PHABSIM/SEFA Application for Minimum Flows and Levels Development in Florida

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Physical Habitat Simulation System (PHABSIM) or System for Environmental Flow Analysis (SEFA) are typically used to simulate the relationship between river flow and physical habitat of various life stages of a fish species. They are a component of the Instream Flow Incremental Methodology (IFIM) and are widely used across the globe for deductive estimation of biological effects of stream flow alteration. These models have been applied at various spatial and temporal scales corresponding to the objectives of the specific applications. The objectives of this work effort are to review spatial and temporal scales of previous habitat modelling applications and to recommend a best practice approach for the application of physical habitat simulation software. Two leading software packages are considered-PHABSIM and SEFA, both are improvements of IFIM framework. Specifically, this research paper recommends best practices that can be used in environmental flows development. The review was focused on literature related to selecting species, and the time steps for developing and applying Area Weighted Suitability (AWS) vs. discharge curves used for developing environmental flows. The term AWS in SEFA replaces the original weighted usable area (WUA) in PHABSIM because it is a more accurate description of the physical meaning of the variable.

Keywords: physical habitat, phabsim, sefa, environmental flows, area weighted suitability, AWS, habitat suitability

INTRODUCTION

The objectives of this work effort are to review spatial and temporal scales of previous habitat modelling applications and to recommend best practices for the application of physical habitat simulation software. Two leading software packages are considered- Physical Habitat Simulation System (PHABSIM) (Bovee & Milhous, 1978) (Milhous, Wegner, & Waddle, 1984) (Waddle, 2001) and System for Environmental Flow Analysis (SEFA) (Jowett, Payne, & Milhous, 2014), both are improvements of Instream Flow Incremental Methodology (IFIM) framework (Bovee & Milhous, 1978). Specifically, this research paper recommends methodology and best practices for instream physical habitat modelling during environmental flows development. The literature review was focused on literature related to selecting species, and the time steps for developing and applying Area Weighted Suitability (AWS) vs. discharge curves used for developing MFLs. The term AWS in SEFA replaces the original weighted usable area (WUA) in PHABSIM because it is a more accurate description of the physical meaning of the variable.

LITERATURE SUMMARY

PHABSIM/SEFA, one of the analysis tools used for instream habitat analysis provides AWS vs Discharge for target species and life stages. This output is illustrated with a series of graphs showing curves for each life stage for the fish species of interest (FIGURE 1) and AWS is assumed to be proportional to habitat availability (Bovee, et al., 1998). The highest point on each curve represents the discharge at which AWS is maximum for each life stage for a fish species of interest. PHABSIM/SEFA AWS vs discharge curves are typically used to estimate habitat gain/loss with incremental flow changes. These variations are dependent on the shape of the curve and may not be linear. For example, small flow changes can result in substantial changes in habitat for a fish species/life stage for flows on the steep portion of the AWS-discharge curve.

The PHABSIM model system does not specifically identify acceptable amounts of habitat loss or gain for any given species, taxonomic group, or other criterion. Rather, given hydrologic data and habitat preferences, the model system can be used for minimum flow purposes to establish relationships between hydrology and WUA for target species or other criteria, and allows examination of habitat availability in terms of the historic (e.g., non-withdrawal impacted) and altered flow regimes. The amount of potential habitat loss, or deviation from the optimum, that a water body is capable of withstanding that is determined from these data is often based on professional judgment. Gore et al. (Gore, Dahm, & Klimas, 2002) provided guidance regarding this issue, suggesting that "in general, instream flow analysts consider a loss of more than 15 percent habitat, as compared to undisturbed or current conditions, to be a significant impact on that population or assemblage." In establishing Environmental Flows, multiple water management district reports and the associated peer reviews (SWFWMD, 2017) (SRWMD , 2016) have defined withdrawal related percent-of-flow reductions that result in greater than a 15 percent reduction in AWS from non-withdrawal impacted conditions as limiting factors (*i.e*., the point of "significant harm", a term specified to be utilized when developing Environmental Flows, but not defined in Ch. 373.0421 Florida Statutes).

