RFI 167
Pebble Project EIS

Request for Information

Title/Subject:	**Clarification of Fish Habitat Modeling**
Requestor:	AECOM
Date Transmitted:	4/15/2020
Recipient:	Pebble Limited Partnership
Response Requested by:	4/24/2020
Rationale:	A wide variety of agency comments were received regarding the PHABSIM to predict changes in the amount of suitable habitat for fish species and life-stages during mine operation and closure. Additional information is required to adequately address agency comments on the PFEIS.
Describe the Information Requested and Level of Detail:	Please provide information to the specific requests described in the table below.

Recipient Response Form

Date Received from USACE:	4/15/2020
Response from Recipient (Describe Information Requested to the Level of Detail Requested; Provide Attachments as Needed):	See response below.
List Number and Type of Response Attachments:	1. Reiser_et_al-2018-Fisheries.pdf
Date Returned to USACE:	4/20/2020

AECOM Intake Form

Date Response was Received:	4/20/2020
Received by:	AECOM
Describe any Follow-up Related to this RFI:	Click here to enter text.

Agency Comment (examples)	AECOM RFI	PLP Response
SOA: "Groundwater and streamflow interactions are complex and dependent on multiple factors. Large landscape-scale alterations of the topography, water extraction, diversions, and other mine components and operations could alter groundwater patterns differently than modeling suggests, this is why the models have a degree of uncertainty associated with them. For example, the GW model suggests that GW input to the pit post-closure could be between 600 and 4,300 gpm. The uncertainty of the model and the complexity of the GW complex should be considered and incorporated into the conclusion reached that spawning and over-wintering habitats would be largely unaffected." EPA: "While the PFEIS acknowledges a relationship between salmonid species site selection and groundwater, it does not account for it in habitat modeling (PHABSIM), HSC development, quantification of habitat, or the consequences of fish from the loss of groundwater areas."	Many comments suggest that the habitat analysis did not adequately account for the influence of groundwater in assessing the quantity or quality of suitable habitat. We understand that many PHABSIM transects were placed in reaches exhibiting rising groundwater. Request: Please describe any other specific procedures in which the habitat modeling (PHABSIM) process accounted for groundwater effects on habitat suitability	As described in the technical appendix submitted in response to RFI 147, the watershed model characterizes both baseline and operating mine conditions of surface water expression in the Project Area. It is based upon precipitation, evapotranspiration, sublimation, catchment area, groundwater inflows, mine operational flows and groundwater loss due to the zone of depression. The modeled surface flow value is then fed into the PHABSIM model to predict effects to fish habitat. In this way, the input flows that feed into the PHABSIM model already account for estimated changes in groundwater flow.
SOA: "The statement that reductions in streamflow would result in predicted increased habitat (more suitable acres),	Agencies request that habitat modeling results be produced on a monthly basis. It appears that PHABSIM results (acres of suitable habitat) for each species and life-stage were based on the	As described in the attachment to RFI 149, the instream flow model was run for all target species at a daily time step. This means that the model predicts suitable habitat

