THE BLUE CITY OF THE FUTURE
HYDROINFORMATIC TOOLS FOR THE MANAGEMENT OF ITS WATERS

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ABSTRACT

Human settlements, from the village to the city, depend on the availability and control of clean (blue) water in their surrounding catchments. The new EU directive on water requires member states to adopt a comprehensive approach to water management at the catchment scale. It does not prescribe what hydroinformatic tools are to be used in support of water management and planning.

We argue in this paper that water management and planning in the future will require the creation of a virtual water-world that is accessible on the web to water administrators, planners, engineers, users and the public at large. This virtual water-world will have a spatial resolution, which is sufficient to resolve the "back yard" of individual stakeholders. It will be built from high frequency data on both water quantity and quality, and will be combined with one- two- and three-dimensional hydrodynamic, hydraulic and hydrologic models of both water chemistry and physics, above and below ground.

The Feale project, funded jointly by the Office of Public Works and UCC, will illustrate this thesis. The virtual water-world of the Feale in north Kerry is a "birds eye" animation of its present and future hydraulic infrastructure, consisting of houses, farms, fields, roads, causeways, embankments, berms, bridge openings, back drains, culverts, flap valves, storm surge gates, and pumps. The horizontal resolution varies from 20cm to 1m to 12m over an area of 200 square kilometres. The social calibration of the virtual world will establish its credibility among stakeholders prior to examining engineering alternatives for the relief of flooding. Sediment transport and some water chemistry are also under construction.

The creation of a much more complex virtual-world, of natural and man-made waters, is about to start as an exemplar project under the Directive.

INTRODUCTION

Human settlements, from the village to the city, depend on the availability and control of clean (blue) water in their surrounding watersheds. "It is becoming increasingly accepted at the scientific, industrial and political level that the uses made of all major European watersheds have long-term and wide ranging impacts not only on soil and freshwater resources and their protection, but also on the quality and quantity of water run-off to coastal areas. In order to develop adequate political and technical measures to allow sustainable development of both fresh and marine coastal waters integrated assessment of these systems needs to be undertaken taking into account the characteristics of the major European river basins and the coastal areas under their influence." (Murray et al.1999).

The new EU directive on water requires member states to adopt a comprehensive approach to water management at the catchment scale. It does not prescribe what hydroinformatic tools are to be used in support of water management and planning.

ADVANCES IN ICT

Ever since Project MAC (man and computer) and its ICES (Integrated Civil Engineering System) companion project (Roos, D. 1965) we have envisaged a single integrated computer system for the design, operation and maintenance of complex engineering systems. Only two or three subsystems of ICES survive: STRUDL, COGO, PROJECT, none of which are related to water. Since then, extraordinary advances have been made in hardware, software and communication technologies.

Computing power has increased by a factor of one million, and the cost of hardware has fallen in proportion. In the computer modelling of most natural and man-made waters, the limiting factor is no longer computation. At present, it is the cost of sensor systems for all parameters of interest. A low-cost, disposable "lab-on-a-chip" module, produced by lithography, is an active area of research.

Some commercial laboratories and their software groups are now far in advance of Universities in the development of integrated software systems for water. Internet, intranet, extranet and WAP (wireless application protocol) technologies are developing rapidly and have revolutionary implications for the world of water and human society.

It is timely, therefore, to re-examine the vision of Project MAC, and, for the purposes of this paper, to do so in an Irish context. We call this examination, the Blue City of the Future project – blue as in "blue flag" beach and in clean water.

THE BLUE CITY OF THE FUTURE

Figure 1 indicates a vision of the Blue City of the Future, a "wired water world" connected to a geo-referenced database that acts as a "blackboard". Data may be written on the blackboard and read from it, to any number of display devices that create virtual water worlds for each individual stakeholder. Models that integrate many different kinds of data and knowledge create these virtual worlds. Virtual reality on a PC screen is available on the web through VRML (virtual reality mark-up language). The most-advanced VR devices – immersed virtual reality - are hemispheres, within which groups of stakeholders may observe dynamic 3-D images projected around them, and which they can control.

The virtual water-worlds will have a spatial resolution, which is sufficient to resolve the "back yard" of individual stakeholders. It will be built from high frequency data on both water quantity and quality, and will be combined with one- two- and three-dimensional hydrodynamic, hydraulic and hydrologic models of both water chemistry and physics, above and below ground.