In Florida, PHABSIM/SEFA AWS vs discharge curves are routinely used by the water management districts to develop Environmental Flows (SWFWMD, 2012) (SRWMD , 2016). The application of these curves has varied between the water management districts due to differences in their MFL development methodologies. For example, Southwest Florida Water Management District (SWFWMD) regularly used PHABSIM/SEFA and prescribed flow reductions for the low flow period (Block 1, which runs from April through June) and medium flow period (Block 2, which runs from October of one year to April of the next year), based on review of limiting factors developed using PHABSIM to model potential changes in habitat availability for several fish species and life stages (SWFWMD, 2016) (SWFWMD, 2017). Specifically, a monthly average flow time series was used to generate monthly AWS time series. The monthly AWS time series was then analysed to determine flow change corresponding to a 15% decrease in average AWS for each month. For a species/life stage modelled, the maximum allowable flow reductions are based on the most sensitive or restrictive month. The analysis is repeated for all the relevant species/life stage and the most sensitive species for the most restrictive month and site is used for developing Environmental Flows (Hood, 2006) (SWFWMD, 2017).

SITE/TRANSECT SELECTION

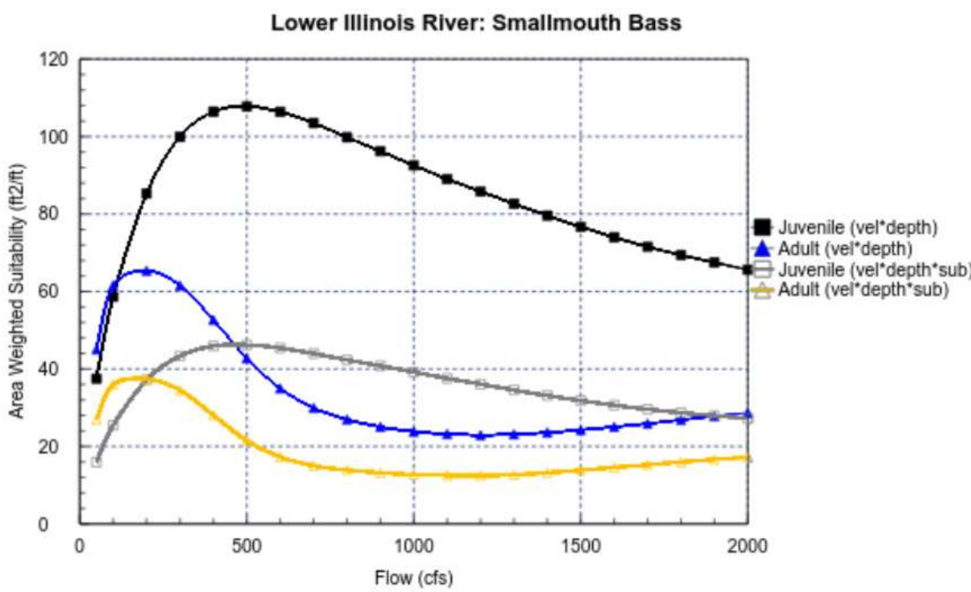
A guidance for instream habitat survey methods and analysis was published by The National Institute of Water and Atmospheric Research, New Zealand's leading provider of atmospheric, marine, and freshwater science (Jowett, Hayes, & Duncan, 2008). This section summarizes the guidance provided for selecting sites and transects and for collecting instream habitat survey data.

The objective of an instream habitat survey data collection effort is to obtain data that reasonably represents the characteristics of a segment of the river. This includes the range of water velocities and depths that occur in a river segment that correspond with the hydraulic conditions, along with the stationary stream elements (such as substrate, bank formations, and cover). In this section, "section or segment of river" denotes a long length of river (usually several miles or more), while a "reach" is shorter, usually a mile or less.

Selecting survey segments, reaches and transect survey locations depends on the river and the issues that are being addressed. Survey reaches are usually selected to represent the average conditions in a river section that is morphologically similar. Reaches may also be selected to represent some critical habitat or ecological function, such as a known spawning area or fish passage constriction. The number and location of transects in a reach should reflect the variation in morphology and extent of the morphologically similar sections. Multiple reaches may be surveyed and then the hydraulic characteristics and habitat combined for analysis when a river section is morphologically similar. It is often appropriate to divide a river into multiple sections where the flow varies, such as upstream and downstream of a tributary or sinkhole.

