A GIS-based approach to river network floodplain delineation

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Abstract

The main goal of this continuing study is to develop a GIS-based procedure for delineating and displaying in 3-D the desired floodplain zones of river networks using data generated by the HEC-2 numerical model. The methodology is applied to the Bear Brook sub-watershed of the South Nation river system, located near Ottawa, Ontario, Canada. First, HEC-2 data are imported and reproduced in HEC-RAS. Next, HEC-RAS in-stream data are geo-referenced and mapped in GIS domain and then integrated with digital elevation model (DEM) over-bank data to build a terrain triangular irregular network (TIN) model. This integrated terrain model is then overlaid with water surface TIN for selected storm events for 3-D floodplain visualization. Data query models, relating to ‘local flood depth’ and ‘channel section’ information, are also constructed.

Keywords: floodplain delineation, river network, GIS-based approach, HEC-2 model, HEC-RAS model, geographic referencing, 3-D visualization, integrated digital terrain model, data query model.

1 Introduction

For over 40 years, various computer models have assisted in river floodplain delineation exercises. A widely applied model in this category is the Hydrologic Engineering Center’s HEC-2 model, USACE [1]. An improved ‘Windows’ version of this model: HEC-RAS (for River Analysis System) was released in 1995. The RAS version, which includes a graphical user interface, a hydraulic analysis component, data management and storage capabilities, graphics tools and reporting utilities, offers significant improvements over the original DOS-
based HEC-2. However, despite these improvements, the inundated portions of floodplain zones predicted by HEC-RAS are not geographically referenced.

Recently developed procedures that link models like HEC 2 and HEC-RAS to GIS allow for display of floodplain delineations in GIS. Examples include: (i) a methodology to delineate watershed boundaries and stream networks extracted from digital elevation models (DEM) in GIS, Jenson and Dominique [2], (ii) ARC/HEC-2 which links HEC-2 with ARC/INFO, for the purpose of extracting terrain information from contour coverage and exporting it into HEC 2, Beavers [3], (iii) the ArcView extensions: AvRAS, ESRI [4] and HEC-GeoRAS, USACE [5], which produce HEC-RAS import files containing geometric attribute data from existing digital terrain models (DTM).

In general, the approach that is used in a particular case depends on the type of stream geometry that is available. Many companies working in this area have existing HEC-2 or HEC-RAS models of various river systems. Procedures are now available that permit integration of DTM (in the form of a triangular irregular networks (TIN)) with existing HEC-RAS channel geometry data, Tate [6]. Also, commercial floodplain mapping software packages, like RiverCAD, Boss [7], now allow the user to display HEC-RAS output data in both AutoCAD and GIS.

The main goals of this continuing study are (i) development of a GIS-procedure for delineating the (HEC-2 predicted) inundated floodplain zones of a river system directly onto topographic maps, and (ii) a methodology for displaying these regions in 3-D. The river system selected as a test case for the study is the South Nation River and its tributaries, located just east of Ottawa, Ontario, Canada. The South Nation Conservation Authority (SNC), which manages the entire South Nation watershed, relies on an established HEC-2 model of the system for management purposes. Because of limited space, this paper presents the results of phase 1 of the study only.

2 Study area

The South Nation watershed consists of four sub-watersheds: Bear Book, Castor River, and the upper and lower portions of the South Nation River (fig.1(a)). The entire watershed drains an area of about 3900 Km\(^2\). Phase 1 considered only the most westerly portion of the Bear Brook sub-watershed, encompassing approximately 81 Km\(^2\) (Fig.1(b)). The total fall in elevation, from the upstream (south-west) to the downstream (north-east) extremities of this portion of the watershed is about 43 m over a distance of approximately 13.5Km. In this region ten tributaries feed the Bear Brook main channel and the total length of the stream network is 48 river Km.

3 Modeling considerations

HEC-RAS is designed to perform one-dimensional steady and unsteady flow calculations to determine water-surface profiles for natural and man-made channels. In phase 1, floodplain delineations were determined for steady,
gradually-varied flows in the system. The generally similar computational procedures of HEC-2 and HEC-RAS to model steady flows in streams are based on solution of the one-dimensional energy equation using the ‘standard step’ iterative procedure and assumed values of the Manning roughness coefficient $n$. The main differences between the two programs are seen in the methodologies used to calculate cross-section conveyance and critical depth, and in the computational routines used to model bridges and culverts. In the case of HEC-2, energy losses through bridges and culverts are computed using the Normal Bridge method, the Special Bridge method, or the Special Culvert method. Depending on the local flow conditions, bridge losses in HEC-RAS are determined using either the Low Flow or High Flow methods. In view of these different modeling approaches, corresponding water surface profiles predicted by the two models will differ slightly, Yang [8].

![Figure 1](image_url)

**Figure 1:** (a) South Nation River watershed; (b) phase 1 study area of the Bear Brook sub-watershed.

Incorporating hydraulic data with spatial data in a GIS environment has proven to be highly effective in regards to 2-D and 3-D floodplain visualization. GIS provides a graphic interface for the creation and maintenance of spatial data, a database interface for the creation and maintenance of attribute data, and can relate spatial and attribute data to each other through either interface, Shamsi [9]. By establishing connectivity between features in the landscape, the user can integrate hydraulic data with the spatial data in GIS. Recent improvements in the availability and accuracy of terrain data have encouraged the use of GIS, re: development of DTM for streamflow representation on land surfaces. The DTM permits water surface profiles calculated by HEC-RAS to be combined with terrain models to generate 3-D topographic floodplain representations.
4 Methodology and implementation

4.1 Hydraulic modelling

The first step in the model integration exercise was importation of the existing HEC-2 data into HEC-RAS. Several issues had to be addressed here, including among others: (1) the fact that HEC-RAS does not permit importation of HEC-2 data in free format, and the river station order sequence of the imported reach must start at the upstream end and proceed downstream, (2) some HEC-2 options are not available in HEC-RAS, (3) the aforementioned different methods for calculating conveyance and critical depth in natural channels and flow analysis at bridges and culverts, and (4) more detailed ‘bridge’ and ‘culvert’ data are required for HEC-RAS operation.