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particularly for juvenile life stages is reached based on a simplistic view of the system, a model with uncertainty, and it isn't clear if the seasonal needs of juvenile fish or increased runoff and hydrograph spikes from landscape development are considered. The analysis should include more explanation of these complex factors and breakdown suitability by month or season. Predicted quantity of suitable juvenile rearing habitat by species (Table K4.24-2) should include monthly or at least seasonal estimates of predicted habitat not just for the entire year as juvenile fish habitat preference changes with the seasons."	month or range of months as indicated in the Figure 5 life-history stage periodicity chart (RFI048 HABSYN Methods Closure Update 092818.pdf). For example, rainbow spawning over May & June, and Chinook spawning over July & August. Page 34 in the HABSYN methods document states that the winter (Dec-Mar) distribution of treated water among the three tributaries was determined using the hydrological method rather than the designated species/life-stages shown for those months in Table 1 (pg 9). Consequently, it is uncertain if habitat modeling was conducted over the winter months for juvenile and adult (resident) salmonids, given the known limitations of PHABSIM during periods of ice cover and the differences in HSC between summer and winter periods. Request: Please clarify if the habitat modeling results for juvenile Chinook, coho, and resident species and resident adult life-stages are based on a 12-month period Request: Please verify that the winter (Dec-Mar) distribution of treated water among the three tributaries was determined using the hydrological method rather than the designated species/life-stage listed in Table 1 in the HABSYN methods document	available to fish every day of the year under both baseline and operating mine conditions. As described in the attachment to RFI 147, the periodicity table was used determine which priority species would be used in any one month to determine how restoration flows (treated mine operational flows) should be distributed. For example, since Chinook spawning occurs in August, we modeled the restoration flow that would optimize Chinook spawning habitat, as best as possible, compared to the pre-mine condition. These restoration flows from the mine were then distributed by the model across the streams and combined with mine-affected surface flow to predict future August flow condition. The HABSYN model was then run using that restoration flow for every target species and lifestage. As described in the attachment to RFI 147, this flow "optimization" step is species and life stage specific. Spawning was always the priority lifestage if occurring and species were prioritized in the following order: Chinook, Coho, Rainbow Trout, and Arctic Grayling. The periodicity identified which month priority species were spawning, and which would be used that month for restoration flow optimization. This resulted in using Rainbow Trout spawning flow needs to determine "optimized" flow in May, Chinook in August and Coho in September, for example. A different approach was used to determine restoration flow distribution because the behavior and habitat needs of fish under ice are likely very different than those for spawning and rearing lifestages during open water periods. As described in the attachment to RFI 147, in lieu of optimizing flow distributions as described above, for the winter months we used a hydrologic approach to distribute

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		restoration flows with the objective of replicating as close as possible the pre-mine hydrologic condition.
SOA: "The PFEIS states that for some species, reduced stream flow will increase habitat suitability (as measured in acres). The rationale used is that slower water velocities are preferred habitat by juvenile salmonids. This explanation does not hold consistent for different stream reaches and flows. For example, during mine operations SFK-C is expected to see an annual change of -1.7% (loss) mean monthly flow and an increase of rearing habitat by 9.2%. After operations (closure) this same stream reach is expected to see an annual change of +17.3% (gain) mean monthly flow and an increase of rearing habitat by 7.4%. So, less water equals more habitat and more water also equals more habitat in the same stream reach."	As noted by the agency comment, comparing the relationship between predicted changes in surface flows and the associated changes in the amount of suitable habitat sometimes produce confusing and seemingly contradictory results. The specific example noted by ADFG involved coho juvenile rearing in SFC-C (scenario S0, 50% exceedance w treated water), where a drop in flow from baseline to operation would result in an increase in suitable habitat, but an increase in flow (from baseline to post-closure) would also result in an increase in habitat. Other similar cases exist. Although it appears that estimated changes in suitable habitat in many such cases are very minor (e.g., in tenths of acres), it is unclear what mechanisms would result in these flow:habitat relationships. Request: Please verify this is a valid result and explain the process that would lead to such a conclusion.	The review appears to be trying to equate estimated changes in annual hydrology and with specific instream flow model outputs. Because of the scale of the models such a direct comparison is not appropriate. Average annual hydrology is estimated on annual basis, while the instream flow model was refined to operate at a daily time step and thus, is predicting habitat based on estimated daily changes in flow. Given this difference of scale it is not surprising that the reviewers saw potential discrepancies in the model outputs. Nevertheless, the pattern observed is still a possible viable outcome of the instream flow model. First, the daily model is consistent with the interpretation that there will be an overall reduction of flow in Reach SFK-C during operations, and that there will be an overall increase of flow in Reach SFK-C under post-closure conditions. Intuitively, it would seem that less flow would translate to less habitat, and that more flow would translate to more habitat. However, it doesn't always work this way for juvenile rearing habitat, especially when overall project effects on habitat can be influenced by seasonal changes to hydrology. For example, low flows in Reach SFK-C during the winter months will be increased, and high flows during the summer months will be decreased during operations. The combined effect of both changes to the hydrology may result in an overall increase in juvenile rearing habitat. Thus, while there will be an overall reduction in flow in Reach SFK-C during operations, there could also be an overall increase in juvenile rearing habitat during operations. Similarly, low flows in Reach SFK-C during the winter months, and low to intermediate flows during the summer months will be increased during post-closure

