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Use of HEC-RAS and HEC-HMS models with ArcView for hydrologic risk management

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Abstract: The paper discusses how the well known USACE HEC models, RAS and HMS, are fully integrated within the decision support system of the Romagna River Basins in order to predict flood effects. The models are fully available from the web and cope with such a variety of problems as rainfall-runoff modeling, river and civil works hydraulics, and the mapping of hydraulic hazard. The paper illustrates the methodology followed to integrate existing topographic and hydrologic data, calibrate both hydrologic and hydraulic models, and produce maps directly usable in land planning. The paper stresses the organizational problems involved in the development of such a decision support system, and sketches the main issues in pipelining general planning analysis and river training and management design, in order to achieve a fully self-updating decision support system which feeds back analysis results to design evaluations and again updated information from developed works to the prediction models.

Keywords: Hydrologic and Hydraulic modeling, river basin planning

1. INTRODUCTION

Increasingly, there is a need for supporting environmental planning choices with simulation and prediction models, due to the development of regulatory and planning tools, such as the river basin masterplan, which involve a direct link between the description of physical phenomena (such as floods) and the attribution of land planning constraints. Usually, morphologic analyses were in use for the definition of river floodplain, but the need to associate to the flooding of an area a return period and thus a risk measure requires to use computational hydraulic-hydrologic models.

Similarly, there is a need to establish rules for the use of water resources which require to know the flow virtually in each section of the hydrographic network, for instance when authorizing the maximum rate of abstraction for irrigation taking into account the water budget for the whole basin in order to support water ecosystem equilibria.

In recent years, the Romagna River Basins Authority (RRBA) has been involved in an effort towards making a system of the available hydrologic and hydraulic information over its area of interest. These data include:

- historical registrations of rainfall, temperature, river discharge at a few gauge stations, made available until late 1970's from the National

Hydrographic Survey (Servizio Idrografico e Mareografico Nazionale – SIMN)

- a hydraulic cross section database describing the morphology of the rivers in the area, currently under upgrading with present-state topographic survey

- a digital terrain model of the whole river basins

- a recently established rainfall and temperature gauge network with remote data acquisition

- a network of water level gauging stations with remote data acquisition

- a campaign of field measures of discharges during the last years.

The above mentioned data were usually exploited for very general purposes and only in a few cases were of real support to river management planning and river training works design. The development of an early stage of the river basin masterplan, aimed at coping with hydrologic risk, has put in full evidence a need for pipelining the procedures of basin planning and design, basing both on shared databases and computational procedures. The evaluation of areas at risk and the implementation of measures of risk mitigation delineate a dynamic context in which an upgraded representation of the river network and its hydrologic parameters play a relevant role in supporting environmental as well as urban planning.

The availability on the web of freeshare software for hydrologic and hydraulic modeling, tightly

coupled with the GIS package ArcView (ESRI, 1997) through dedicated extensions, gives the river basin authorities a unique chance to build a decision support system which has the following points of strength:

- it is easily shared between the river basin authority and the technical services devoted to develop the design and maintenance of river and hydraulic works efficiency;
- it copes with needs of geographic representation of data and modeling results;
- it facilitates the agreement on the design values of the variables (rainfall and discharge) which are always subject to relevant uncertainty and, when evaluated under different assumptions, can give discrepancies which reflect in different rules and constraints of land use and in different design choices;
- it favours a “system view” on the river network, supporting computations which do not involve consideration of the river reach of interest in itself, but also the effects downstream and upstream. This is particularly important in a situation in which different technical services manage separately different parts of the same river.

In the following, a general framework for the operation of the integrated hydrologic and hydraulic models at the RRBA is described, and expected benefits in terms of hydrological management are described.

The paper focuses particularly on the full exploitation of the data presently available to build the rating curves in the four main rivers, which allow to reconstruct the water budget and to identify rainfall flood response.

2. DESCRIPTION OF THE MODEL HEC-RAS

The model package “River Analysis System” (RAS) by the US Army Corps of Engineers – Hydrologic Engineering Center (HEC) includes:

- a steady flow model (the computing routine SNET)
- an unsteady flow model (the routine UNET)
- the consideration of a wide range of hydraulic works, bridges, storage areas
- facilities for hydraulic design such as computation of localised scour at the piles of a bridge

Due to its capability of describing that wide range of physical processes it has proven very helpful in supporting all phases of river management planning.

