COLUMN
COMMENT

Comment 1: Why It Is Time to Put PHABSIM Out to Pasture

Hal A. Beecher, instream flow biologist, Washington Department of Fish and Wildlife. E-mail: halbeecher@comcast.net

Steve Railsback has contributed significantly to the science of instream flow, but his suggestion that Physical Habitat Simulation System (PHABSIM) be put "out to pasture" (Railsback 2016) seems premature. Like Railsback, I took my first PHABSIM training in 1979 and have been one of those in an agency who "required" use of PHABSIM to address instream flow issues. (In fact, the guidelines we started in the early 1980s identified a default approach to PHABSIM use, while making it clear that Washington State agencies were open to consideration of other approaches or modifications if justified and that consultation should be an ongoing process in any application.)

My experience with PHABSIM is that it provides a flexible framework for incorporating new information, whether biological, hydrologic, hydraulic, or geomorphologic. It provides information, but it is not a black box that spits out "the answer." As the developers of PHABSIM and instream flow incremental methodology (IFIM; Clair Stalnaker, Bob Milhous, and Ken Bovee, who have all been recognized by the Instream Flow Council for their major contributions to instream flow science and management) have always made clear, the two are not the same and the latter requires integrating PHABSIM results with the best understanding of river ecology, particularly as it relates to target communities or species.

Railsback identifies some very real concerns and questions concerning conventional use of PHABSIM, and anyone using it should give these issues serious consideration. One issue he did not raise is the lack of three-dimensional modeling, which would be a boon in large rivers where fish layer themselves from surface to bed. Plunge pool hydraulics and habitat might also be modeled better with three-dimensional velocity vectors rather than one- or two-dimensional velocity vectors, and Brian Marotz (Montana Department of Fish, Wildlife, and Parks) reported significant progress on three-dimensional modeling. Addressing his concerns may mean using another tool, as he suggests, or it may mean upgrading PHABSIM. Tim Hardin (Oregon Department of Fish and Wildlife) reminds me that some simple adaptations have also given useful results, such as confining suitable habitat (weighted usable area [WUA], the habitat index generated by PHABSIM) for juvenile salmon in large rivers to stream margins by assigning substrate suitability to zero in mid-channel areas away from bank-associated cover.

One of Railsback's criticisms of PHABSIM is spatial scale. This is a legitimate issue to be considered, and users of two-dimensional modeling have also emphasized the value of high sampling density to match actual variation in channel morphology and fish habitat attributes, such as cover. Agencies in California and Oregon, and perhaps elsewhere, have standards for numbers of transects and sampling density that can address spacing as well as more measurement points per transect in one-dimensional modeling or an open-ended number and distribution of points in two-dimensional modeling.

Railsback cited a paper I coauthored (Beecher et al. 2010) as part of his rationale for rejecting PHABSIM. Recent studies by Jordan Rosenfeld and colleagues (Rosenfeld and Ptolemy 2012; Rosenfeld et al. 2016) followed up on our earlier study and provided some resolution. I would argue that in this case PHABSIM was not "wrong" but rather that it showed the way to other knowledge; that other knowledge is necessary to incorporate PHABSIM results into IFIM and into reasonable management in the case of juvenile Coho Salmon *Oncorhynchus kisutch* (0+, and similar concerns may apply to juvenile Chinook Salmon *O. tshawytscha*). In contrast, steelhead parr distribution within a reach seemed to match WUA reasonably well (Beecher et al. 1993, 1995), perhaps because the parr age-class (I+) has been reduced to the point where there are no longer large numbers of subdominants. The recent paper by Hall et al. (2016) demonstrates the complexity of steelhead life history. Our steelhead work suggested that WUA was a reasonable indicator of habitat quality at the scale of parr territories.

Railsback's point that WUA has no biological meaning is correct, but it is still an index that can be used as a variable in research on the relationship of aquatic organisms to habitat as influenced by hydrology and hydraulics. He cites the work of Poff et al. (1997, 2010) as an excellent foundation for instream flow management, and it certainly is, but the specifics that allow water management at a local level still need further research (e.g., Poff and Zimmerman 2010; Reidy Liermann et al. 2011). In the absence of the standards envisioned by Poff et al. (2010), the relationship between WUA and flow can be useful information. Where we find a relationship between WUA and fish habitat use, particularly where we have some evidence of a relationship between flow and survival or growth or population dynamics, the flows where WUA increases, peaks, decreases, or reaches minimum values, might provide some indication of habitat sensitivity to flow and suggest management decisions, depending on relevant policy and law. The natural flow regime is certainly a default position for conservation, but agencies must make decisions where more justification is demanded, often at a fine scale for flow.