We foresee environmental management and planning in the future, requiring the creation of virtual water-worlds that are accessible on the web to water administrators, planners, engineers, users and the public at large. In other words, VR will be a forum for building political consensus. Consequently, the socio-cultural dimension of such hydroinformatic tools is of central importance and is an area of active research. (Abbott, M., 1991; and the Journal of Hydroinformatics).

The following section illustrates the construction of one such virtual water world in north Kerry. We have recently begun to build several more, using Cork City and the Lee valley as our laboratory. These experiments will test our vision of the future.

AN ILLUSTRATION – THE LOWER FEALE FLOOD STUDY

The Lower Feale Catchment in north Co. Kerry is a large area of flat, peaty land that lies less than 10m above sea level. During the 1940's, an extensive hydraulic infrastructure was built to protect surrounding agricultural lands against flooding. It consists of 5 main tidal channels, embanked on both sides, and a network of backdrains and land drains that empty into these channels through sluiced culverts. It no longer performs adequately. During heavy rain the rivers run high and drains cannot empty, so the land floods. By integrating a one dimensional hydrologic/hydrodynamic computer model (Mike11) of the complete hydraulic infrastructure (incorporating a full rainfall runoff model) with a very fine resolution Digital Elevation Model (DEM), we can identify the causes of flooding and assess the performance of various alternatives for the flood alleviation. The result is a virtual water-world of the catchment consisting of houses, farms, fields, roads, causeways, embankments, berms, bridge openings, back drains, culverts, flap valves, storm surge gates, and pumps.

Differential global positioning systems (dGPS), acoustic depth surveys (ADS) and traditional surveying methods provide topographical data required for the hydrodynamic model. Autographic

