Review of Hydraulic – Habitat Models

Name	**FVM-BASED CCHE2D**
Spatial scale	-
Time step	-
Integration with hydrodynamic model	High
Approach to solving governing equation	-solves depth-averaged 2D shallow water equations using finite volume method on a non-staggered, curvilinear grid. -Uses SIMPLE(C) procedures with Rhie and Chow's momentum interpolation technique to handle the pressure-velocity coupling, and employs Stone's Strongly Implicit Procedure to solve the discretized algebraic equations. -FVM version is a finite volume method with a semicoupled procedure for flow and sediment transport
Data needs	-input discharge, assign WS, roughness, and bed elevation
Model output	-The habitat module computes **weighted usable area (WUA)** **overall habitat suitability index (OSI) or ratio of the weighted usable area and the total flow area in the horizontal plane** **Composite suitability index (CSI) product of the corresponding suitability weights for water velocity, depth, and channel property (substrate), as suggested by Milhous (1999).** for a particular species in a life stage of interest under a given flow discharge using the concepts in PHABSIM.
Example applications	-Wu (2004, 2005, 2006) Kananaskis River, Alberta & Topashaw Creek, North Central Mississippi & Wind River Range, WY

Name	**PHABSIM**
Spatial scale	mesohabitat
Time step	
Integration with hydrodynamic model	-PHABSIM WSP uses step-backwater method to obtain 1D representation of flow, STGQ and MANQ models use empirical means to obtain transect based representations of flow. Assume fixed bed profile
Approach to solving governing equation	-IFIM Instream Flow Incremental Methodology -Scott, D. and Shirvell, CS. Critique of the Instream Flow Incremental Methodology and Observations on Flow Determination in New Zealand Regulated Streams: Advances in Ecology. Plenum Press, New York 1987. p 27-43, PHABSIM These assumptions are: (1) that water depth, water velocity, and substrate size are the only physical habitat variables determining position choice by fish; (2) Manning 's n remains constant with changes in streamflow; (3) mean water velocities in individual cells change in the same way as the mean velocity for a cross-section with changes in streamflow; (4) water velocities at 6/10 of the depth affect fish preference; (5) habitat preference curves can be treated as probability functions; (6) habitat variables are independent in their influence on position choice; (7) large areas of less than optimum habitat have the same productive capacity as small areas of optimum habitat; and (8) that areas of stream not occupied by fish are useless. -can use HABTAE, HABEF, HABTAM to get habitat-flow relationship
Data needs	-cross-sections, discharges, coordinate data, suitability curves
Model output	-WSL & velocity calibrated & then simulated -habitat time series (mesohabitat)
Example applications	-W Wu, P Inthasaro, Z He, SSY Wang, 2006 Comparison of 1D and depth averaged 2D fish habitat suitability models -Wu et al Analysis of aquatic habitat suitability model using depth-averaged 2D model PHABSIM uses 1D model to predict depth and velocity and with substrate and cover models habitat suitability, but 1D models ignore transverse flow & eddies. -Gallagher, S.P and Gard, M.F. 1999. Relationship between chinook salmon (*Oncorhynchus tshawytscha*) redd densities and PHABSIM-predicted habitat in the Merced and Lower American rivers, California Can. J. Fish. Aquat. Sci. 56(4): 570–577 -Wentzel and Austin 2000 Fish Habitat Modeling for Instream Flow Assessment combining 2D hydrodynamic and GIS modeling 4th Int Conference on Integrating GIS and Environmental Modeling GIS/EM4 No. 71

Name	**RHABSIM** **-The RHABSIM 3.0 free on request (707) 822-8478 or** **t.payne@trpafishbiologists.com** **http://trpafishbiologists.com/rindex.html#features**
Spatial scale	-Up to 100 cross-sections per data file, 300 data points per cross-section,five Stage/Discharge calibration sets,30 Calibration Flows (HYDSIM) and Simulation Flows (HABSIM).
Time step	-Time Series data files and production run parameters may contain: Up to 600 streamflow columns (50 years as daily data). Up to 10 Flow Releases. Up to 20 Exceedance Percentiles to report (although all 99 may be reported). Weighted Usable Area data may have up to 30 flows and ten species (criteria curves). -Streamflow data matrix can be set up as days by months, months by years, weeks by years or hours by days. Up to 600 columns of data (50 years as daily).
Integration with hydrodynamic model	High
Approach to solving governing equation	
Data needs	-PHABSIM, ASCII files, acoustic Doppler data types can be used -FIELDAT: cross-section raw data, Stage-Discharge data entry worksheet, Weight-distance-slope worksheet
Model output	-FIELDAT: Cross-section graph of bottom profile and velocities. Long-profile graph of high/low banks, WSLs, thalweg and SZF. 3-dimensional view of cross-sections. View entire reach, rotate in full X/Y/Z orientations. Velocity histogram of single or all cross-sections. Complete hydraulic report including wetted cell count, wetted area, wetted width, hydraulic radius and average depth for each calibration stage at each cross-section. Summary Discharge table with average velocity and velocity with meter angles included or not. Velocity histogram of single or all cross-sections. -HYDSIM: hydraulic calibrations Eight Hydraulic Calibration graphs: 1. Rating Curve (WSL vs. Flow) 2.Long Profile WSLs 3. Single Calibration Flow/WSL 4.Cross-section WSLs and Velocities 5.WSL Regression 6.Velocity Adjustment Factor 7.Channel Conveyance Stage/Discharge 8.Roughness Manning Cross-section -HABSIM: Habitat simulation, Weighted Usable Area calculation. Tables of simulated discharge, total surface area, weighted usable area and percent of total area. Cell details include width, depth, velocities, and individual calculated suitability factors for each variable. Cross-section summary reports include WSLs, reach lengths, gross and usable areas, gross and usable areas per 1000 distance, and percent usable for each simulation flow with each curve set at

