A New Method of Building Digital Elevation Model for Hydrologic Modelling

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ABSTRACT

Digital elevation model (DEM) can be produced using different sources of data. When theses DEMs are used to calculate topographical characteristics in spatially distributed hydrological models, the errors in the DEM will propagate through the hydrological model. The accuracy of simulation therefore depends on the accuracy of the DEM. This study focuses on various steps involved in building a DEM for hydrologic modelling with particular emphasis on the importance of specifying the surface (breaklines) within ARC/INFO-GIS. A new method of building DEM for hydrologic modelling has been developed and applied successfully to the study area. Proposed method showed an improvement over the conventional method when used for watershed and stream network delineation.

1. INTRODUCTION

An important factor in determining the runoff response to rainfall is topography. Spatially distributed hydrological modelling takes this factor into account through the use of DEM. Many sources of data can be used for producing DEM of the region: field survey, topographic maps, aerial photographs and satellite images. The sampling patterns can also differ considerably: irregularly spaced points, contour registration, and slope discontinuity registration.

The interpolation technique and grid size of the DEM can also vary. Geographic Information Systems (GIS) algorithms (e.g. CREATETIN in ARC/INFO) allow the user to combine different topographical data layers to build a single DEM. The accuracy of these different DEMs is extremely variable. As DEM errors propagate through the hydrological model so, the accuracy of the simulated hydrographs is strongly related to the accuracy of the DEM used (Lagacherie, et. al., 1996).

DEM is the basic digital data set necessary to perform hydrologic modeling. Several characteristics about the surface hydrology of a particular area can be determined using DEM. Processing DEM data to extract hydrological features has become common procedure ((Garbrecht and Martz, 1996), (Guercia et. al., 1996)). The users of such data often perform this task without carefully considering the accuracy of the data and how it could affect the reliability of extracted hydrological features (Lee and Chu, 1996). Readers are referred to Mark (1982, 84), Band (1986), Hutchinson (1989), Goodchild and Mark (1987) for further reading on this topic.

Hutchinson (1989) developed a method of removing spurious pits (sinks) from elevation and streamline data. Hutchinson's method has been incorporated as a function, named TOPOGRID, into the latest release of Arc/Info software. TOPOGRID addresses the issue of spurious sinks during the building of DEMs. However, the method discussed in this research paper focuses on DEM building for hydrologic modeling, drawing on the surface parameters' (breaklines) in ARC/INFO's TIN module. A new method of DEM building is proposed here, which has been applied successfully to delineate river networks and watersheds. A comparison with the currently available methods is discussed, including the TOPGRID function in Arc/Info.

2. STUDY AREA

The study area covers approximately 350 km2, 14km southwest of Tauranga City, New Zealand. The Kaimai Hydropower project consists of three Hydropower stations, Lloyd Mandeno (LMS), Lower Mangapapa (LMPP) and Ruahihi, commissioned in 1976, 1979 and 1981 respectively. The total system production is 41.6 MW. Based on the geology and topography the study area can be divided into the northern Mamaku Plateau (which comprises the bulk of the area), the lower eastern Kaimais and the southern Whakamarama Plateau. Native forest, with smaller areas of exotic forest and scrub, covers the catchment almost entirely. A variety of native trees grow in the gorges and valleys of the study area, particularly in the more inaccessible areas. Figure 1 shows the digital elevation model (DEM) of the study area along with the description of Kaimai Hydropower scheme.

3. SURFACE DESCRIPTION

Breaklines define and control surface behavior in terms of smoothness and continuity. As their name implies, breaklines are linear features. They have significant effect in terms of describing surface behavior when incorporated in a surface model. Breaklines can describe and enforce a change in the behavior of the surface. Z values (3D coordinate) along a breakline can be constant or can vary throughout its length. Three types of breaklines can be employed to describe surface behavior: hard breaklines (e.g. rivers, ridges, dams, shorelines etc.), soft breaklines (e.g. section of pipe with constant elevation), and faults (ESRI, 1996).

