Chapter 22

Flood Plain Management Integrating GIS and HEC-2

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Little has been done over the years to either automate the more labour intensive activities involved in flood plain mapping and management or to increase the efficiency and accuracy of handling applications for development or modification of hazard lands. A logical approach to addressing both of these shortcomings is to integrate a Geographic Information System (GIS) into the flood plain management process. For the water resources professional, a GIS-based flood plain management system would serve two primary functions. Firstly, it would serve as a front end to the modelling process, providing digital data for input into both hydraulic and hydrologic modelling programs.

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Secondly, it would act as a dynamic output medium for results of the modelling process, converting the output data into flood elevation contours on digital base mapping. For watershed planners, such a system would provide immediate access to current information about potential and/or historical flooding potential and related property-based data through interactive GIS inquiries.

This chapter outlines the continuing development of a GIS-based flood plain management system, **GISFPM**, which interfaces Geo/SQL® and the hydraulic modelling package, HEC-2.

22.1 Introduction

GIS technology has developed dramatically over recent years to allow for its direct application in many areas of infrastructure and facilities management. Historically, GIS systems have been mainframe-based with limited direct user access due to the high cost of hardware platforms, proprietary database systems and graphical engines inherent in traditional "*integrated*" systems.

Today's evolution toward increased personal computer power, low-cost graphics packages, networked database systems, digital mapping, and micro-computer based mathematical modelling tools, has promoted the development of "*linkage-based*" systems as the leading edge approach to GIS and information management.

Currently, "*linkage-based*" GIS technology allows for direct access through engineered interfaces to disparate database management systems and datafiles and their subsequent connection, or geo-referencing, to existing spatial (mapping related) databases. Low-cost computer aided drafting systems like AutoCAD® working in a micro-computer environment are used as the graphics engine for display and creation in this process.

Water resources engineering, and specifically flood plain management technology, lends itself to an innovative application of this "*linkage-based*" approach to GIS. A structured interface

between digital mapping information and the hydraulic database allows for a streamlined analysis procedure and on-demand interrogation using a geographic information/flood plain management system (GISFPM).

By establishing the link between the map and the hydraulic database, the GIS component of GISFPM enables the creation and manipulation of hydraulic information within an easily understood and intuitive graphic environment.

Imagine a process where a qualified flood plain analyst/manager who has been charged with the task of analyzing the impact of a filling proposal within a flood plain;

1. The flood plain map is "*loaded*" into AutoCAD®;
2. The user modifies topography to reflect modifications within the flood plain, as might be expected with a golf course development, for example;
3. The GISFPM link is executed and an existing hydraulic dataset is modified, with cross-sections extracted by the GIS component, and executed;
4. The results displayed are revised flood lines on the flood plain map;
5. A statistical query is then executed which quantifies the impact on flood levels within a particular area of interest (i.e. number of homes flooded);
6. The map is plotted and a statistical summary printed to assist in justifying the flood plain analyst/manager's decision on the matter.

The flood plain analyst/manager is faced with making decisions of varied complexity regarding the topographic characteristics of flood plains on a daily basis. A GIS can manage pertinent information related to each cross-section and enable it's

recall, modification and input into an appropriate model for analysis.

22.2 The Current System

Hydraulic modelling output, namely flood levels and limits, and the topographic mapping base, are the primary databases for the establishment of a flood plain. Current procedures which ultimately yield the required flood information are, at times, very cumbersome and subject to random error and misinterpretation.

22.3 "Standard" Flood Plain Mapping Procedures

The HEC-2 program is the hydraulic "*corner stone*" of most Ontario flood plain mapping studies. HEC-2, developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers, was designed to compute water surface profiles for steady, gradually varied flow in open channel systems. Essentially, HEC-2 calculates flood elevations at locations of interest for specified flows. Standard input variables include: cross-sectional geometry, reach lengths, discharge and loss coefficients.

The following generally describes the typical step by step procedure which takes place during the creation, execution and evaluation of a HEC-2 dataset.

1. The engineer reviews the topographic mapping of the watercourse and specifies where appropriate sections should be located, and establishes which structures should be modelled.
2. A survey crew goes into the field to survey sections and structures as required.

3. The engineer undertakes a field reconnaissance of the watercourse looking for potential flood and erosion zones.
4. Field survey notes are reduced by a technician and cross-section overbanks are abstracted from topographic mapping. Sections and structures are then coded into HEC-2 format. Cross-sections are plotted for debugging purposes and for inclusion in the final report.
5. The engineer reviews the code through the debugging procedures and corrects code where necessary. In this procedure, the engineer incorporates roughness factors, expansion and contraction factors, and special bridge (if any) co-efficients into the dataset.
6. The engineer inputs QT (flow) cards at appropriate nodal locations along the watercourse.
7. The engineer executes the dataset and corrects any errors not found in initial debugging. The output is evaluated to determine its validity (such as determining which sections require extension as a result of computed water surface elevations exceeding the minimum end station of the section).
8. The engineer identifies spill zones and determines control sections for subsequent spill calculations.
9. The engineer uses the facilities which are part of the HEC-2 package to generate summary tables of output parameters.
10. The engineer determines the maximum permissible velocities for erosion zone determination and compares these with channel velocities from HEC-2 output to confirm potential erosion zones.
11. A technician plots the flood plain on topographic mapping while the engineer reviews the significance of spill routes.