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		conditions. Under these conditions, an overall increase in flow in Reach SFK-C could result in an overall increase in juvenile rearing habitat during post-closure conditions.
EPA: “We recommend revising this general summary statement in the FEIS to better capture the full range of factors that contribute to impacts to suitable habitat, which includes changes during the construction phase and changes to tributaries. In addition, we recommend acknowledging that this conclusion is based on instream flow modeling using PHABSIM. The EPA notes that we have concerns with limitations of the PHABSIM model for fish habitat. As such, we have made recommendations in our comments regarding revising the habitat analysis.” EPA: “We continue to recommend revising the analysis of impacts to fish habitat, and recommend revising the figures to present clear and accurate information. Model selection should be based on what is trying to be understood relative to alterations and impacts to fish and fish habitat … We are not recommending any particular model, but are providing examples of models that go beyond flow and channel characteristics in order to address limitations in the PHABSIM model. In addition, we recommend	Commenters have asserted that the limitations and uncertainties associated with the PHABSIM model produces results insufficient to assess the effects of project-related flow alternations on fish habitat. We understand that IFIM and PHABSIM approach is the most frequently used and agency accepted flow assessment model in the U.S. and Canada (Instream Flow Council), and that all models possess limitations and uncertainties. Request: Briefly summarize where the primary uncertainties exist in the PHABSIM estimates of suitable habitat (e.g., incorporation of groundwater, treatment of overwintering habitat, etc.).	The IFIM and PHABSIM models are accepted approaches for predicting potential changes to fish habitat as a result of changes in flow. All models, including PHABSIM and HABSYN, have limitations and uncertainties, but they are a valuable tool for providing comparable predictions that can be used to inform decisions. Please see attached publication by Reiser et al. 2018 for a summary of limitation and continued value of PHABSIM.

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that the FEIS discuss how model limitations, sensitivities, and uncertainties impact model outputs and FEIS conclusions."		

COLUMN
PERSPECTIVE

A Practitioner's Perspective on the Continuing Technical Merits of PHABSIM

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Since its initial development and application in the mid-1970s, the Physical Habitat Simulation System (PHABSIM) and models, which are part of the instream flow incremental methodology (IFIM) developed by the U.S. Fish and Wildlife Service (Bovee and Milhous 1978; Bovee 1982), has been extensively used (Reiser et al. 1989; Hatfield and Bruce 2000; Locke et al. 2008), reviewed (e.g., Wesche and Rechard 1980; Morhardt 1986; Annear et al. 2004), and occasionally criticized (Mathur et al. 1985; Scott and Shirvell 1987; Hudson et al. 2003). Its most recent critic, Railsback (2016), went so far as to title his paper "Why It Is Time to Put PHABSIM Out to Pasture." This prompted comments from Beecher (2017) and Stalnaker et al. (2017) and a corresponding response from Railsback (2017). Kemp and Katopodis (2017) also provided comments noting the timeliness of the Railsback (2017) paper and promoting further dialogue on the subject. We read all three comments and the author's response to the first two, and as active instream flow practitioners and independent reviewers of the original Railsback (2016) article, we felt there was more to be said. We note that we have the highest respect for Railsback and his colleagues; we also admit that at the outset of our review of the 2016 article, we were somewhat expecting to be convinced and echo the strident cry for PHABSIM retirement. Instead, we found that many of the core criticisms (of PHABSIM) were weak, wrong (at least by our interpretation), or outdated and misaligned with contemporary PHABSIM practices.

The critique itself was organized around five headings housed within an overarching negative theme portraying PHABSIM as an antiquated model. Our review basically follows the same order of headings. However, before proceeding, we wish to re-emphasize the point made by Stalnaker et al. (2017), which is that PHABSIM is only one component of the much broader IFIM that entails a comprehensive evaluation of flow and riverine ecology. Unfortunately, we still find PHABSIM and IFIM incorrectly used interchangeably when they refer to much different processes.

