cover, groundwater influence, turbidity, etc.). The criteria will ultimately be linked with Habitat Models and used to evaluate Project operational effects on the habitats of different species and life stages. Specific comparisons will be made between Existing Conditions and several alternative operational scenarios including but not necessarily limited to a Maximum Load Following scenario (OS-1b) and an Intermediate Load Following scenario (ILF-1).

The development of HSC/HSI criteria has been a central topic for discussion during a number of Technical Workgroup (TWG) and Technical Team meetings in 2013 and 2014, with methods more fully described in RSP Section 8.5.2.6. Detailed information describing the data collection and analytical methods being used for HSC development were provided in the Study 8.5 Initial Study Report (ISR) Part A, Section 4.5 (R2 2014a); Study 8.5 ISR Part C, Appendix M (*Habitat Suitability Curve Development*) (R2 2014b); Study 8.5 *2014-2015 Study Implementation Report* (SIR), Section 4.5 (R2 2015a); and most recently and comprehensively in Study 8.5 SIR, Appendix D (*Habitat Suitability Curve Development*) (R2 2015b). The analytical methods to date have centered around the development of site-specific HSC criteria for certain high priority fish species and life stages based on empirical data collected in the field at locations where fish have been observed/collected. Field efforts have correspondingly been focused on the collection of habitat use information for these high priority species/life stages. However, development of site-specific HSC/HSI criteria will not be attainable for some species and life stages due to their low abundance, seasonal presence during difficult/dangerous sampling periods (e.g., high flows, winter conditions including break-up), or primary use of tributary rather than mainstem and lateral habitats. In those cases, alternative HSC development methods will be needed. This TM (a supplement to Study 8.5 *2014-2015 Study Implementation Report* (November 9, 2015) and filed with FERC as Attachment 4 to *Response of the Alaska Energy Authority to Comments on the Initial Study Report*) discusses several options that could be applied in developing alternative HSC criteria for those species and life stages.

The TM first provides an overview of the current status of the HSC/HSI model development for the Project (Section 2), then reviews alternative methods for HSC/HSI model development (Section 3), and ends with identification of a method/approach AEA suggests should be followed for developing draft HSC/HSI criteria for species and life stages lacking sufficient data for development of site-specific criteria (Section 4). The latter section also includes resulting draft HSC/HSI criteria.

2. STATUS OF CURRENT HSC/HSI MODEL DEVELOPMENT

A priority ranking of the 19 fish species considered for site-specific HSC/HSI development was prepared in collaboration with TWG members and is presented in (Table 3-1). The high and moderate ranked species are generally considered the most sensitive to habitat loss through manipulation of flows and are the most widely distributed in the Susitna River. Five of the original 19 species (Lake Trout [*Salvelinus namaycush*], Northern Pike [*Esox lucius*], Sculpin [*Cottid*], Arctic Lamprey [*Lethenteron japonicum*], and Threespine Stickleback [*Gasterosteus aculeatus*]) were considered low priority for development of site-specific HSC/HSI due to low numbers within the study area, and/or because their habitat needs were similar to other species for which HSC/HSI criteria were being developed.

To date, and after two years (2013 and 2014) of HSC data collection, over 7,000 site-specific microhabitat use and availability measurements have been collected during 267 unique sampling events (Study 8.5 SIR, Appendix D, Tables 5.2-1 and 5.2-2 [R2 2015]). This has resulted in the development of 12 statistically robust multivariate HSC models that represent select lifestages of nine high priority fish species. Specifically, models were developed for Chinook Salmon (*Oncorhynchus tshawytscha*) fry and juvenile, Chum Salmon (*O. keta*) spawning, Coho Salmon (*O. kisutch*) fry and juvenile, Sockeye Salmon (*O. nerka*) spawning, Arctic Grayling (*Thymallus arcticus*) fry and juvenile, whitefish fry and juvenile, and Longnose Sucker (*Catostomus catostomus*) juvenile and adult. The numbers of observed fish for the other high and moderate priority species were insufficient to develop multivariate HSC models, and therefore alternative methods for criteria development will be needed, which is the subject of this TM.

For the multivariate HSC models, habitat observations were taken where fish were observed (utilization data) and at systematic random locations (availability data) at each selected sampling site, comprised of a 50- or 100-meter reach. The probability of fish presence as a function of habitat variables was modeled with univariate and multivariate logistic regression, using availability measurements as a “0” response and utilization measurements as a “1” response (Manly et al. 1993).

Developing site-specific HSC/HSI models from a diverse data set collected over a wide range of habitat conditions in the Susitna River required certain model assumptions, data groupings or consolidations, and applying thresholds to set minimum and/or maximum ranges within the

HSC/HSI models. Some of the more significant model assumptions, data considerations, and variable thresholds include:

- Priority ranking for development of HSC/HSI models was given to those species and life stages that are assumed to select and utilize specific microhabitat areas for rearing or spawning purposes (i.e., outmigrating fry were not included).
- Because both habitat utilization and availability measurements are necessary for development of preference curves, only physical and biological data collected concurrently were used as part of the model development.
- Only those sampling events that included fish observations were used for developing the multivariate HSC model for each species and life stage.
- Due to the large number of categories and combinations of substrate and cover types, the full suite of categories or levels could not be individually assessed.
- Threshold values have been proposed for many of the variables to set minimum and/or maximum ranges in conjunction with the HSC/HSI models.
- Although it is generally assumed that a correlation exists between site selection by spawning Chum Salmon and Sockeye Salmon and the presence of groundwater upwelling, a strong quantifiable relationship between the two has not been identified to date.

A detailed description of the HSC/HSI model development process, including data collection, analysis, statistical modeling, and assumptions, is provided in Study 8.5 Initial Study Report (ISR) Part C, Appendix M (R2 2014b) and Study 8.5 SIR, Appendix D (R2 2015b), which also contains draft final HSC/HSI for the 12 species/life stage combinations listed above.

3. ALTERNATIVE HSC/HSI MODEL DEVELOPMENT METHODS

HSC/HSI models provide a quantitative relationship between environmental variables and habitat suitability. They represent an assumed functional relationship between an independent variable, such as depth, velocity, substrate, groundwater upwelling, turbidity, etc., and the suitability or preference of the variable to a particular species and life stage. HSC/HSI models are used to translate hydraulic and channel characteristics into measures of overall habitat suitability or preference which are displayed on a relative scale ranging from completely unsuitable to highly suitable.

Bovee (1986) suggested three options or categories for HSC/HSI development, depending on the extent of data available: 1) from literature or professional opinion (Category 1); 2) from physical and hydraulic measurements made in the field in areas used by the species and life stages of interest (i.e., utilization model; Category 2); or 3) by correcting or adjusting the habitat use data in a utilization model by the quantity and diversity of habitat available to the target species at the time of observation (i.e., preference model; Category 3). Preference models are designed to reduce the bias associated with the availability of environmental variables (Bovee 1986).

HSC/HSI can take on several different forms depending on attribute type, such as continuous curve distributions for depth and velocity, stepped functions for categorical attributes such as substrate or cover, or binary criteria where the attribute is either fully suitable or fully unsuitable. In most cases, HSC/HSI models are based on multiple variables (i.e., multivariate), but they are sometimes developed separately for each individual variable (univariate), and then combined by multiplication or geometric averaging. In general, HSC/HSI models are hypotheses of species-habitat relationships and are intended to provide indicators of habitat suitability or preference, not to directly quantify or predict the abundance of target organisms.