	each cross-section. Habitat Simulation and Weighted Usable Area graphs: Flow vs. WUA graph with option to show as Flow vs. Percent of Total Area. View any combination of curve sets. Graph cross-sections showing individual suitabilities, WSLs, velocities and bottom profiles. -TIME SERIES: -Flow and Habitat Duration Analysis, Five results graphs: 1. Flow Habitat Duration graphs. Show single or all flows, bounds of WUA data, range of all percentiles or minimum and maximum user input. 2. Flow and Habitat Time Series graphs. Show any combination of available flows. 3. Total Weighted Usable Area histogram. Show "area under curve" for all percentiles or minimum to maximum user percentile range. Color coding shows Release Flows which are greater/lesser than Natural. 4.Compare different runs with Time Series Results Overlay module. Summary table shows comparison results for all flows in Flow and WUA matrices. 5. Four Overlay graphs: Flow Duration overlay graph. Habitat Duration overlay graph. All flows histogram. Single flow histogram.
Example applications	- WEN, MAO, WU Modeling the Influences of Weir on Habitat Condition in Da-Han River, Taiwan - Mark Gard and Ed Ballard. 2003. Applications of New Technologies to Instream Flow Studies in Large Rivers**.** *North American Journal of Fisheries Management* 23: 1114-1125

Name	**CASIMIR-Fish module** -Used mainly in Europe. -uses exclusively 1D hydraulic calculation -Manual p..8 "To inquire about the use of CASiMiR -Fish with 2-D modeling results please contact sje GmbH." -Website: "An expanded version of CASiMiR allows for the use of 2D hydraulic calculations (eg. from HYDRO_AS-2D) to be included as well. Currently under development is a GIS-based Meso CASiMiR model which allows for an unlimited number of user-defined input parameters. smallest watershed 200 sq. km" no link for downloading, no manual -for reference: HYDRO AS-2D performs 2D modeling of bodies of water. The procedure integrated in HYDRO AS-2D is based on the numerical solution of the 2D current equations with Finite-volume-Discretization. In addition to 2D current simulation, HYDRO AS-2D can also simulate pollutant and sediment transport.
Spatial scale	-
Time step	-
Integration with hydrodynamic model	
Approach to solving governing equation	-
Data needs	-cross sections, mapping of substrate conditions, refuge types, shading, water surface elevation at variety of location and under different flow rates or results from HEC-RAS or MIKE11, fish counts to calibrate fuzzy sets
Model output	-reach plan view (water depths, flow velocity, substrate, refuge, habitat suitability) -cross sections -profile views -3D view -fish maps -wetted area -frequency distributions for water d, v, substrate -habitat distribution -composite habitat suitability WUA HHS
Example applications	- Kerle et al.(2002) used Delft3D and CASIMIR

Name	**ELAM – Fish Surrogate Model** -Under the sponsorship of SWWRP and the U.S. Army Engineer Districts of Walla Walla and Portland, the Corps has developed an analysis and modeling technology called the numerical fish surrogate. This technology is used to mathematically decode the three- dimensional movement behavior patterns of individual fish responding to hydrodynamics, water quality, and other stimuli in the aquatic environment. The technology couples a fish swim path selection model to a three-dimensional computational fluid dynamics model. Complex movement behavior patterns are translated into a mathematical description of behavior. - *Eulerian-Lagrangian-Agent Method* (*ELAM*) is a mechanistic mathematical approach for decoding and forecasting the multi-dimensional movement behavior patterns of individual animals responding to patterns in abiotic and biotic stimuli available to engineering (e.g., hydrodynamic, water quality, eutrophication, GIS, etc.) models or *a priori* field data.
Spatial scale	-
Time step	-
Integration w/ hydrodynamic model	- *ELAM* framework to couple a particle-based individual-based model (IBM) to a time-varying simulation of hydraulic and water quality information output from CE-QUAL-W2.
Approach to solving governing equation	-
Data needs	-Development of a Numerical Fish Surrogate for Improved Selection of Fish Passage Design and Operation Alternatives for Lower Granite Dam: Phase I by John M. Nestler used Multi-beam Hydroacoustical Data, computational fluid dynamics CFD modeling of hydraulic conditions, biological information (observations of fish movement)
Model output	
Example applications	- R. Andrew Goodwin, John M. Nestler, James J. Anderson Larry J. Weberand Daniel P. Loucks 2005 Forecasting 3-D fish movement behavior using a Eulerian–Lagrangian–agent method (ELAM) - We describe a Eulerian–Lagrangian–agent method (ELAM) for mechanistically decoding and forecasting 3-D movement patterns of individual fish responding to abiotic stimuli. A ELAM model is an individual-based model (IBM) coupling a (1) Eulerian framework to govern the physical, hydrodynamic, and water quality domains, (2) Lagrangian framework to govern the sensory perception and movement trajectories of individual fish, and (3) agent framework to govern the behavior decisions of individuals. The resulting ELAM framework is well suited for describing large-scale patterns in hydrodynamics and water quality as well as the much smaller scales at which individual fish make movement decisions. This ability of ELAM models to simultaneously handle dynamics at multiple scales allows them to realistically represent fish movements within aquatic systems. We introduce ELAMs with an application to aid in the design and operation of fish passage systems in the Pacific Northwest, USA. Individual virtual fish make behavior decisions about every 2.0 s. These are sub-meter to meter-scale movements based on hydrodynamic stimuli obtained from a hydraulic model. Movement rules and behavior coefficients are systematically adjusted until the virtual fish movements approximate the observed fish. The ELAM model introduced in this paper is called the Numerical Fish Surrogate. It facilitated the development of a

