THE INTERNATIONAL RIVER INTERFACE COOPERATIVE: PUBLIC DOMAIN SOFTWARE FOR RIVER MODELING

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Abstract The International River Interface Cooperative is an informal organization made up of academic faculty and government scientists with the goal of developing, distributing, and providing education for a public-domain software interface for river modeling. Formed in late 2007, the group released the first version of this interface, iRIC, in 2009. The iRIC software interface includes models for two- and three-dimensional flow, sediment transport, bed evolution, groundwater-surface-water interaction, topographic data processing, and habitat assessment, as well as comprehensive data and model output visualization, mapping, and editing tools. All of the tools within iRIC are specifically designed for use in river reaches and utilize common river data sets. The models are embedded within a single graphical user interface so that many different models can be made available to users without requiring them to learn new pre- and post-processing tools. The first version of iRIC was developed by combining the U.S. Geological Survey public-domain Multi-Dimensional Surface Water Modeling System (MD_SWMS), developed at the USGS Geomorphology and Sediment Transport Laboratory in Golden, Colorado with public-domain river modeling code developed at the University of Hokkaido and the Foundation of the River Disaster Prevention Research Institute in Sapporo, Japan. Since this initial effort, other universities and agencies have joined the effort, and the interface has also been expanded to allow users to integrate their own modeling code using Executable Markup Language (XML), providing easy access and expandability to the iRIC interface. The current components of iRIC are described and results from both idealized and practical applications are presented to illustrate the capabilities of the system. Education and supporting documentation including tutorials are available at www.i-ric.org. The model codes, interface, and all supporting documentation are in the public domain and are freely available.

INTRODUCTION

Over the past two years, a group of USGS and academic researchers have been working to develop a new public domain river modeling software package. This software was constructed by combining two existing interfaces: the Multidimensional Surface Water Modeling System (MD_SWMS) developed by the USGS, and a similar system developed at Hokkaido University with support from the Foundation of the Hokkaido River Disaster Prevention Research Institute. The goal of the combined effort was to produce a public-domain, open-source modeling package that could be used by students and practitioners for learning river mechanics and for carrying out applied projects on rivers. The resulting software package is called iRIC, which is an acronym for International River Interface Cooperative. In constructing the software, we intentionally developed an interface that could be used with a wide variety of different kinds of river models, including models that predict flow, morphologic change (bed and bank evolution over time), and habitat for a variety of organisms. Importantly, we also tried to develop a system that was complete in the sense that users could start with raw river data, edit that data, construct a wide variety of coordinate systems appropriate for different modeling techniques, run any of a variety of models, and visualize model results in two and three dimensions. This method frees users from learning a new interface for each model they may want to apply. The system also allows users to easily modify existing models and incorporate their own modeling codes using executable markup language (XML).

In this short paper, the models currently available within the iRIC system are briefly described along with some simple examples. Techniques for altering existing models or introducing new ones into iRIC are also presented. Students or researchers interested in using the iRIC package can find the software, user's guide and tutorials at www.i-ric.org or at wwwbrr.cr.usgs.gov/gstl.

MODELS

The iRIC system currently (2010) includes four models for river flow (three of which include sediment transport and bed evolution) and one habitat assessment model, as described below.

FaSTMECH The Flow and Sediment Transport with Morphologic Evolution of Channels (FaSTMECH) model was originally developed at the USGS for predicting flow and bed evolution in typical rivers (see Nelson and McDonald (1997) and Nelson et al. (2003) for mathematical and numerical details). The model assumes flow is incompressible, hydrostatic, and quasi-steady, where quasi-steady indicates that the dynamic part of discharge variations can be neglected in the equations expressing conservation of momentum. Thus, flow over a hydrograph is approximated by a sequence of steady solutions with different discharges. This approximation is valid unless temporal discharge variations are large, such as found in a dam break or other steep flood wave. FaSTMECH is quasi-three dimensional, which means the model solves the vertically averaged equations expressing conservation of mass and momentum, and then uses that solution along with simple vertical structure functions and the streamlines of the vertically averaged flow solution to assign vertical structure along those streamlines. In addition, the model computes secondary flow components associated with channel or streamline curvature perpendicular to those streamlines. The model equations are solved on a curvilinear orthogonal coordinate system (the so-called "channel-fitted" coordinate system). The model uses an isotropic eddy viscosity characterized by the local depth and bed stress; an additive lateral eddy viscosity terms can also be specified to account for unresolved lateral processes. Figure 1 shows a simple flow solution from FaSTMECH.

In addition to providing flow solutions, FaSTMECH incorporates computations for both bed and total load including simple gravitational corrections to account for the effects of sloping boundaries on sediment motion. These calculations yield sediment flux vectors at each computational grid. Using conservation of sediment mass, these fluxes can be used to determine local erosion and deposition rates. With an assumed time step, these rates predict the bed morphology at some short time into the future, i.e, the evolution of the bed. There are many practical problems where predicting changes in bed elevation is of critical importance.

