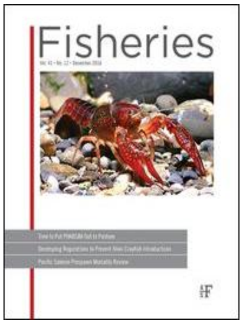

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# Why It Is Time to Put PHABSIM Out to Pasture

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FEATURE

# Why It Is Time to Put PHABSIM Out to Pasture

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The Physical Habitat Simulation System (PHABSIM) was developed in the 1970s to fill an important void in instream flow assessment. Although considerable progress has been made in ecological modeling since the 1970s, there has been little change in instream flow assessment. PHABSIM has two general problems. First, PHABSIM is a habitat selection model (HSM)—but not a good one: it no longer conforms to standard practices in the wider fields of ecological and wildlife modeling, especially by using inappropriate spatial scales and outdated methods for modeling habitat preference and by producing output that lacks clear meaning. Second, HSMs, in general, are not well suited for many instream flow decisions. HSMs cannot consider variation in flow over time, whereas dynamic flow regimes are now considered essential, and HSMs do not make testable predictions of fish population responses. Alternatives to PHABSIM include analyses based on explicit understanding of species ecology, individual-based models, and more powerful modern habitat selection modeling methods.

### Por qué es hora de jubilar al PHABSIM

El sistema de simulación de hábitat físico (SISIHF) se desarrolló en la década de los setenta para cubrir un vació importante en las evaluaciones del caudal circulante. Pese a que se ha conseguido un progreso considerable en la modelaje ecológica desde los setenta, ha habido pocos cambios en el tema de la evaluación de flujo fluvial. Existen dos problemas generales con el SISIHF. Primero, el SISIHF es un modelo de selección del hábitat (MSH)—pero no uno bueno: no se adhiere a las prácticas estándar actuales en los ámbitos de la ecología y la modelación de vida silvestre, en particular por que no utiliza las escalas apropiadas de tiempo y espacio, por utilizar métodos obsoletos de modelación de preferencia del hábitats y por producir salidas carentes de significado claro. Segundo, los MSH no suelen ser adecuados para tomar decisiones relativas al manejo del flujo fluvial. Los MSH no toman en cuenta las variaciones del caudal a lo largo del tiempo, cuando hoy en día la dinámica en los régimen de caudales es esencial, y los MSH no hacen predicciones falsables sobre la respuesta de las poblaciones ícticas. Alternativas al SISIHF incluyen aquellos análisis basados en un entendimiento explícito de la ecología de poblaciones, modelos basados en el individuo y mejores y más modernos métodos de modelación de selección de hábitat.

### Pourquoi il est temps de mettre le PHABSIM au rancart

Le système de simulation de l’habitat physique (PHABSIM) a été développé dans les années 1970 pour combler un vide important dans l’évaluation des débits réservés. Bien que des progrès considérables aient été accomplis dans la modélisation écologique depuis les années 1970, il y a eu peu de changement dans l’évaluation du débit réservé. PHABSIM présente deux problèmes généraux. Tout d’abord, PHABSIM est un modèle de sélection de l’habitat (MSH), mais pas un bon : il ne se conforme plus aux pratiques habituelles dans les domaines plus larges de la modélisation écologique et de la faune, en particulier en utilisant des échelles spatiales inappropriées et des méthodes dépassées pour modéliser l’habitat et en produisant des résultats sans signification claire. Ensuite, les MSH, en général, ne sont pas bien adaptés pour de nombreuses décisions de débit minimal. Les MSH ne peuvent pas prendre en considération la variation de débit au fil du temps, alors que les régimes d’écoulement dynamiques sont désormais considérés comme essentiels, et les MSH ne permettent pas de faire des prédictions testables des réponses des populations de poissons. Les alternatives au PHABSIM comprennent des analyses basées sur la compréhension explicite de l’écologie des espèces, des modèles basés sur l’individu, et des méthodes modernes de modélisation de sélection de l’habitat plus puissantes.