Instream habitat is typically surveyed using one of two ways –by stratified sampling/habitat mapping or by representative reach(s) (Jowett, Hayes, & Duncan, 2008).

FIGURE 1
AWS VS. DISCHARGE CURVE FOR A SPECIES-LIFE STAGE



(Normandeau Associates, Inc., 2017)

Habitat Mapping – Stratified Sampling

Stratified sampling or habitat mapping is used to represent the physical habitat in the segment of river (over which the survey is intended to apply) and should provide a good representation of available habitat. In habitat mapping, mesohabitat types with similar hydraulic characteristics are defined and their locations and lengths are mapped. Riffles, runs, pools, bars, and divided channels are some stream features that are commonly classified as mesohabitat types.

Stratified sampling first requires that habitat mapping be undertaken over the segment of river under study so that proportions of the different mesohabitat types (e.g., pool, riffle, and run) can be determined. The entire extent or a large portion of the segment of interest is explored, allowing the length of each pool, run, and riffle to be determined (tape measured or GPS), and locations are recorded. The proportion of each mesohabitat is then determined by dividing the total length of that mesohabitat by the length of the segment of the river. Representative cross-sectional transects are then chosen in each of the mesohabitat types.

Transects should be selected without bias; however, transects are not completely random but targeted to include the full range of habitat with selected cross-sections. Habitat mapping also defines the percentage of each mesohabitat in the study reach and each transect represents the percentage of the mesohabitat type in the reach divided by the number of transects in that mesohabitat type. For example, if riffles make up

25% of a 2-mile segment of river and 6 transects were surveyed in riffles, then each transect would represent 25/6 or 4.2% of the river section.

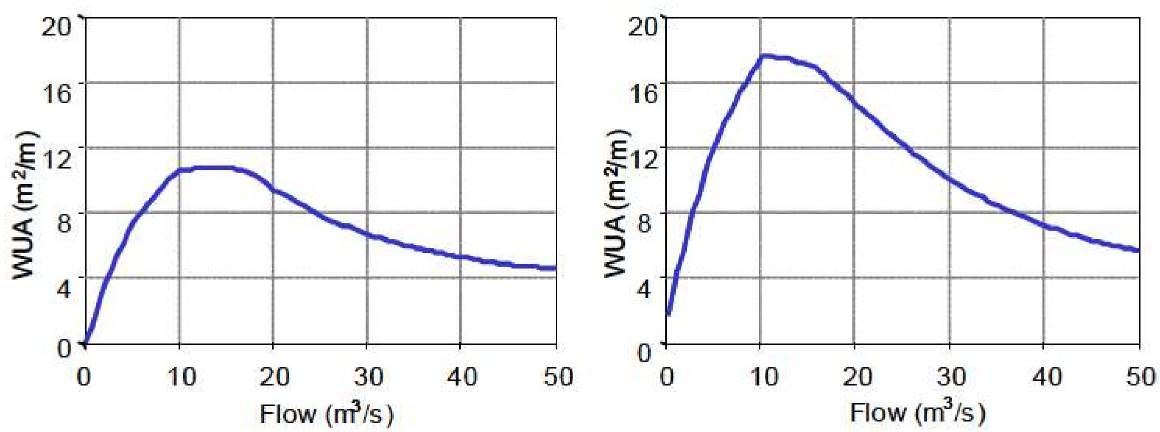
Representative Reach

Habitat modelling can be based on one or more "representative" reaches along a river, with closely spaced transects along the reach that are used for one-dimensional (1D) or two-dimensional (2D) modelling. Significant changes in channel structure and/or flow regime typically warrant designation of a separate reach. Hence, depending on the channel structure and flow regime, one or more representative reaches are selected for modelling *(Normandeau Associates, Inc., 2015)*. A representative reach contains a range of habitats, usually one or two pool/run/riffle sequences that are considered representative of a longer segment of the river. In representative reach 1D modelling, the distance between transects is usually used to calculate the proportion of the reach that each transect represents. The length of reach that each transect represents is half the distance between the adjacent upstream and downstream transects. However, it is also possible to specify percentage values for each transect as described in Habitat Mapping.