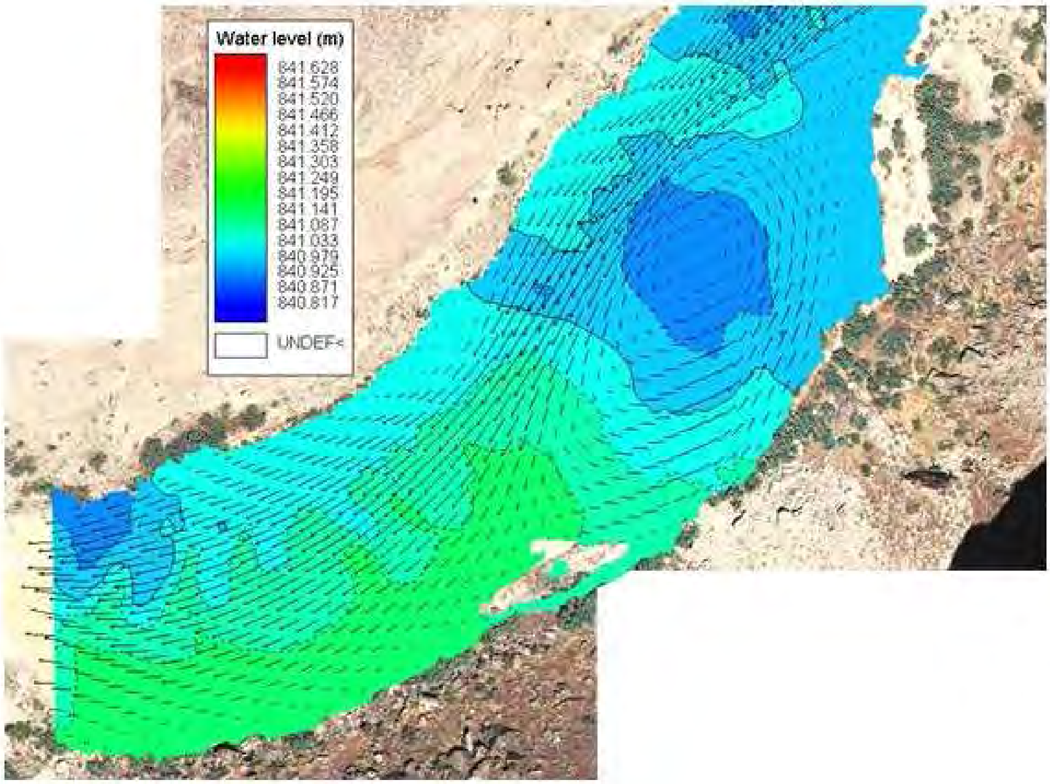


Figure 1. Water-surface elevation contours and vertically averaged velocity vectors from FaSTMECH solution for Eminence Break reach of the Colorado River in Grand Canyon.

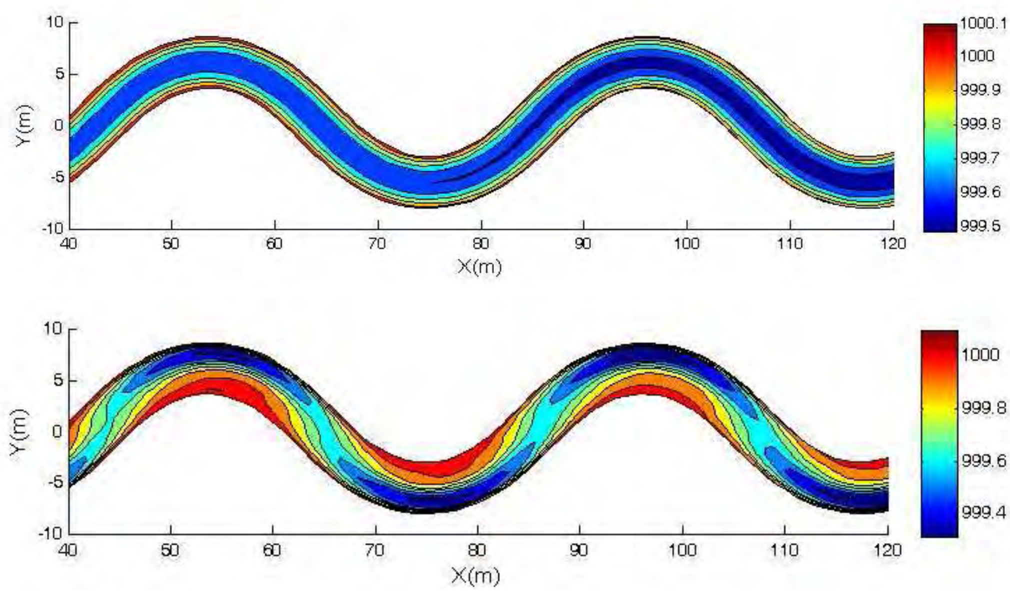
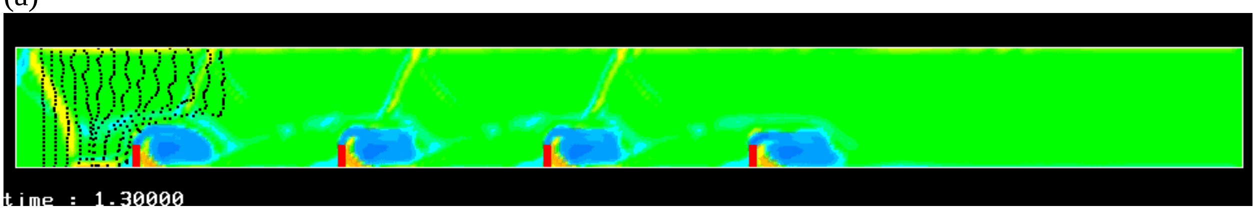