Spawning salmon and trout seemed initially to be an excellent fit with depth, velocity, and substrate as key variables to identify spawning habitat. However, Shirvell (1989) found shortcomings in modeling Chinook Salmon spawning habitat. Subsequent work by Pacific Northwest National Laboratory scientists (Geist and Dauble 1998; Geist et al. 2000; Hanrahan 2007) and Scottish scientists (Moir et al. 2004, 2005, 2006) emphasized that mesohabitat scale is also important for modeling salmon spawning. The importance of other spatial (and temporal) scales does not mean that WUA and PHABSIM need to be rejected just that they should be used with the overlay of the other scale. In Washington applications, John Blum (then at Cascades Environmental Services) reviewed study sites and used subjective overlays (based on understanding of mesohabitat-scale suitability) on one-dimensional models to designate transects as potential or not potential spawning habitat and then added the overlay of seasonal hydrology with the stage–discharge relationship. Therefore, in the end, WUA was based on additional understanding of salmon and trout spawning ecology. When a spawning use of a reach is well known, WUA–flow relationships can be very useful for developing spawning flow recommendations.

Phil Hilgert (R2 Resources Consultants, Redmond, Washington) used Holly Coccoli's (1996) work on side channel rearing and the importance of flow and fish passage between side channels and a main channel to evaluate the effects of flows on side channel habitat. He used PHABSIM in side channels and at the connection between the side channel and main channel as an indicator that agencies found informative for flow management decision making. It was a case of thinking about the ecology of the fish and what mattered for their survival and incorporating that into PHABSIM. The Brazos River oxbow lake study by Zeug et al. (2005) struck me as a situation that might be approached in a similar way.

Treating depth, velocity, and substrate as equally important and independent was recognized early on as an assumption that might not be appropriate. I remember Ken Bovee presenting a variety of options for joint suitability or weighting different variables differently in one of his training classes. I remember discussing with Bob Milhous how to model selection of slow water adjacent to fast water, a tool he added to one of the PHABSIM components. The tools can be developed where they do not already exist to address these concerns and incorporate newer knowledge or understanding.

If other approaches work better for answering management questions, they will be welcomed by the instream flow community. Certainly Railsback has shown that individual-based models have a lot to contribute to instream flow science, and therefore to management. He also highlighted Piotr Parasiewicz's MesoHABSIM (Parasiewicz 2001), which seems promising for diverse non-salmonid streams and rivers draining to the Atlantic, Gulf of Mexico, and perhaps even the Colorado basin (I specify nonsalmonids because of the relatively long duration of salmonid incubation and the need to account for incubation conditions at time of salmonid spawning, rather than using the shifting boundaries of mesohabitats and drifting incubation for many other fish). Choice of method seems to depend on the ecology of the species or communities of interest and the sensitivity and reason for the sensitivity to flow changes. However, Ken Bovee and colleagues (Freeman et al. 2001; Bowen et al. 2003) also demonstrated utility of PHABSIM on diverse warmwater streams.

Agency staff need tools that can be used consistently and produce results that make sense. They have neither time nor budgets to change tools frequently unless there is a persuasive case for doing so; for most, reviewing such studies is only part of the job duties. They also need to have relatively standard procedures to meet standards of transparency and consistency. Legal and policy factors also come into play. Legal factors include the ability of agency personell to testify credibly in litigation that they thoroughly understand the tools they are using, and repeated use adds to that confidence and understanding. In my experience, PHABSIM results were useful in decision making and subsequent legal defense of that decision making (including before the U.S. Supreme Court, although at that point the method was not under review).

Rather than recommending putting a tool out to pasture, I suggest, as Railsback mentioned, readily available training on use of other tools is needed. Coordination with the Fort Collins Science Center or with the Instream Flow Council might be a useful way to make such tools more widely available and used. Parasiewicz has provided such training and Tom Payne (Normandeau Associates) has provided training on the system for environmental flow analysis tool he and colleagues are developing, based on IFIM. Comparisons of PHABSIM with other methods might win converts if the case is compelling. I am not convinced yet that PHABSIM is not a tool that can be adapted to address relevant streamflow management fisheries issues.