HSC/HSI models developed using site-specific habitat use and availability data are considered the most defensible models for predicting habitat selection/use and as described above, represented the first priority in development of HSC/HSI models for the Project (Study 8.5 SIR, Appendix D [R2 2015b]). However, for species and life stages where few or no fish observations were made, multivariate HSC models would not be statistically defensible or stable. For example, some authors have recommended a need for 10 (Peduzzi et al. 1996) to 20 (Van der Ploeg et al. 2014) (utilization) observations per model parameter for robust application of the statistical methods used for these models. The HSC/HSI preference models that have been developed for the Susitna River were based on species with utilization counts ranging from 67 to 397, which resulted in a range of 13 to 31 utilization observations per model parameter (note that models had differing numbers of estimated parameters). For those priority species that were never, or rarely, observed (fewer than 10 observations per model parameter), alternative HSC/HSI development methods are needed (Table 4-1).

Several options are available for developing curves for species with limited site-specific observations, including: 1) literature reviews of species life history requirements, existing HSC/HSI criteria and expert opinion; 2) transference of HSC/HSI developed for a different basin (Thomas and Bovee 1993; Groshens and Orth 1994); 3) application of Bayesian statistical methods for including multiple sources of information (Hightower et al. 2012); 4) use of a species and life stage guilding process based on similarities of habitat use between species (Vadas and Orth 2001; GSA BBEST 2011); and 5) development of envelope models using data collected from the other times or locations that capture the extremes of habitat use as defined by combined data sets (Jowett et al. 1991; GSA BBEST 2011). These cover the range of methods presented in RSP Section 8.5.4.5.1.1.

Each of these methods has its own strengths and weaknesses depending on the quantity and quality of information/data, statistical challenges, and assumptions. The advantages, disadvantages, and data needs for each of these methods are presented in Table 4-2. A brief summary of each of the five alternative HSC/HSI model development methods is provided below. It is important to note that none of the alternatives described here is a direct multivariate method, so the process for combining univariate HSC/HSI (e.g., multiplying, geometric mean, etc.) criteria will also need to be considered.

3.1. Literature/Professional Opinion Based Models

The development of HSC/HSI models for large, basin-scale projects that target species do not currently inhabit (e.g., reintroduction planning), or are in low abundance, generally involves the use of models that were developed for other river systems that were subsequently modified or adjusted by a group of regional experts to “fit” the target system. The origin of many of these

HSC/HSI models can be traced back to models developed from small, site-specific data sets that have been altered numerous times to fit a particular river system. The development of literature/professional opinion based models entails obtaining behavioral information on the species and life stages of interest, summarizing pertinent information in an easily reviewable format, evaluating this information with regional biologists or experts familiar with the target species, and constructing the best possible curves based on habitat use information in reference to the stream of interest.

Habitat use information can be obtained from a variety of sources including university and government libraries; agency, utility, and consultant data files and reports; and technical journals. Much of this information is classified as "gray literature" that falls outside the mainstream of published journal articles and includes difficult to find studies, reports, or dissertations. Through this process, a considerable amount of information about the species can be accumulated. However, few references contain complete HSC/HSI models with raw field data, descriptions of the physical characteristics of the stream, and the data collection and analysis methods used.

The goal for developing the literature/professional opinion based HSC/HSI models is to reach an understanding and agreement (among the species experts) about the levels of data quality and the applicability of any available HSC/HSI curves to the stream of interest. This will likely require modifications to any existing HSC/HSI curve sets deemed appropriate for adapting the curves to species inhabiting the Susitna River and the process for making such modifications needs to be fully documented.

Literature/professional opinion based HSC/HSI models are attractive due to low cost and the ability to encompass a broad range of accumulated knowledge. However, the method is largely qualitative and relies heavily on the opinions of local and regional species experts for developing each of the curve sets. Therefore, one of the primary considerations in the successful application of this method is the identification of experts whose opinions will serve to guide the HSC/HSI model development.

3.2. Transferability of HSC/HSI Models

Having HSC/HSI models that are transferable to multiple rivers would allow evaluation of instream flow models when local field data are sparse or new data cannot be collected. The basic assumption of transferability of HSC/HSI models between two river systems is that the criteria established in one stream can be used to determine the quality and quantity of microhabitat in another stream (Thomas and Bovee 1993). The success of the transfer is generally tested by determining whether or not high quality habitat in the source stream is used in greater proportion in the destination stream (Thomas and Bovee 1993; Groshens and Orth 1994; Freeman et al. 1999). A commonly used method to test or evaluate the transferability of HSC/HSI models is to simply visually compare histograms of habitat use for individual variables (e.g., depth, velocity, and substrate) between river systems and if there is good agreement then the HSC/HSI models are considered transferable. Recently, more sophisticated, statistically based methods have been proposed for use in testing transferability (Thomas and Bovee 1993; Williams et al. 1999; Bondi et al. 2013).

Unfortunately, many authors have reported that HSC/HSI models developed in different river systems for the same species often differ, and therefore should not be transferred (Heggenes

1990; Thomas and Bovee 1993; Groshens and Orth 1994; Freeman et al. 1997; Glozier et al. 1997; Williams et al. 1999). There are several reasons why habitat utilization may differ between systems; the most obvious being the impact of habitat availability. Even preference curves (i.e., utilization adjusted for habitat availability) can differ due to factors such as food availability, competition, water quality, and predation (Modde and Hardy 1992; Moyle and Baltz 1985; Orth 1987; Leftwich et al. 1997). All of these factors can vary between systems and even within large systems making it difficult for criteria to transfer accurately both across regions (Novinger and Coon 2000) and within regions.

3.3. Bayesian Models

Bayesian statistical methods are useful in situations where there is a base of prior knowledge and new information, so that the base knowledge can be "updated" with the new information. In terms of HSC/HSI modeling, if habitat preference parameters have been previously estimated in similar systems for a particular species and life stage, and there are current site-specific data, the "prior" knowledge can be updated for the site-specific data to provide a combined estimate of habitat preference. An example of using Bayesian statistics in development of HSC/HSI is provided in Hightower et al. (2012). In this paper, information on habitat use is combined with expert opinion and a limited amount of site-specific data to develop HSC/HSI models using Bayesian statistical methods.

Despite some of the apparent advantages of using Bayesian statistics to construct HSC/HSI models, their use has been somewhat limited in fisheries studies. A major drawback is the selection of "prior" information and its incorporation into the data analysis. This process can be a subjective, contentious issue with regards to source data from a range of objective references and subjective opinions and beliefs regarding habitat use and the importance of specific habitat variables.

Nevertheless, combining information about species presence developed through sampling or prior knowledge, with models of habitat suitability has the potential to produce cost-effective models that require less sampling effort.

3.4. Species Guilding Models

Although most HSC/HSI models are built for individual species and life stages, it is possible to construct models that represent similar habitat use/selection by several different fish species or guilds (Leonard and Orth 1988; Vadas and Orth 2001; Persinger et al. 2011). Species guilds have generally been applied to warm or cool water systems with high species diversity and significant overlap in habitat use. The diversity, distribution, and similarity in habitat use by many fish species found in the Susitna River systems make it a candidate for development of HSC/HSI guild models. Example species and life stage based guilds may include:

- Chinook and Coho salmon fry;
- whitefish, Rainbow Trout (*O. mykiss*), Arctic Char (*Salvelinus alpinus*), and Dolly Varden (*Salvelinus malma)* adult;
- Eulachon (*Thaleichthys pacificus*) and Bering Cisco (*Coregonus laurettae*) spawning; and

- The guilds can also be habitat based (e.g., species that prefer pools with cover, off-channel spawning habitat; etc.).

The strategy of using guilds to consolidate species is based on the idea that the habitat needs of a representative of each guild will be able to account for the habitat needs of the entire guild (Gorman 1988; Leonard and Orth 1988). It is assumed that species and life stages within a habitat-use guild generally exhibit similar habitat response to changes in river flow. Guild determination or selection is generally based on a combination of professional opinion and limited available utilization data and could fit within an "expert opinion" based method. Each habitat guild can then be treated as a "super species" for which analysis of instream flow needs can focus.