	mechanistic biological-based hypothesis describing observed 3-D movement and passage response of downstream migrating juvenile salmon at 3 hydropower dams on 2 rivers with a total of 20 different structural and operational configurations. The Numerical Fish Surrogate is presently used by the U.S. Army Corps of Engineers and public utility districts during project planning and design to forecast juvenile salmon movement and passage response to alternative bypass structures.

Name	**RMA2** – hydraulic model only
Spatial scale	-
Time step	-
Integration with hydrodynamic model	
Approach to solving governing equation	-RMA2 is a two-dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two-dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.
Data needs	
Model output	
Example applications	-Henderson and Kenner 2003 Application of SMS to Characterize Spawning Habitat for Brown Trout ASCE Conference Proceedings using RMA2 Surface Water Modeling System SMS in Rapid Cr, SD to assess hydraulic conditions and their impact on Brown Trout -Mussetter et al 2004 Two-Dimensional Hydrodynamic Modeling of the Rio Grande to Support Fishery Habitat Investigations ASCE Conference Proceedings RMA2 computer program, a depth-averaged, finite element model that computes water-surface elevations and horizontal velocity vectors in a 2-D flow field, with the BOSS Surface Water Modeling System graphical user interface. The 2-D hydrodynamic results were then combined with habitat use data in an ArcView GIS format to evaluate the quantity, quality, and distribution of habitat at the study sites. Middle Rio Grande and lower Rio Chama -Stewart, Anderson, and Wohl (2005) hydraulic modeling used RMA2 from EMSI calibrated with measured depth and velocity and USU 2D calibrated with measured water-surface elevation. meso-habitat types defined through depth & velocity

Name	**RIVER2D** – hydraulic model only
Spatial scale	-flow boundaries described on p.77 of manual
Time step	-
Integration with hydrodynamic model	High
Approach to solving governing equation	-2D depth averaged finite element model based on conservative Streamline UPwind Petrov-Galerkin residual formulation. -upstream biased test functions are used to ensure solution stability under full range of flow conditions -computational nodes of finite mesh -hydrodynamic component 2D depth averaged St. Venant Equations limits accuracy -pressure distribution in the vertical is hydrostatic -bed features of horizontal size less than 10 depths will not be modeled accurately -slopes in the direction of flow in excess of ~10% will not be modeled accurately -distributions of horizontal velocities over the depth are essentially constant -Coriolis and wind forces assumed negligible -**habitat model is based on PHABSIM weighted usable area (IFIM) approach** -WUA is calculated as an aggregate of the product of a composite suitability index (CSI 0 - 1) at every point in the domain & the "tributary area" (Thiessen polygons) associated with that point where CSI at each node is calculated as a combination of separate suitability indices for depth & velocity and channel index -suitability index for each parameter is evaluated by linear interpolation from an appropriate fish preference curve
Data needs	-bed topography (simple cross sections are generally inadequate, usually need combined GPS and depth soundings for large rivers or distributed total station surveys for smaller streams) -bed topography created by separate application R2D_Mesh -estimate of flow resistance (roughness height, k) -parameters describing transverse eddy viscosity -boundary conditions (inflow discharge, estimated water surface elevation at downstream end of reach) methods
Model output	-models usually 10,000 nodes and 20,000 elements -two horizontal velocity components and a depth at each point or node
Example applications	-Loranger and Kenner (2004) PHABSIM and River2D are comparable for evaluating relative changes in weighted usable area WUA, but not if spatial variation of WUA is considered -Wu (2006) CCHE2Dfvm and River2D gave comparable results for WUA -Schwartz (2004 ASCE Conference Proceedings) Use of a 2D Hydrodynamic Model (River2D) for Stream Restoration Design of High-flow Habitat in Low-gradient Midwest Streams -Steffler and Blackburn 2002 River 2D two dimensional depth averaged model of river hydrodynamics and fish habitat