Selecting reach and transect locations poses the question of how "representative" they are of a longer section of river or the hydraulic conditions within the reach. However, experience has shown that although the amount of habitat may vary between reaches, the shape of the instream habitat-flow relationship is usually similar and neither reach selection nor survey type should affect flow assessments (Jowett, Hayes, & Duncan, 2008) (FIGURE 2).

Differences in appearances of reaches in a river section do not necessarily result in difference in the shape of WUA habitat-flow relationships, although they likely indicate differences in the amount of amount of available habitat.

FIGURE 2
COMPARISON OF INSTREAM HABITAT PREDICTIONS FROM TWO SURVEY REACHES ON THE ARNOLD RIVER



(Jowett, Hayes, & Duncan, 2008)

General guidance has been provided by instream habitat experts for site and transect selection. The total number of transects needed to generate a representative result should be proportional to the complexity of the habitat hydraulics: 6-10 for simple reaches and 18-20 for diverse reaches (Jowett, Hayes, & Duncan, 2008). The number of transects in each mesohabitat type should ensure that no individual transect is given a weight of more than 5-10% to minimize the influence of outliers. A representative reach should include at least one morphological (pool/run/riffle) sequence.

Other guidance suggests that abundant mesohabitat types should be sampled at a higher frequency than less abundant types, roughly in proportion to their abundance. The number of transects to represent a reach should be, at minimum, in the range of 17-20 (Payne, Eggers, & Parkinson, 2004). This approach provides enough transects to replicate each of the predominant mesohabitat types (e.g. Riffle, Run, and Pool).

Assuming full access to a reach, the specific locations and lengths of the study sites should be selected in the field (Normandeau Associates, Inc., 2015). The study sites used for transect placement to represent the different geomorphic and hydraulic conditions should be selected using a random sampling approach based on the least-available sampled mesohabitat type (Payne T. R., 1992). Other more-available mesohabitat types will be represented using transects placed in mesohabitat units near the least-available selector. This approach minimizes the effect of selection bias, results in transect clustering that limits travel time, and assures transect representation in proportion to habitat availability.

- Actual transect selection and placement is typically accomplished with a combination of random selection and professional judgment through the following procedure (Normandeau Associates, Inc., 2015):
- All reaches that are accessible and open to study are identified and designated for random transect placement.
- Within the accessible areas, the habitat type with the lowest percentage of abundance (from the habitat mapping data) is used as the basis for random selection (provided that the habitat type is ecologically significant and subject to modeling). If the distribution of the initial least common selector is too limited to provide an adequate choice of representative habitats, the next least common selector will be used.
- All habitat units of this type within the accessible distance that were judged to be adequate for model application during the geomorphic mesohabitat mapping are sequentially numbered and a minimum of five units selected by random number.
- In the field, the first selected unit is relocated and one or more transects is/are placed to best represent the habitat type.
- At least one example of each remaining habitat type is then located in the immediate vicinity of the random transect (upstream or downstream) until transects are placed in all significant types.
- This process is repeated with the second, third, fourth or higher random selector to place additional clusters until the different geomorphic and hydraulic conditions are adequately characterized or the target total number of transects is reached.

Although the outlined steps are fairly rigorous, all decisions regarding transect placement are subject to revision through the exercise of professional judgment by study participants, including selecting specific study areas and transects that include ecologically important locations (e.g., spawning areas or passage-limiting shallow areas). In the event only one portion of a reach can be accessed, the study site and transect locations should be selected to represent the reach (representative reach approach).

In Florida, the SWFWMDs Ecological Evaluation Section provided guidance and described procedure to collect PHABSIM data for developing Environmental Flows (Hood, 2006). The criteria for selecting sites include:

- sites should be representative of the river reach for which minimum flows are to be developed,
- sites should be reasonably accessible,
- sites should be located between established USGS river gauging stations, and
- sites should coincide with floodplain vegetation sites and at flow control points (i.e., shoal and riffle sites which can be used for PHABSIM analysis).

Three instream river transects are established for a given study site. A central instream transect is initially designated and this typically coincides along the same line as the floodplain transect or a shoal/riffle identified from an earlier reconnaissance trip. A second transect is established 50 feet down river and designated a downstream transect. The final transect is located upriver also at 50 feet of the central instream transect and designated the upstream transect. Many Environmental Flows currently established were evaluated based on data collected using this procedure (SRWMD , 2016) (SWFWMD, 2017) (SWFWMD, 2012).