Figure 2. Initial (top) and final (bottom) topography for a simple channel described by a sine-generated curve with crossing angle of 45^o and an initially parabolic bed. The discharge is 1.0 m^3/s and the grain size is 0.5mm. Legends show bed elevation in meters.

This is especially true in situations where flow or sediment supplies from upstream are altered either naturally or anthropogenically and scientists need to predict the channel response to that change. In Figure 2, a simple example of bed evolution is shown for the case of a meandering channel. Initially, there are no point bars in the channel bends, but the model predicts that the point bars will appear on the bed over a period of time, as expected. Similar computations can be made for a variety of common riverine bar forms, including alternate bars and higher mode bars, lending credence to the idea of using the bed evolution approach in more complex, natural situations.

NAYS NAYS is a model developed at Hokkaido University; the details of the model are described in Shimizu (2002). The title of the model is not an acronym; it is an Ainu word meaning “small river”. There are four primary differences between NAYS and FaSTMECH: (1) NAYS is two-dimensional (vertically integrated), (2) NAYS is fully unsteady, (3) NAYS is cast in a general, nonorthogonal coordinate system with variable cell size, and (4) NAYS includes a much more sophisticated method for treating turbulence that includes both a horizontal large-eddy simulation and a suite of turbulence closures. The nonorthogonal coordinate system allows more precise fitting of the coordinate system to suit arbitrary channel curvature and variable width. More importantly, the more detailed treatment of turbulence and large eddies allows predictions of time-variable behavior even for steady discharges.

(a)



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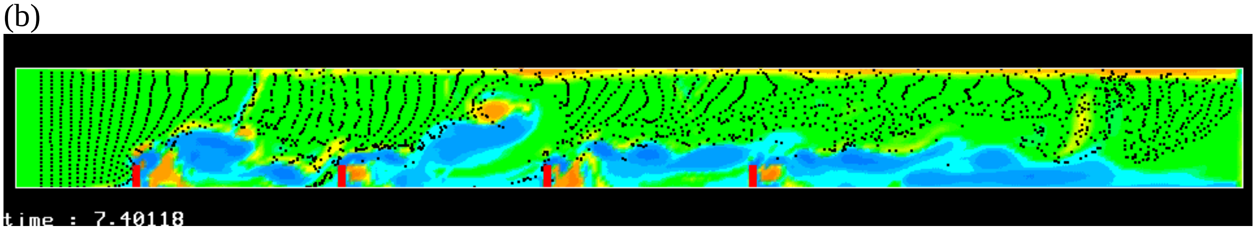

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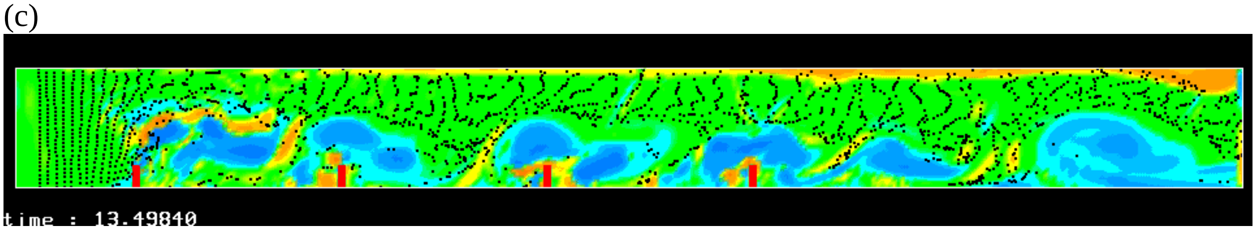


Figure 3. Particle motion and vorticity contours for a NAYS computation of flow through a simple channel with four spur dikes. Flow is left to right and the images are shown times of (a) 1.3s, (b) 7.4s, and (c) 13.5s.