Grouping species and life stages into guilds offers several advantages:

1. Resulting HSC/HSI models may be less variable resulting from a larger sample size (combined data sets).

2. More species and life stages can be included which should lead to better representation and evaluation of potential Project impacts on the ecosystem.

3. Fewer HSC/HSI models (representing more species) are needed to evaluate and quantify Project effects resulting from different operational scenarios.

A disadvantage of this approach is that a lack of information on habitat use by any given species makes guild placement difficult. Incorrectly placing a species into a guild can result in inaccurate habitat criteria and poor evaluation of Project effects for that species. Additionally, discrete habitat guilds may be difficult to detect or establish in dynamic systems with a high diversity of temporal and spatial conditions and where species and life stages lack consistent association with a single habitat type.

3.5. Envelope Models

In general, enveloped HSC/HSI are derived by "drawing" a composite HSC/HSI that encompasses all observation data or a set of HSC/HSI models derived from several sources (Figure 4-1). Developing envelope curves based on multiple literature based HSC/HSI has been shown to be a valid approach for HSC/HSI model development when site-specific data are not limited (Jowett et al. 1991; Bozek and Rahel 1992; Hardy and Addley 2001). Jowett et al. (1991) found that using enveloped preference curves from four rivers performed almost as well as stream-specific criteria in predicting abundance in benthic invertebrates, and were better than HSC/HSI models developed at one river and applied to another. DeVries et al. (2007) determined that regional based HSI curve sets generally performed as well as site-specific empirical data collected from streams of similar size and channel types.

Enveloped HSC/HSI models developed from literature based curves generally assume that the different model sources are equally relevant and follow the same assumptions in terms of life stage definitions. Thus, it is important that the enveloped conditions be sufficiently constrained so that extraneous conditions that are not likely to be within the realized habitat use of a species/life stage are not included. In particular, when flows change or fish competitors/predators change, the realized habitat use of a species/life stage may change and not be encompassed by "narrowly" defined site-specific data (e.g., time, fish density, habitat availability, flow, etc.). In fact, narrowly defined site-specific curves frequently perform poorly when applied in locales other than where they were developed (e.g., Bozek and Rahel 1992; Jowett et al. 1991).

If multiple, well-derived HSC/HSI models of the same type (i.e., utilization or preference curves) are available for the given species and life stage in similar systems, the enveloping procedure is a good option. This method is particularly attractive given the existence of a number of HSC data sets provided from the 1980s Su-Hydro studies. As with any combining method, the accuracy of the result is dependent on the quality, quantity, and relevance of the available data.

4. DEVELOPMENT OF DRAFT ALTERNATIVE HSC/HSI MODELS

Given the availability of information and data regarding the target species from the 1980s Su-Hydro studies, AEA gave first consideration to methods that would utilize that information along with new data in the development of alternative HSC/HSI models. Also, since site-specific data were limited or non-existent for several of the target species, AEA further sought a method or methods that would likely be conservative in the development of curves. Conservative in this case refers to curves that would reflect broad rather than narrow bands of utilization for the given species and life stage. Because any of these alternative curves will be based on combinations of different data and information, some site-specific, some from other systems, and some from the literature, it will be important to allow for their review by licensing participant technical representatives. Based on these considerations, AEA believes the use of a modified enveloping approach would be the most appropriate for use on the Project. This method is described below and is followed by a set of draft HSC/HSI models developed in accordance with the method.

The method includes an initial screening process based on availability of site-specific information, and the selection of potential habitat utilization ranges[1] as follows:

1. for species and life stages with greater than 20 site-specific observations collected during the 2013-2014 HSC/HSI surveys – the suggested range of habitat utilization (depth, velocity, and substrate) would represent 80 percent of the total observations (Table 5-1);

2. for species and life stages with less than 20 site-specific observations collected during the 2013-2014 HSC/HSI surveys – the suggested range would be defined by habitat utilization (depth, velocity, and substrate) with greater than or equal to 0.5 suitability from the 1980s HSC/HSI models where available; and

3. for species and life stages with less than 20 site-specific observations collected during the 2013-2014 HSC/HSI surveys and no HSC/HSI models developed during the 1980s studies – use the generalized range of habitat utilization (depth, velocity, and substrate) reported during the 1980s studies.

Application of the above process provides ranges of specified variables (velocity, depth, substrate composition, and use of cover) that could serve as binary univariate envelope HSC/HSI criteria for seven species and two life stages (spawning and adult) (Table 5-2). Prioritizing the

[1] The final approach for screening and selecting specific ranges from which to define envelop HSC/HSI criteria will be made in consultation with licensing participants.

data sources and suitability ranges for each variable in this way promotes the use of the most contemporary, site-specific information and simplifies the HSC/HSI models as binary, i.e., habitat is either suitable or non-suitable. Defining the range of suitable habitat as 80 percent of the total 2013-2014 observations, or greater than 0.5 suitability from the 1980s HSC/HSI models, is one approach that can be used[2] and in this case was suggested to ensure a defined response in habitat quantity to changes in river flow. As previously stated, the primary goal in development of HSC/HSI for the Project is to utilize site-specific data to characterize habitat suitability or preference for the target species and life stages. Correspondingly, the draft alternative HSC/HSI were entirely based on existing site-specific data, either from the 1980s studies or from limited 2013-2014 HSC/HSI surveys. Importantly, these data sources are not sufficient to estimate intermediate levels of suitability, so the suggested HSC/HSI models would be limited to defining ranges of suitable versus unsuitable habitat.

A brief description of the available data and rationale for each of the binary univariate HSC/HSI criteria for each species and life stage is presented below.

4.1. Pink Salmon Spawning

Utilization data were not collected for Pink Salmon (*O. gorbuscha*) spawning during the 1980s surveys of the Susitna River. Rather, Vincent-Lang et al. (1984) developed depth, velocity, and substrate HSC/HSI for Pink Salmon spawning based solely on previously published information (Terror Lake environmental assessment [Wilson et al. 1981]) with modifications by project biologists familiar with spawning site selection by Susitna River Pink Salmon stocks. During the 2013-2014 HSC/HSI surveys of the Susitna River, 53 Pink Salmon spawning sites (active redds) were identified and measurements of site characteristics were collected (Table 5-1). However, these sites were concentrated within a few areas and were not considered representative of Pink Salmon spawning habitat more broadly. A comparison of the HSC/HSI model developed during the 1980s studies and Pink Salmon velocity, depth, and substrate utilization data collected during the 2013-2014 surveys is presented in Figure 5-1.

The suggested suitable habitat conditions for Pink Salmon spawning was based on the range of habitat utilization (depth, velocity, and substrate) representing 80 percent of the total observations collected during the 2013-2014 surveys (Table 5-1). Although the number of 2013-2014 observations were insufficient to generate a multivariate HSC model, this information was more contemporary and deemed better than the 1980s literature based HSC/HSI model for Pink Salmon spawning. If additional site-specific data are collected in the future at Pink Salmon spawning sites in other locations within the Middle River Segment of the Susitna River, AEA can proceed with development of a multivariate HSC model.

4.2. Arctic Grayling Adult

During the 1980s study of the Susitna River, Suchanek et al. (1984) captured a total of 140 adult Arctic Grayling by boat electrofishing (n=138) and hook-and-line sampling (n=2). Measurements of microhabitat use (depth, velocity, and cover) were recorded for each observation, and HSC/HSI models were developed by fitting catch distributions to values of

[2] Licensing participants may have different suggestions regarding specific ranges for use, as well as the shapes of the envelope curves (i.e., binary or stepped), which can be discussed as part of the curve development process.

observed velocity and depth. Adult Arctic Grayling were often found to use cobble and boulder size substrate for cover as well as high velocity and relatively deep water (Suchanek et al. 1984). As with other adult resident species, depth was only thought to limit the distribution of adult Arctic Grayling as a minimum. Therefore, for all HSC/HSI models developed during the 1980s for adult resident species, depth suitability was conservatively set to 1.0 for all depths greater than 0.5 feet and non-limiting for depths greater than 0.5 feet (Figure 5-2).