SPATIAL SCALES

Railsback's (2016) discussion of mishandling of spatial scales by PHABSIM is centered around three broad assertions that largely pertain to either the application of PHABSIM from an earlier time period (hence, an outdated criticism) before more advanced modeling techniques became available, or from misapplication of the method by inexperienced practitioners. For example, referencing the "20 cells across a stream channel" recommendation by Bovee and Milhous (1978) appears to be referring to the earlier one-dimensional (1-D) models that were at the heart of PHABSIM in the early 1980s. The 1-D applications of today are linked to the hydrology of a given system and are often coupled with a series of other biologically relevant models designed to address aspects outside the realm of PHABSIM. Such models may include those related to fish passage (e.g., Thompson 1972; Woodard 2012), invertebrate food production (Gore et al. 2001), water quality (Hamrick 1992; Cole and Wells 2000), sediment transport (Pitlick and Wilcock 2001), channel maintenance (Schmidt and Potyondy 2004), riparian processes (Chapin et al. 2002; Rood et al. 2003), and hourly ramping rates (Hilgert et al. 2008). PHABSIM is commonly applied as one of several models that are jointly used for providing a holistic approach for addressing instream flow issues. Consistent with the original description of PHABSIM as one component of the IFIM, the state of California provides guidance on conducting instream flow studies that specifically includes consideration of the biology, hydrology, geomorphology, and water quality of a given system, with selection of specific methods based on combined resource issues (https://wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/SOP). Likewise, the state of Washington provides a set of instream flow guidelines that includes PHABSIM and IFIM analyses, but indicates that the derivation of an instream flow recommendation transcends simply referring to model output and must consider other factors. Today's ever-increasing demands and competition for water require that instream flow studies extend beyond relying on a single methodology for deriving environmental flows.

Today's PHABSIM is sensitive to the importance of spatial scale, and with the advent and application of two-dimensional (2-D) modeling (Leclerc et al. 1995; Ghanem et al. 1996; Gard and Ballard 2003), the scale of the hydraulic models can be adjusted to more closely match biological functions. Today's 2-D PHABSIM analysis provides the option for selectively adjusting the modeling mesh to more closely match biological activities, whether it relates to spawning habitats, juvenile rearing and feeding zones, adult holding areas, and so forth. The assertion that PHABSIM only represents how habitat varies over space is also not true as the 2-D analysis can be coupled with hydrologic records, including hourly and daily flow fluctuations, to provide an assessment of how habitats may morph over different time scales (see also Comment by Stalnaker et al. 2017).

An example of this is afforded by recent work being completed by the Alaska Energy Authority as part of hydroelectric licensing activities for a proposed dam on the Susitna River, Alaska, where 2-D models were being developed for segments

DOI: 10.1002/fsh.10082

of river known to be important to fish. In one such area that spans a 2.5-km (1.6 mi) segment of river, separate models have been developed for both open-water (using HEC-RAS and SRH-2D) and ice-covered (using River1D and River2D) conditions, enabling an assessment of how flow regulation and winter ice conditions may influence fish habitats (open water and under ice; see R2 et al. 2014). Changes in groundwater patterns (vertical flux) and water quality (water temperature, dissolved oxygen, and turbidity) were also considered via development and integration of groundwater model outputs using the modular three-dimensional finite difference groundwater flow model (MODFLOW) and outputs from 2-D water quality modeling based on Environmental Fluid Dynamics Code (EFDC). Finally, adjustments in bed elevation changes that may occur over the life of the project were considered using a 2-D bed evolution model (BEM). The work also included the development of site-specific, multivariate, random effects habitat suitability criteria (HSC) models for different species and life stages that, in addition to depth, velocity, and cover, also considered water temperature, turbidity, and groundwater upwelling (R2 Resource Consultants 2015). Outputs from the resource models can then serve as inputs to PHABSIM-type analyses, which incorporate geographic information system mapping to depict changes in fish habitats for different species and life stages. The analysis has not been fully completed but is illustrative of the type of multidisciplinary approach for evaluating flow regulation effects on fish habitats via integration of a suite of different resource specific models into a PHABSIM-type analysis (see instreamflowcouncil.org/instreamflowcouncil/wp-content/uploads/2015/09/Dudley-Reiser.pdf). While these types of 2-D analyses represent a tremendous improvement over the historical 1-D PHABSIM models, further improvements are needed that attempt to account for fish habitat changes resulting from behavioral shifts aligned for example to predator avoidance, opportunistic feeding forays, competition, and antagonistic interactions.