A full description of the model and its computational schemes is given in [USACE, 1997, 2001]

Recently, a geographic information system (GIS) interface called HEC-GeoRAS has been developed at the University of Austen, Texas, by improving a previously issued Arc-View extension (AV-RAS) [Maidment and Djokic, 2000].

This modeling extension allows to cope with quasi-2D aspects of flow through connecting the river geometry with a digital terrain model in the form of a Triangulated Irregular Network (TIN). In this way, the distributed output provided by HEC-RAS for each cross section is interpolated between cross sections and results in a water depth and a water velocity surface. When compared with a fully-2D flow model, the only limitation is in giving a flow velocity which disregards transversal components of the flow field vectors, on their side usually deemed negligible in stream hydraulics.

Based on the above sketched model, it is possible to map with appreciable realism the morphology of river and floodplain and to detect the flooded areas for a discharge and flood hydrograph with given return period.

The model HEC-RAS delineates a fully functional modeling environment which allows to cope with virtually all types of problems concerning river networks, and for this reason it has been taken as a basic part of the general hydrologic modeling system at the RRBA, as better described in section 5. In the application case described below, the advanced capabilities of the software for modeling hydraulic singularities such as bridges and weirs was exploited to derive theoretical rating curves based on steady non uniform flow.

3. DESCRIPTION OF THE MODEL HEC-HMS

HEC-HMS is a rainfall-runoff model which allows to calibrate a few different models including, at the event based level:

- Clark’s model
- Snyder’s model
- SCS-UH model
- Kinematic wave model

Runoff volume is computed through the well known SCS_Curve Number methodology, or alternatively using a runoff coefficient, or separated from the total rainfall using infiltration laws such as Green and Ampt Loss model.

As far as continuous simulation is concerned, a nonlinear reservoir model is made available which includes the following processes:

- Evapotranspiration according to the SMA (Soil moisture accounting) model

- Baseflow, as a constant, monthly varying, component, or through an exponential recession or a linear reservoir model.

HEC-HMS comes with an Arc-View extension which automates the construction of the model input and especially the averaging of soil type and land cover properties, topography and local drainage delineation, through the full exploitation of GIS hydrographic delineation capabilities.

Further details can be found in [USACE, 2000].

For reasons similar to those for HEC-RAS, HMS also was included in the general hydrologic modeling system at the RRBA, as better described in section 5.

In the application case described below, the capabilities of HMS for rainfall-runoff simulation have been exploited for describing single events on which the rating curves to be estimated were tested. Thus continuous simulations were not performed and the modeling was limited to single events.

4. USE OF THE MODELS FOR THE RECONSTRUCTION OF RATING CURVES AND RIVER BASIN WATER BUDGET

The application case hereby described concerns the reconstruction of discharge rating curves in the four rivers under the jurisdiction of the RRBA. The study area is a region in North-Central Italy bounded southward by the Apennines, eastward by the Adriatic coast including four main rivers (Savio, Lamone, Ronco and Montone) with catchment areas ranging from about 400 to about 700 square km. Soils are quite uniform all over the area, with a dominance of sandstones and clayey soils, morphology is quite mild and regular, elevations range from the sea level to peaks of about 1600 m asl on the Apennines, and the response to rainfall is quite quick resulting in moderately high peak discharges of short duration, with long periods of low flow due to the dry season form may to september. The reader is referred to Pistocchi *et al.*, elsewhere in this book, for the location of the area.

Time series of rainfall and water depth at a few gauged stations are available for the basins since 1995, but so far no systematic estimation of water budget and flood parameters has been done due to the lack of reliable rating curves to convert the water depth measurements into discharge values. Thanks to the availability of the modeling system provided by the HEC-RAS and HEC-HMS packages, it has been possible to reconstruct the rating curves. For the purposes, a few measures of depth and discharge were available, although referring mainly to the lower water depths. These

measurements were used as the starting point of the analysis described in the following .

First of all, a power law has been fitted to the experimental data in order to have a rough estimate of the rating curve expression.

The power law used involves three calibration parameters, namely an exponent b , a coefficient a and a reference depth at zero-flow h_0 , according to the following expression:

$$Q = a (h - h_0)^b \quad (1)$$

Q being the flow rate and h the water depth (figure 2).

