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INTEGRATION OF THE FLOOD MODELLING PROCESS WITH A GEOGRAPHIC INFORMATION SYSTEM

Abstract:

The demand for the development of flood prone land, particularly in coastal tourist oriented regions, is increasing significantly. The local and regional authorities responsible for urban and regional planning are under constant pressures to effectively manage these areas.

This paper reports on a pilot study undertaken by WBM Pty Ltd Engineers and the Queensland Department of Lands, which integrates hydrologic and hydraulic engineering software with a geographic information system (GIS). A digital elevation model (DEM) derived using photogrammetric techniques formed the basis for the analysis.

The production of topographic data in a form suitable for use in a computer has traditionally been the most time consuming and therefore costly component of flood modelling for engineers. The use of digital elevation data acquired by photogrammetric techniques and the associated costs compared to traditional engineering methods are discussed. The ability of a GIS to provide improved analysis and display of results by incorporating other data sets and the re-usability of data for other urban planning issues enhances the viability of this method. Possible future links with flood warning systems and cost sharing for data acquisition are other topics discussed.

Background:

Queensland is the second largest State in area in Australia. Its area of 1.7 million square kilometres supports a population of 2.8 million, mostly concentrated within the coastal region extending some 5200 kilometres. The capital city of Brisbane has a population of approximately 1.2 million people. The State is characterised by widely diverse environmental conditions varying from parched deserts through rich agricultural plains, dense tropical rainforests, to the worlds largest coral structure, the Great Barrier Reef.

Over the past forty years the State has experienced rapid economic development. Today, this growth has focused on the development of tourism and mineral resources. The rapid development taking place particularly in coastal tourist-oriented centres and the heavy use of the land has unearthed a range of environmental and resource management problems.

Low lying and flood prone areas, especially those close to popular holiday and tourist centres have been subject to increasing redevelopment schemes and proposals. In the past, flood impact studies for these developments have been completed in a piecemeal manner in lieu of developing an overall floodplain management scheme.

INTRODUCTION

Numerical flood models are a powerful tool for the development of flood plain management strategies. In a flood model, accurate representation of the terrain is essential if correct reproduction of a flood event is to be achieved, or an accurate impact assessment of a development proposal is to be made.

Numerical flood models and a Geographic Information System (GIS) can be used to analyse the same data base - the geometrical representation of the river and its flood plain. The integration of a GIS with numerical flood modelling opens a wide range of possibilities. Mathematical models of river and flood plain systems can potentially be developed with greater efficiency and accuracy. The presentation and the conveyance of flood related information can be greatly enhanced.

To establish a link between the numerical modelling of floods and a GIS, a joint research project was instigated between the Queensland Department of Lands, Division of Information and consulting engineers WBM Pty Ltd.

The project objectives were:

(a) To evaluate the use of a Digital Elevation Model (DEM), derived using photogrammetric techniques, for assisting in the development of a numerical flood model.

(b) To use a GIS in conjunction with the DEM to present the results of a numerical flood modelling investigation.

(c) To assess the use of this method in practise compared to traditional methods.

The 1-D hydrodynamic network program, ESTRY, and the ARC/INFO GIS system were used for the flood modelling and GIS components respectively.

This paper presents a discussion on the methodology employed with some conclusions on this process compared to traditional methods. Illustrations developed using the GIS are also presented.

THE PROJECT AREA

The area chosen for the pilot study was the lower Noosa River flood plain in Queensland, Australia. It covers approximately 110 square kilometres and incorporates 8827 properties. The Noosa River is located approximately 100 kilometres north of the city of Brisbane in a region known as the Sunshine Coast.

This region is a popular tourist centre and is expanding rapidly. The demand for development to meet the needs of the tourist industry and local population is increasing constantly.

The main arm of the Noosa River flows from north to south through Cooloola National Park and past the townships of Tewantin and Noosaville. The mouth of the river lies to the west of the resort township of Noosa Heads. An important feature of the Noosa River is its three large tidal lakes which have significant attenuation effects on the tidal and flood hydraulics. Lakes Cootharaba and Cooroibah lie on the main arm of the river while Lake Weyba is located at the head of Weyba Creek which flows into the Noosa River near its mouth. Lake Cootharaba is by far the largest lake with an area of $37km^2$.