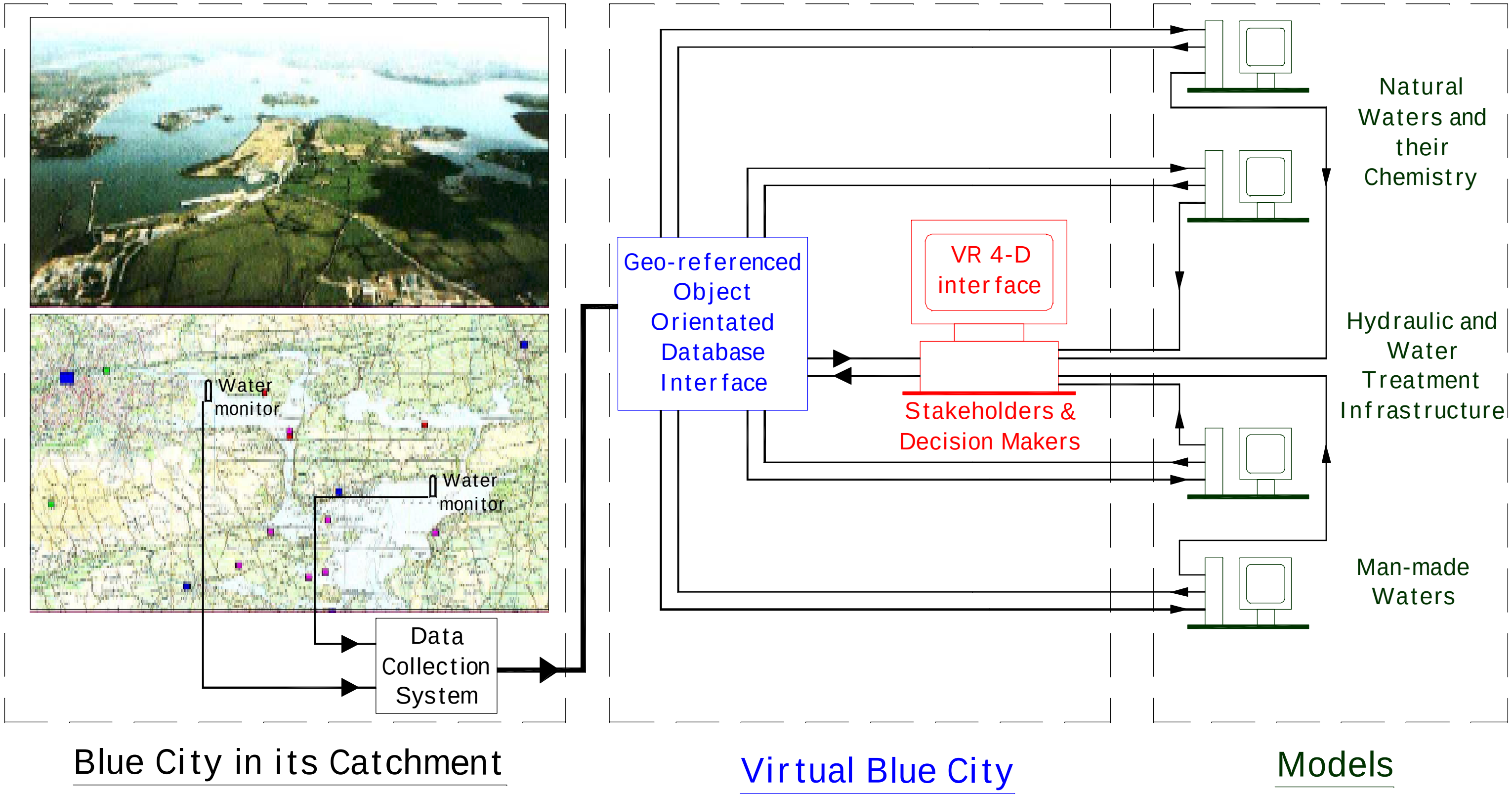

Figure 1: Blue City of The Future.

recorders and automatic data loggers, strategically located at various point around the channel network, collect the hydrodynamic data. Radar and rain gauges collect rainfall data. The German Aerospace Centre's High Resolution Stereo Camera, Airborne (HRSC-A) collected the data for very high-resolution multi-spectral images and DEMs. The HRSC-A, developed for the exploration of Mars by the international space mission Mars96, is the world's first fully automated, digital, multi-spectral, high-resolution, image acquisition and 3D-processing system in civilian use. For this study, the HRSC-A provided data at resolutions of 100cm over 200 km^2, and 50cm and 20cm over smaller selected areas.

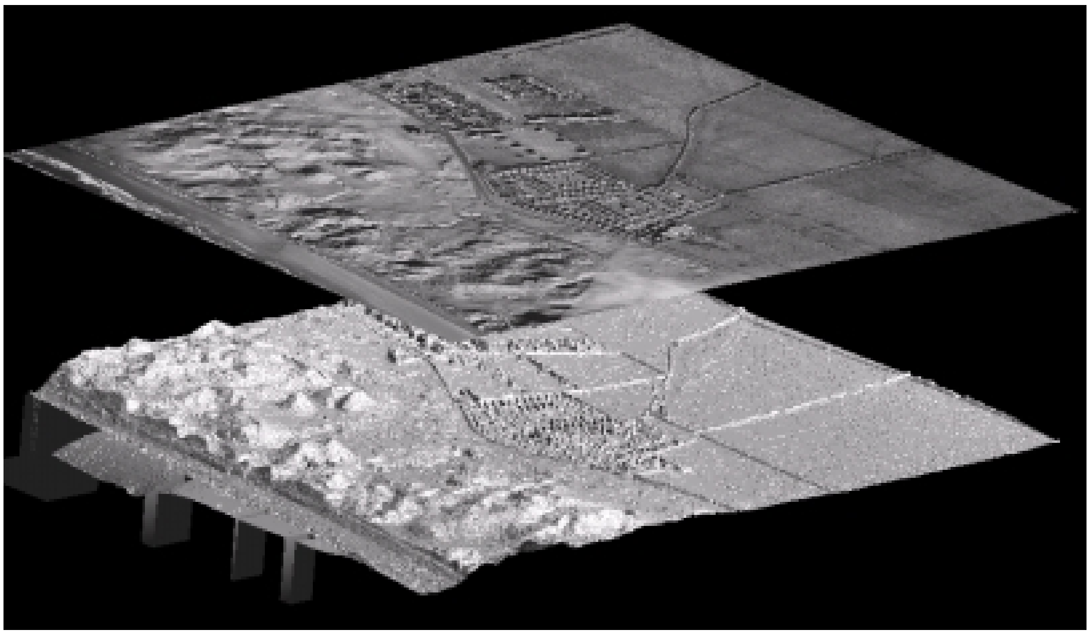

Figure 2 : This figure shows a perspective view of 20cm panchromatic imagery over-lying a 20cm DEM of the area around Ballybunnion Golf Course collected by the HRSC.