ACKNOWLEDGMENTS

Thanks to Kiza Gates (Washington Department of Fish and Wildlife) and Tim Hardin (Oregon Department of Fish and Wildlife) for helpful suggestions to improve the article.

REFERENCES

Beecher, H. A., B. A. Caldwell, S. B. DeMond, D. Seiler, and S. N. Boessow. 2010. An empirical assessment of PHABSIM using long-term monitoring of Coho Salmon smolt production in Bingham Creek, Washington. North American Journal of Fisheries Management 30:1529–1543.

Beecher, H. A., J. P. Carleton, and T. H. Johnson. 1995. Utility of depth and velocity preferences for predicting steelhead parr distribution at different flows. Transactions of the American Fisheries Society 124:935–938.

Beecher, H. A., T. H. Johnson, and J. P. Carleton. 1993. Predicting microdistributions of steelhead parr from depth and velocity criteria: test of an assumption of the instream flow incremental methodology. Canadian Journal of Fisheries and Aquatic Sciences 50(11):2380–2387.

Bowen, Z. H., K. D. Bovee, and T. J. Waddle. 2003. Effects of flow regulation on shallow-water habitat dynamics and floodplain connectivity. Transactions of the American Fisheries Society 132(4):809–823.

Coccoli, H. A. 1996. Effects of springtime flow alteration on side channel habitat in the Green River. Master's thesis. Department of Civil Engineering, University of Washington, Seattle.

Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11(1):179–190.

Geist, D. R., and D. D. Dauble. 1998. Redd site selection and spawning habitat use by fall Chinook Salmon: the importance of geomorphic features in large rivers. Environmental Management 22:655–669.

Geist, D. R., J. Jones, C. J. Murray, and D. D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of fall Chinook Salmon (*Oncorhynchus tshawytscha*) spawning habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57(8):1636–1646.

Hall, J., P. Roni, T. Bennett, J. McMillan, K. Hanson, R. Moses, M. McHenry, G. Pess, and W. Ehinger. 2016. Life history diversity of steelhead in two coastal Washington watersheds. Transactions of the American Fisheries Society 145(5):990–1005.

Hanrahan, T. P. 2007. Bedform morphology of salmon spawning areas in a large gravel-bed river. Geomorphology 86(3–4):529–536.

Moir, H. J., C. N. Gibbins, C. Soulsby, and J. H. Webb. 2004. Linking channel geomorphic characteristics to spatial patterns of spawning activity and discharge use by Atlantic Salmon (*Salmo salar* L.). Geomorphology 60:21–35.

Moir, H. J., C. N. Gibbins, C. Soulsby, and J. H. Webb. 2006. Discharge and hydraulic interactions in contrasting channel morphologies and their influence on site utilization by spawning Atlantic Salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 63(11):2567–2585.

Moir, H. J., C. N. Gibbins, C. Soulsby, and A. F. Youngson. 2005. PHABSIM modelling of Atlantic Salmon spawning habitat in an upland stream: testing the influence of habitat suitability indices on model output. Rivers Research and Applications 21:1021–1034.

Moir, H. J., and G. B. Pasternack. 2008. Relationships between mesoscale morphological units, stream hydraulics and Chinook Salmon (*Oncorhynchus tshawytscha*) spawning habitat on the lower Yuba River, California. Geomorphology 100(3–4):527–548.

Parasiewicz, P. 2001. MesoHABSIM: a concept for application of instream flow models in river restoration planning. Fisheries 26(9):6–13.