**Almost half a century later, PHABSIM is still widely used and even required by many regulatory agencies in the United States and abroad, even though it violates important conventions of modern modeling.**

In the 1970s, a new movement to protect instream flows was hampered by a lack of methods for assessing the effects of instream flow on fish populations and aquatic communities. To address this void, the U.S. Fish and Wildlife Service sponsored the formation of the multi-agency Cooperative Instream Flow Service Group, a team of biologists and engineers that then produced the instream flow incremental methodology. The instream flow incremental methodology is a set of procedures for designing and negotiating instream flows for aquatic resources, with a key component being the Physical Habitat Simulation System (PHABSIM; Bovee 1982). The Instream Flow Service Group was successful in many ways: it produced models and documentation, conducted training classes—I took my first in 1979—and supported users throughout the world. Almost half a century later, PHABSIM is still widely used and even required by many regulatory agencies in the United States and abroad.

The popularity of PHABSIM is no doubt related to its conceptual simplicity. Especially intuitive are PHABSIM’s major assumptions that (a) “preferred” habitat types, where relatively high densities of fish are observed, must be good habitat and (b) flows that provide more of the preferred habitat types are better for fish populations. Also simple and intuitive is the way PHABSIM models habitat preference: via univariate curves that are easy to create and interpret.

PHABSIM has important limitations and flaws, some recognized early in its history and others becoming more apparent as ecological modeling has advanced over time. PHABSIM violates important conventions of modern modeling, as detailed by Railsback (1999), Electric Power Research Institute (EPRI 2000), and Anderson et al. (2006). Here, I summarize problems with PHABSIM, starting with ways in which it is particularly out of date and then ways in which this general model type is not suitable for modern instream flow assessment. Finally, I recommend more credible approaches that are already available.

## WHAT IS WRONG WITH PHABSIM?

PHABSIM belongs to a category of ecological models now known as “habitat selection models” (HSMs). These models are developed by identifying (via statistical modeling) the types of habitat that are selected (occupied at higher density) by the organisms of interest and then analyzing how the availability of selected habitat varies among management alternatives. In recent decades, there has been a great deal of research on HSMs, both to develop better statistical models of habitat selection and to understand the strengths and limitations of this model type. However, this research is primarily in the literature of wildlife and ecological modeling, not freshwater fisheries management. (A Google Scholar search for the general term “habitat selection modeling” identified 313,000 citations; of the 100 highest-ranked citations, only four addressed stream fishes and two addressed instream flow modeling.) PHABSIM is now an antiquated HSM. The following subsections discuss limitations of PHABSIM that are clear from the modern HSM literature.

## PHABSIM Is Not a Good Habitat Selection Model

### *Spatial Scales Are Mishandled*

Widespread recognition that processes and parameters may differ among spatial scales was a major step forward for ecology in the 1980s and 1990s (e.g., Levin 1992). Consequently, careful selection of an ecologically appropriate spatial resolution is now a fundamental first step when developing an ecological model (e.g., Starfield and Bleloch 1986; Manly et al. 2002; Scott et al. 2002). Modelers are trained to carefully identify a spatial resolution (in PHABSIM, spatial resolution is the cell size) that is biologically appropriate for the animals and processes being modeled and to make sure that all model assumptions, parameter values, and input data are valid at that resolution. Careful consideration of spatial scales is particularly important when using models such as PHABSIM that only represent how habitat varies over space.

Unfortunately, PHABSIM does not handle spatial scales in standard or consistent ways (Railsback 1999). For example, the spatial resolution used in PHABSIM is not traditionally based on ecological appropriateness; instead, cell sizes are typically an artifact of hydraulic modeling convenience. The convention of placing about 20 cells across a stream channel was recommended by Bovee and Milhous (1978) to make flow estimates accurate, not because it is relevant to fish habitat modeling. Small cells of 1–2 $m^2$ horizontal area may make sense for drift-feeding trout, which defend territories of about that size, but not for fishes that actively search much larger areas for prey. PHABSIM-like models that operate at larger scales such as mesohabitat units have been developed (e.g., Parasiewicz 2001). However, the critical point remains that the choice of spatial scale should be based on the ecology of the fish being modeled, not on hydraulic considerations or convenience.