This section of the paper deals with the issue of whether rivers/streams should be included as hard breaklines or soft breaklines while creating tins surface model for hydrologic modeling. It is important to mention the possible commands that were used for defining rivers as hard breaklines. As the rivers did not have a Z value throughout their length, the following commands were used to give rivers Z values in order to define them as hard breaklines.

a. <u>INTERSECT</u> computes the geometric intersection of two coverages. Only those features in the area common to both coverages will be preserved in the output coverage.
b. <u>LINEGRID</u> converts the line feature into a defined grid size. The grids are then used with the "LATTICE" option of creating TIN in order to give rivers Z values.
c. <u>VIP</u> command creates point coverage containing the best possible set of LATTICE mesh points from which to construct a triangular irregular network (TIN).

These commands did more or less the same task but it was important to compare all available methods. In order to define rivers as a hard breakline, the rivers were intersected by contours using the INTERSECT command so that the features common to both coverages could be captured as one coverage. The intersected coverage was converted into a LATTICE using the LINEGRID command. This LATTICE was then converted to point coverage using the VIP command. The VIP command has the option of selecting a percentage of data points for creating TIN. The higher percentage only makes data coarser. It was interesting to note that by using 10% option, 16930 points were generated.

The computer made it possible to add Z value to these points, which was otherwise difficult to do manually unlike other features such as lakes and dams. No difference in the TIN was detected using LATTICE or VIP point data as both showed irregular river networks. Another TIN was created using rivers as soft breaklines (without adding Z value). It was interesting to note that the river network defined as a soft breakline showed smooth behavior and maintained the exact location in the catchment when overlaid with the digitized river network (fig. 2). As far as hydrologic modeling is concerned, it is more important that the river should represent the exact location in the catchment. The depth and height of the rivers in the catchment throughout their length is usually unknown so it seemed reasonable to maintain rivers as linear features (soft breakline) while building a tins surface model.

The ARC/INFO users manual recommends rivers to be included as a hard breakline, which did not seem appropriate for hydrologic modeling because surface showed smooth behavior on both sides of the river but not at the river location. This uneven behavior could create errors in the modeling process when using FLOWDIRECTION, FLOWLENGTH and FLOWACCUMULATION functions, which are the basic steps, required for hydrologic modeling using GIS.

The reason for this abrupt change was that the contour arcs split at the location of defined hard breaklines in order to take into account the exact height of the river at that particular location. The height at the rivers' location was interpolated using the grid data structure and quintic interpolator (which interrupts the normal interpolation process at the location of defined hard breaklines) and the values at the both sides of the rivers were interpolated using linear interpolation. The surface on both sides of river showed smooth behavior as a result of continuous interpolation or triangulation but not at the river location because of different data structure and interpolator at that particular location. This resulted in a different value than the other data sets and caused abrupt changes in those locations. Figure 3 explains the clear difference between hard and soft breaklines using VIP function.

It was justifiable to define lakes and dams as a hard breakline or hard replace because is simple to give height to the boundary of the lakes. The hard replace interpolates the same height for the total polygon to represent inside the lake as a flat area. The lakes are usually bounded by two contours and assigning height to lakes is not difficult and the same is true for the dams as well.

4. NEW METHOD OF DIGITAL ELEVATION MODEL (DEM)

A 10x10 m DEM was created using ARCTIN, CREATETIN and TINLATTICE functions by writing an AML. Creation of error free DEM is prerequisite of hydrologic modeling. During the processing, sinks were created. It was necessary to find whether these sinks are natural closed catchments or artifacts of the processing. Filling sinks is a repetitive procedure. When a sink is filled, the boundaries of the filled area may create a new sink, which then need to be filled. Sinks were investigated and then filled by using an automated procedure (Choudhry et. al., 1997). This procedure is specially developed for hydrologic modeling purposes and requires that the user must have knowledge of the catchment topography. An error free DEM will be produced as a result.

Rivers were overlaid with the GRID data structure of the LATTICE. This was done to find out which cells of the LATTICE contain rivers and those cells' depth were reduced by 3m (program has the option for the users to change depth value according to their need) so that the river should take part in the modeling process. Filling of DEM before overlaying is very important otherwise there may be confusion between self-created depth of the rivers and DEM errors. This whole process has been automated by writing an AML within ARC/INFO-GRID program.

The TOPOGRID function of Arc/Info clears spurious sinks from DEMs by inferring drainage lines, via the lowest saddle point in the drainage area surrounding each spurious sink. According to Hutchinson (1989), the output drainage cover will match very closely with the input streams. Hutchinson's function gives good results where the purpose of the study is to produce an error-free DEM.