Figure 3 shows computed particle locations and vorticity contours for a simple, straight, flat-bedded channel with four spur dikes. A FaSTMECH solution for this case would yield a steady result with eddies behind each spur dike similar to that found in the Colorado River example shown in Figure 1. While this is the correct time-averaged solution, NAYS allows prediction of the instantaneous flow field, including vortex shedding at the channelward ends of the spur dikes and strong unsteadiness in the separated flow in the lee of each spur dike. Although predicting this detail requires greater computational time, the temporal variability is important for certain problems, including the morphologic evolution of deposits in the lee of the simple spur dikes shown here. NAYS is currently the most sophisticated model within iRIC in terms of handling advection of momentum and strong local unsteadiness.

NAYS also includes full sediment-transport capabilities and morphologic change prediction, so the impacts of unsteadiness on bed change can be assessed with this approach. Furthermore, NAYS provides a variety of particle-tracking information. Figure 4 shows a realistic application of NAYS to flooding on the Red River near Hanoi. All model results from iRIC can be displayed as either still images or animations suitable for display in any software using kml input file format, as exemplified in Figure 4.

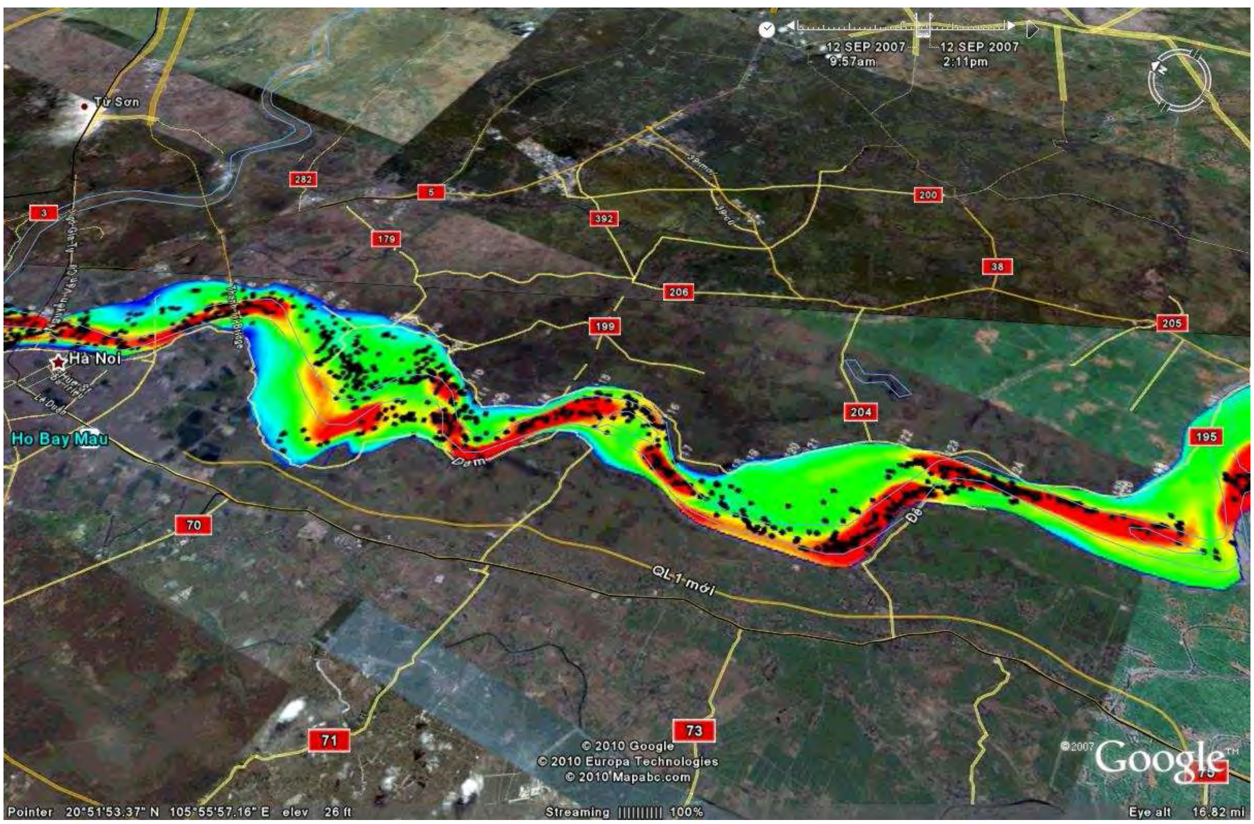
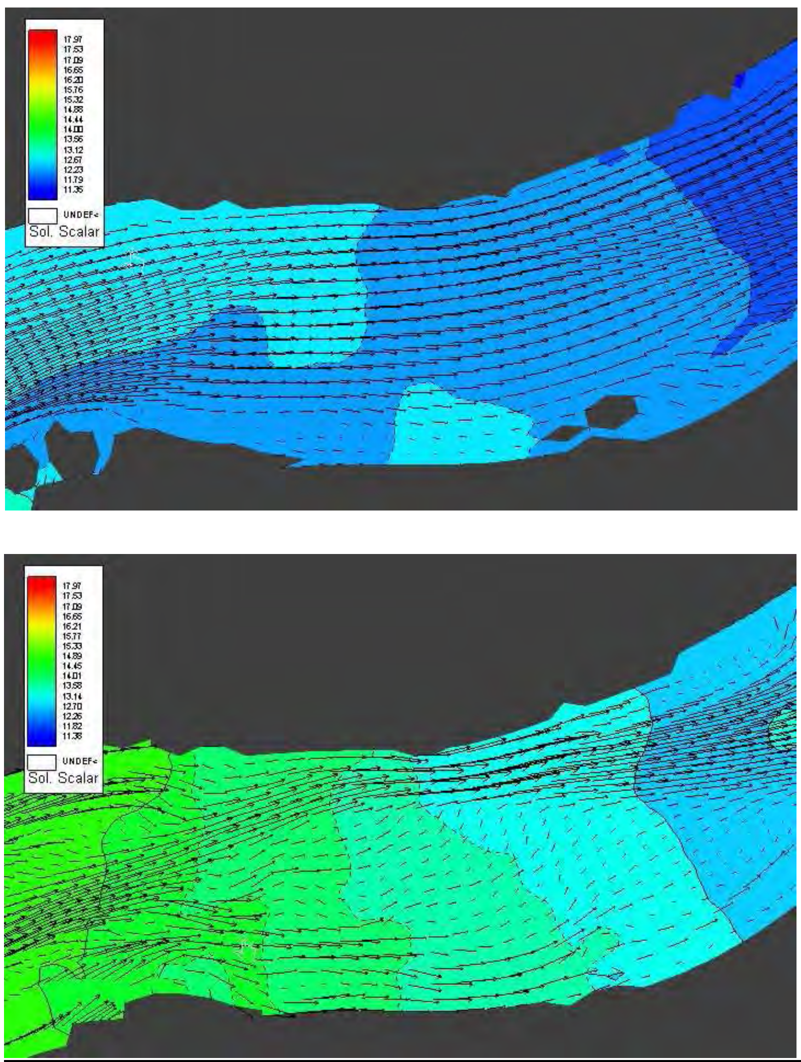