Another major spatial problem is that PHABSIM applications often combine hydraulic simulations at one resolution with habitat use data, in the form of preference curves, observed at a different resolution. Preference curves are typically developed from fine-resolution observations—most often, from measurements made as close as possible to the observed fishes, as recommended by Bovee (1986). These fine-resolution curves are applied to habitat cells that are several square meters or larger in size. Mixing spatial scales this way, assuming that depths and velocities measured at the exact location of a fish represent preference at the larger scale of a habitat cell, is a fundamental modeling mistake (Wu and Li 2006). Drift-feeding fishes illustrate this problem: a fish may shelter behind a rock to reduce its swimming speed while feeding on prey drifting in nearby areas of higher velocity. Hence, the lower velocity observed exactly at the fish will misrepresent the higher velocity needed to supply food. This disparity between observed fish-scale and cell-scale velocities may account for severely underestimated flow needs for juvenile salmon by PHABSIM (Beecher et al. 2010).

Unfortunately, the preference curve methods of Bovee (1986) that produce these scale mismatch errors have been widely used. Though there are examples of PHABSIM-like models that use the same spatial resolution for fish observations as for habitat simulation (e.g., Guay et al. 2003), most PHABSIM preference curves do not and are therefore likely to be biased.

### *Weighted Usable Area Lacks Clarity and Biological Meaning*

PHABSIM produces a habitat index called “weighted usable area” (WUA), which is nonstandard and has no clear biological meaning. In contrast, well-understood measures of habitat selection are in common use elsewhere (Manly et al. 2002). The simplest of these is a direct estimate of density: field observations can be used to develop statistical models of fish density as a function of habitat variables, with density and habitat observed at the same spatial resolution. Model output can then be used to predict fish abundance, estimated as predicted density × cell area, summed over all cells. Predicting abundance only from physical habitat variables in this way will still be tenuous but would have the advantage, relative to PHABSIM, of a clear and measurable model output that is much easier to integrate with other factors affecting abundance.

**The spatial resolution used in PHABSIM is not traditionally based on ecological appropriateness; instead, cell sizes are typically an artifact of hydraulic modeling convenience. The choice of spatial scale should be based on the ecology of the fish being modeled, not on hydraulic considerations or convenience.**

### *“Preference Curves” Are Obsolete*

The univariate preference curves used by PHABSIM to model fish habitat selection are simple and intuitive but less powerful than modern techniques. The PHABSIM assumptions that habitat variables act independently and have equal effects on habitat selection (preference curves for all variables are scaled from 0 to 1) are unnecessary and likely introduce considerable error (e.g., Orth and Maughan 1982). Modern multivariate “resource selection functions” avoid these assumptions and can produce better fit to observed data (e.g., Rubin et al. 1991; Guay et al. 2003).

### *Depth, Velocity, and Substrate Type Are Not Always the Most Important Habitat Variables*

PHABSIM applications rarely consider habitat variables other than depth, velocity, and substrate type, perhaps as an artifact of the method’s original focus on trout. Variables that best predict fish habitat selection and abundance are likely to differ among species and sites, so they should be carefully considered when designing instream flow models and the field studies that support them. Instead of assuming in advance which variables to include, modelers can observe a variety of habitat variables and then use modeling methods that determine, from the field data, which variables best explain habitat selection.

## Habitat Selection Models Are Not Well Suited for Modern Instream Flow Assessments

Models cannot be judged simply as good or bad; instead, we must define the exact purpose of a model and then judge how useful it is for that purpose. The purpose of many modern instream flow assessments is to rank alternative flow regimes by their effect on resident fishes; some assessments even design dam release schedules specifically to meet fish population objectives (e.g., NRC 2008). The most relevant measure of flow effect on fish can vary: for a robust sport fishery, managers may be most concerned with population abundance and sustainable harvest rates; for a warmwater community, the focus may be on maintaining diversity; and for species of special concern, the focus may be on long-term persistence. For several reasons, HSMs are not well suited to any of these common instream flow management purposes.

First, flow regimes are dynamic, but HSMs are not. Flow variability is now a fundamental concept of river management (e.g., Poff et al. 1997). However, HSMs cannot address variation through time: PHABSIM models a static relation between habitat availability and flow, with no consideration of time. PHABSIM cannot, by itself, be used to compare flow regimes with biologically important differences in flow variation, such as in the timing or duration of flow pulses or summer low flows.