Only 15 measurements of habitat use were obtained for Arctic Grayling adults during the 2013-2014 HSC/HSI surveys (Study 8.5 SIR, Appendix D [R2 2015b]). The 2013-2014 utilization data for Arctic Grayling adults were plotted as a frequency histogram for comparison with the 1980s HSC/HSI (Figure 5-2). Although there was little agreement between the velocity utilization data collected during the 2013-2014 surveys and the 1980s HSC/HSI model, it is assumed that the difference in sampling techniques between the two surveys (1980s boat electrofishing and 2013-2014 backpack electrofishing and stick seining) accounts for most of this difference. Lacking sufficient data from the 2013-2014 surveys to develop a multivariate HSC model, and in accordance with the screening process and potential habitat utilization ranges noted above, the range of habitat conditions (depth and velocity) that provide greater than or equal to 0.5 suitability from the 1980s HSC/HSI model would be used to define suitable habitat for Arctic Grayling adult (Table 5-2). However, it is assumed that the proposed range of suitable habitat for Arctic Grayling adult would be re-evaluated after completion of the second year of sampling upstream of Devils Canyon.

4.3. Rainbow Trout Adult

A total of 143 adult Rainbow Trout observations were collected by boat electrofishing (n=44) and hook-and-line sampling (n=99) in the Middle Susitna River Segment (MR) to develop HSC/HSI curves in the 1980s (Suchanek et al. 1984). Results of the 1980s hook-and-line sampling suggested that adult Rainbow Trout preferred pools with depths greater than 2.0 feet. As with the other adult resident species HSC/HSI models developed during the 1980s Susitna River studies, depth suitability was set to 1.0 for all depths greater than 0.6 feet, and to 0.0 for depths less than 0.5 feet (Figure 5-3). During the 1980s boat electrofishing surveys adult Rainbow Trout were typically found in cells with water velocities less than 1.5 feet per second (fps), whereas results of hook-and-line sampling suggested that adult Rainbow Trout preferred pools with velocities less than 0.5 fps. Because electrofishing data were collected at more cells in a wider variety of habitat types compared to hook-and-line sampling, velocity HSC/HSI were fit to the boat electrofishing data.

Only eight adult Rainbow Trout observations were collected in 2013-2014. This total was deemed insufficient to warrant the development of utilization summary statistics or histograms for comparison with the 1980s HSC/HSI. Lacking sufficient data from the 2013-2014 surveys to develop a multivariate HSC model, and in accordance with the screening process and potential habitat utilization ranges noted above the range of habitat conditions (depth and velocity) that provide greater than or equal to 0.5 suitability from the 1980s HSC/HSI model would be used to define suitable habitat for Rainbow Trout adult (Table 5-2).

It is assumed that the proposed range of suitable habitat for Rainbow Trout adult will be re-evaluated after completion of the second year of sampling upstream of Devils Canyon.

4.4. Burbot Adult

During 1980s HSC/HSI surveys 18 adult Burbot (*Lota lota*) were captured by boat electrofishing in the MR (Suchanek et al. 1984). Other catch data from the 1980s consistently documented adult Burbot in the mainstem during the summer (ADF&G 1983), suggesting they prefer areas of moderate to high turbidities (Suchanek et al. 1984). Telemetry data (4 radio-tagged adult Burbot) also found Burbot consistently in the mainstem. While in these mainstem areas, radio-tagged Burbot appeared to prefer low velocities (<1.5 fps) and shallow depths (approximately 2.5 feet). Burbot also appeared to prefer areas with small cobble (referred to as rubble) or large cobble (referred to as simply cobble) substrate; however, nearly all of the mainstem river between the Chulitna River confluence and Devils Canyon, where the radio-tagged fish were found, had predominately small or large cobble substrate. The 1980s catches of adult Burbot were insufficient to develop HSC/HSI models.

As part of the 2013-2014 HSC/HSI surveys, a total of 22 adult Burbot were observed with all but one of the observations occurring in the MR (Study 8.5 SIR, Appendix D [R2 2015b]). Depth utilization measurements for adult Burbot ranged from 0.4 to just over 3.0 feet while velocity ranged from 0.0-1.9 fps. Dominant substrate utilization for adult Burbot ranged from fines to boulder, although fines had the highest frequency.

Lacking sufficient data from the 2013-2014 surveys to develop a multivariate HSC/HSI model for adult Burbot, and in accordance with the screening process and potential habitat utilization ranges noted above, the range of utilized habitat conditions (80 percent of use observations) reported from the 2013-2014 surveys would be used to define the HSC/HSI model for depth, velocity, substrate, and cover habitat variables (Table 5-2).

4.5. Eulachon Spawning

Surveys to determine Eulachon spawning site characteristics were completed during two separate sampling efforts in the Lower Susitna River Segment (LR) during 1983 and 2013. During the spring (mid-May to mid-June) of 1983, habitat surveys of Eulachon spawning were conducted at 20 sites in the downstream most 40 miles of the Susitna River to characterize spawning site selection and associated environmental parameters (Vincent-Lang and Queral 1984). At each spawning site, representative measurements of water depth and velocity were collected along with a visual determination of substrate composition. Similar surveys were completed again in the spring of 2013 in the LR at a total of 28 Eulachon spawning sites (Study 9.16 ISR Part A [AEA2014]).

For both surveys, Eulachon spawning sites were identified using radio telemetry and visual observations of large concentrations of adult Eulachon. Spawning site characteristics (depth, velocity, and substrate) were similar during the 1980s and 2013 surveys with water depth ranging from 0.5-4.9 feet and velocity ranging from 0.0-3.5 fps. Channel substrate at utilized spawning sites ranged from silt to large cobble.

Lacking sufficient data from the either the 1980s or 2013 surveys to develop a multivariate HSC/HSI model for spawning Eulachon, and in accordance with the screening process and potential habitat utilization ranges noted above, the range of most commonly utilized habitat conditions reported from the 1980s and 2013 surveys would be used to define the HSC/HSI model for depth, velocity, substrate, and cover habitat variables (Table 5-2).

4.6. Bering Cisco Spawning

Bering Cisco were collected in the LR from the mouth of Kroto Slough (Historic River Mile[3] [RM] 30.1) to a selected fish habitat site just upstream of Talkeetna (RM 100.8) from August to October 1981. Prior to this study, this anadromous whitefish was not known to inhabit the Susitna River drainage (Delaney et al. 1981). Boat mounted electrofishing was the primary collection method utilized to locate Bering Cisco in the LR between (RM 70.0) and (RM 100.8). Bering Cisco spawning sites were observed at Sunshine Station (RM 78.0-79.0), opposite the mouth of Montana Creek (RM 76.0-77.5) and along the west bank of the mainstem Susitna River (RM 74.3-74.8).

Habitat parameters were measured at each identified spawning site using a grid sampling approach. Sampling sites ranged from 100 to 2,500 feet in length and 10 to 80 feet in width (Delaney et al. 1981). Measurements of water depth and velocity were then systematically collected from within the spawning site to represent the range of conditions/habitat utilized by spawning Bering Cisco. The dominant and subdominant substrate found within the site was also characterized. At the three spawning sample sites, velocities varied from 0.5-5.8 fps and depths ranged from 0.5-2.5 feet (Delaney et al. 1981). The spawning substrates were predominantly composed of 1 to 3-inch size gravel.