The foregoing procedures are very labour and data intensive, particularly those requiring manual interaction with a topographic mapping base (i.e. tasks 1, 4, 5, and 11). Many of the above-noted tasks require iterative assessment and evaluation as well.

22.4 Policies and Practices

Current flood plain mapping or flood damage reduction studies result, in part, with the definition of Regulatory flooding limits as well as flooding limits for a variety of computed (i.e. 2, 5, 10, 25 year etc. frequency events) or recorded (historical) flows. However, the primary objective of flood plain mapping projects is the definition and illustration of the Regulatory (Regional or 100 year event) flooding limits. Information on lesser event flooding is rarely displayed on flood plain mapping.

Damages resulting from the modelled flooding events may be estimated, perhaps using a computer program such as FDAM (Flood Damage Analysis Model).

Information from the hydraulic analysis is used to determine erosion susceptible zones along modelled watercourse reaches. Channel velocities, channel and overbank flow distributions, and flood levels, based on the 2 and/or 5 year frequency flows are typically used as bench marks for the identification of potential erosion zones.

22.5 Constraints

The most significant constraints of the current approach to the development of flood plain mapping are directly tied to those tasks requiring manual interaction with hardcopy topographic mapping. As a result, valuable time is spent by engineers and technicians obtaining *all* required mapping, piecing mapping together, obtaining properly scaled mapping for inclusion in reports, abstracting contour data, plotting flood lines and damage

areas etc.. This time could be more effectively utilized gaining a better understanding of the hydraulics of the watercourse(s), in more intense investigation of spill zones and routes, in better definition of flood, erosion and damage zones, etc.. In essence, water resources personnel could spend their time more efficiently investigating the hydraulics assessment rather than spending time managing mapping and data.

22.6 Technology

22.6.1 Geo/SQL®

The GIS system which has been chosen for integration with HEC-2 is Geo/SQL®. Geo/SQL® represents the first true, topological, continuous, hardware independent spatial database. It contains an imbedded SQL interface which conforms to the ANSI'86 standard and emulates the DB2 standard for database querying. The advantage of this system over other GIS technologies is its inherent *"Linkage-Based"* approach to GIS technology. Rather than containing an internal, proprietary attribute database structure, Geo/SQL® *"links"* to external databases which conform to the SQL and DB2 standards, such as Oracle, Ingres and Sybase (in addition to dBASEIII) and to AutoCAD® which it uses as it's graphics operating environment.

Geo/SQL® is an integrated set of programs for managing spatial information. In this context, spatial information means anything which has a location in space (e.g. a floodline), and/or can be defined in terms of its own geometry (e.g. a building).

Some of the highlights of the Geo/SQL® include:

1. Geo/SQL®, integrated with AutoCAD®, runs on a variety of hardware platforms: IBM, COMPAQ, NEC, TOSHIBA, or any IBM compatible computer as well as SUN SPARCSTATION, and VAX systems (or in fact any future hardware which will support AutoCAD®).

2. Geo/SQL® runs under a number of operating systems including DOS, UNIX, OS/2.
3. Geo/SQL® works from within the AutoCAD® graphic environment or externally, using a fourth generation language, a natural language interface and/or a menu front-end; all of which can be provided with the base system.
4. Geo/SQL® supports the ability to geo-reference color photographs, video images, word processing documents, spreadsheets and as-built drawings (either raster or vector images).
5. Geo/SQL® is a *"linkage-based"* GIS, which integrates industry standard AutoCAD® to a number of SQL databases including R:BASE, ORACLE and dBASE. Other SQL databases such as DB2, INFORMIX and INGRES can be accessed via inter-database linkage utilities.

22.7 HEC-2

The February 1991 version of HEC-2 has been used in the development process. This version of HEC-2 will run on any hardware platform which is compatible with Geo/SQL®.

22.8 Functionality

22.8.1 Scope

The basic functionality of the GIS to HEC-2 interface, termed GISFPM, can be subdivided into three basic aspects:

1. Provide a means of getting new data into an HEC-2 model or HEC-2 format (i.e. GIS to HEC-2 link).

2. Provide a means of transferring numerical HEC-2 output into a GIS database for subsequent digital display and inquiries (i.e. HEC-2 to GIS link).
3. Facilitate logical and efficient editing abilities and data handling (i.e. HEC-2 to GIS and/or GIS to HEC-2 link).

Clearly, this link to the HEC-2 program will be a valuable tool to the water resources engineer. The primary advantages of such a system are:

1. Faster and more effective dataset debugging resulting in more representative modelling. Visualisation of cross-section and other flood plain data will lead to faster identification of modelling anomalies and errors.
2. The ability to peruse hydraulic output "tagged" to it's location on a map much earlier in the analysis process, thereby improving the appreciation of the flooding mechanism under investigation.
3. Improved access to floodplain information through on-line inquiry based procedures.