Figure 4. NAYS model result showing particles moving with the flow and color contours of velocity magnitude (red represents high velocity, blue low) for a reach of the Red River near Hanoi. Model output is shown in Google Earth for educational purposes only and does not imply endorsement by the U.S. Geological Survey.

MORPHO2D MORPHO2D was developed at Kyoto University; mathematical and numerical details of the model are given by Takebayashi (2005) and Takebayashi and Okabe (2009) . Like NAYS, this model is two-dimensional, fully unsteady, and is cast on a nonorthogonal structured grid with variable cell size. Unlike NAYS, MORPHO2D does not include numerical treatment for horizontal large-eddy simulation. The strength of this model lies in its detailed treatment of mixed grain sediment, vegetation effects, and interactions between sediment motion and vegetation. This model treats vegetation form drag effects explicitly through drag terms in the equations of motion, rather than simply treating them through specification of local roughness; an example is shown in Figure 5. The treatment requires detailed mapping of stem diameters and densities and other parameters related to the specification of vegetation form drag. While there are some simple at-a-section or 1-dimensional models that treat vegetation roughness explicitly, this is one of the first multidimensional models that includes this treatment. The MORPHO2D approach also includes a groundwater/surface-water interaction submodel.



(a)

(b)

Figure 5. Water-surface elevation contours and velocity vectors for flow over a vegetated bar in the Yoshino River without (a) and with (b) the effect of vegetation included in MORPHO2D.

STORM SToRM stands for System for Transport and River Modeling. This model is a two-dimensional flow model using a completely unstructured coordinate system described by a triangular mesh. Details on the model can be found in Simoes (2009). Although this model does not currently have sediment transport or morphodynamics, it has two other distinct advantages relative to the other models. First, because it is an unstructured grid, it easily allows very complex channel geometries, including multiple inflows and outflows. Second, the computational methods were chosen to allow treatments of rapidly varied flow, including dam break flows in initially dry channels, for example. Figure 6 shows an example calculation which illustrates both of these features. The diagram shows a plan view of a levee break where river water debouches onto a flood plain in an urban area. Typically, solutions for this kind of problem are found using the ground-surface elevation ignoring the presence of buildings or other structures. For the unstructured grid model, setting boundary conditions on arbitrarily shaped obstacles is relatively simple, so the buildings can actually be explicitly included in the model. Notably, predictions of water-surface elevations including the building are locally significantly different than those computed using a model that ignores the buildings, as there are local runup effects on the buildings themselves, as can be seen in Figure 6. The water-surface elevation field in Figure 6 is only an instantaneous snapshot of this rapidly varying flow field.