Railsback (2016) also refers to a spatial problem whereby hydraulic simulations derived at one resolution are combined with preference curves derived from different, generally finer resolution scales, potentially compromising the interpretation of results. This criticism has some merit, but as discussed below, there have been substantial advances in the statistical analysis of HSC and habitat suitability index (HSI)-related data that result in more robust, multivariate habitat functions that consider spatial scale.

WEIGHTED USABLE AREA LACKS CLARITY AND BIOLOGICAL MEANING

In terms of clarity, it has been repeatedly acknowledged (see Stalnaker et al. 1995; Annear et al. 2004; Payne 2003) and reaffirmed in the comments of Beecher (2017) and Stalnaker et al. (2017) that weighted usable area (WUA) represents an "index" of habitat quantity and quality, not precise habitat amounts. Some of the misunderstanding might be averted if WUA output is considered a relative suitability index (Payne 2003) since PHABSIM was never intended to serve as a precise quantifier of habitat area or numbers of fish. Rather, the WUA versus flow relationships serve as indicators of how species and life stage habitats may vary with streamflow within a modeled section of stream. The results provide one metric that decision makers can consider when assessing instream flow requirements. Much of the lack of clarity espoused in the Railsback (2016) article comes from the interpretation of WUA by investigators who try to portray it as more than what it was intended. It is the sometimes overzealous interpretation of WUA that have misaligned its core strength, which is providing an index of how potential habitat changes with flow.

As to its lacking biological meaning, we assume this pertains to its lack of predictive capabilities to translate WUA to numbers of fish. Many water resource managers seek a metric that quantifies fish abundance–flow relationships. If water is being set aside for environmental protection, water managers want to put a dollar value on the fish and provide a cost–benefit analysis. However, the time allotted for completing many (most) projects involving instream flow assessments is generally short (1–2 years), negating the ability to develop all of the necessary biological and physical data needed to develop life-cycle-type models (or individual-based models [IBMs], as proffered by Railsback) that include flow as one of many parameters. In addition, attempting to place a monetary value on fish undermines its inherent value as a public resource. The IFIM approach (of which PHABSIM can be a part) is designed to capture the value of fish in terms of habitat while also considering other values inherent within a public resource.

Railsback (2016) infers that there are models available that attempt to quantify numbers of fish and argues that those models are needed to prescribe instream flow recommendations. Hendrix et al. (2008) reviewed 47 documents that attempted to predict flow or habitat relationships to fish abundance. There were three theoretical mechanisms suggested in the documents by which flow could affect abundance: (1) through a direct mechanism—flow increases and decreases population abundance, (2) through a survival mechanism—flow increases or decreases survival, and (3) through a carrying capacity mechanism—flow increases or decreases carrying capacity, which only affects abundance if it is above or slightly below carrying capacity. Linear regression models (direct mechanism) were the most commonly applied analyses, and the amount of variability in the abundance data explained by the flow (and other) covariates was reported as the coefficient of determination (r^2). There were conflicting results regarding flow as a direct predictor of abundance. Population dynamics models (both survival and carrying capacity mechanisms) had more flexibility in the underlying theoretical mechanisms employed but did not quantify the amount of variability in the abundance data. Without such quantitative measures, it was unknown whether the population dynamics models made accurate predictions of population abundance as a function of flow. The bioenergetics models (which included IBMs) that track the physiological demands of an individual (survival mechanism, as poor growth and other factors may reduce survival) were not capable of scaling predictions from individuals to populations; therefore, they were not suitable for addressing the relationship between flow and population abundance. Studies that did incorporate flow as one of the determinants of population size were all retrospective (rather than prescriptive) evaluations, where the goal was to try and understand factors that may influence fish population size, not to identify specific flow amounts needed to produce a given population size. Even if there are significant advancements in quantitative modeling, instream flow practitioners should continue to rely primarily on methods that define habitat—flow relationships, rather than relationships of flow—population abundance.