In addition to the lakes the Noosa River has significant areas of floodplain. A large proportion is in its natural or near natural condition with the vegetation varying from long grasses to thick scrub. Redevelopment proposals are constantly submitted to the regional local government (Noosa Shire Council) regarding the future use of this land.

The main beach front, which has suffered erosion problems over recent years, has urban development on the foreshore. Some nearby low lying marsh areas have been redeveloped into exclusive canal estates. The construction of a major seawall has relocated the position of the river mouth approximately 500 metres westerly of its natural location.

THE SOFTWARE

1. ESTRY

The 1-D network hydrodynamic program ESTRY (WBM Pty Ltd) was used for simulating the flood hydrodynamics of the Noosa River. ESTRY, which has been developed by WBM since 1974, is a proven and accepted computer program for modelling floods and tides. It has been applied to well over one hundred separate investigations along the east coast of Australia. These applications have varied from simple analyses of limited tidal exchange lakes to complex quasi-dimensional models of major rivers and their flood plains for flood plain management purposes.

ESTRY solves the full one-dimensional equations of continuity and momentum for unsteady free surface flow using an explicit finite difference solution. The area of interest is represented as a system of networked channels and nodes. The channels represent the conveyance or flowpaths of the system while the nodes represent the storage characteristics. As the solution technique includes the inertia term in the momentum equation, it can accurately reproduce the dynamic behaviour of tides and the interaction of flood flows with an ocean tide or storm tide. A comprehensive, menu-driven computer graphics system is used for processing input and output data and for the presentation of results.

2. ARC/INFO

The ARC/INFO system, running on a PRIME 6550 computer was used for the GIS component. ARC/INFO is a commercially available GIS package which has the TIN or Triangulated Irregular Network module which allows the user to perform three dimensional analysis and display. TIN provided the linkage of the DEM, ESTRY and the GIS.

The analytical capabilities of the GIS allowed further analysis of the results from the numerical flood model to be incorporated with other data sets such as cadastre.

DIGITAL ELEVATION MODEL

Height data for numerical flood modelling has generally been acquired from;

- existing contour maps
- extensive field survey
- existing contour maps, selected field survey and other available level data

Such data is generally time consuming and tedious to acquire and costly to convert into digital form for use in a computer. Accuracy limitations are encountered when existing contour maps are of an unsatisfactory scale.

In many projects the acquisition of more accurate height data is confined to areas of importance with regard to flood hydraulics and is usually limited by economic constraints. The extent of this data is specified by the hydraulic engineer.

Consequently, the acquisition of a DEM became a focus as an alternative source of height information and data reduction for the numerical flood model.

Early forms of DEM's stored surface data in a regular or equally spaced grid. Often peaks and pits located inside a grid cell were not recorded. These points are very surface specific and necessary for the accurate definition of the terrain. Other disadvantages of this method were:

- high storage requirements.
- dense grids were necessary in areas of highly varying elevations and areas of little elevation variation contained redundant data.

Contour line maps are still used as a source for digital height data. Some disadvantages of digital contours are;

1. Vertices representing the contour lines only indicate the surface values along the contours and their accuracy depends on the chosen contour interval of the source map.

2. Digital contour strings tend to have many redundant vertices resulting in high storage requirements. However, filtering algorithms to generalise digital lines by extracting the critical points are available to alleviate this problem. (eg) Douglas and Peucker (1973).

Most modern methods of defining and storing surface data make use of a Triangulated Irregular Network or TIN. An advantage of this method is that each point is treated equally and not stored as an interpolation of other data. Mark (1975) studied the performance of a TIN compared to other surface representation methods (such as regular grids). Peucker et al (1976) also investigated the digital representation of three dimensional surfaces by Triangulated Irregular Networks. These studies showed that a TIN can be used to more efficiently record, capture and store height data and allow greater computational accuracy. Points are located on specific surface features (eg) ridge lines, pits, peaks, gullies with fewer points necessary in flatter areas.

Poiker et al (1976) concluded that the development of an integrated GIS based on the concepts of the TIN and a topologically structured polygonal system will offer many practical and theoretical advantages. The authors believe this project is a practical example of that principle.

