SEFA - COMPUTER SOFTWARE SYSTEM FOR ENVIRONMENTAL FLOW ANALYSIS BASED ON THE INSTREAM FLOW INCREMENTAL METHODOLOGY

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ABSTRACT

Several recent technological and generational changes have led to the need for improved approaches to riverine habitat modeling and more comprehensive environmental flow assessments. The Instream Flow Incremental Methodology (IFIM) described an impact assessment framework but did not create the comprehensive software which would allow for a complete implementation of that framework. SEFA, System for Environmental Flow Analysis, is new software that implements the substance of the IFIM. SEFA has been created through a collaboration of the primary creative forces behind the principal versions of existing physical habitat simulation software. Bob Milhous (PHABSIM), Ian Jowett (RHYHABSIM), and Tom Payne (RHABSIM) have contributed their considerable experience acquired through development and use of these programs, and Juan Manuel Diez Hernández provides both his experience and Spanish-language capability. In a single Windows 7-compatible 32-bit program currently available on the internet, SEFA contains one dimensional habitat hydraulics analysis, habitat suitability criteria development, water temperature modeling, sediment transport analysis, dissolved oxygen modeling, riparian modeling, and time series analysis, and externally references to legal-institutional analysis and two dimensional modeling. This new tool and a not-for-profit technical and educational support structure will ensure continuity into the future for the critical science of instream flow evaluation and environmental flow protection.

1 INTRODUCTION

The Instream Flow Incremental Methodology (IFIM) was originally developed by the Instream Flow Group (IFG) of the U.S. Fish and Wildlife Service (USFWS) in Fort Collins, Colorado, as a decision-making framework (Figure 1) for assessing the impacts of water development projects on aquatic ecosystems Bovee [1], Bovee *et al.* [2]. Computer models provided a mechanism for quantifying aquatic habitat per unit length of stream by linking stream channel hydraulics with habitat suitability criteria to create an index to habitat called weighted usable area (WUA). Additional models then could link the habitat index to hydrology to put the index into the context of flow variability and perform a time series analysis of total habitat.

The collection of models to perform the quantification of microhabitat area per unit length of stream are collectively known as PHABSIM, or Physical Habitat Simulation, and have been described in detail by Bovee and Milhous [3], Milhous *et al.* [4], and Waddle [5]. Several software versions to accomplish the same objectives have been written over the years in addition to the current one, PHABSIM for Windows by the U.S. Geological Survey, successor agency for the IFG. These include RHABSIM in the U.S., RHYHABSIM in New Zealand, EVHA in France, RSS in Norway, and others.