No Bering Cisco were captured or observed during the 2013-2014 HSC/HSI surveys of the MR or LR. Lacking sufficient data from either the 1980s or 2013-2014 surveys to develop a multivariate HSC/HSI model for spawning Bering Cisco, and in accordance with the screening process and potential habitat utilization ranges noted above, the range of most commonly utilized habitat conditions reported from the 1980s surveys would be used to define the HSC/HSI model for depth, velocity, substrate, and cover habitat variables (Table 5-2).

4.7. Whitefish Adult

HSC/HSI models developed in the 1980s for adult whitefish were based on a total of 138 adult Round Whitefish (*Prosopium cylindraceum*) observations collected by boat electrofishing in the MR (Suchanek et al. 1984). Most of the 35 adult whitefish observations collected in 2013-2014 were also from the MR. As part of the 2013-2014 HSC/HSI surveys, no distinction was made between whitefish species (Round or Humpback [*Coregonus pidschian*]). For the 1980s HSC/HSI models, depth was only thought to limit the distribution of adult whitefish as a minimum. Therefore, like adult Rainbow Trout and Arctic Grayling, the 1980s HSC/HSI model

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[3]The Project River Mile (PRM) system for the Susitna River was developed to provide a consistent and accurate method of referencing features along the Susitna River. During the 1980s, researchers often referenced features by river mile without identifying the source map or reference system. If a feature is described by river mile or historic river mile (RM), then the exact location of that feature has not been verified. The use of PRMs provides a common reference system and ensures that the location of the feature can be verified. The PRM was constructed by digitizing the wetted width centerline of the main channel from 2011 Matanuska-Susitna Borough digital orthophotos. Project River Mile 0.0 was established as mean low water of the Susitna River confluence at Cook Inlet. A centerline corresponding to the channel thalweg was digitized upstream to the river source at Susitna Glacier using data collected as part of the 2012 flow routing transect measurements. The resultant line is an ArcGIS route feature class in which linear referencing tools may be applied. The use of RM will continue when citing a 1980s study or where the location of the feature has not been verified. Features identified by PRM are associated with an ArcGIS data layer and process, and signifies that the location has been verified and reproduced.

depth suitability for adult whitefish was set to 1.0 for all depths greater than 0.6 feet, and to 0.0 for depths less than 0.5 feet (Figure 5-4). Results of the 2013-2014 HSC/HSI surveys indicated similar depth utilization.

The 1980s HSC/HSI for velocity was developed by fitting suitability values to catch distributions. Although velocity did not appear to have a strong effect on distribution, observations most frequently occurred at velocities of 2.0-3.0 fps (Suchanek et al. 1984). In contrast, 100 percent of the observations from the 2013-2014 surveys were at velocities less than 2.6 fps (Figure 5-4).

Lacking sufficient data from the 2013-2014 surveys to develop a multivariate HSC/HSI model for adult whitefish, and in accordance with the screening process and potential habitat utilization ranges noted above, the range of utilized habitat conditions (80 percent of use observations) reported from the 2013-2014 surveys would be used to define the HSC/HSI model for depth, velocity, substrate, and cover habitat variables (Table 5-2). However, it is also assumed that the proposed range of suitable habitat for whitefish adult will be re-evaluated after completion of the second year of sampling upstream of Devils Canyon.

5. CONCLUSIONS

The first priority in development of HSC/HSI models for this Project was the use of site-specific field measurements. The HSC/HSI models developed as part of the IFS will be used to provide quantitative indices of existing aquatic habitats that enable a determination of the effects of alternative Project operational scenarios. For those species and life stages with insufficient observations to develop site-specific HSC/HSI models, alternative model development approaches need to be considered.

Currently, multivariate HSC/HSI models have been developed using 2013-2014 sampling data for Chinook Salmon fry and juvenile, Chum Salmon spawning, Coho Salmon fry and juvenile, Sockeye Salmon spawning, Arctic Grayling fry and juvenile, whitefish fry and juvenile, and Longnose Sucker juvenile and adult (Table 4-1). As recommended in the FERC-approved Study Plan Section 8.5 (AEA 2012), for those species' life stages with insufficient site-specific data, alternative methodologies were needed to develop recommended HSC/HSI models (Study 8.5 SIR, Appendix D [R2 2015b]). A detailed review of the advantages and disadvantages of five alternative methods was completed. Although each of the reviewed methods were found to have some acceptable aspects for use in development of HSC/HSI models for the target fish species, AEA believes the use of a modified enveloping approach would be the most appropriate for use, and this approach would likely include a technical review forum to discuss existing curve sets over the range of parameter values expected to be used by the target species.

A suggested process for the development of envelope curves was described, which included an initial screening process based on availability of site-specific information, and the selection of potential habitat utilization ranges. Using that approach, alternative HSC/HSI models were derived and presented for the spawning life stage of Pink Salmon, Eulachon, and Bering Cisco and the adult life stage of Arctic Grayling, Rainbow Trout, Burbot, and whitefish (Table 5-2). These binary univariate HSC/HSI models rely on site-specific data collected as part of the 1980s and 2013-2014 studies of the Susitna River. All seven models considered water depth, velocity, substrate composition, and cover. In general, the range of habitat utilized by each species' life stage was considered along with the HSC/HSI models developed during the 1980s study, to define the suitability of each of the habitat variables.

All HSC/HSI curves (multivariate and alternatives) will be linked with Habitat Models and used to evaluate Project operational effects on the habitats of different species and life stages. Specific comparisons will be made between existing conditions and several alternative operational scenarios including but not necessarily limited to OS-1b (Maximum Load Following) and ILF-1 (Intermediate Load Following). Results of these analyses will be presented in the Updated Study Report.

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7. TABLES

Table 3-1. Updated priority ranking of fish species and life stages for development of Habitat Suitability Criteria for the Susitna River, Alaska. (Presented to Technical Team during March 21, 2014 meeting - http://www.susitna-watanahydro.org/wp-content/uploads/2014/03/2014-03-21TT_IFS_Presentation-HSC.pdf.)

Life Stage	Priority Ranking		
	High	Moderate	Low
	Multivariate Preference Curves	Univariate Utilization / 1980s Curves	Literature Based / Expert Panel
Spawning	Chum		
	Sockeye		
	Pink		
Adult	Whitefish[1]	Rainbow Trout	Bering Cisco
	Arctic Grayling	Dolly Varden	Eulachon
	Longnose Sucker	Burbot	
Juvenile	Coho	Arctic Grayling	
	Chinook		
	Longnose Sucker		
Fry	Coho	Whitefish[1]	
	Chinook	Arctic Grayling	
	Sockeye	Longnose Sucker	

Notes:
[1]To eliminate potential for miss identification, no distinction was made between whitefish species (Humpback and Round).

Table 4-1. Status of HSC/HSI model development for target fish species and life stages in the Susitna River, Alaska.

Species [1]	Life Stage	Number of Microhabitat Use Measurements	Multivariate Preference HSC Model	Proposed Alternate HSC Method	No HSC Proposed
Chinook Salmon	Fry	217	X		
	Juvenile	67	X		
Chum Salmon	Fry [2]	253			X
	Spawning	397	X		
Coho Salmon	Fry	274	X		
	Juvenile	87	X		
	Spawning	3			
Pink Salmon	Fry [2]	39			X
	Spawning	53		X	
Sockeye Salmon	Fry [2]	357			X
	Spawning	244	X		
Arctic Grayling	Fry	120	X		
	Juvenile	78	X		
	Adult	15		X	
Rainbow Trout	Fry	4			X
	Juvenile	7			X
	Adult	8		X	
Burbot	Fry	1			X
	Juvenile	5			X
	Adult	22		X	
Dolly Varden	Fry	21			X
	Juvenile	2			X
	Adult	3		X	
Eulachon	Spawning	0		X	
Bering Cisco	Spawning	0		X	
Longnose Sucker	Fry [3]	88	Proposed		
	Juvenile	97	X		
	Adult	71	X		
Whitefish (undiff [4])	Fry	105	X		
	Juvenile	101	X		
	Adult	35		X	

Notes:

[1]No HSC/HSI model development is proposed for low priority species Northern Pike, Sculpin, Threespine Stickleback, Arctic Lamprey, and Lake Trout.