SPECIES SELECTION

To focus integration of the various modelling results and relevant species and life stages, a priority species and life stage ranking approach should be developed for each river (USGS, 2005). A USGS Scientific Investigations Report provided guidance on species selection for habitat modelling as part of the Instream Flow Characterization of Upper Salmon River Basin Streams in Central Idaho (USGS, 2005). For example, the United States Forest Service (USFS) prioritized Endangered Species Act (ESA)-listed anadromous species with the highest ranking, followed by Species of Special Concern (SSC), in their adjudication of water right claims for selected streams in central Idaho (Hardy, 1997). Prioritizing life stages for the month or period of concern (e.g., spawning or dry periods) would benefit the target flow selection using the assumption that the priority life stage or drought consideration would maintain flows during critical events for species survival. This priority ranking generally would be (from high to low) for small tributary streams of the upper Salmon River Basin: passage > spawning > adult > juvenile. The ranking approach should involve discussions among resource management agency representatives familiar with the streams of interest (USGS, 2005). Once the priority species and life stage are ranked, each study site should be examined to determine streamflow and passage conditions for the period of interest.

In the low gradient, warm water river systems that dominate the south-eastern coastal plain region in general and Florida in particular, fish communities can be very diverse and often dominated by a large suite of species with similar habitat needs (Leonard & Orth, 1988). Because a species' habitat use will often shift as a function of the fish community diversity, the species-specific habitat suitability curves are more appropriately thought of as both species and river specific (Freeman, Bowen, & Crance, 1997). Thus, although a single habitat suitability curve, representing one species and life stage combination is typically used for PHABSIM/SEFA, numerous authors have suggested that, when assessing south-eastern coastal plain ecosystems, criteria representing habitat guilds (grouping classes with comparable habitat preferences) would be more useful. These guild-based models group taxa based on their functional preference for particular habitat types, such as shallow-fast riffles in contrast to deep-slow pools, instead of taxonomic status (Leonard & Orth, 1988) (Welcomme, Winemiller, & Cowx, 2006).

TIME SERIES ANALYSIS

The Time Series Library (TSLIB) is a group of DOS-based computer programs used to create monthly or daily habitat time-series and habitat duration curves using the habitat-discharge relationships produced by PHABSIM/SEFA. USFWS (United States Fish and Wildlife Service) developed the TSLIB and published a reference manual for generation and analysis of habitat time series (USFWS, 1990).

According to the reference manual, the choice between a daily or monthly time series analysis depends on the objective of the analysis and on the data and funds available. For example, daily values could be used for a gaged site and where the water resource system is being simulated using daily flows. In contrast, monthly streamflows would be used for a location with few streamflow measurements and where the streamflow record was synthesized by regression with nearby sites (Milhous, Bartholow, Marlys, & Alan, 1990). Usually, a time series of daily habitat is transformed to an index of monthly habitat for further analysis (USFWS, 1990). The monthly habitat values are often transformed to some type of annual habitat index, which is (in most situations) the actual decision variable (Milhous, Bartholow, Marlys, & Alan, 1990).

In most situations, a time series of daily streamflows would be the most appropriate; unfortunately, there are few situations where both a pre- and a post project time series of daily streamflows are available (USFWS, 1990). There are few cases where the biological system does not respond to daily conditions but to some integration of conditions over time. (The exceptions to this may be extreme events, such as peak flows.) However, to use TSLIB to analyse the time series, the results from the transformation of the streamflow data to physical habitat *must be a monthly habitat time series*. For daily habitat simulations, the user must supply the programs to calculate monthly values based on daily values or perform the analysis manually.

OTHER CONSIDERATIONS

Arkansas Method

The most widely used desktop methodology for MFLs (also referred to as Environmental Flows) development is the Tennant method (formerly referred to as the Montana method) (Tennant, 1976), (Reiser, Wesche, & Estes, 1989), (Sale, Cada, Chang, Railsback, & Sommers, 1991). A fixed percentage of mean monthly flow was introduced in 1980 as a modification of the Tennant method. This modified approach has since become one of the most widely used techniques in the United States (Reiser, Wesche, & Estes, 1989) (Mathews & Bao, 1991).