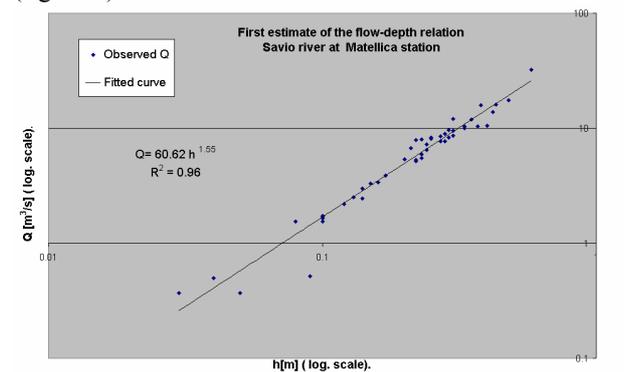


Figure 2 – example of estimation of the rating curve from field data

Later, a steady nonuniform flow model has been calibrated with the same experimental data as before, by this relating the river reach geometry to the rating curve. An estimate of local Manning's roughness is provided by this calibration. The steady nonuniform model provides a relationship between water depth and discharge from which the parameters a , b and h_0 can be extrapolated; this allows to provide a range of variability of the parameters depending on which calibration criterion is adopted. No automatic calibration has been made, but all evaluations have been made by informal trial and error procedures in the spirit of data mining. Due to the lack of flow measurements with high discharges, the range of variability of the parameters has resulted quite high at this stage.

This range has been subsequently reduced by trial and error procedures aimed at excluding those values which were deemed not applicable, on the basis of:

- a constraint of consistency between discharges estimated in two sections along the same river (the hydrographs in two subsequent sections need to be similar, the discrepancies being in ranges explainable by flood routing processes and lateral discharge contributions)

- a constraint on rainfall-runoff balance for single events (the ratio of rainfall input to runoff output is expected to stay between 0.4 and 0.7; about four flood events have been considered for each river station, and the flood event has been separated from the baseflow through commonly used practical methods [Maione, 1995].

The parameter range has been eventually reduced to the final values reported in the following table.

	Manning n [m ^{-1/3} s]	[α]	[β]	[h_0]
Savio- Cesena	0.03	8.12-8.8	2.24-2.31	
Savio- Matellica	0.011	60.62-67.4	1.5-1.55	
		69.84-71.17	1.13-1	
Ronco- Ronco	0.031	22.5-20.37	2.41-2.42	
		1.5-1.52	1.49-1.54	0.02-0.08
Ronco- Coccolia	0.015	13.2-13.62	2.1-2.21	0.05-0.15
Montone- P. Eraldo	0.015	7.8-8.1	1.65-1.85	0-0.1
Montone- P. Vico	0.015	8-8.8	1.6-1.71	0.10-0.23
Lamone- Sarna	0.02	8.8-10.34	2.27-2.38	0.02-0.06
Lamone- Reda	0.025	5.81-6.12	1.93-2.16	0-0.06

Table 1 – Rating curve parameters for expression (1). The presence of two different flow-discharge relations for some stations is due to the different behavior in low and high flow conditions, with a transition range of flow depth [m] evidenced between the two values of the parameter α .

A calibration of event-based rainfall-runoff models using HEC-HMS has been also accomplished, to test the system identifiability of the rainfall-runoff transformation using the computed rating curves. Infiltration has been modelled through the “Initial and constant” method, runoff transformation through the Clark Unit Hydrograph and open channel routing through the Muskingum model after calibration with a trial and error procedure. For parameters with physical meaning the obtained value were found to reflect acceptably the basin or event characteristics; for example the K parameter in Muskingum model ranges from 1 to 5 hours and is related to the delay between discharge peaks measured in the two river stations, while infiltration rate in Initial and constant method ranges from 1 to 2 mm/hr, that is generally acceptable for medium-low permeability areas. Although calibration and hydrologic modeling details are beyond the scope of the paper, one can have an idea of the acceptability of the results obtained by inspecting figure 3 as an example

representing rainfall, discharge hydrograph given by the rating curve judged as the “best available solution” (in the sense explained below) and the one obtained through hydrologic modeling.