22.9 System Overview

The attribute database structure must accommodate both "fixed" (read only) and "variable" (read/write) information. From a water resources perspective, three general conditions describe the state of a valley watercourse system insofar as floodplain definition is concerned, namely:

1. A floodplain (HEC-2 dataset) that has been established (mapped) and no encroachment will be allowed.

2. A floodplain (HEC-dataset) that has been established (mapped) and engineered encroachment/channelization will be allowed.
3. A floodplain (HEC-2 dataset) has not been established (mapped).

Condition 1 represents a 'fixed' information type whereas conditions 2 and 3 represent 'variable' information types.

The GISFPM system is based on two primary links:

1. HEC-2 to Geo/SQL®
and
2. Geo/SQL® to HEC-2.

22.10 HEC-2 to Geo/SQL® Link

The HEC-2 to Geo/SQL® link includes processes such as the following:

1. Transformation of HEC-2 input information, contained in an existing HEC-2 input dataset, into the Geo/SQL® spatial and/or attribute databases as necessary.
2. Transformation of HEC-2 output information contained in the detailed or binary output files generated from HEC-2 into the Geo/SQL® spatial and/or attribute databases as necessary.
3. Interactive use of pre-defined or ad hoc inquiries for access to any of the available HEC-2 output data items associated with each defined cross-section for any/all modelled profiles, for example:
 - Display sections experiencing hydraulic jumps.
 - Display sections where the K-Ratio is out of range.

- Display reaches susceptible to erosion based on digital soils information.
- Display sections requiring extension (i.e. CWSEL > TELMX).
- Display sections experiencing critical depth.
- Display sections where the increase in the computed water surface elevation from the previous section is more than a user defined value.
- Display flows at a section.
- Display computed floodline for any frequency flow available. The floodline is generated via digital comparison of topographic and flood surface digital terrain models which are generated via menu choice.
- Automatic annotation of section information with user specified symbology.
- Display comparison between various floodlines.
- Display buildings in the flood plain or pre-defined search area.
- Display and report on damages associated with buildings in a user selected flood plain.
- Display a user selected cross-section.
- Display the rating curve for a section or a reach.

The list above represents sample inquiries which will allow the user access to primary watercourse, floodline, and damage information.

4. Interactive, automated plot file (i.e. flood plain map plot) generation based on user selected parameters such as scale, sheet size and surround, required topology, etc.
5. Interactive display of digital photographs and documents.

22.11 Geo/SQL® to HEC-2 Link

The Geo/SQL® to HEC-2 link includes processes such as the

following:

1. transformation of HEC-2 information contained in the spatial and/or attribute databases into a workable HEC-2 input dataset in DOS:
 - subcritical or super-critical input file format,
 - only part of an overall dataset,
 - sensitivity analysis on input parameters;
2. interactive definition of overbank (flood plain) section directly from digital mapping;
3. interactive alteration of existing topographic mapping base contour information to represent excavation and/ or filling in the flood plain;
4. interactive modification of bridge/structure definitions for both normal and special bridges types as well as culverts; and
5. interactive user manipulation of sections (i.e. delete a section, insert a section, alter section configuration, etc.).

22.12 Other GIS Applications In Water Resources

Geo/SQL® has other applications as a graphic link for water resources systems. Many of these capabilities are already being exploited for the management of planning-related features such as zoning boundaries, delineating areas sharing common land uses and for areal discretization. The full capabilities of GIS have not yet been applied to the water resource sciences. Many existing uses of GIS technology are limited to conventional graphical data management separate from the linkage to other structured information bases. A GIS has many potential applications in water resources:

1. automatic drainage area delineation from topographic plans;
2. land use optimization based on economic modelling;
3. determination of hydrologic and hydraulic parameters based on soil conditions, land use patterns and slopes;
4. storm sewer network analysis from as-built details;
5. analysis of spatial distribution of rainfall in flood forecasting applications;
6. real-time, geographic display of streamflows, rainfall and other remotely sensed environmental parameters; and
7. consolidation of all data into a common, geographically referenced database of the users choice.

The advantage of using GIS to front-end such applications is the consistent user interface. The same computer station can be used to access multiple applications using virtually any computer technology in stand-alone and/or networked, distributed information environments. The Geo/SQL®/ AutoCAD® GIS manager offers significant advantages in that the user employs industry-standard CAD technology as the graphics operating system. In addition, the double precision accuracy and the inherent vector-based technology of Geo/SQL®/AutoCAD® provides agencies charged with the responsibility of creating and managing flood plain mapping for legal purposes with the requisite tool without compromise.

22.13 Summary

In the increasingly complex world of graphical data management, particularly in water resources engineering, GIS technology provides an innovative approach to integration of both textual and

graphical databases. GISFPM, an interface utility, has been developed for use by flood plain analysts and managers for hydraulic data abstraction and display on micro-computer workstations in stand-alone and/or networked information environments. The technology currently links digital topographic mapping data with the hydraulics program HEC-2. Future developments in GISFPM technology will extend into enhanced hydraulics applications as well as hydrologic data management and real-time flood forecasting.