The hydrodynamic/hydrologic computer model includes all the features of the hydraulic infrastructure such as bridge openings, sluiced barrages, sluiced culverts, backdrains, land drains and channel embankments. By scanning a 1:50,000 map of the catchment and placing it in digital form on the graphical grid in the River Network Module of Mike11 (with the grid co-ordinates being the same as those on the map), points can be drawn at regular intervals along the river channels and joined together by branch lines to define the branches. Differential GPS surveys along the banks of the rivers were conducted in 4 lines: along the riverbank, the inside and outside toes of the embankment, and the top of the embankment. The ADS sections were measured across the river at 200m intervals. This data yielded full cross sections across the river. All of the backdrains and land-drains are modelled using a standard, roughly trapezoidal cross-section. The datum of these backdrain cross sections is adjusted for each section to correspond to the elevation of the surrounding land at that location. The hydraulic structures in the infrastructure consist of sluiced culverts, sluiced barrages and culvert crossings across drains. The model identifies the location of all features along the branches of the network using the branch name and the chainage along the branch. The full model is run for a period of one year, with a computational time-step of 3 minutes. It is calibrated against (a) water levels recorded in the channels by automatic data loggers, and (b) in the case of some hydraulic structures (such as sluiced culverts), data from laboratory models at reduced scale. Calibrated results of a rainfall run-off model feed the hydrodynamic model.

An interface between the hydrodynamic/hydrologic model and a high resolution DEM (in a Geographic Information System, GIS) generates dynamic flood (depth/duration and comparison) maps at a resolution of 10m. These DEMs are obtained by downscaling the 1m resolution DEM from the HRSC-A to a courser resolution, for the purpose of saving computation times and memory.

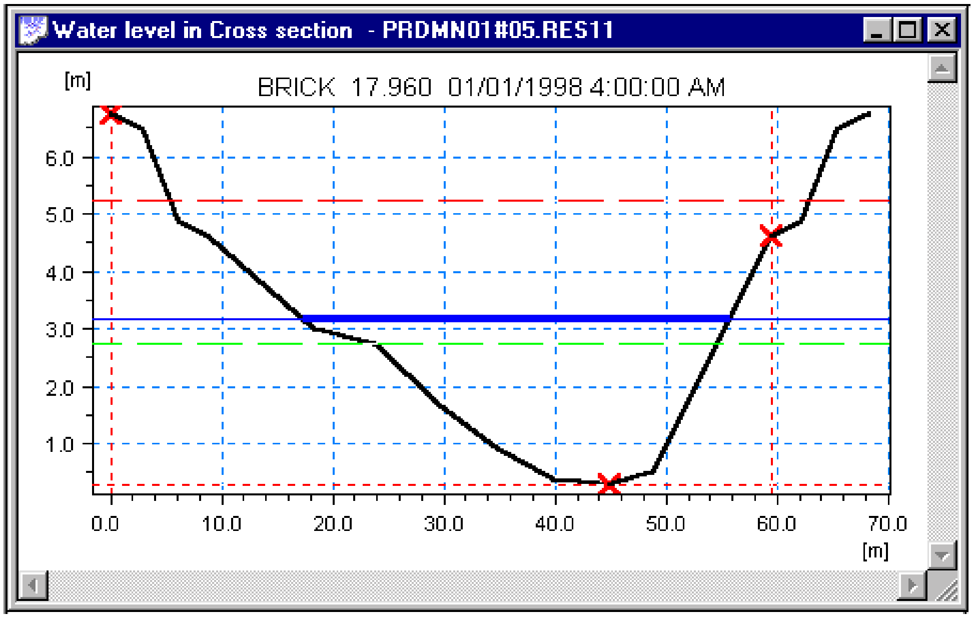

Figure 3 : An animated cross section of an embanked river, showing the water level and the max. / min. envelope