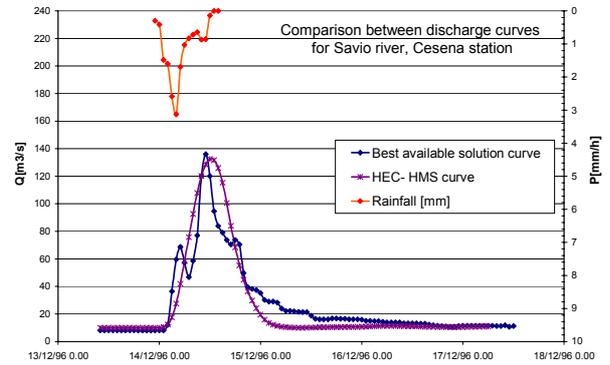


Figure 3 – example of comparison between the discharge hydrograph given by the best available solution and the one obtained with HEC-MHS

The choice of the rating curve parameters representing the best available solution has been done subjectively, starting from the average value for each parameter and modifying it, if necessary, inside the range to better represent the discharge as compared to rainfall, also considering the possibility to identify parameters of Clark's model which keep stable over the different events considered, and to better respect the constraint of consistency between flow estimated in two sections along the same river over the entire time series. No continuous simulation has been done in this case due to some incompleteness in data. By applying Taylor's rule of propagation of variance, assuming as a variance estimation the range of variability of the parameters, one obtains the theoretical uncertainty associated with the discharge estimation provided by the rating curve as a function of the input variable h . An example of the uncertainty function is given in figure 4. Using the previously computed rating curves, it is possible to convert the time series of water depths into series of flow thus allowing to evaluate water budgets according to the classical Thorthwaite's procedure.

As an example, figure 5 shows the estimated components of water budget at monthly time step. Figure 6 shows the impact of uncertainty of discharge estimation (as the one in figure 4) in defining the monthly discharge output (for Savio basin in this case).

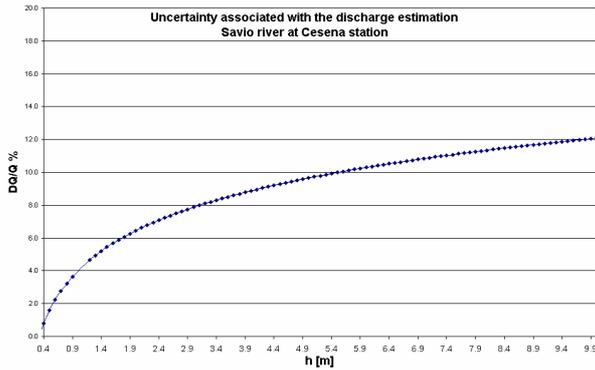


Figure 4 - theoretical error propagation in flow rate estimations

5. THE USE OF MODELING SYSTEMS WITHIN THE PROCESS OF BASIN PLANNING AND MANAGEMENT

The modeling system here presented copes with a basic need of standardization of the databases. The main goal is to provide an environment in which all computations made by the different regional and municipal offices involved in river training, hydraulic works and similar activities can converge, share the same fundamental assumptions as far as roughness coefficients and hydrologic data are concerned, and keep a continuous updating of the database including ongoing works, so to have a consistent and always realistic representation of the river network, its critical reaches and the priorities of intervention.

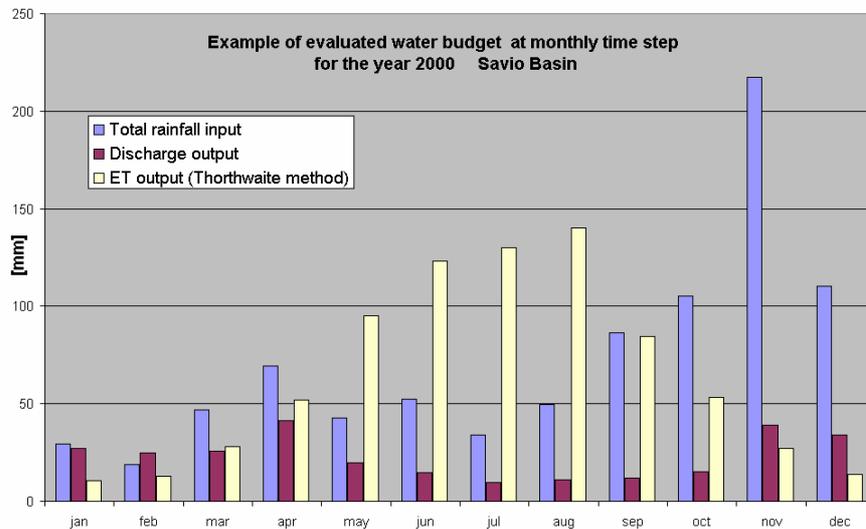


Figure 5 - Example of continuous water budget obtained from the estimated rating curves