The best available photography was used for the project and 10 stereo models were observed.

The approximate scale of this photography was 1:40 000 which allowed spot heighting in the order of +/- 1.0 metre relative to ground control. It is recognised that flood modelling for flood plain management would require more accurate height data. Information with an accuracy in the order of +/- 0.1 metre would be desirable. As this project was a conceptual pilot study to develop a method of integrating numerical flood modelling and a GIS, in the interest of economy it was not considered necessary to acquire new photography at a larger photo scale to attain greater accuracy.

The x,y,z co-ordinates of a total of 21,940 points were measured using a Zeiss E3 stereo plotter, in the photogrammetric laboratory of the Queensland Department of Lands, Division of Information. The measurements were completed during 40 man hours of operation as follows:

1. A broad based grid of 80 metres. The stereo plotter can automatically locate the co-ordinates of these grid points allowing fast data acquisition. The 80 metre spacing was chosen as being that which would most effectively describe surface characteristics in the flatter areas.

2. A series of points along changes of grade or breaklines. These points specifically describe surface characteristics such as ridge lines, pits, peaks, passes and the banks of the river.

FLOOD MODEL DEVELOPMENT

The flood model utilised for this project was based on that developed for flood impact assessment purposes of the lower Noosa River flood plain. It was calibrated to peak flood levels recorded during the flood of January, 1968. The model network, which is illustrated in Figure 1, extends from 12km upstream of Lake Cootharaba through to the Pacific Ocean.

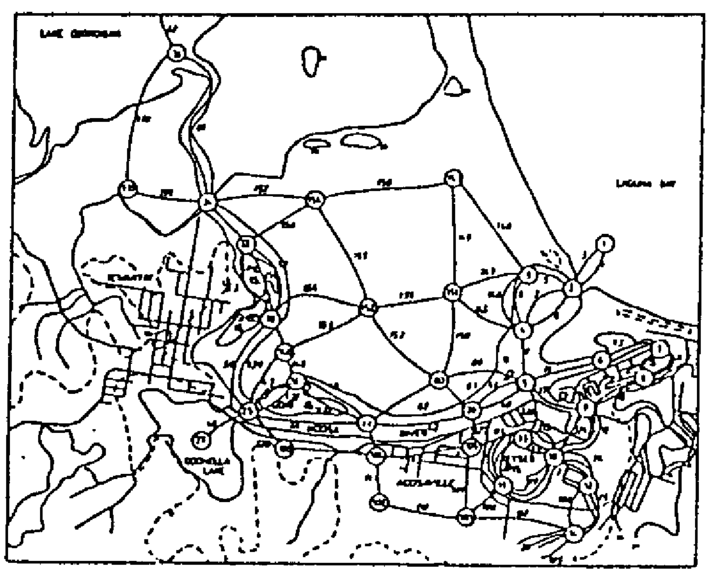

Figure 1

The tidal reaches of the flood model were calibrated to tide level recordings taken in July 2, 1985, and verified to further recordings from July 3 to 7.The flood model was developed in the following manner:

1. Hydrologic analysis of the river catchment;

   Hydrology of the Noosa River catchment was modelled using the computer program RORB (Laurenson, 1985). The RORB model predicts flood water flow from the catchment onto the floodplain taking into account the surface topography and rainfall distribution over time. Parameters for this model were derived by calibration of part of the catchment to four historical events.

2. Hydrodynamic analysis of the river flood plain;

   The river catchment and flood plain were subdivided into a series of channels and storage nodes. The storage nodes represent the storage/pondage and volume characteristics computed using surface areas at various levels in each node. Channels are used to calculate the conveyance of the flood waters and link the storage nodes together to form a network or quasi - 2D representation. The resolution and detail of the nodes is greatest in specific areas of interest and where steep hydraulic gradients occur. The network characteristics, designed using available topographic maps were set-up and used by ESTRY to simulate the dynamic behaviour of the flood wave and the interaction of the flood waters with the ocean tide.

<u>INTEGRATION OF THE GIS</u>

Figure 2 shows a flow chart of how the GIS was integrated.