Second, fish habitat selection varies not only among species and life stages but also with factors such as temperature, turbidity, food availability, time of day, and local fish density (Bovee 1986; EPRI 2000, Appendix B; Railsback et al. 2005). Unfortunately, variation in habitat selection is difficult to handle in HSMs and, therefore, generally ignored by PHABSIM users.

Third, the fundamental assumption of HSMs—habitat types with the highest observed fish densities offer high fitness—is no longer considered reliable (Garshelis 2000; Johnson 2007). For example, the best feeding sites may be dominated by a single individual, with other fishes relegated to lower-quality habitats with higher densities (Beecher et al. 2010). In a simulation experiment, Railsback et al. (2003) found no consistent relation between the density of drift-feeding trout and the actual fitness value of habitat and that habitat selection modeling often predicted population responses poorly. This experiment identified seven reasons why observed habitat preference may be a poor indicator of habitat quality in addition to competition for food and feeding sites:

1. Unused habitat: relatively good habitat may be vacant when there are not enough fish to occupy it;
2. Individual variability: what constitutes good habitat can vary strongly even among members of the same age class;
3. Nonuniform habitat availability: when little medium-quality habitat is available, subdominant fish are forced to use low-quality habitat at high densities;
4. Nonlinear relations between fitness and resources such as food and predation risk;
5. "Catchability" of drift: as velocity increases, the area over which a fish can capture food decreases, so more fishes can feed in the same area while each captures less food;
6. Uncontested resources: cover for hiding or feeding may be critical for fitness while, if abundant, having little effect on density; and
7. Limited ability to explore and find available habitat, especially for small fishes.

Fourth, HSMs predict the area of "selected" habitat but not the direct measures of population status identified above as meaningful for management. The output of these models is not directly translatable into population measures such as abundance, sustainable harvest, or persistence.

Together, these HSM limitations have significant consequences for instream flow assessment. One such consequence is that subjective interpretation of model results is necessary to rank flow alternatives because PHABSIM does not directly predict population-level responses or the effects of changes in flow through time. After using PHABSIM to predict how WUA responds to flow, managers must still decide how to interpret those results for various species and life stages and how to deal with temporal variation in flow, despite the lack of well-supported methods for doing so. An instream flow study conducted for Klamath River salmon (reviewed by NRC 2008) is a particularly telling example. Its authors produced typical PHABSIM results and then used them to design a regime of monthly instream flows for multiple species. Doing so required a long sequence of assumptions that resulted in recommendations based more on historic flows than on PHABSIM. The NRC review (NRC 2008) recognized many of the inevitable problems identified here: the PHABSIM-type model did not adequately address flow variability and did not synthesize life stage and species results into population-level predictions.

Another consequence of HSM's limitations is that PHABSIM is impossible to validate. Studies showing correlation between WUA and various fish population measures (e.g., Nehring and Anderson 1993; Freeman et al. 2001) have sometimes been misrepresented as validation of PHABSIM. However, these studies suffer from flaws such as mining for correlations among multiple measures of WUA and fish abundance and failing to test whether WUA predicted fish abundance better than simpler variables such as flow. I participated in a study intended to avoid those flaws by making and then testing PHABSIM predictions of population response to flow changes (Studley et al. 1996). However, the study instead highlighted the validation problem. Predicting how adult trout abundance would respond to future changes in flow regime required us to make post-PHABSIM assumptions (about how adult abundance is related to WUA for various life stages and the effects of seasonal and episodic flow variations) that likely were as important as the PHABSIM results.

## MOVING ON: INSTREAM FLOW WITHOUT PHABSIM

How can we instream flow scientists and managers replace PHABSIM with more useful and credible methods? I make four recommendations for doing so. (Note that these recommendations do not address the more "holistic" approaches such as those discussed by Anderson et al. [2006] and Poff et al. [2010].)