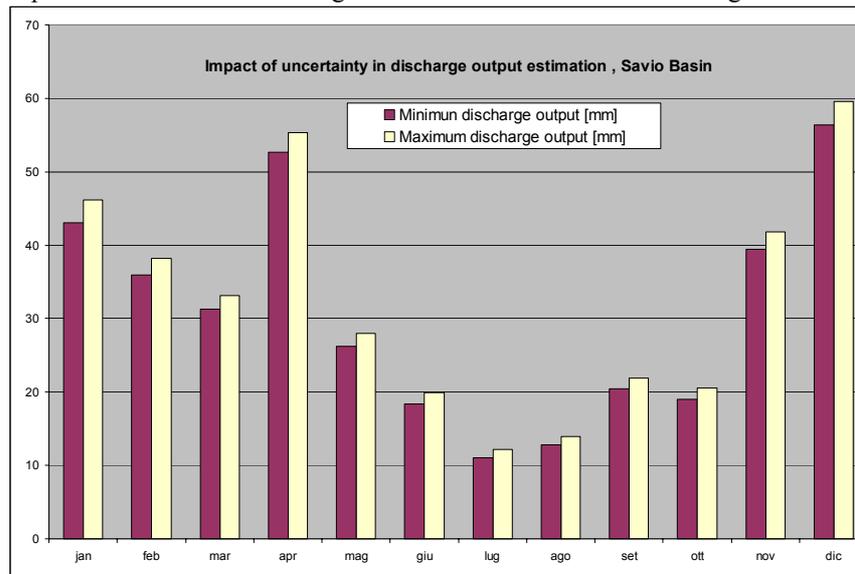


Figure 6 –example of the impact of uncertainty of discharge estimation) in monthly discharge output[mm/month]

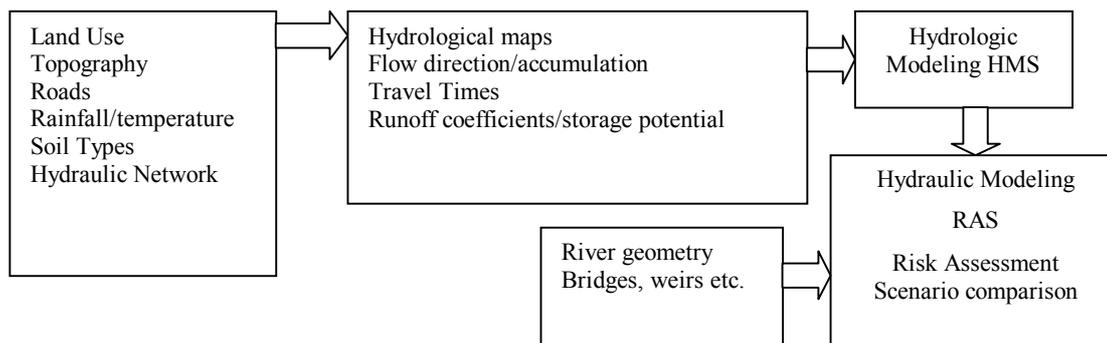


Figure 7. Flow chart of the modeling system

The need of such a modeling system is stimulated, and sometimes even enforced, by the many activities required by river basin planning and management, ranging from flood timely alert to the individuation of areas at risk of flooding, to the programming of water budget at the basin scale, according to the national and regional regulations in the field.

The main trouble with the construction of such a consistent and self-updating database is in that many different offices have been so far working separately in the field of hydraulic protection, river training and related public works. The availability of comprehensive software in the public domain allows to link databases to computing and design tools so to allow a strict pipelining of the activities of database construction, river basin planning, management, programming and financing of the interventions, and design and construction of the works. The system bases on the sharing of a database linked to the above described hydrologic and hydraulic models, which can be embedded into a geographic environment provided by the ArcView GIS and thus produce easily shared results in cartographic format. Figure 7 shows the information flow chart in the system.

In this way, a unique planning arena is defined in which all analyses must be reported and the alternatives must be discussed.

This facilitates the building of consensus and the negotiation of priorities keeping the approach at a comprehensive level of the whole river basin rather than reasoning at the single reach level.

Future improvement of the system will concern extensive acquisition and use of field data to improve the determination of the rating curves, which are a fundamental component of the system and are presently affected by a degree of uncertainty mainly due to the lack of flow measurements at high flows.

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