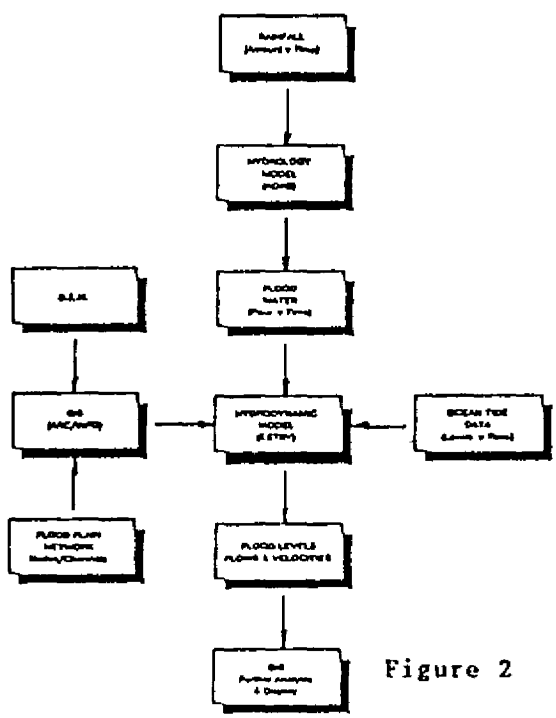

Figure 2

1. The surface areas at various levels in each storage node, have traditionally been calculated using a planimeter on the printed topographic map. Errors due to map scale limitations and the use of the planimeter are therefore introduced into the modelling process. By incorporating the digital elevation model and the network design for the flood plain into the GIS, desired computations are achieved with greater efficiency and accuracy.

   To achieve this, the DEM was topologically related in ARC/INFO as a TIN and used to compute one metre contours for the project area. By polygonising the derived contours and overlaying the result with the digitising network of storage nodes, surface areas were automatically computed in each storage node for levels delineated by the contour polygons. Enhanced analysis for the channels was also achieved by interpolating from the TIN, a series of elevation versus distance curves. A horizontal sampling distance of 10 metres was used. Channel cross sections are typically derived from available hydrographic maps and/or field surveys.

Table 1 shows some surface area data; where S Area /x etc = area under the x metre contour line.

TABLE 1. SURFACE AREAS IN SQUARE METRES

Node-id	S Area/5	S Area/4	S Area/3	S Area/2	S Area/1
151	898137.9	898125.5	805206.7	340304.4	11838.7
152	1598115.9	1598115.9	1066843.3	31420.8	2791.9
153	2200443.6	2178008.1	1644366.4	433127.3	5455.9
154	1831678.7	1744743.1	512115.8	36711.3	17440.0
170	4211542.8	3821376.1	2148350.4	183534.6	10619.0

2. The results were transfered to the ESTRY program for hydrodynamic modelling.

   The flood model was simulated for a nominal flood event which would cause minor flooding of the lower flood plain. The flood hydrographs were based on those established for the January 1968 event.

   A table of calculated flood levels over time were derived for each storage node. These levels cater for the hydraulic gradient of the flood plain as it approaches the river mouth.

Table 2 shows some reduced levels for the flood over time.

TABLE 2. REDUCED LEVELS OF FLOOD IN METRES

Node-id	36 HRS	48 HRS	60 HRS	72 HRS	84 HRS	96 HRS	PEAK
151	1.13	1.13	1.13	1.20	1.33	1.35	1.38
152	1.35	1.37	1.38	1.69	1.83	1.86	1.86
153	0.97	1.13	1.33	1.42	1.41	1.38	1.43
154	1.38	1.39	1.42	1.77	1.90	1.91	1.92
170	0.78	1.09	1.53	1.89	2.03	2.04	2.04

3. The calculated flood levels, were stored as attributes of the polygons defining the storage nodes. Using the DEM, contour lines defining these flood levels within each storage node were computed for specified time intervals of the flood to define the areas of inundation.

   Computer graphic displays of the areas inundated at different stages of the flood were created giving a clear pictorial representation of the propagation of the flood wave. Alternatively the maximum area of inundation over the duration of the flood can be presented by contouring peak levels calculated. All graphical output was colour coded.