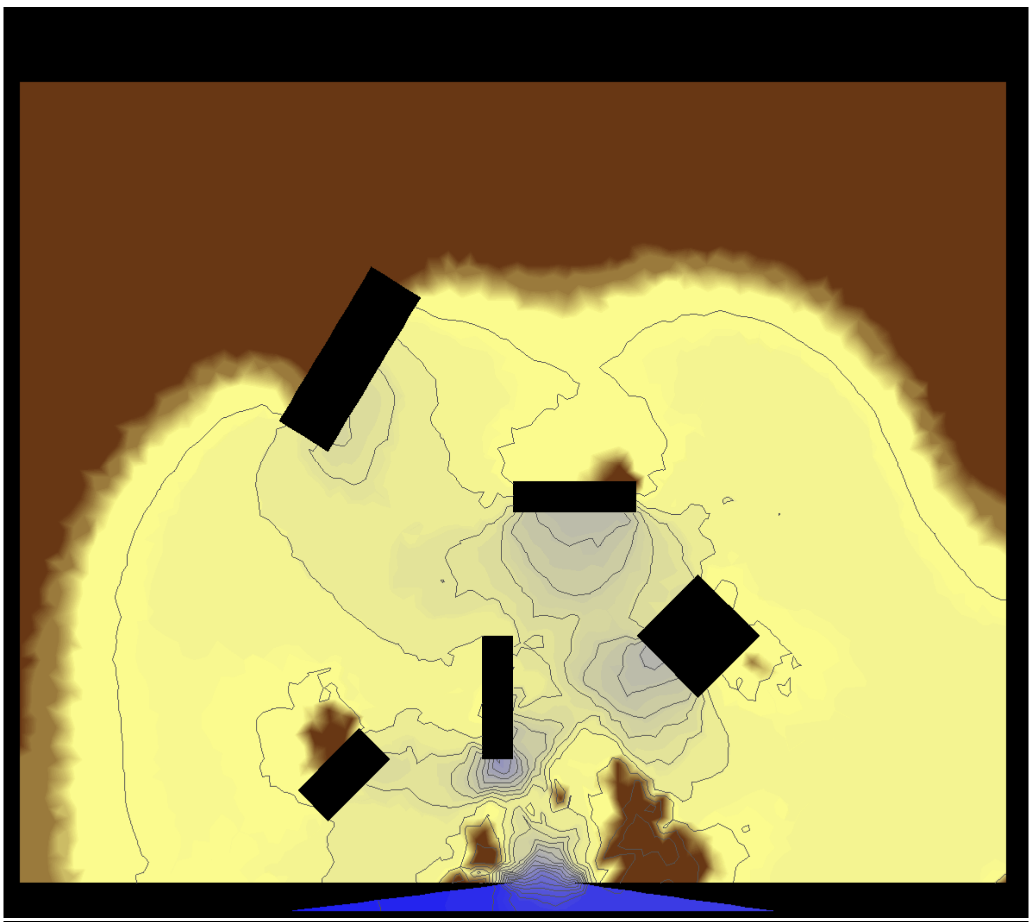


Figure 6. Contour map of water-surface elevation produced by levee break (lower center) flowing out into urban area with structures (black). Blue corresponds to relatively high water levels, yellow to relatively low; brown is not indundated.

Habitat Calculator The Habitat Calculator is an application for calculating the spatial distribution of a user defined habitat index by combining the hydraulic output from the iRIC two-dimensional models with appropriate Habitat Suitability Curves (HSC) expressing the quality of habitat for a given species (or life stage of a species). For example, model-predicted values of depth, velocity, and substrate could be combined with suitability curves for each to develop a map of habitat index on the grid (Hardy, 1998). Suitability curves can be imported as text files or specified as a user-defined power functions or threshold values. Quantities such as substrate or distance-to-cover which are not output from a model can be mapped to the grid from either measured or calculated data outside the iRIC application. The user can calculate the geometric mean of any combination of habitat indices or multiply by another habitat index to create a weighted index. For example, the geometric mean of velocity and depth indices can be multiplied by the distance-to-cover index. Output also included the weighted useable area (WUA) of each habitat index calculated, from which plots of WUA as a function of time or discharge can be developed. Thus, the simple methodology allows assessment of habitat area for a suite of flows or for flows before and after modification of the channel or hydrograph. Figure 7 shows a simple schematic depiction of the process of habitat assessment facilitated using the habitat calculator in iRIC.