PREFERENCE CURVES

Railsback's (2016) assertion that preference curves are obsolete has some merit, but we assume this is directed toward the older univariate curves that were described and applied during the early years of the Instream Flow Group; see, for example, Bovee (1978). However, the arena of HSC development has undergone scrutiny and improvements over the years; see for example Ahmadi-Nedushan et al. (2006), and Jowett and Davey (2007). At the crux of this process is the desire to develop and apply the most biologically sound criteria that are reflective of the species and its general affinities relative to flow-sensitive parameters. The need for criteria that are flow-sensitive is often lost on critics of the method who argue that parameters such as predation, disease, nutrients, and chlorophyll *a* should be included in a PHABSIM analysis even though they are insensitive to flow.

In a general sense, HSC can be considered as a series of hypotheses of species–habitat relationships that are intended to provide indicators of habitat suitability or preference. They are not intended to directly quantify or predict the abundance of target organisms, but rather to translate biological (e.g., habitat use, benthic food productivity, adult passage, smolt production, predation, and cover), water quality (e.g., temperature, dissolved oxygen, and turbidity), and hydraulic and channel characteristics (e.g., depth, velocity, and substrate) into measures of overall habitat suitability. As noted by Railsback (2016), a common criticism of univariate curves is that habitat selection by a fish is not based on single variables acting independently, and therefore, simply multiplying or using the mean suitability index from univariate methods for overall habitat suitability requires an assumption of independence as well as an assumption regarding the relative importance of each predictor (usually assumed equal). We agree and point out that experienced practitioners are turning to multivariate methods, for example, using bivariate histograms of depth and velocity utilization samples combined with bivariate smoothing. When available habitat has been sampled, preference models such as logistic regression for used versus unused habitats are easily extended from single-variable (e.g., depth) to multiple-regression models. Using this method, nested models including polynomial (e.g., quadratic) terms and interactions can be statistically compared and the best model selected. Guay et al. (2000) compared an HSC approach that multiplied univariate forage ratios to a multivariate logistic regression approach to predicting Atlantic Salmon *Salmo salar* parr occurrence and concluded that multivariate logistic regression was a more powerful biological model. Beakes et al. (2012) compared a multiplied univariate composite HSC with a multivariate model-based HSC for juvenile Chinook Salmon *Oncorhynchus tshawytscha* and found the multivariate model to provide greater predictive accuracy. Dunbar et al. (2011) suggests that multivariate approaches should be the default for instream flow studies.

Experienced practitioners of PHABSIM have continued to improve the manner in which fish habitats are characterized and linked into the modeling so that multiple variables are considered together. We agree that some elements of PHABSIM (such as univariate utilization HSC criteria) have become outdated and new procedures must be adopted; however, when determining the value of PHABSIM, one should consider its ongoing refinements and improvements.

DEPTH, VELOCITY, AND SUBSTRATE TYPE ARE NOT ALWAYS THE MOST IMPORTANT HABITAT VARIABLES

Another criticism by Railsback (2016) was that depth, velocity, substrate, and cover type are not the only habitat variables defining suitability. While the developers of PHABSIM considered them to be important variables, the entire IFIM framework is based on questioning the assumption that other variables may be controlling fish habitat suitability. We believe that depth and velocity are important factors defining habitats of fish, but refinements in the HSC development and application process are clearly designed to consider more than just parameters of depth, velocity, substrate, and cover.