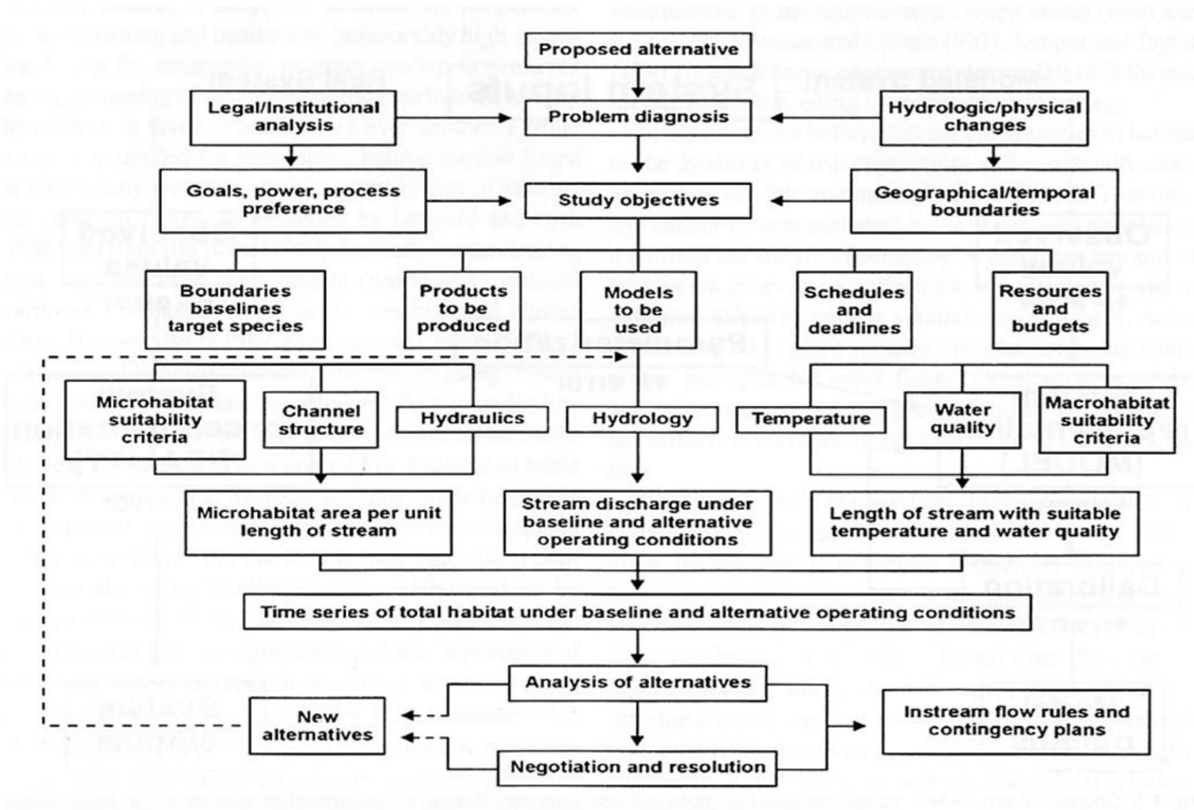

Figure 1. Schematic diagram of the Instream Flow Incremental Methodology (from Bovee *et al.* [2]).

In addition to the hydraulic habitat modeling program PHABSIM, the IFG created TSLIB for time series analysis of baseline and alternative hydrology, SNTEMP for stream network temperature analysis, and LIAM for legal-institutional analysis, but did not write any software to implement the complete IFIM. Even though the IFG constantly reminded U.S. and international users of the PHABSIM approach that it should be applied within the context of IFIM, there was no software written to do so, and PHABSIM the model eventually came to be perceived as synonymous with IFIM the process. There are other reasons besides the lack of software, of course, some psychological, some driven by cost, some due to inexperience, but the end result was the same: the IFIM was criticized as being only a physical fish habitat model instead of being correctly known as a multi-disciplinary, multi-component framework for alternatives analysis and negotiation.

Consequences of the conflation between PHABSIM and IFIM include the multiplication of alternative and often similar methods, fragmentation of analysis among scientific disciplines, loss of study integration, and ultimately weaker protection for natural resources. Correction of the misperception is very difficult in the absence of a fresh approach, especially since the original staff of the IFG is nearly all retired and the group has been given a different direction by the parent agency. In addition, the IFG has no plans to program PHABSIM to function under the newest operating systems, RHABSIM and EVHA require similar upgrading and recompiling, related software packages have not been widely distributed, translated, or adopted, and no national or international organization appears ready to step in and replace the function of the IFG.

2 SEFA – SYSTEM FOR ENVIRONMENTAL FLOW ANALYSIS

To help maintain hydraulic habitat modeling in particular and the IFIM approach in general, several individuals have combined resources to create a new software package that will function on the latest generation of computers and operating systems. Collaborating on the project are Bob Milhous, programmer for the original PHABSIM, Ian Jowett, creator of RHYHABSIM, Tom Payne, author of RHABSIM, and Juan Manuel Diez Hernández, who completed his doctorate in hydraulic habitat modeling. The software package has been named SEFA, the acronym for System of Environmental Flow Analysis, and will be managed by an independent software company called Aquatic System Analysts. System was chosen because the software, like the IFIM, can follow numerous pathways depending on the outcome of a scoping process and can be adapted to the types of studies determined to be needed. Environmental Flow refers to the comprehensive nature of most current instream flow methods, rather than a static minimum flow that, for example, might be based on only a narrow view of complex and dynamic ecosystems. Analysis is part of the name due to the inclusion of several major components, including hydrologic analysis, hydraulic and habitat modeling, water temperature modeling, habitat selectivity criteria development, sediment scour, transport, and deposition analysis, riparian habitat evaluation, and hydrologic and habitat time series analysis.

