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The international river interface cooperative: Public domain flow and morphodynamics software for education and applications

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ABSTRACT

This paper describes a new, public-domain interface for modeling flow, sediment transport and morphodynamics in rivers and other geophysical flows. The interface is named after the International River Interface Cooperative (iRIC), the group that constructed the interface and many of the current solvers included in iRIC. The interface is entirely free to any user and currently houses thirteen models ranging from simple one-dimensional models through three-dimensional large-eddy simulation models. Solvers are only loosely coupled to the interface so it is straightforward to modify existing solvers or to introduce other solvers into the system. Six of the most widely-used solvers are described in detail including example calculations to serve as an aid for users choosing what approach might be most appropriate for their own applications. The example calculations range from practical computations of bed evolution in natural rivers to highly detailed predictions of the development of small-scale bedforms on an initially flat bed. The remaining solvers are also briefly described. Although the focus of most solvers is coupled flow and morphodynamics, several of the solvers are also specifically aimed at providing flood inundation predictions over large spatial domains. Potential users can download the application, solvers, manuals, and educational materials including detailed tutorials at www.-i-ric.org. The iRIC development group encourages scientists and engineers to use the tool and to consider adding their own methods to the iRIC suite of tools.

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1. Introduction

In this paper, we introduce a recently developed suite of public-domain tools for computing flow and morphodynamics in geophysical flows, with particular emphasis on rivers and other similar channels. The package was developed by an international group of scientists and engineers on an entirely voluntary basis. This group named itself the International River Interface Cooperative; the software developed by that group goes by the same name, generally shortened to iRIC. The motivation for the development of the software and a repository of manuals, tutorials, and other educational materials accompanying that software was two-fold. First, this group of researchers felt that undergraduate and graduate students had inadequate access to state-of-the-art tools for understanding and predicting morphodynamics in rivers in a physically-based manner. Second, we felt that recently developed tools for predicting flow fields and morphodynamic adjustments of channels to natural or anthropogenic changes in flow, sediment supply, or channel form were sufficiently developed to move from the research arena into practical applications. Thus, our initial challenge was to develop a user-friendly software system that would bridge the range of responses from relatively simple bar and bedform instabilities in idealized channels (as required for education) all the way to calculating realistic assessment

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of flow and channel change for evaluating proposed channel restorations and other engineering projects in rivers.

To a significant degree, the timing of the development work described here was dictated by the evolution in perspective on channel form and process. A great deal of early river science was predominantly based on a one-dimensional view of river processes, with emphasis on streamwise changes in discharge, loads, dispersion, etc. However, over the last few decades, this emphasis has shifted to a more spatially distributed view of river process [4,7]. This change was driven by efforts to better understand physical river morphology, especially forms like point bars and alternate bars, but was also driven by the research of biologists and ecologists that pointed out the importance of local variations in flow, depth, substrate and other physical variables in riverine ecosystems (e.g., [9]). This attention to a more spatially explicit view of rivers was supercharged by the development of measurement technology that allowed detailed realizations of flow, depth, water-surface elevation, and more. As ADCPs, multi-beam echo sounders, laser scanners, and survey-grade Global Positioning Systems (GPS) became readily available, so too did unprecedented data sets for testing and refining computational and conceptual models for river flow, morphodynamics, habitat, and vegetation. Scientists from outside the typical river science fields of civil engineering and earth science began to need and use computational models for flow, sediment transport and morphodynamics. One-dimensional models were of little use, as the need was specifically for models that provided detailed, spatially explicit information (at least 2-dimensional and in some cases, 3-dimensional approaches). Over the past twenty years or so, multidimensional models that had been primarily tools for developing simple understanding of bar forms in rivers evolved into practical tools for a wide variety of real-world river problems. This includes the assessment of river restoration plans (e.g., [19]), prediction of channel response to a variety of changes (dams, diversions, sediment mining or augmentation), prediction of fish habitat [10] and vegetation effects [11], detailed prediction of extreme flood inundation and flow patterns well outside the river channel (e.g., [13]), prediction of bar and bedform sedimentology [24,25], and so forth.