HABITAT SELECTION MODELS ARE NOT WELL SUITED FOR MODERN INSTREAM FLOW ASSESSMENTS

The assertion by Railsback (2016) that habitat selection models are not well suited for modern instream flow assessments fails to consider the long-term implications of tying instream flow requirements to fish production. If ocean conditions (or other nonflow related limiting factors) limit salmon (or other fish species) populations, do we provide less freshwater habitats since they may not result in more fish? The answer should be "no." Rather, focusing instream flow assessments on habitat preserves the potential for fish populations to thrive absent these other limiting factors. This is why most environmental flow studies are targeting some aspect of the provision or protection of habitat associated with the setting of flows.

The use of population-based modeling in instream flow assessments would seem to be most appropriately reserved to projects where (1) flow is but one of many anthropogenic factors under consideration, (2) flow can be sufficiently regulated to allow testing of different regimes and monitoring population responses, (3) there is a sufficiently long time horizon to allow development and validation of such models (related to 2), and (4) the project can be managed under an adaptive management construct that allows for changes in flow regulation or other parameters and monitoring.

REVIEW OF RECOMMENDATIONS

Under the section Moving On: Instream Flow without PHABSIM, Railsback (2016) makes four recommendations. The first is that instream flow scientists need to take a broader ecological view of flow needs (e.g., stepping beyond depth, velocity, and substrate). We agree wholeheartedly, but as noted above, experienced instream flow methods practitioners are already doing this and recognize the importance of understanding the fish species assemblages of concern and crafting an instream flow analysis sensitive to fish life history needs and the range of flow conditions they may experience under project conditions. The three questions Railsback (2016) poses are relevant ecological questions: (1) What fishes eat and how do they feed? (2) What eats the fishes and how do they avoid being eaten? (3) How do they reproduce? However, when the issue is flow regulation, we are more concerned with determining the types of habitats fish (all life stages) use and rely on, when they use them, and how these habitats will be influenced under project operations. As the Susitna River example above demonstrates, the answer to this question requires thinking beyond the obvious existing in-channel surface-water-based characteristics and considering other physical and hydrologic processes (e.g., groundwater, geomorphology, water quality, and flow dynamics) that influence fish and fish habitats and how those may be altered by project operations.

Railsback's (2016) second recommendation refers to the need for better spatial resolution, expanding the list of variables to include others that are biologically meaningful, refining the habitat selection index process (i.e., HSC/HSI), and considering how variables like temperature and turbidity may change habitat use. Again, many contemporary practitioners of PHABSIM are already making great strides to address these issues as evidenced by the application of 2-D models, the development of HSC models using multivariate statistical analysis, and the integration of a broader suite of habitat-defining variables.

The third recommendation by Railsback (2016) is to consider IBMs for flow assessments. Railsback has been a developer and advocate of the application of IBMs (Railsback et al. 2005, 2009, and 2013) and touts them as being able to overcome the limitations of habitat selection models. However, his arguments would be strengthened by providing evidence that these models have been used in an applied sense for determining ecological flow releases for a water resource project where there are competing interests or by defining instream flow requirements in a water rights context. These models, like other life cycle models, are useful for evaluating and estimating the influence of multiple biotic and abiotic parameters on fish population metrics that may include flow, but they are not centered on flow and do not explicitly lead to environmental flow prescriptions. These models may suggest that for certain time periods, flow is not the controlling parameter, leaving water resource managers with a void on what flows to provide during these periods. Moreover, as Railsback (2016) noted, few off-the-shelf IBMs are available and the development of new models is not trivial.

Railsback's (2016) final recommendation, that of direct observation of habitat under different flows (Railsback and Kadvany 2008), is a throwback to the original days of PHABSIM and is a welcome acknowledgment that all models, PHABSIM and IBMs alike, are only tools intended to support flow management decisions. The direct observation method, which was originally developed by Collings (1972) during the formative years of instream flow methods, was one aspect of a more quantitative approach developed to incrementally assess how spawning habitat varied over different flow conditions. Direct observation by parties participating in flow management decisions should also be considered a part of PHABSIM and other instream flow studies. Rather than blindly relying on modeling outputs to determine instream flow requirements, direct observation can serve as a reality check on model outputs. In most cases, observations are supplemented by representative photographs of different habitats taken under different flow conditions. This admittedly less-quantitative approach shows specific channel features over a range of flow conditions and provides a visualization of habitat changes with flow that assists in the interpretation of results. We agree that direct observation is certainly a useful tool in instream flow assessments, in concert with other tools, including PHABSIM.