   Figure 3 illustrates the cadastral information (roads and property boundaries) along with the tidal waterway areas. Figure 4 shows the areas inundated at time 48h which is prior to the flood peak, while Figure 5 illustrates the maximum area inundated based on the peak flood levels calculated over the flood duration.The area of inundation can also be shown in three-dimensional form as depicted in Figure 6. Figure 7 depicts a shaded plan of the maximum depth of inundation achieved by subtraction of the DEM from the calculated flood levels.

The output provided by the GIS, presented the results of the flood study in a far superior form to that currently available to the engineers.

EVALUATION OF METHOD

The project was undertaken in an applied research and development environment in the GIS laboratory at the Department of Lands.

Key considerations arising from the project to date are summarised in point form below.

(a) A well planned photogrammetric survey will provide a comprehensive digital elevation model of the river catchment and flood plain. The digital height data can be directly and easily linked with the Geographic Information System to provide a more effective and efficient process compared to current methods.

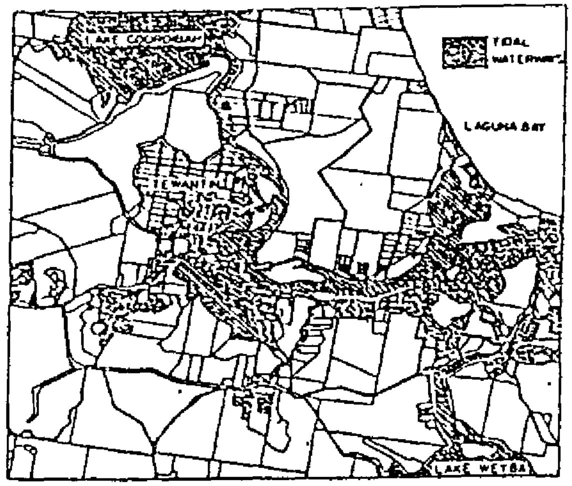

Figure 3

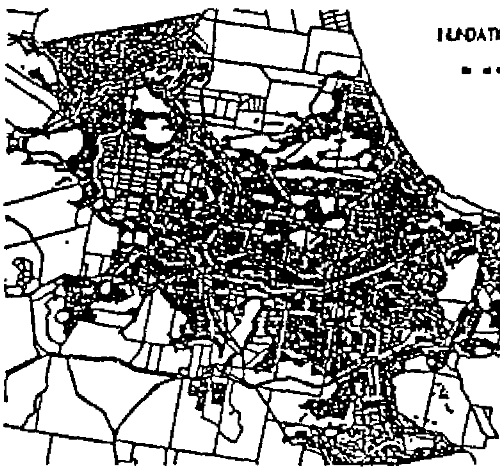

Figure 4

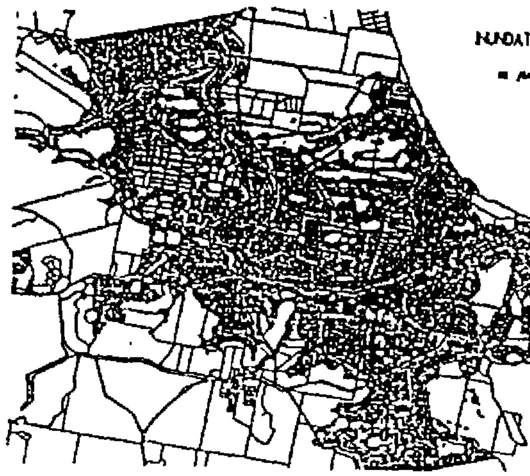

Figure 5

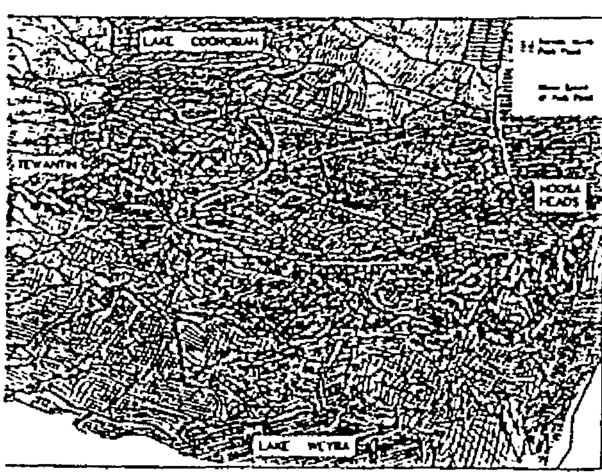

Figure 6

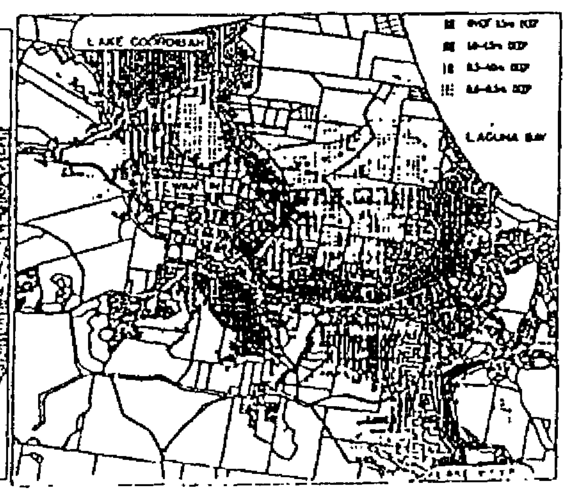

Figure 7

Data quality can be assured and a more accurate representation of the surface terrain described by the flood model can be made.

(b) The photogrammetry must be supported or confirmed by field surveys especially where there is difficulty in determining the actual ground surface from the aerial photography, ie. where there is thick vegetation, long grasses. Heights in areas of the floodplain which are of special interest should also be verified by the land surveys. The amount of extra levelling by field survey is expected to be very minimal. For this project, it is estimated that a field party of 1 surveyor and 2 assistants would need only two days to provide all extra verification heights in critical areas.

(c) The accuracy of the photogrammetry over the floodplain must be of the order of +/- 0.1m. Aerial photography at a scale of approximately 1:9000 gives a theoretical heighting accuracy of 0.2m. In practice, field verification checks have proven heighting in the stereo model to 0.1m is very often achievable from this scale of photography.

(d) If any hydrographic information of the river system is available, this should also be incorporated into the DEM.