Basically, all these changes suggested that it was time for the model developers to make state-of-the-art research tools for river modeling available to students and other non-specialists so they could assimilate these tools into their own suite of capabilities, both in order to better understand river flow and morphodynamics at a fundamental level, and to gain the ability to make meaningful assessments of various river processes using modeling tools for practical river problems. At our initial meeting in 2009, the members of the iRIC group made a joint commitment to try to develop and supply both software tools and educational materials for river modeling. From the beginning, our commitment was to make this work freely available in the public domain with open-source code and support for other developers. In this paper, we describe the structure of the iRIC modeling interface, present basic information on the solvers contained within iRIC, and provide more detailed information along with some simple examples of iRIC computations for a subset of these solvers. All the iRIC software and educational materials are freely available at www.i-ric.org.

2. Structure of iRIC

At our initial meeting in 2009, iRIC members discussed basic principles of river modeling and subsequently made use of those observations in designing the structure of iRIC. These general ideas are adequately captured by the following observations: (1) no single model is sufficient for efficiently dealing with all the flow and morphodynamic problems iRIC should address; (2) models are evolutionary in the short term; (3) models are transitory in the long term; (4) building an interface for each model is inefficient, as many tools and algorithms can be shared between different models; (5) a great deal of the modeling process involves editing and otherwise improving large data sets, so tools for that procedure should be part of iRIC; (6) importing data and imagery for inclusion with model results is of central importance; (7) we are unlikely to construct every visualization tool that might be desired by our users, so we need to make model inputs and outputs readily available in a compact, generic format for importation into any of a suite of common visualization tools (e.g., Matlab, Tecplot, Python, VisIT, Paraview, Google Earth, etc); (8) because there are many different objectives within our user audience, output files should be user specifiable; and (9) as many solvers are computationally intensive, parallelization of solver codes should be easily treated within iRIC.

With all these in mind, the general structure of iRIC was conceptualized as shown in Fig. 1. The fundamental feature of this design is that solvers are kept separate from the interface itself. Solvers interact with the interface through a solver definition file that instructs the interface how to configure itself for the solver to be used (an executable markup language, or XML, file) and through a compact binary data structure that exchanges information between the solver and the interface itself. Thus, iRIC is only an interface, although it contains many generic tools for importing and editing basic data, importing a variety of other kinds of information, visualizing both input and computed data in 2- and 3-dimensions, and constructing computational meshes and grids, including orthogonal, curvilinear orthogonal, and general non-orthogonal grids as well as triangular and quadrilateral meshes with quality controls and local refinement. With the list of goals in mind, the fundamental feature of the method chosen is the relative simplicity of adding new solvers or modifying existing ones. In this case, the interface itself is not recompiled, the developer only makes changes in the solver definition file and adds the new or modified executable solver to the iRIC solver folder. Thus, in addition to the solvers offered by the iRIC group, developers may freely insert their own solvers into the iRIC framework. This process is straightforward in the case of solvers written in C or Fortran, as we supply a library (iriclib, see Fig. 1) that allows easy access to the binary data structure. The binary data structure used in iRIC is CGNS (Computational Fluid Dynamics General Notation System, see [27,28]) which was originally developed in the aeronautics industry; this format can be easily read into common graphics packages. Developers wishing to include solvers in iRIC should consult the iRIC Developer's Guide available at www.i-ric.org.

Because of the ease with which solvers can be added (or modified and reinserted) into iRIC, the interface is a complete community-based tool for sharing modeling codes and modeling results. The initial version of iRIC contained only 4 solvers, but 13 are now available, with several others in the preparation process. Importantly, once the user has learned the interface capabilities using any single solver, using other solvers is straightforward, as the interface retains the same structure and basic capability for any choice of solver. This makes comparison of different approaches simple and allows users to choose the solver that is most appropriate for their problem without concern about the need to learn a new interface.

3. Solvers

Initially, the solvers in iRIC were all multidimensional flow models tailored specifically for river applications. Most of these initial solvers also treated sediment transport and bed evolution. Over the past few years, this suite of models has evolved to include bank erosion, vegetation effects, more comprehensive treatments of sediment transport, and other improvements. At the same time, additional solvers have broadened the scope of iRIC, which now includes a 1-dimensional flow model, a model for predicting the evolution of bedforms, a hillslope runoff model for generating hydrographs, a tsunami model, and a model for predicting the behavior of debris and mud