The proposed method discussed in this paper differs from the TOPOGRID function in one important way: it reduces the depth of the stream network by a user-defined value (after overlaying with the GRID data structure which has already been filled as discussed earlier). Stream network delineation using the method proposed here will pick up any change in the natural river course as mentioned in next section, but would otherwise follow the digitized stream network.

5. APPLICATION OF NEW METHOD

A watershed is the up slope area contributing flow to a given location. The watershed is also referred as a basin, catchment, or contributing area. Watershed boundaries are a key requirement for all surface hydrologic modeling and can be delineated from a DEM using flow direction and accumulation grid as input. If the false flow direction has been calculated as a result of an anomalous procedure of building DEM then the delineation procedure will also be affected. River or stream network can also be delineated from a DEM using the flow accumulation grid as input in a GRID algebraic expression.

Rivers network and watersheds were delineated using the proposed method and a conventional method (without removing DEM errors). 5000 cells were used as a threshold for the delineation procedure. River network using proposed method followed the digitized river coverage exactly except at three significant circled locations (fig. 4) where streams have changed their path naturally. The river network using conventional method deviated 2-6 cells when compared with the new method at different locations in the catchment. All the changes were noted and confirmed by the field survey using global positioning system (GPS). Watershed delineation using proposed method and conventional method was also compared and showed false polygons at many locations in the catchment shown in fig. 5.

The deviation in delineation procedure using conventional method is a result of false flow direction and accumulation, which may be avoided by using the proposed method. Watershed coverage produced by proposed and conventional methods was UNIONED and INTERSECTED. The sliver areas for the subwatersheds were determined and found in the range of 100 m^2 to more than 2 km^2. Finally, it can be concluded that the proposed method of building DEM gave better results than the conventional method and also had the advantages of simplicity and accuracy over the conventional method.

6. CONCLUSION

This study has demonstrated the need to consider the basic steps involved in building TINs or DEMs. The new automated method of building DEM gave better results than the conventional method when compared for stream network and watershed delineation processes. The proposed method gives a more hydrologically relevant outcome, when compared with the TOPOGRID function of the Arc/Info.

This paper proposes that rivers or streams be used as soft breaklines for specifying surface parameters' in ARC/INFO's TIN module, rather than as hard breaklines as mentioned in the ARC/INFO users manual. The proposed method of DEM building offers a significant advantage, over other alternatives, for hydrologic modeling.

7. REFERENCES

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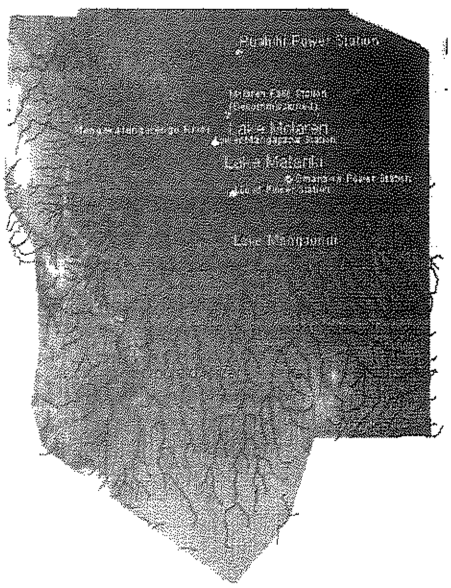

Fig. 1 Kaimai Hydropower scheme and digital elevation model of the catchment area.

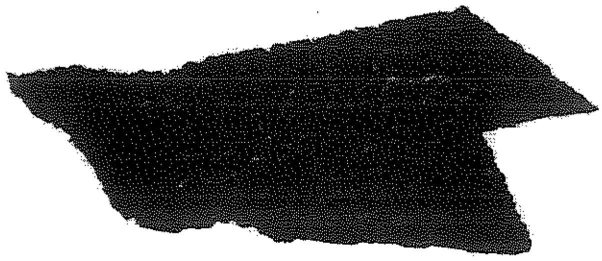

Figure 2. Surface description using rivers as a soft breaklines.