[2]No HSC model development proposed for fry that outmigrate shortly after emergence.

[3]Proposed for multivariate model development.

[4]undiff = undifferentiated (no distinction made between Humpback and Round whitefish).

Table 4-2. Review of relative strengths and weaknesses of alternative HSC/HSI development methods considered for use as part of the IFS Study 8.5.

HSC/HSI Method	Advantages	Disadvantages	Data Requirements	Level of Effort
Literature and/or Professional Opinion	• No site-specific data required • Incorporates broad understanding of life history and habitat use/selection	• Limited to extent of expert knowledge • Susceptible to strong opinions • May require transfer of knowledge of habitat use from outside systems	• Workshop or Delphi process to define life history requirements and identify candidate HSC/HSI models	Low
Envelope Models	• Incorporates broad base of knowledge that may include HSC/HSI criteria from other basins as well as site-specific information (if available) • Conservative approach based on ecological niche theory	• May overestimate range of habitat use if HSC/HSI models considered from different subbasins and/or regions	• Multiple sets of HSC/HSI to define extent of habitat use by individual species and life stages; some site-specific data preferred	Moderate
Transferability	• No site-specific data required • Limited number of candidate HSC/HSI models needed for consideration	• Assumes similarities in habitat use between subbasins and/or regions • Mixed results in predictability of habitat use • Requires selection of the most suitable HSC/HSI model for transfer	• Detailed information on subbasin characteristics • Minimum of one HSC/HSI model for each target species	Low – Moderate
Guilding	• Additional fish species can be considered in the analysis • More consistent results for habitat-flow relationships • Greater sample sizes for building HSC/HSI model • Analysis efficiency - fewer models to interface with habitat-flow data	• Assumes similarities in habitat use between species • Requires site-specific HSC/HSI models	• Life history descriptions to define ecological niche for each species • Some site-specific data to define guild characteristics	Moderate
Bayesian Statistics	• Relies on existing information • Limited site-specific or regional field data required • Incorporates broad range of knowledge • Can be periodically updated with new information	• Requires multiple data sources and expert opinion • Requires investment in statistical analysis method and explanation	• Workshop or Delphi process to define life history requirements and identify candidate HSC/HSI models • Some site-specific data	High

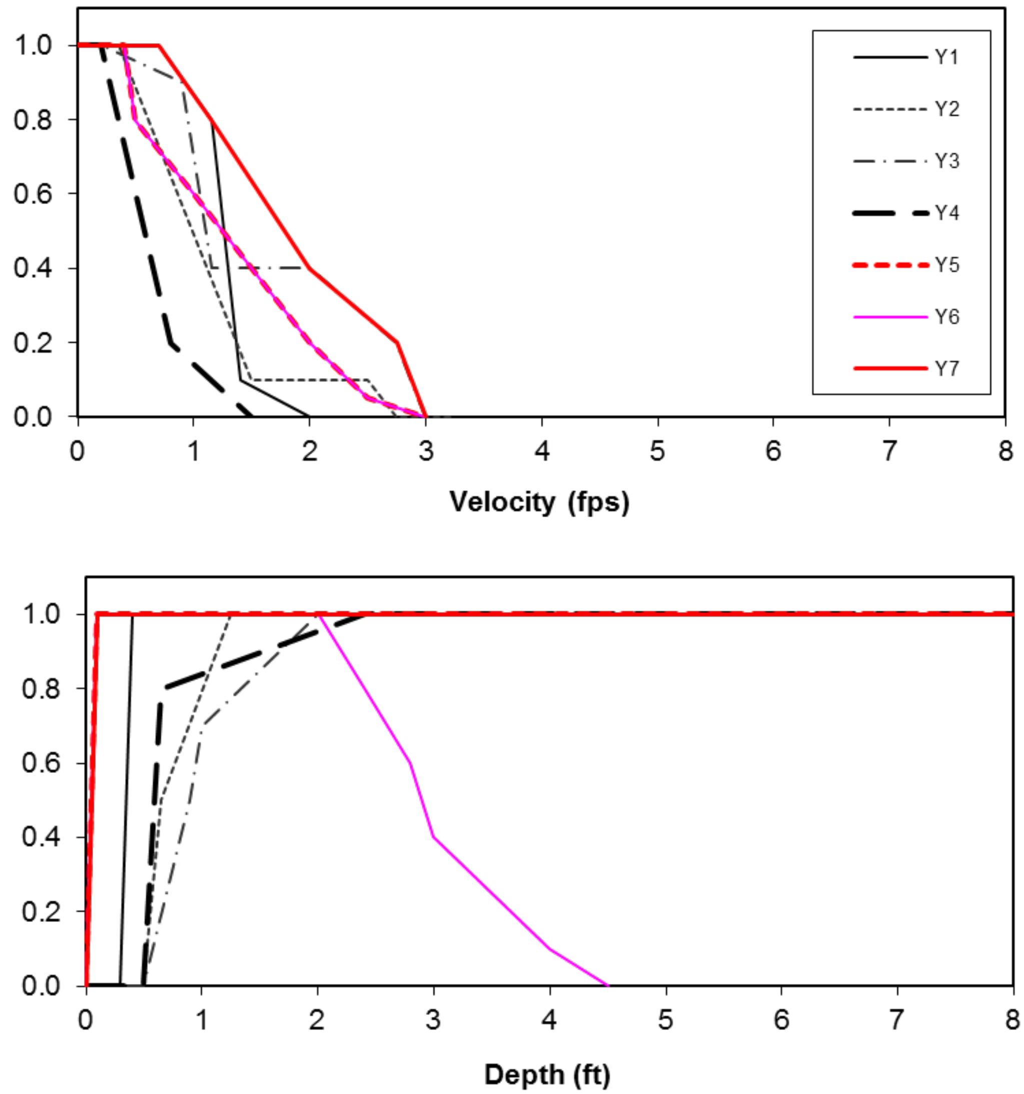
Table 5-1. Habitat utilization ranges for select species and life stage observations collected during 2013-2014 HSC/HSI surveys of the Susitna River, Alaska.

Species	Life Stage	Number of Observations	Percent of Total Observations in Range	Velocity (fps)	Depth (feet)	Substrate
Pink Salmon	Spawning	53	100% 80%	0.05 – 3.5 0.5 – 2.7	>0.3 >0.5	Cobble or Gravel
Arctic Grayling	Adult	15	100% 80%	0.1 – 2.5 0.3 – 1.9	>0.4 >0.8	All substrates suitable
Rainbow Trout	Adult	8	100% 80%	0.01 – 1.07 0.05 – 0.8	>0.5 >0.6	All substrates suitable
Burbot	Adult	22	100% 80%	0 – 1.9 0 – 1.3	>0.4 >0.8	All substrates suitable
Whitefish	Adult	35	100% 80%	0.0 – 2.6 0.01 – 1.4	>0.25 >0.6	All substrates suitable

Table 5-2. Envelope based HSC/HSI models for priority species and life stages with insufficient site-specific data for development of multivariate HSC models.