Poff, N. L., J. D. Allan, M. B. Bain, J. R. Karr, K. L. Prestergaard, B. Richter, R. Sparks, and J. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47:769–784.
Poff, N. L., B. D. Richter, A. H. Arthington, S. E. Bunn, R. J. Naiman, E. Kendy, M. Acreman, C. Apse, B. P. Bledsoe, M. C. Freeman, J. Henriksen, R. B. Jacobson, J. G. Kennen, D. M. Merritt, J. H. O'Keefe, J. D. Olden, K. Rogers, R. E. Tharme, and A. Warner. 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55:147–170.
Poff, N. L., and J. K. H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55:194–205.
Railsback, S. 2016. Why it is time to put PHABSIM out to pasture. Fisheries 41(12):720–725.
Reidy Liermann, C. A., J. D. Olden, T. J. Beechie, M. J. Kennard, P. D. Skidmore, C. P. Konrad, and H. Imaki. 2011. Hydrogeomorphic classification of Washington State rivers to support emerging environmental strategies. River Research and Applications.
Rosenfeld, J. S., H. Beecher, and R. Ptolemy. 2016. Developing bioenergetic-based habitat suitability curves to improve the biological accuracy of instream flow models. North American Journal of Fisheries Management 36(5):1205–1219.
Rosenfeld, J. S., and R. Ptolemy. 2012. Modelling available habitat versus available energy flux: do PHABSIM applications that neglect prey abundance underestimate optimal flows for juvenile salmonids? Canadian Journal of Fisheries and Aquatic Sciences 69(12):1920–1934.
Shirvell, C. S. 1989. Ability of PHABSIM to predict Chinook Salmon spawning habitat. Regulated Rivers: Research and Management 3(1–4):277–289.
Zeug, S. C., K. O. Winemiller, and S. Tarim. 2005. Response of Brazos River oxbow fish assemblages to patterns of hydrologic connectivity and environmental variability. Transactions of the American Fisheries Society 134(5):1389–1399. AFS

COMMENT 2:
WHY IT IS TIME TO PUT PHABSIM OUT TO PASTURE

Don't Throw Out the Baby (PHABSIM) with the Bathwater: Bringing Scientific Credibility to Use of Hydraulic Habitat Models, Specifically PHABSIM

Clair B. Stalnaker, U.S. Geological Survey, Retired, 5415 East County Road 58, Fort Collins, CO 80524.
E-mail: clair_stalnaker@cowisp.net

Ian Chisholm, Minnesota Department of Natural Resources, Ecological and Water Resources Division, River Science Unit Supervisor, Saint Paul, MN

Andrew Paul, Provincial Environmental Flow Specialist, Alberta Environment and Parks, Cochrane, AB, Canada

HISTORY: PHABSIM IS NOT INSTREAM FLOW INCREMENTAL METHODOLOGY

Railsback (2016) raises valid points directed toward inadequate use of habitat selection models (HSMs) and Physical Habitat Simulation System (PHABSIM) specifically. Although Railsback (2016) notes that PHABSIM is a component of instream flow incremental methodology (IFIM), this important distinction is subsequently lost in his article. The IFIM is a multifaceted decision support system that looks at riverine ecology for the purpose of making water management decisions. As a refresher, consider the design and intended use of PHABSIM as a module within the suite of IFIM models. The IFIM uses physical stream descriptions, hydraulic simulation models, and stream hydrology to produce time series of hydraulic habitat simulations and water temperatures for comparing alternative flow regimes. The process can be based on detailed field descriptions of the physical attributes of stream segments. This two-dimensional description of physical habitat features throughout sampled stream reaches provides the base upon which hydraulic simulations are conducted. Physical habitat features such as substrates, spawning gravel, vegetation, undercut banks, large rock, woody debris, and other objects used as cover are derived from observation, experience, and the literature as habitat associations known to be important for defined life stages of fish or other organisms (e.g., mussels or benthic invertebrates). The hydraulic submodel provides nothing more than a hydraulic simulation overlay that determines which areas of the river's surface are suitable or unsuitable for life stages by way of changes in depths and velocities. The simulation simply summarizes for each life stage habitat classes of good quality (optimal suitability), low quality (marginal suitability), and unusable. The proportion of the stream that periodically becomes unusable for a life stage can be equally, if not more, important to other areas. The simplest example is habitat where hydraulics result in zero depth (i.e., no surface water; Figure 1). However, as Hynes (1972) noted, velocity is often the distinguishing characteristic of riverine environments to which organisms must adapt. Therefore, good and poor habitat in riverine environments can also depend on hydraulics of velocity (Figure 2).

The IFIM has evolved over the 1980s, 1990s, and 2000s. Likewise, PHABSIM software has evolved, resulting in many versions, including two-dimensional hydraulic submodels. Early use was based on empirical measurements at closely spaced transects providing input into one-dimensional hydraulic models. Closely placed transects and verticals produce cells or tiles that are assumed to have internal homogeneity (Bovee 1982), which can mimic two-dimensional analyses. The assumption of internal homogeneity is constrained by transect placement for describing the habitat patchiness unique to each sampled stream reach. Increased use of two-dimensional hydraulic models within the last decade produces many more small cells as the computational mesh. Two-dimensional models give vertically integrated velocities, simulate the variation in the cross-stream and downstream directions, and are assumed to provide better hydraulic output (depth and velocity) when calibrated to empirical measurements.