(e) The automatic generation of data describing the geometry of the floodplain from the DEM reduces the development time of a numerical flood model. Changes to the geometry of the flood model or increasing the resolution in an area should also become an easier process.

(f) The role of the hydraulic engineer in defining the storage/pondage areas and connecting channels of water flow of the model is paramount. A clear understanding of the hydraulic processes involved and the satisfactory calibration and verification of the flood model are necessary. Where no flood calibration data exists experience in calibrating models of similar terrain is essential.

(g) The presentation of the results from a flood modelling exercise can be presented using a GIS in forms which are significantly easier to interpret and understand. Typical forms of graphical output which can be presented with cartographic quality in 2D plan and 3D perspectives include:

- Inundation maps at different stages of the flood;
- Inundation maps of the maximum area of inundation over the duration of the flood;
- Colour coded depth of inundation maps;
- Colour coded flood velocity contours;

- Flood hazard maps based on the depth of inundation and velocity of flow;

- Cadastral maps depicting residences and roads which would be inundated or some other attribute for a given flood event.

A major success factor for the integration process was the ability of the GIS to incorporate other graphical and attribute data such as property details with the flood information for further assessment and analysis. This capability is a tangible benefit also for the land use planner.

ECONOMIC CONSIDERATIONS

Cost estimates for data acquisition were sought to gain an insight into the economics of the process and in particular to compare photogrammetric data capture to methods usually employed by engineers. For this project area the following estimates were collated and based on completion by private contract.

Photogrammetric Survey

(Photo scale 1:9000 38 Stereo Models). These figures assume that no suitable photography nor field control data is available.

Aerial Photography	$ 5 700
Field Control Survey	$ 28 000
Spot field verification levels	$ 2 000
Materials	$ 1 300
Aero Triangulation	$ 5 700
Acquisition of DEM (22,000 points)	$ 13 000
Management	$ 1 000
Sub-Total	$ 56 700
Initial GIS Component (digitise model network, compute surface areas and channel cross-sections).	$ 800
Quality control / assess Cross-sections (by Engineer)	$ 2 000
TOTAL	$ 59 500

Method normally adopted by Engineers.