Species	Life Stage	Suitable Velocity Range (fps)	Suitable Depth Range (feet)	Suitable Substrate Range	Cover / Substrate	Source
Pink Salmon	Spawning	0.5 – 2.7	>0.5	Small Gravel – Small Cobble	n/a	• 2013-2014 HSC Database (Study 8.5 SIR, Table 5-1, R2 2015a). • Vincent-Lang et al. 1984. Habitat Suitability Criteria for Chinook, Coho, and Pink Salmon. Alaska Power Authority (APA) Document 1938.
Arctic Grayling	Adult	1.8 – 4.4	>0.5	All Substrates	Cobble and Boulder	• Suchanek et al. 1984. Resident and Juvenile Anadromous Fish Investigations 1983. APA Document 1784.
Rainbow Trout	Adult	0.05 – 1.5	>0.5	All Substrates	Cobble and Boulder	• Suchanek et al. 1984. Resident and Juvenile Anadromous Fish Investigations 1983. APA Document 1784.
Burbot	Adult	0.0 – 1.3	>0.8	All Substrates	Turbid Water (Summer Only)	• 2013-2014 HSC Database (Study 8.5 SIR, Table 5-1, R2 2015a). • Suchanek et al. 1984. Resident and Juvenile Anadromous Fish Investigations 1983. APA Document 1784.
Eulachon	Spawning	0.5 – 2.5	>0.5	Small Gravel – Large Cobble	None	• Vincent-Lang and Queral 1984. Eulachon Spawning Habitat in the Lower Susitna River. APA Document 1934. • HDR and LGL 2014. Initial Study Report, Study 9.16: Eulachon Run Timing, Distribution, and Spawning in the Susitna River.
Bering Cisco	Spawning	0.5 – 3.5	>0.5	Small – Large Gravel	None	• Delaney et al. 1981. Resident Fish Investigation on the Lower Susitna River. APA Document 318.
Whitefish	Adult	0.01 – 1.4	>0.5	All Substrates	Cobble and Boulder	• 2013-2014 HSC Database (Study 8.5 SIR, Table 5-1, R2 2015a). • Suchanek et al. 1984. Resident and Juvenile Anadromous Fish Investigations 1983. APA Document 1784.

8. FIGURES



Location:
Y1-Sustina River (1980s), AK
Y2-Upper Talarik Creek, AK
Y3-North Fork Koktuli River, AK
Y4-South Fork Koktuli River, AK
Y5-Wilson River and Tunnel Creek, AK
Y6-Terror and Kizhuyak rivers, AK
Y7-Envelope Model

Figure 4-1. Example of juvenile Coho Salmon envelope HSC/HSI model using existing information from other river systems within Alaska.

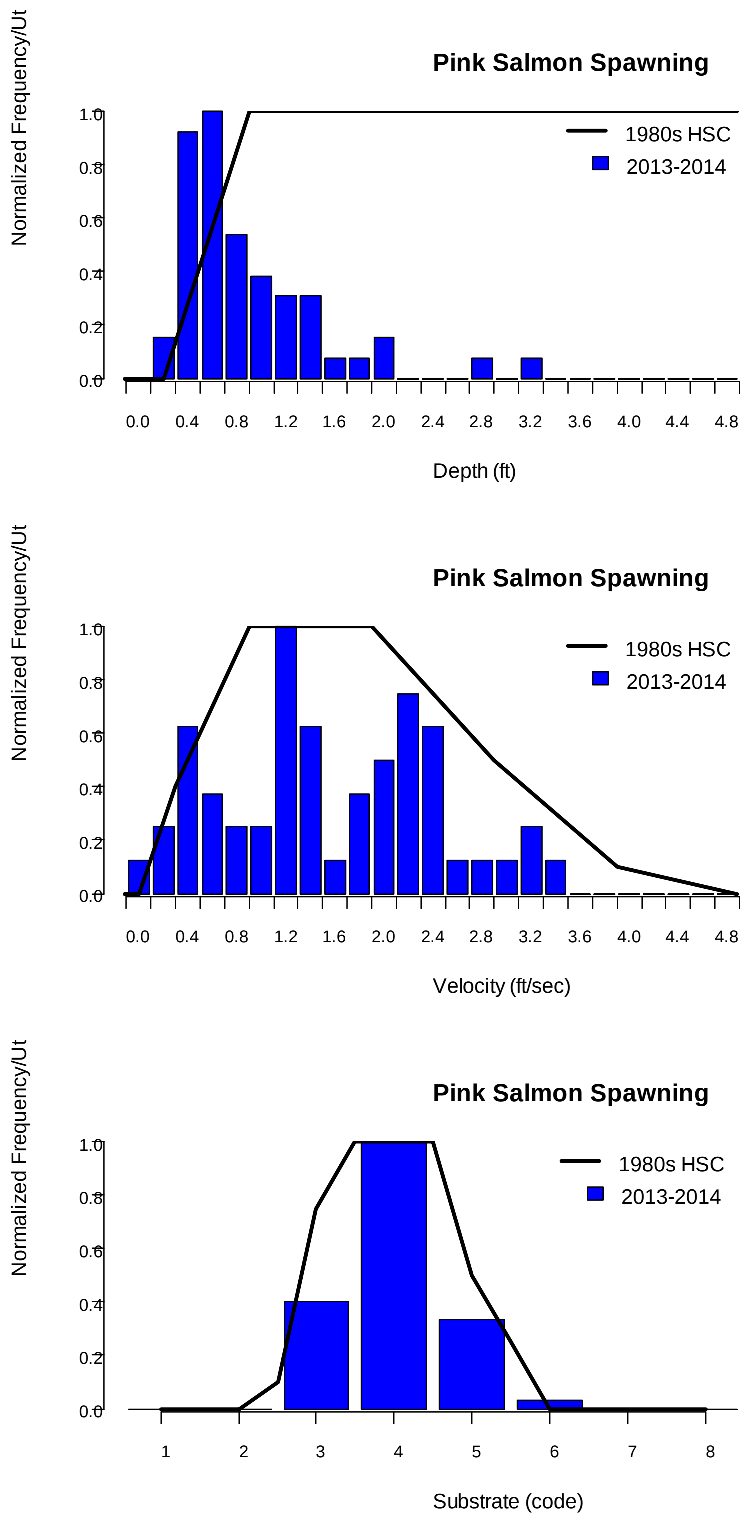


Figure 5-1. Comparison of HSC/HSI developed for Pink Salmon spawning during the 1980s Su-Hydro instream flow studies (Vincent-Lang et al. 1984) for the Middle River Segment of the Susitna River, Alaska and histogram plots generated from 2013-2014 HSC/HSI observations and normalized to the maximum frequency equal to 1.0 for depth (top), velocity (middle), and substrate (lower) microhabitat components (2013-2014 HSC database).