Figure 2 shows a screen capture of the initial view of SEFA. The general layout follows the IFIM schematic from Figure 1 to both illustrate the features of the software and put the various elements into context. Moving the computer cursor and clicking on any of the SEFA flow path boxes will bring up short paragraphs describing their features and purpose. Available options at this point are limited to habitat selectivity criteria development (HSC on the main menu bar) and Time Series analysis because there is no river channel file yet opened. Clicking the File option on the main menu bar will allow users to load existing SEFA format river model files or to import channel cross section data files in existing PHABSIM, RHABSIM, or RHYHABSIM formats, and from Microsoft Excel, delimited text files in a specified format. Once a river model file is loaded, all of the remaining options that depend on channel morphology will become active and appear on the main menu bar.

The software is designed for maximum flexibility in application and is not constrained to a particular pathway or analytic approach, with the exception of elements that should be common to most instream flow studies. These include legal-institutional analysis (either formal or informal, to assess the likely political perspectives of study participants and the type of studies needed for the legal arena under which the study is implemented), scoping and planning (to select study methods and identify baselines, project boundaries, and potential alternatives), study objectives (to provide a clear purpose to any study found to be needed), and ecological evaluation (to link existing knowledge between biology and physical processes) and negotiation (to resolve conflicting goals and develop recommendations).

Once study objectives are specified and a hydrologic data base is developed or acquired, the environmental flow analysis can proceed to standard setting methods such as Tennant [6], the Range of Variability Approach of Richter *et al.* [7], or any of several percentage of flow duration techniques. If a channel width method such as Wetted Perimeter by Leathe and Nelson [8] is appropriate to meet the objectives, it can be applied once the required channel morphology data is collected. If the environmental flow question is more complex (usually where considerable flow change or seasonal flow modification from storage is involved), then the pathway can lead to more sophisticated hydraulic assessments and study of potential ecological effects on water quality, sediment, riparian habitat, or similar topics that will often require participation from experts in these disciplines.