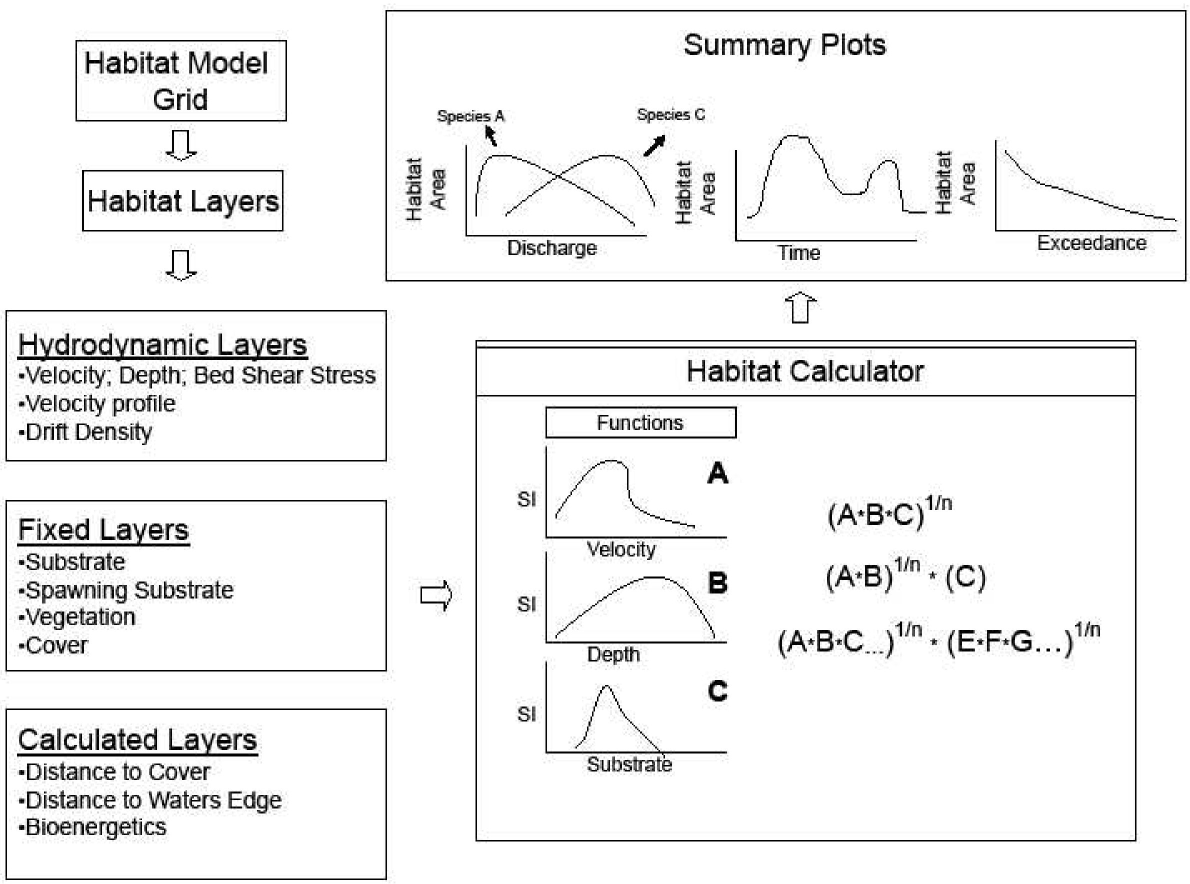


Figure 7. Summary schematic of the habitat calculator methodology incorporated in iRIC.

INCORPORATING NEW METHODS IN iRIC

One of the most important features of iRIC is that it provides an easy methodology for users to modify the models contained within the interface or to introduce their own riverine models into the iRIC framework. In this section, that capability is briefly described, but in order to make this clear, some information about the basic structure or iRIC is required.

As already described above, iRIC is a pre- and post-processing software application and framework for computational models of flow and sediment-transport in rivers. The application is a Graphical User Interface (GUI) that allows the model user to build, run, and visualize the results of the system's computational models. The GUI provides tools for building both structured and unstructured grids, defining topography and other boundary conditions on the grid, and defining grid-dependent values such as grain size, vegetation, and obstacles by mapping measured values to the grid or by creating user-defined polygons with attributes of grid-dependent value. Model calculation conditions are easily edited from a single model-independent menu. The application also provides the ability to visualize and post-process results, such as mapping time-dependent solution scalar and vector quantities to Google Earth. Figure 8 shows a schematic of the overall iRIC structure and the relation between the iRIC interface and various models (solvers).