FINAL ASSESSMENT

To summarize, we first hearken back to the results of the 1981 and 1986 surveys of instream flow practices in North America (Reiser et al. 1989), which found that the IFIM, which is the overarching method within which PHABSIM is contained, was the most commonly applied method in North America based on a survey of 46 states and 12 Canadian provinces. We recently conducted some strategic Google Web surfing using the keywords of a given state or province followed by "PHABSIM instream flow study" and found, in most cases, one or more references where PHABSIM had either been recently applied or considered for application. Moreover, there have been more than 400 downloads from one PHABSIM software host site (http://www.millereco.com/index.php/phabsim) since 2012 (W. Miller, Miller Ecological Consultants, personal communication). This suggests that in 2018, PHABSIM, or its derivatives, remains one of the most commonly used methods for assessing instream flow needs. The Instream Flow Council (IFC), which represents a consortium of state water resources agencies across the United States and Canada, recognizes the IFIM and its associated software—PHABSIM—as one of many instream flow methodologies for consideration (see Annear et al. 2004). The IFC also lists important constraints and limitations regarding the application of IFIM/PHABSIM, most notably that it pertains to habitat and that it would need to be coupled with other physical-based models to address questions regarding relationships among flow, water quality, sediment, channel structure, groundwater, and other parameters. The suggestions proffered by Stalnaker et al. (2017) on ways to improve the PHABSIM models are especially noteworthy. Some states, for example California (California Department of Fish and Wildlife, https://wildlife.ca.gov/Conservation/Watersheds/Instream-Flow/Studies) and Washington (WDFW and Ecology 2008) have provided specific guidelines to instream flow practitioners regarding the use of different instream flow methods, with PHABSIM or equivalent (e.g., Riverine Habitat Simulation [RHABSIM]) often being employed in developing habitat–flow relationships. California has even provided a series of standard operating procedures for different methods as one means to help standardize how instream flow studies are conducted. The point here is that many jurisdictions responsible for flow management have identified methodologies for application, ostensibly because they consider them reliable and scientifically defensible. PHABSIM is one of those methods.

PHABSIM IS NOT READY FOR PASTURE

No single model or approach works for all instream flow assessments, and we as instream flow practitioners are fortunate to have a wide range of tools currently available for evaluating environmental flow issues. In addition, as Railsback (2016) notes, new methods are on the horizon that most certainly will prove to be valuable instream flow assessment tools. There have also been substantial advancements in models like PHABSIM that have been necessary to address the increasing complexity of water resource projects.

The majority of purported shortcomings of PHABSIM listed by Railsback (2016) have either been, or are in the process of being, addressed, and PHABSIM today still remains one of the most germane, widely applied, and jurisdictionally recognized analytical tools for assessing instream-flow-related issues. Part of the reason for this is likely due to its ability to be contemporized and linked with other resource models, and part is related to its being readily understood across both the scientific and nonscientific communities. We have participated in projects where highly sophisticated models were developed only to be essentially abandoned due to their complexity and the difficulty in explaining the models to nonscientists, for example to a judge in a legal setting. Often the sheer number of assumptions and associated uncertainty that underlie various mortality functions cannot be defended, leading researchers to request more and more field investigations with ambiguous results. Some of the problems with assumptions are now being addressed via incorporation of uncertainty into model structures, but for models to be meaningful in a water resource management context, they need to be technically sound, transparent, and understandable. PHABSIM fulfills this need and continues to demonstrate its value and purpose.

ACKNOWLEDGMENTS

We appreciate the constructive comments and suggestions of Alice Shelly, Paul DeVries, William Miller, Noble Hendrix, and Mike Gagner, and those of Editor Kristen Anstead and Senior Science Editor Jeff Schaeffer. There is no conflict of interest declared in this article.

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