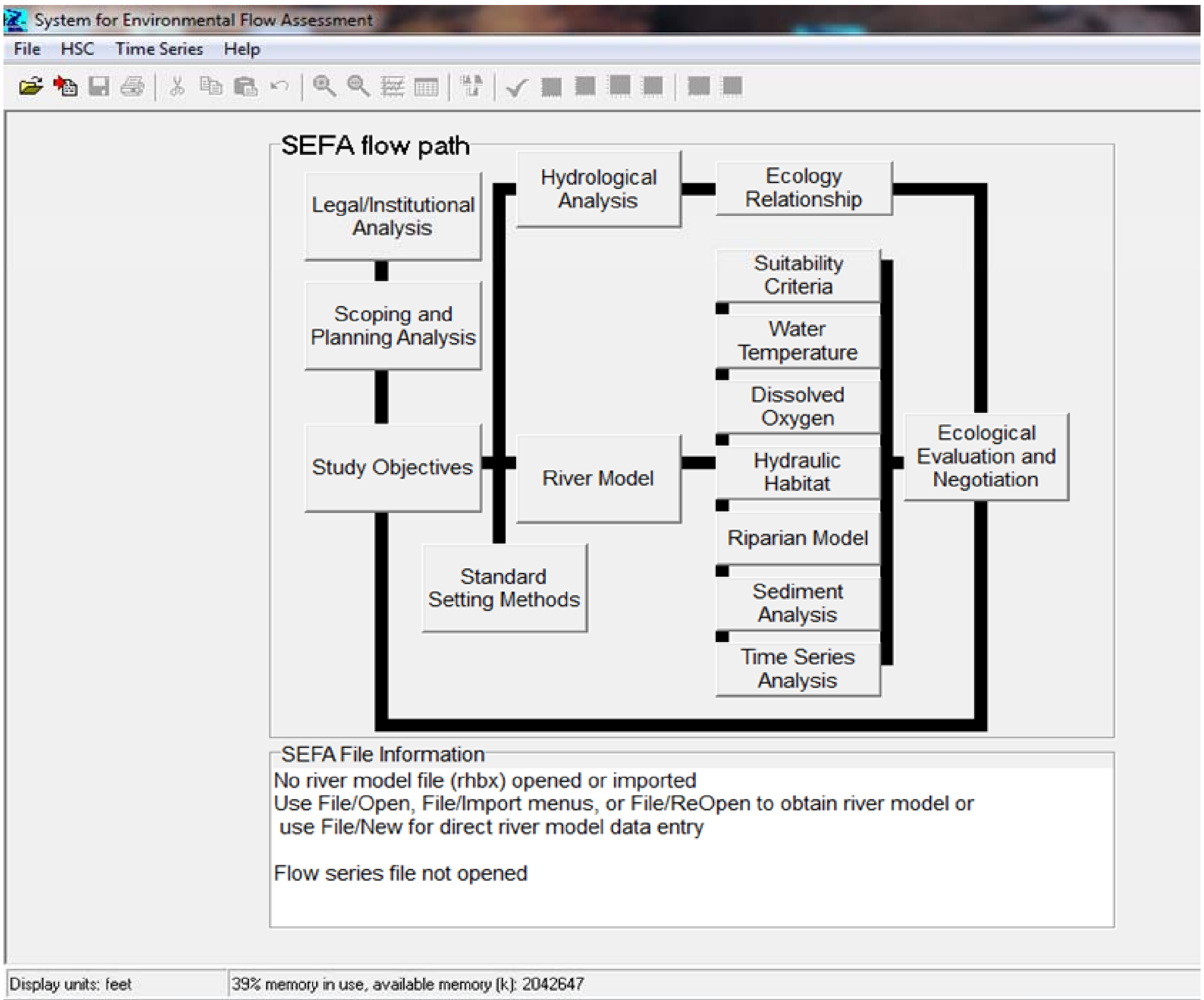

Figure 2. Screen shot of the initial SEFA showing pathway layout and available analytical options.

3 RIVER MODEL OPTIONS

The capabilities of SEFA are extensive and the technical knowledge required for several internal programs can be considerable, so only a brief description of each is provided here. Within SEFA are options for using the standard, cross-section based one-dimensional hydraulic models of PHABSIM, RHYHABSIM, and RHABSIM, external reference to and import of results from two-dimensional models, and incorporation of results from most other empirical assessment approaches for further linkage with other SEFA models and performance of habitat time series analysis. The program is completely switchable between metric and U.S. measurement units with a wide range of acceptable date formats.

3.1 One-Dimensional Hydraulic Modeling

The one-dimensional hydraulic models of SEFA are based on surveyed cross-sections of river channel profile that are placed either in representative reaches or separately by habitat mapping, where they are given weight based on their respective percentages of habitat type. Water surface elevations can be calibrated and simulated with log stage-log discharge rating curves, channel conveyance parameters, or step-backwater models, be entered either empirically for each flow, or be derived and entered from any external model or source. Water velocities are calibrated and simulated from measured patterns, derived from water depth relationships, or created from experience and professional judgment. Two velocity simulation methods can be used, with velocities calculated either from conveyance at each measurement point (as in PHABSIM, RHABSIM and RHYHABSIM) or by LogD, a new algorithm contributed by Dr. Diez Hernández. Within SEFA, there are no set limits on the number of cross-sections or the number of verticals that define the cross-sections. Calibration of the models starts out with default calibrations which can be modified through interactive graphics. Both the rating curves and velocity patterns can be visually adjusted within the range of measured data or created through professional knowledge and experience. A checking procedure creates a text file identifying most common problems. In addition, SEFA incorporates the ability of RHYHABSIM to allow use of transverse (non-perpendicular) cross-sections, retention of all measured velocities at the calibration flows (through a correlation between calculated and best-estimate discharges), and any mixture of complete-channel and split-channel transects for islands and braided rivers.

3.2 Two-Dimensional Hydraulic Modeling

The current version of SEFA does not internally contain a two-dimensional hydraulic model but can make use of any existing standard 2-D model. For example, River2D from Steffler and Blackburn [9] can either be completely implemented and habitat index results brought back into SEFA, or the simulated hydraulic data can be imported through an Excel file template and habitat index computations completed in SEFA. Hydraulic data from any other two-dimensional model can be imported and analyzed the same way. Habitat analysis, however, is at this time limited to the standard multiplicative options for habitat suitability criteria; patch metrics or other habitat association approaches are best kept external to SEFA. River channel cross-sections can be created from 2-D models and imported to SEFA for water quality, sediment movement, and similar morphology-dependent studies.