First and foremost, instream flow scientists should take a broader ecological view of instream flow needs. PHABSIM can inadvertently train people to think about instream flows through the limited framework of depth, velocity, and substrate preference. Instead, we can develop much stronger models and studies by using the fundamental issues of individual fitness as a framework. We should begin each instream flow assessment by thinking about several questions: (1) What do the target fishes eat and how do they feed? (2) What eats the fishes and how do the fishes avoid getting eaten? (3) How do the fishes reproduce? For example, applying this framework to warmwater streams may lead to the conclusion that the direct effects of flow on fishes are minor compared to the effects of flow on food production; instead of focusing solely on depth and velocity, the study design should consider variables that affect food production, such as riffle areas (a proxy for invertebrate availability) and nutrient transport.

Second, in cases where HSMs are truly appropriate (e.g., because habitat use is readily observable but mechanistic understanding of feeding and predator avoidance is lacking), we should use more modern methods in place of PHABSIM. The extensive literature on HSMs (Manly et al. 2002 is a starting place) is only beginning to penetrate the instream flow literature (e.g., Ayllón et al. 2009, 2011); most expertise in this type of model resides with wildlife biologists and ecologists. Any HSM for instream flow assessment should avoid the kinds of problems identified above by consistently using an ecologically appropriate spatial resolution, carefully considering which habitat variables are most meaningful, using a habitat selection index that has a clear and well-understood meaning, using modern resource selection functions, and considering how habitat selection can vary with factors like temperature and turbidity. Such methods could often result in models quite different from PHABSIM. Warmwater fishes, for example, might perhaps best be modeled at the scale of whole channel units and with flow-dependent habitat variables such as the area of pools deep enough to provide predation protection and the area of invertebrate-producing riffles.

The third recommendation is to consider individual-based models (IBMs). IBMs for instream flow assessment have been explicitly designed to overcome the limitations of HSMs (e.g., Jager et al. 1993; Van Winkle et al. 1998; Railsback et al. 2009). IBMs simulate populations by representing individual fish and how they do things like select habitat, feed and grow, survive or die, and spawn. They are dynamic, often operating at time steps of one day or less, so they can predict how fish populations or communities respond to variable regimes of flow and temperature. Mechanistic IBMs of well-studied species can integrate a variety of existing knowledge and submodels to represent the processes from which fish population or community dynamics emerge. The assumptions of a good IBM are explicitly defined and justified. Initially, IBMs may seem more complex than HSMs, but their use can actually simplify the assessment process. For example, the salmonid models my colleagues and I develop require no more input than PHABSIM and no preference curves (Railsback et al. 2005, 2009, 2013). Importantly, these IBMs produce results directly applicable to decision making (e.g., predicted fish abundance under each flow alternative) without the postmodeling interpretation required with PHABSIM.

One drawback of IBMs is that few "off-the-shelf" models are available (but see the trout, salmon, and frog models of Railsback et al. 2009, 2013, 2014, and 2016) and developing new ones is nontrivial. New IBMs require digesting the literature on the target species' ecology, physiology, and behavior; specifying and testing model assumptions; and developing and testing software. This process takes time but can have a high payoff (Stillman et al. 2015), and recent developments in modeling strategies, theory and techniques, and software (Railsback and Grimm 2012) make IBMs more accessible.

The final recommendation addresses situations when it is not feasible to assess instream flow needs via modeling: the species of concern may be too diverse or unobservable or money and time may not be available. In such cases, assessments are now sometimes based on direct observation of habitat at several flows. The scientific credibility of this direct observation approach can be enhanced by first developing conceptual models of how flow affects the resources of interest (i.e., addressing the basic ecological questions discussed above) and then formulating relevant habitat metrics and measuring or estimating them at different flows (EPRI 2004; Railsback and Kadvany 2008). The results can be similar to those of HSMs—estimated areas of specific habitat types at different flows—so this approach can also require subjective interpretation to apply results to decision making.

## CONCLUSIONS

Over the decades, instream flow priorities have changed and ecological modeling has progressed, with PHABSIM becoming more outdated and less useful compared to other approaches. The divergence between instream flow practice and standard scientific practice has no doubt been exacerbated by the current lack of active instream flow research programs. In the long term, this divergence could be reduced by providing future fisheries managers with more formal training in modeling and by generating new interest in instream flow among ecological researchers and modelers. However, the alternatives to PHABSIM discussed above are certainly accessible to many agencies and consultancies now and could immediately improve our ability to protect stream resources and balance competing uses of scarce water resources.

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