The Arkansas Game and Fish Commission and State Department of Pollution Control and Ecology developed the Arkansas Method of instream flow determination for fish and wildlife needs. The Arkansas Method is a modification of the Tennant Method (Tennant, 1976) for instream flow assessment. The modification uses mean monthly (instead of annual) flows because researchers thought that the original Tennant method did not adequately address seasonal flow variability across the full range of Arkansas streams. With the Arkansas method (TABLE 1), the year is divided into three seasons based on stream physical-biological processes: November-March (channel clean and recharge), April-June (fish spawning), and July-October (fish production). The methodology evolved through a review of hydrologic records, years of experience reviewing flow-habitat relationships, and a knowledge of seasonal processes as applied to Arkansas streams.

Seventy percent of the Mean Monthly Flow (MMF) is recommended for fisheries instream flow needs during April through June because it is the primary spawning time for most native Arkansas fish. Native fishes must spawn successfully in the spring of each year; otherwise, detrimental effects will be experienced by the population for several consecutive years. Decreases in stream flows contribute to increased mortality by stranding fish eggs and fry or by reducing a sufficient flow of oxygenated water to developing fish eggs or fry. Reduced flows can also result in increased deposition of silt in spawning areas (Peters, 1982).

Using the Arkansas Method, specific monthly instream flows for fisheries were computed for major river basins in the state (Filipek, Keith, & Giese, 1987). Recommended monthly mean flows and corresponding stream gage heights are guidelines for the Arkansas Soil and Water Conservation Commission (ASWCC) for minimum values to maintain and protect stream fisheries.

TABLE 1
THE ARKANSAS METHOD FOR PROVIDING ADEQUATE INSTREAM FLOWS FOR VARIOUS SEASONS OF THE YEAR, BASED ON PHYSICAL/BIOLOGICAL PROCESSES

Physical/Biological Process	Season	Recommended Flow
Channel Clean and Recharge	November-March	60% of mean monthly flow
Fish Spawning	April-June	70% of mean monthly flow
Fish Production	July-October	50% of mean monthly flow (or median monthly flow)

(Evans & England, 1995)

Indicators of Hydrologic Alteration (IHA)

The Nature Conservancy has developed a statistical method and software, called the "Indicators of Hydrologic Alteration" (IHA), for assessing the degree to which human activities have changed flow regimes. The IHA method is based on 32 biologically-relevant hydrologic attributes, divided into five major groups to statistically characterize intra-annual hydrologic variation. Most importantly, they entail hydrologic statistics commonly employed in limnology studies because of their great ecological relevance (Poff & Ward, 1989) (Hughes & James, 1989).

The first major grouping (IHA Group #1: Magnitude of Monthly Water Conditions) includes 12 parameters, each of which measures the central tendency (mean) of the daily water conditions for a given month. The ecosystem influence corresponding to this parameter group include habitat availability for aquatic organisms.

RECOMMENDATION

Habitat modelling can be based on one or more "representative" reaches along a river, with closely spaced transects along the reach. A representative reach contains a range of habitats, usually one or two pool/run/riffle sequences that are considered representative of a longer segment of the river. The total number of transects needed to generate a robust result should be proportional to the complexity of the habitat hydraulics: 6-10 for simple reaches and 18-20 for diverse reaches.

For Species Selection, ESA listed species, state-listed species (Threatened species or Species of Special Concern) and Species of Greatest Conservation Need, and other fish species of recreational interest should be included for analysis. Species that are recreationally or culturally important should be considered. In addition to individual species, habitat guilds (Deep-Slow, Deep-Fast, Shallow-Slow, Shallow-Fast) should be considered for instream habitat analysis. Analysis by life stages for species/guilds should be conducted and has biological relevance. Other aquatic life, such as invertebrates, should be considered if habitat suitability curves exist.

Multiple reference documents (Arkansas Method, IHA, TSLIB) describe the importance of maintaining the monthly average flows for fish habitat maintenance. Based on these reference documents and some of the applications of PHABSIM/SEFA change in monthly AWS values is recommended for analyzing the AWS vs. discharge output from PHABSIM/SEFA.

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