3.3 Empirical Assessments

Taking advantage of the power of SEFA does not require the use of hydraulic habitat modeling – any empirical or judgment-based method can be incorporated. These types of methods include MesoHABSIM by Parasiewicz [10], which computes habitat suitability indexes from the proportions of habitat-type strata at different flows; the demonstration flow approach documented by Railsback and Kadvany [11], also known as Expert Panel Assessment by Swales and Harris [12] or Judgment Based Habitat Mapping by Goodman *et al.* [13]; empirical hydraulic habitat assessments using cross-sections (without modeling) by Trihey & Baldridge [14]; the random-sampling method advocated by Williams [15]; or virtually any other method that creates an index relationship between habitat suitability and discharge. Empirical approaches should be used with care, however, since they have a limited interpolation capability and are of questionable value when extrapolated beyond non-studied flows when attempting to take advantage of habitat time series analysis.

4 ADDITIONAL ANALYTIC MODULES

One important aspect of hydraulic habitat modeling concerns the development of habitat suitability (or electivity) criteria. SEFA contains a module for the compilation, analysis, and creation of suitability functions, and another module to link hydraulics and compute habitat indices. If an open channel fish passage evaluation is useful, SEFA can compute either total or contiguous passage widths from user-specified criteria. A good portion of SEFA, however, is not related to hydraulic habitat and can use channel cross sections to perform analysis of several flow-related physical processes useful for developing more-comprehensive environmental flow recommendations. Modules included in SEFA can be either linked to hydraulic habitat (or other) indices or used independently in making recommendations. The existing version of SEFA contains either individual or multiple reaches (future versions will have SNTEMP by Bartholow and Waddle [16]), dissolved oxygen and pollutant dilution models, sediment scour, transport, and deposition models, a model for testing the frequency and extent of riparian vegetation inundation, and extensive hydrologic and habitat time series analysis. SEFA currently links to the legal-institutional analysis method of the IFIM, while future versions plan to contain the method internally.

4.1 Habitat Suitability Criteria Development

The habitat suitability criteria module of SEFA makes it possible to determine the relative quality of the different habitats from the abundance of animals in them. Usually, animals are most abundant where the habitat quality is best, in lesser numbers where the habitat is poor, and absent from totally unsuitable habitat. The module was developed to make life easier for people who carry out habitat suitability analyses by providing a series of linked procedures to display histograms of habitat use, availability, and suitability, fit kernel smoothed curves to these data, and normalize values for use in habitat analyses. Both histograms and kernel density plots can be used to display frequency of habitat use and availability, data can be analyzed by groups, such as habitat types, fish sizes, or river systems, and frequency histograms can be derived for any habitat variable, numeric or categorical. Curves may be fit to data by several methods, and generalized additive models can be created by logistic fit, binomial, Poisson, and gamma. Multivariate analysis can be conducted to test for interactivity among variables and adjustments can be made to use data through comparison with availability data.

4.2 Habitat Index Computation

The habitat index within SEFA is expressed either as area weighted suitability (AWS) in units of m^2/m or ft^2/ft or as the average combined suitability index (CSI) for the reach or cross-section. The terminology used for the habitat index is AWS, which used to be called weighted usable area (WUA). The change was made in SEFA because the index does not represent an actual area – calling it WUA is misleading and has lead to considerable misunderstanding. Area weighted suitability (AWS) is the CSI for each measurement point (1D or 2D) weighted by area the point represents. The CSI based on the physical character (water depth, velocity and substrate and other attributes, if required) specified in the habitat suitability curves. If habitat suitability is specified so that suitable habitat has a weight of 1 and unsuitable habitat a weight of 0, the area is the usable area in units of width or units squared per unit length of reach (m^2/m or ft^2/ft). SEFA implements the standard procedures to link riverine hydraulics and selected habitat suitability criteria and can display the results by reach, by cross section, by points on each cross section, and by habitat variable. Habitat variables can be combined by multiplication, geometric mean, or the minimum of individual suitabilities. Two statistical models (generalized additive models, or GAMs, and multiple linear regression) which predict probability of use or abundance are also available in SEFA, and can be used in place of CSI on any cross-section, reach or combination of reaches.