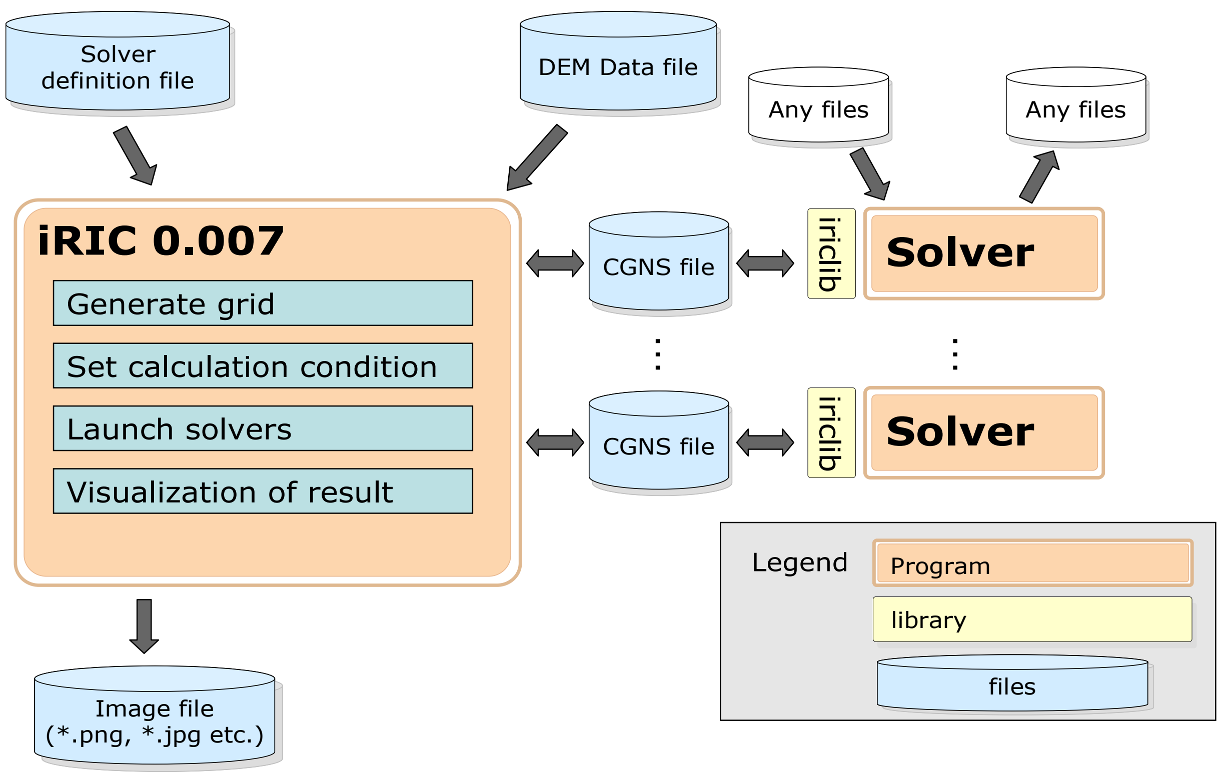


Figure 8. The overall structure of the iRIC interface and the linkage to solvers implemented in the interface.

As shown in Figure 8, solvers only interact with iRIC in two simple ways. First, an executable markup language file (XML) called the "solver definition file" provides information about the model, including inputs, outputs, needed dialogues, parameters, and so forth to the iRIC interface. Essentially, this part of the iRIC framework provides an easy structure for model developers to develop a graphical user interface (GUI) for their models. In addition to specifying the data, grid and calculation condition requirements of the model, the XML file can be formatted to create rich and user-friendly dialogs at run-time for easy specification of model calculation conditions. Second, both model input and output is accomplished by reading from and writing to a model-independent CGNS database (Legensky and others, 2002; http://www.cgns.org). High level software interfaces (in iRIClib on the schematic in Figure 8) are provided in both C and Fortran for model developers to easily adapt their I/O routines to the CGNS file format. The IRIC framework makes it easy for model developers to make changes in existing models and simply reinitialize the XML file to introduce those model changes into iRIC. The structure also allows users to develop a GUI for their own models. By using a consistent and user-friendly GUI for a range of models, it becomes much easier for the model user to compare modeling approaches and choose the best model for their modeling context.

FUTURE DEVELOPMENT

The most significant advantage of making the iRIC platform function with a wide range of models is that it provides an easy way to add new developments or make improvements to existing ones. Currently, members of the cooperative group that built the first version of the software are working on several new models and extensions to existing ones. These include adding sediment transport to SToRM, introducing bioenergetics modeling into the habitat assessment tools, adding a non-hydrostatic fully three-dimensional model, and developing a model for predicting inundation in urban flooding situations.

More information on iRIC, including the software itself, user's guide, and tutorials for all of the current iRIC models are available on the web at www.i-ric.org and wwwbrr.cr.usgs.gov/gstl.

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