. Collation of available level data	$ 2 000
. Acquisition of data from topographic maps	$ 3 000
. Field survey	$ 30 000
. Reduction of data to digital form compatible with flood modelling software	$ 6 000
. Management	$ 1 000
(Note: Approximately only 30% of points compared to DEM) TOTAL	$ 42 000

Although the cost estimates show that existing methods to be more economical, they are not a conclusive comparison of photogrammetry with traditional methods. There are a number of other factors to consider.

1. The engineering data would only be located in areas critical for the flood study. The DEM will provide a composite data set of height points covering a whole region. The cost comparisons are not assessing "like" data sets.

2. The cost estimates for the aerial survey would diminish substantially if suitable aerial photography and field control was available. The costs for the engineering methods would remain the same as shown.

3. The DEM acquired by photogrammetry can be re-used for many other land use planning and engineering applications both within and beyond the flood plain. This greatly enhances the economic viability of the DEM.

4. Height data can still be acquired by normal methods if need be and the modelling process can still incorporate the GIS applications and output advantages.

5. All of the above need to be assessed in regard to the requirements of the survey. eg. broad based reconnaissance or detailed survey. The DEM would be suited to a detailed survey.

The needs for each project would vary and should be assessed individually.

STATUS

The conceptual phase was completed satisfactorily. The next phase will entail software development to automate the process.

The Noosa Shire Council has publicised its intentions to undertake a flood study in this area. Approaches will now be made to the Council engineers and elected officials to demonstrate the process with a view to soliciting specific planning applications and providing a service to the Council. This will allow real world testing of the process.

CONCLUSION

The integration of numerical flood modelling and a GIS was successfully achieved. The results of the project detailed significant benefits regarding development of a flood model and the presentation and conveyance of flood related data.

The reduction of topographic data to a form suitable for a numerical flood model was more effective through the use of a GIS and DEM, with more accurate computations achievable.

The results of the flood modelling exercise, presented using the GIS provided greatly enhanced output compared to techniques currently available to the engineers. Output in the form of colour coded flood inundation maps and depth of inundation contours in plan or perspective views conveyed the results of the flood study in clear easily understood products. Through the features of a GIS, flood related information such as flood heights, depth of inundation and water velocities, can be included in a geographic data base. This information can be recalled or processed with the many other data sets relating to property such as address, phone number, floor height, road levels, street network routing, ownership, zoning, soil type, and services.

The data acquired for such a project, particularly the digital elevation data and aerial photography, can be re-used for numerous other planning tasks eg. utility services planning and maintenance, land resource management. This factor makes the initial cost of data acquisition more justifiable and less prohibitive.

A number of technologies have been or are being developed to assist the flood forecaster. Hall A.J. and Elliot J.F. (1986) have suggested that co-operative ventures between agencies collecting environmental data are seen as the first step in cost effective data collection. Agencies such as Federal, State and Local Governments should consider jointly contributing towards acquisition of digital topographic data to allow economic access by organisations such as hydrology engineers to this data. There could be a role for private industry organisations such as the insurance industry to participate in such a scheme.

The combination of numerical flood modelling and GIS's are potentially a powerful tool for local government authorities where flooding and the management of flood prone land is a major concern. Comprehensive land and resource management beyond the flood risk area will also be possible.

FUTURE

If a flood warning system is linked to a GIS, the properties and roads which are likely to be affected and the information required to take evasive action could be displayed in either graphical or tabular forms. The link with a flood warning system may provide many benefits to systems already in use.

The city of Brisbane suffered a devastating flood in January 1974 which caused economic losses exceeding an estimated $178 million dollars. More than 13000 buildings were affected with some 45 homes swept away by strong flood currents. Human lives were lost and enormous personal trauma occurred. Although many flood warnings were broadcast, the full extent of the flooding and accurate definition of risk areas was a problem for the authorities. Public apathy to heed warnings also proved a major cause for concern.

The clear presentation of easily understood and accurate flood prediction maps will provide an effective guide to the areas in most need of risk assessment and will also aid disaster organisations to plan any evacuations necessary due to a flood event. The maps should also assist the general public to comprehend the extent of flood risks and encourage less apathy to emergency warnings.

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