4.3 Fish Passage Evaluation

The width of river that provides suitable water depths and velocities for the passage of fish or boats can be calculated for the reach, either at the surveyed flow or for simulated flows. Results are presented as the contiguous width with the required minimum depth and velocity, or as the total width, which is the sum of all the elements of the cross-section that meet the specified criteria. Minimum depth requirements can be found by setting the required velocity to zero; similarly, minimum velocity requirements can be found by setting depth to zero. The minimum passage width for the reach is the minimum of all the cross-sections.

4.4 Water Temperature Modeling

Water temperature modeling is included in SEFA to help aquatic biologists and engineers predict the consequences of stream manipulation, either flow or shade, on water temperatures. Water temperatures may affect aquatic systems in many ways, ranging from acute lethal effects, to modification of behavioral cues, to chronic stresses, to reductions in overall water quality. The model is a mechanistic, one-dimensional heat transport model that predicts the daily mean and maximum water temperatures as a function of stream distance and environmental heat flux. Net heat flux is calculated from long-wave atmospheric radiation, direct short-wave solar radiation, convection, conduction, evaporation, streamside vegetation (shading), streambed fluid friction, back radiation, and groundwater influx. The change in water temperature is calculated as the water flows downstream using the initial water temperature at the beginning of the reach. A number of reaches or a selection of cross-sections may be specified and water temperatures will be calculated for a section of river with hydraulic characteristics that are an average of all reaches.

4.5 Dissolved Oxygen Modeling

In addition to stream geometry and water temperature data, three other parameters are required to calculate flow effects on dissolved oxygen concentration. These are: 1) daily community respiration rate (the average rate of oxygen consumption by aquatic plants and micro-organisms); 2) production/respiration ratio (ratio of the daily rates of photosynthetic production of oxygen to daily oxygen respiration by plants and micro-organisms), and 3) re-aeration coefficient (the coefficient that describes the rate at which oxygen is exchanged between the atmosphere and the stream). SEFA includes both a single station DO model which applies to streams with a reasonably homogenous distribution of aquatic plants, and a multiple station DO model which calculates dissolved oxygen concentration and biological oxygen demand (BOD) along a reach that can have inflows from tributaries, point source discharges and outflows (abstractions/diversions).

4.6 Sediment Analyses

SEFA can compute sediment flushing, transport, and deposition in relation to flow with three individual models. Flushing flows remove fine sediments and periphyton accumulations from stream substrates, and are necessary in most streams to remove accumulated fine sediments and to restore interstitial space in gravel substrates. Surface flushing flows remove fine sediments from the surface layer, leaving the armor layer largely intact, while deep flushing flows disturb the armor layer, removing the sediments that have deposited within the gravel matrix. Sediment deposition occurs in areas where the water velocity is low enough to allow sediment to settle. The area of potential sediment deposition is calculated for two sizes of sediment: sand (2 mm) and silt (0.064 mm) over the specified range of flows. The reduction in suspended sediment concentration due to deposition/trapping of sediment in dead zones is calculated using the method described by Einstein [17]. This process results in the water clarity improving with distance downstream. The rate at which clarity (suspended sediment concentration) improves depends on the particle size and hydraulic characteristics of the river.

4.7 Riparian Vegetation Assessment

Riparian vegetation analysis can be conducted within SEFA with a river model having good high flow stage-discharge rating curves and a daily average flow time series. Inundation heights and areas are calculated as a height above a specified base flow, along with the frequency, timing, and duration of inundation. These modeling results then need to be interpreted by a botanist familiar with the life history and biological responses of riparian species to inundation.

4.8 Time Series Analysis

SEFA incorporates the ability to view time series data for flow or AWS, conduct event analysis for the number of recorded instances or the number of separate specified events (such as floods or droughts), calculate seasonal flow or AWS statistics (minimum, maximum, mean, median, standard deviation, 25 percentile, and 75 percentile, mean annual 7-day low flow, frequency of floods greater than 3 times the median), the Indicators of Hydrologic Alteration from Poff and Ward [18], habitat duration analysis using AWS to show the frequency where the values are equaled or exceeded, and the Uniform Continuous Under-Threshold (UCUT) analysis method of Parasiewicz [19] and Capra *et al.* [20].