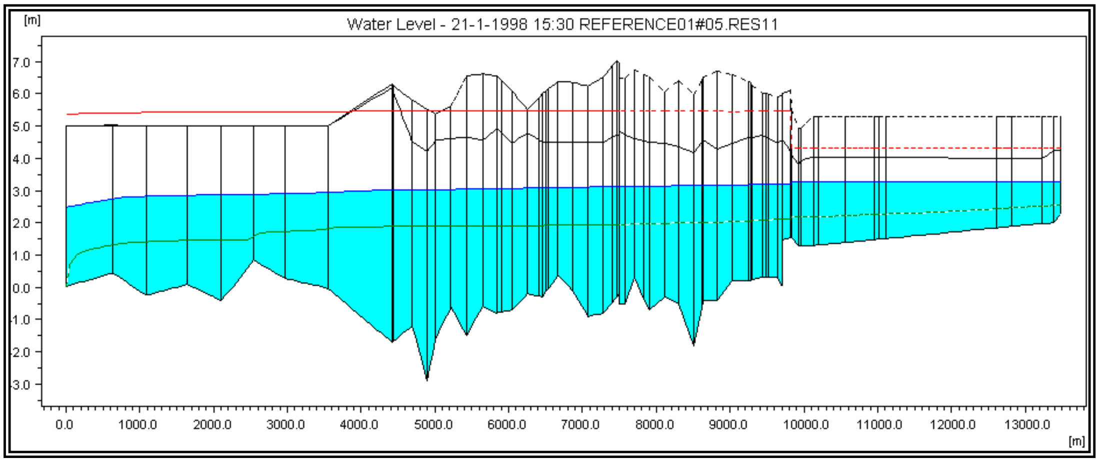

Figure 4 : An animated longitudinal section, showing water levels and the max./min. envelope. Note the effect of the storm gate on the tributary at the right side of the image.

The hydrodynamic model branch network (branch layout) file is imported into the GIS as a Branch Route System (BRS) and saved as a "shape-file". Files, containing the location of every point at which water level (H) and discharge (Q) are computed during the simulation, are imported into the GIS. Every H-point and Q-point is assigned to its corresponding location on the BRS. Text files that contain water level and discharge data for each point, for every time-step, are then joined to these H-point and Q-point themes. The GIS interpolates a water surface across the study area for any selected time-step using the H-points at their assigned locations. The resolution of this interpolated surface corresponds to that of the original DEM, in this case 10m. It then compares the level of the water surface to that of the interpolated land surface (DEM surface) and computes the difference between them.

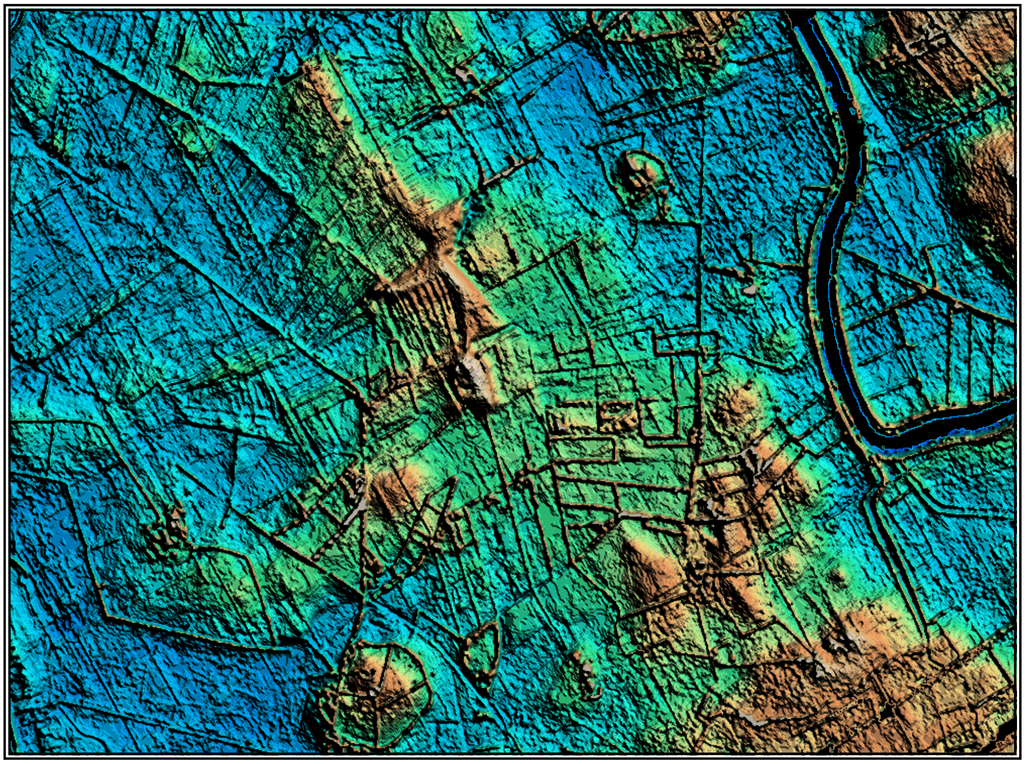

Figure 5. A portion of a 1 metre resolution DEM showing part of the embanked River Feale (top right).