The Bear Brook river system examined in phase 1 contained 11 (main channel and 10 tributary) reaches. In order to connect these 11 reaches and simulate the entire system in HEC-RAS, the GIS stream centreline information (containing the co-ordinates defining the real-world location of the stream network) had to be imported into HEC-RAS. This required: (i) digitizing the stream centerlines in ArcView using a photograph base map, (ii) creating the river network using GeoRAS and using the snap tool in ArcView to connect reaches, (iii) producing a HEC-RAS import file of stream centerline theme containing geometric attribute data from a DTM, (iv) importing GIS format stream centerline data to HEC-RAS, and adding other geometry data (banks, station ID, cross-section geometry etc.) from the aforementioned 11 single–reach models, (v) performing HEC-RAS simulations, and (vi) fine tuning the HEC-RAS model by comparing corresponding HEC-2 and HEC-RAS output data.

4.2 3-D floodplain delineation

In this study a 10m-interval DEM is used to represent area terrain. Compared to HEC-RAS, a DEM offers lower accuracy when describing in-stream channel geometry. Therefore, an integrated digital terrain model in the form of a TIN, containing both HEC-RAS in-stream data and DEM over-bank data, was developed. The resulting TIN model was appropriate for 3-D visualization of the terrain and floodplain zones. A set of ArcView scripts, Tate [6], was used to transfer the HEC-RAS output data for the selected design storms to the GIS domain. The many separate operations associated with (i) importing, geo-referencing, interpolation and location adjustment of stream cross-section data, and (ii) construction and integration of the terrain TIN, are described elsewhere, Yang [8]. The various steps in the hydraulic modeling and 3-D floodplain modeling exercises are summarized in Fig. 2.

Water surface elevation and terrain-water surface interface location data for each flood event were extracted from HEC-RAS and transferred to the GIS cross-section files to generate a water surface TIN. Flooded areas, occurring where water surface elevations exceed terrain elevations, can then be viewed in 3-D format by overlaying the terrain TIN in ArcScene. The impacts of different
storm events on structures located in or near the floodplain zones can be assessed on an aerial photograph of the region as basemap. The steps in this 3-D floodplain visualization process are summarized in Fig.3. Since the cross-section geometry data is a fixed data set for the Bear Brook, its terrain TIN model may be equally applied in all floodplain simulations. Based on the respective water surface elevation and terrain-water interface location data, separate water-surface TIN was generated for each flood event investigated. Fig. 4 shows a sample portion of the inundated floodplain zones of the Bear Brook for the 10-, 50-, and 100-year design storms, projected onto an aerial photograph of the region.

Figure 2: Steps in the hydraulic modeling and floodplain delineation processes.

Flooding occurs to a depth equal to the difference between the water-surface TIN and surrounding terrain TIN. Converting both TIN themes into grids allows for subtraction of the elevation data using the raster calculator in GIS. The terrain raster theme is then subtracted from the water surface grid theme to create a flood depth grid. Using the query tool in GIS and clicking on any point within the floodplain provides the flow depth at that point. To develop an integrated data query model, the cross-section geometry data and flood elevation data for
each event considered are extracted from the cross-section mapping results and the water surface TIN model. A data query is accomplished by simply clicking on a cross-section cut-line using the GIS data query tool. Fig. 5 is an example of the types of information that can be obtained at a particular station on the river using these query models.

Figure 3: Steps in the 3-D floodplain visualization process for the 100-yr flood event (a) water surface TIN, (b) Terrain TIN, (c) floodplain 3-D view, and (d) floodplain 3-D photo view.

5 Conclusions

For river systems that rely on established HEC-2 numerical models for management purposes, the procedures described in this paper are designed to automate and simplify the flood mapping process.
Figure 4: A portion of the inundated floodplain zones of the Bear Brook for the 10-yr, 50-yr and 100-yr design storms.

Figure 5: Floodplain data query models (a) flood depth query, (b) cross-section information query.
The end-products of this (phase 1) study include: (1) a complete HEC-RAS river network model (comprised of a ‘main channel’ and ten ‘tributary’ components); (2) an integrated digital terrain TIN that combines coarse-detail floodplain landscape with detailed in-channel geometry; (3) 2-D and 3-D flood maps that show both lateral extent and depth of inundation for selected design storm events; and (4) river system data query models relating to flood depth and cross-section information at any station.

The following factors influence, to a greater or lesser extent, the accuracy of floodplain delineation: (i) modeling accuracy of HEC-RAS, (ii) reliability of the terrain model, and (iii) cross-section interpolation and extent. The impact of these are discussed elsewhere, Yang [8].

In phase 2, the procedures described herein will be applied to the entire South Nation watershed. Flood maps will be used to establish real-time flood emergency procedures and to assist in calculating flood insurance rates. Using an orthophoto as base map, the effects of selected design storms on both river and nearby structures can be quickly assessed. These exercises will possibly also help in identifying suitable locations and arrangements for flood prevention/control structures.

References