4.9 Legal-Institutional Analysis Method

Legal-Institutional Analysis (LIAM) is a formal, structured process that has always been an integral part of the IFIM process (Figure 1). LIAM promotes communication and understanding among participants in an environmental flow evaluation, helps identify important concerns and opportunities, aids in mutual understanding of the complexities of such studies, and builds cooperative working relationships. The first release version of SEFA shells to the LIAM software created by the IFG and should where possible be done under the guidance of an experienced political scientist. Future SEFA versions will incorporate LIAM directly to maintain the connection to the political and social context under which environmental flow evaluations are conducted.

5 SEFA MAINTENANCE, IMPROVEMENT AND TRAINING

The purpose of SEFA is to provide a more unified framework for environmental flow analysis that continues the decision-making structure of the IFIM, brings back together in a single package several apparently divergent methods (many are not all that different), and will function into the foreseeable future as computer capabilities continue to evolve and improve. Future versions will be compiled in 64-bit architecture (32-bit now) and will run under Windows 8. SEFA will be managed by Aquatic Habitat Analysts to be a living program that will: 1) fix the to-be-expected bugs, 2) solicit feedback from users through an interactive website, and 3) change along with instream flow techniques, needs, and practice. An international technical advisory committee composed of experienced instream flow practitioners will review the capabilities of the program and consider suggestions for improvement and enhancement. A modest initial fee for SEFA will support the web site and continued programming costs for updated versions, which licensed users can download at no additional cost. A Spanish language version will be made available in the near future, along with versions in any other language for which there is a need and a knowledgeable user capable of providing an adequate technical translation. All four authors of SEFA intend to be available for technical assistance and training that can be arranged based on demand.

REFERENCES

[1] Bovee, K., "A guide to stream habitat analysis using the Instream Flow Incremental Methodology", *Instream Flow Information Paper 12*, United States Fish and Wildlife Service FWS/OBS- 82/26, (1982), 248 pp.

[2] Bovee K., Lamb B., Bartholow J., Stalnaker C., Taylor J., and Henriksen J., "Stream habitat analysis using the instream flow incremental methodology", *U.S. Geological Survey*, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004, (1998), 131 pp.

[3] Bovee, K., and Milhous, R., "Hydraulic simulation in instream flow studies: theory and techniques", *Instream Flow Information Paper 5*, United States Fish and Wildlife Service FWS/OBS-78/33, (1978), 129 pp.

[4] Milhous, R., Wegner, D., and Waddle, T., "User's guide to the Physical Habitat Simulation System (PHABSIM)", *Instream Flow Information Paper 11*, United States Fish and Wildlife Service FWS/OBS-81/43, (1984), 320 pp.

[5] Waddle T. (ed.), "PHABSIM for Windows user's manual and exercises", *U.S. Geological Survey* Open-File Report 2001-340, (2001), 288 pp.

[6] Tennant, D., "Instream flow regimens for fish, wildlife, recreation and related environmental resources", *Fisheries* 1(4):6-10, (1976).

[7] Richter, B., Baumgartner, J., Wigington, R., and Braun, D., "How much water does a river need?", *Freshwater Biology* 37:231-249, (1997).

[8] Leathe, S., and Nelson, F., "A literature evaluation of Montana's wetted perimeter inflection point method for deriving instream flow recommendations", *Montana Department of Fish, Wildlife and Parks*, Helena, Montana, (1986), 70 pp.

[9] Steffler, P., and Blackburn, J., "River 2D, two-dimensional depth averaged model of river hydrodynamics and fish habitat, introduction to depth averaged modeling and user's manual", *University of Alberta*, April 23, 2001, (2001), 64 pp.

[10] Parasiewicz, P., "MesoHABSIM: a concept for application of instream flow models in river restoration planning", *Fisheries* 26(9):6-13, (2001).