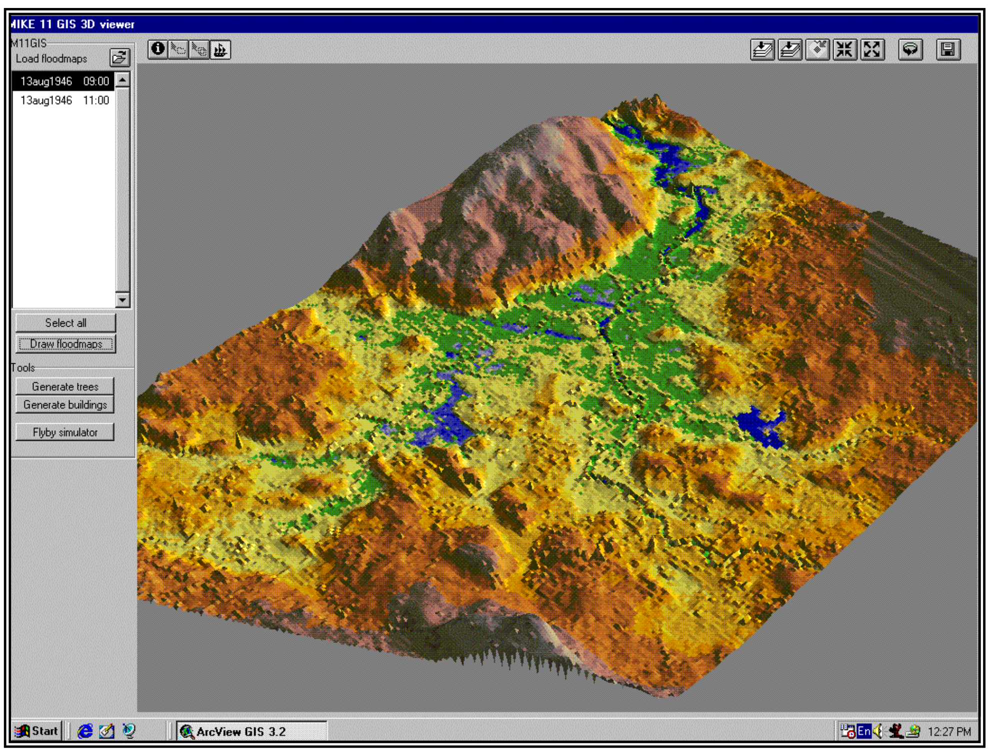

Figure 6 : Perspective View of computer generated flood map over the Lower Feale Catchment for a given flood event (August 1946).

Grid cells where the digital elevation is higher than the interpolated water surface elevation are defined as flood free areas. These flood free areas form land/water boundaries which are called "dynamically located channel boundary lines" (CBL). These CBL's are saved along with user-defined 'Fault Theme Lines' (user-defined lines along features in the study area that will remain flood-free). For every DEM grid cell, the interpolation routine checks whether a CBL intersects the straight line between the actual DEM grid cell and the nearest H-point in each quadrant. If it does, the routine does not interpolate across the CBL, but searches instead for another H-point in the same quadrant. If it cannot find another H-point, no water level information will be taken from this quadrant in the final interpolation, and the cell stays 'dry' for that time-step. When the level of the water surface is greater than the level of the ground surface, the area is mapped as being flooded. The depth of flooding is colour coded. The floodmaps are thus generated.

This integrated flood-mapping model illustrates the drainage characteristics of the Lower Feale River and suggests possibilities for short-term alleviation of flooding. Engineering solutions, such as additional sluiced culverts, dredging options, sluiced barrages, rainfall run-off interceptor drains and pumping, are modeled and evaluated. The one-dimensional hydrodynamic/hydrologic model simulates the effect of any proposed solution on the water levels in the channels of the hydraulic network. The integrated flood mapping model animates the effects of engineering works in the flood plain, such as reduction of flood depths, inundated area relief and duration.

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- See also the recently launched Journal of Hydroinformatics.