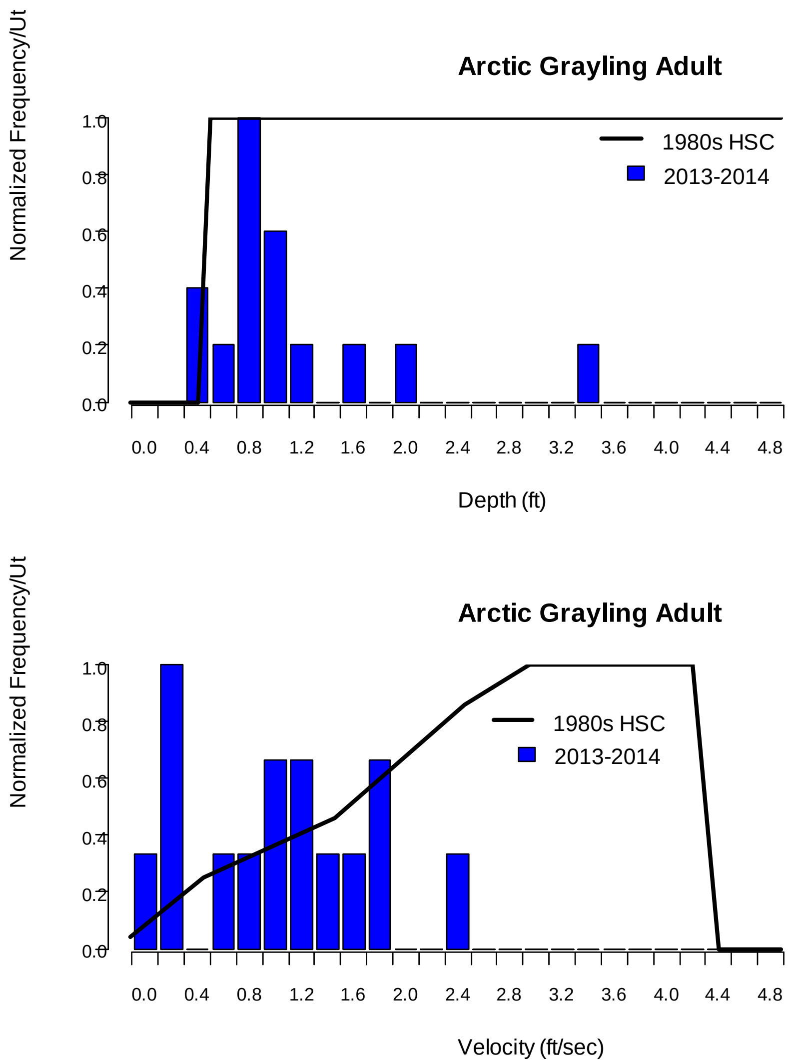


Figure 5-2. Comparison of HSC/HSI developed for Artic Grayling adult during the 1980s Su-Hydro instream flow studies (Suchanek et al. 1984) for the Middle River Segment of the Susitna River, Alaska and histogram plots generated from 2013-2014 HSC/HSI observations and normalized to the maximum frequency equal to 1.0 for depth (top) and velocity (lower) microhabitat components (2013-2014 HSC database).

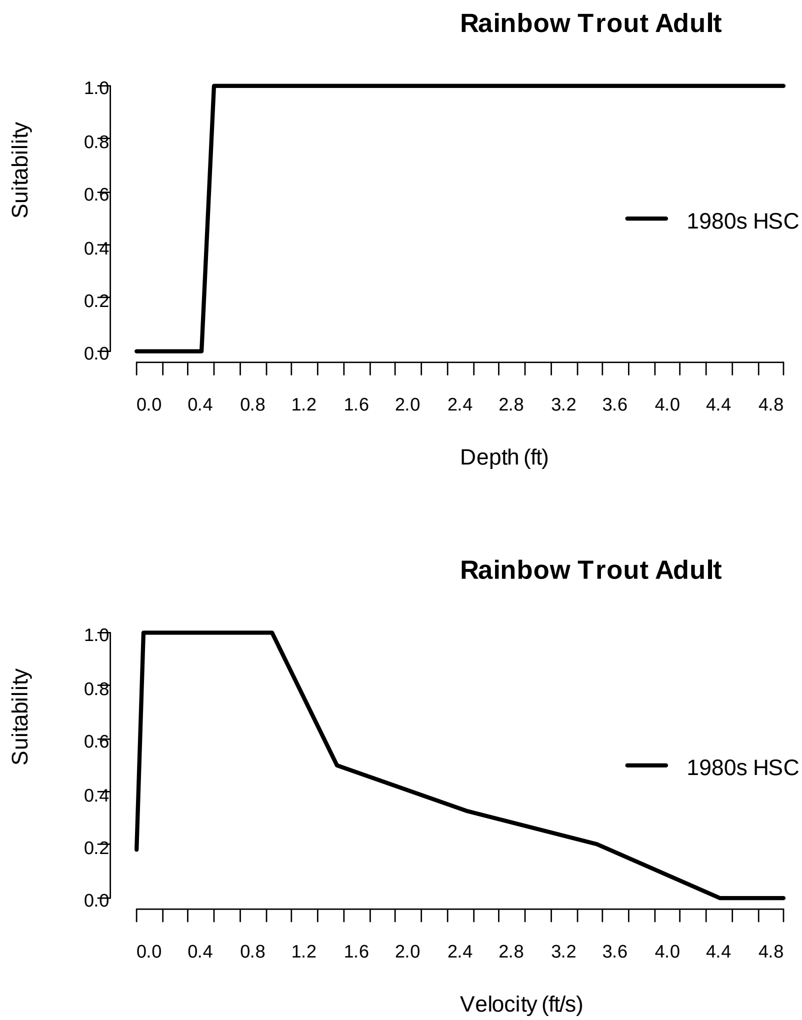


Figure 5-3. Comparison of HSC/HSI developed for Rainbow Trout adult during the 1980s Su-Hydro instream flow studies (Suchanek et al. 1984) for the Middle River Segment of the Susitna River, Alaska and histogram plots generated from 2013-2014 HSC/HSI observations and normalized to the maximum frequency equal to 1.0 for depth (top) and velocity (lower) microhabitat components (2013-2014 HSC database).

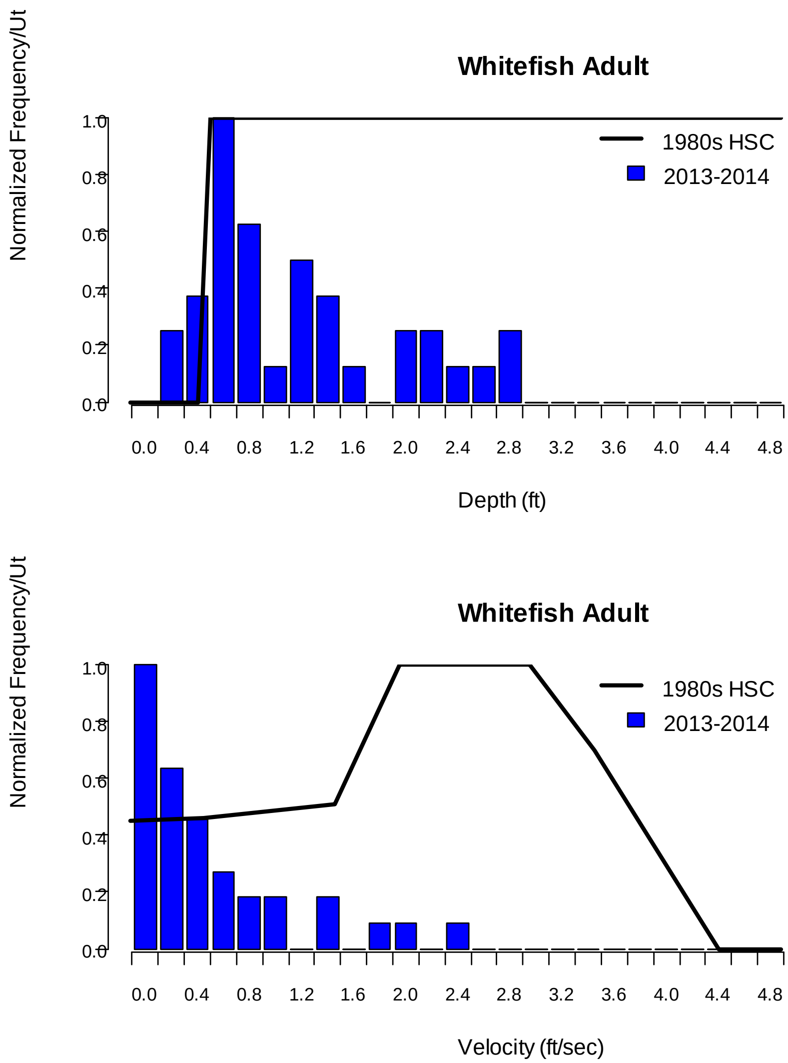


Figure 5-4. Comparison of HSC/HSI developed for whitefish adult during the 1980s Su-Hydro instream flow studies (Suchanek et al. 1984) for the Middle River Segment of the Susitna River, Alaska and histogram plots generated from 2013-2014 HSC/HSI observations and normalized to the maximum frequency equal to 1.0 for depth (top) and velocity (lower) microhabitat components (2013-2014 HSC database).