[11] Railsback, S., and Kadvany, J., "Demonstration flow assessment, procedures for judgement-based instream flow studies", *EPRI* Final Report, March 2004, TR-1005389, (2004), 124 pp.

[12] Goodman, D., Martin, A., Petros, P., and Klochak, J., "Judgment Based Habitat Mapping on the Trinity River, 2006", U. S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, *Arcata Fisheries Technical Report* Number TR2009-12, Arcata, California, (2009).

[13] Swales, S., and Harris, J., "The expert panel assessment method (EPAM): a new tool for determining environmental flows in regulated rivers", pp 184-192, *in* Harper, D., and Ferguson, A. (eds.), "*The Ecological Basis for River Management*", John Wiley & Sons, New York, (1995), 614 pp.

[14] Trihey, E., and Baldridge, J., "An empirical approach for evaluating microhabitat response to streamflow in steep-gradient, large bed-element streams", pp 215-222 *in* F. Olson, White, R., and Hamre, R. (eds.), "*Proceedings of the Symposium on Small Hydropower and Fisheries*", Aurora, Colorado, American Fisheries Society, Bethesda, Maryland, (1985), 497 pp.

[15] Williams, J., "Testing models used for instream flow assessment", *Fisheries* 26(12):19-20, (2001).

[16] Bartholow, J., and Waddle, T, “Introduction to stream network habitat analysis”, *Instream Flow Information Paper 22*, U.S. Fish and Wildlife Service Biological Report. 86(8), (1986), 242 pp.
[17] Einstein, H., “Deposition of suspended particles in a gravel bed”, *Journal of the Hydraulics Division,. American Society of Civil Engineers*, 94(5), 1197-1205, (1968).
[18] Poff, N., and Ward, J., “Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns”, *Canadian Journal of Fisheries and Aquatic Sciences* 46:1805-1817, (1989).
[19] Parasiewicz P. “The MesoHABSIM model revisited”, *River Research and Applications*, 23(8):893–903, (2007).
[20] Capra H., Breil P., Souchon Y., “A new tool to interpret magnitude and duration of fish habitat variations”, *Regulated Rivers: Research and Management* 10: 281–289, (1995).

Thomas Payne recently joined Normandeau Associates as a Senior Associate through a merger with his company, Thomas R. Payne & Associates, which he managed for 29 years. Mr. Payne is a Certified Fisheries Scientist with B.S. and M.S. degrees in Fisheries Biology from Humboldt State University. He specializes in use of the Instream Flow Incremental Methodology (IFIM) to evaluate the impacts of flow alteration on aquatic ecosystems, and has implemented, managed, or reviewed approximately five hundred instream flow studies on proposed and existing hydroelectric and irrigation projects and other water rights issues. Mr. Payne has also done fish population sampling, habitat mapping and typing, hydraulic measurements, habitat use determinations, computer simulations, water temperature modeling, water quality studies, macroinvertebrate studies, license application preparation, agency negotiations, post-project analysis, and expert witness testimony. Mr. Payne has conducted workshops in the use of IFIM to state and federal agencies, taught graduate-level courses as an Adjunct Professor of Fisheries at Humboldt State University, made numerous presentations before professional societies, testified before hearings boards and in other legal proceedings, and published several papers relating to the science of instream flow analysis.

Ian Jowett is a registered engineer with 40 years experience in engineering hydrology, environmental flow requirements, and the biological implications of flow regime alteration on river environments and aquatic populations. Prior to forming his own consulting company, Ian worked many years for the National Institute of Water and Atmospheric Research and the Ministry of Agriculture and Fisheries in New Zealand. His expertise includes hydraulic-habitat, water temperature, dissolved oxygen, and suspended sediment modeling, estimation of probable maximum precipitation and probable maximum floods, power station operation, floods and flood routing, hydrological analyses, sedimentation studies, operational simulation to environmental impact, and fish habitat studies. He developed methods for predicting trout and benthic invertebrate abundance in New Zealand rivers, and has used these methods in the assessment of environmental flow requirements and the impact of flow modifications on a fishery. Ian has developed several computer programs that are in routine use by environmental agencies and consultants. He developed RHYHABSIM for instream habitat flow assessments and other programs that simplify statistical analysis of environmental patterns.