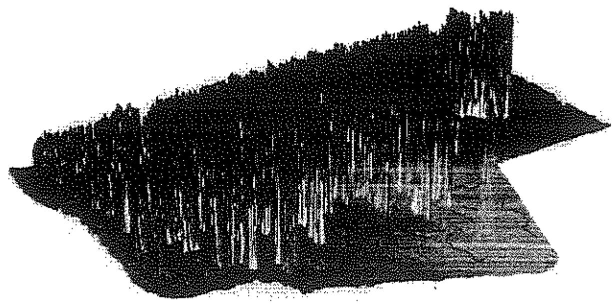

Figure 3. . Surface description using rivers as a hard breaklines (VIP function).

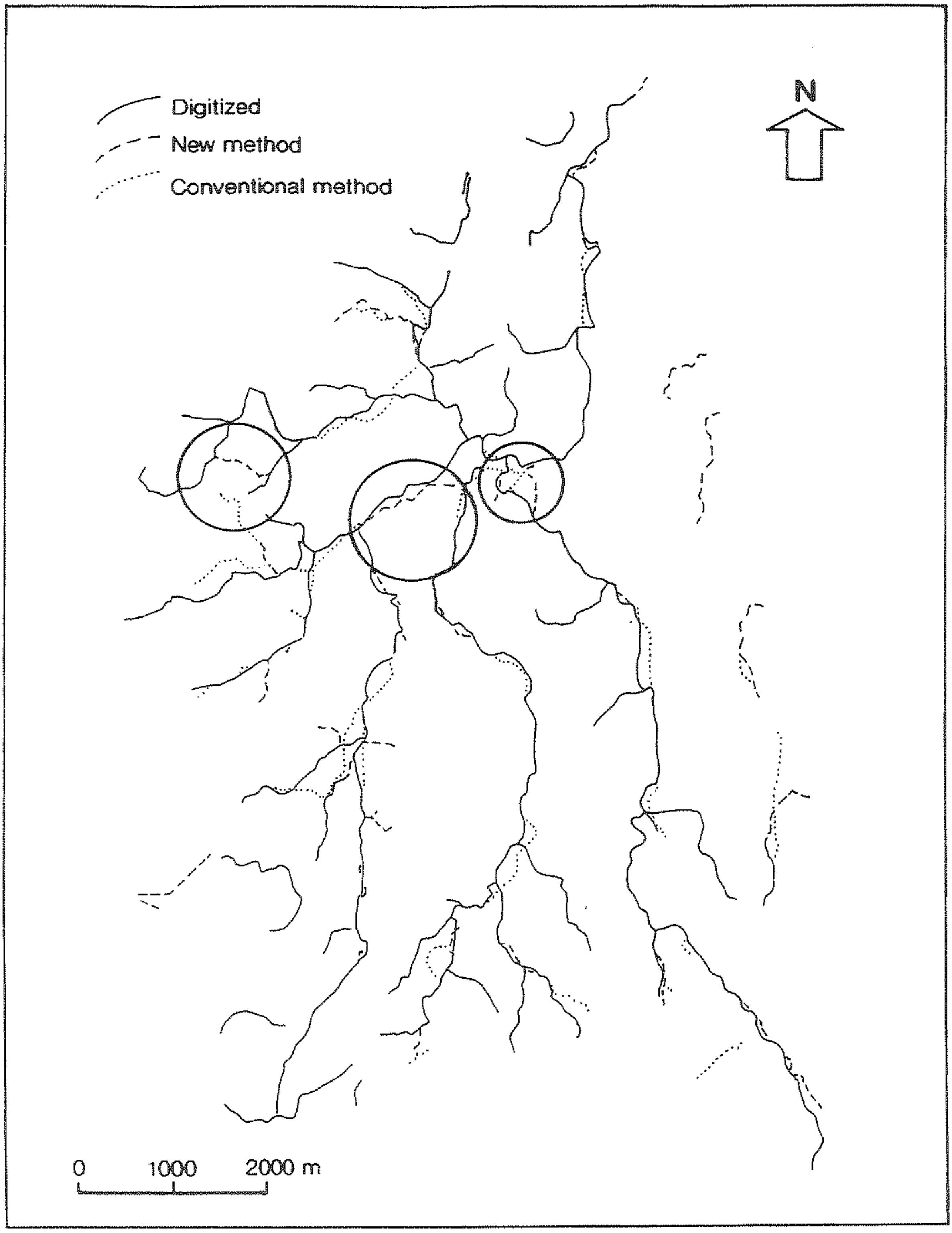

Figure 4. Comparison of different methods of stream network delineation

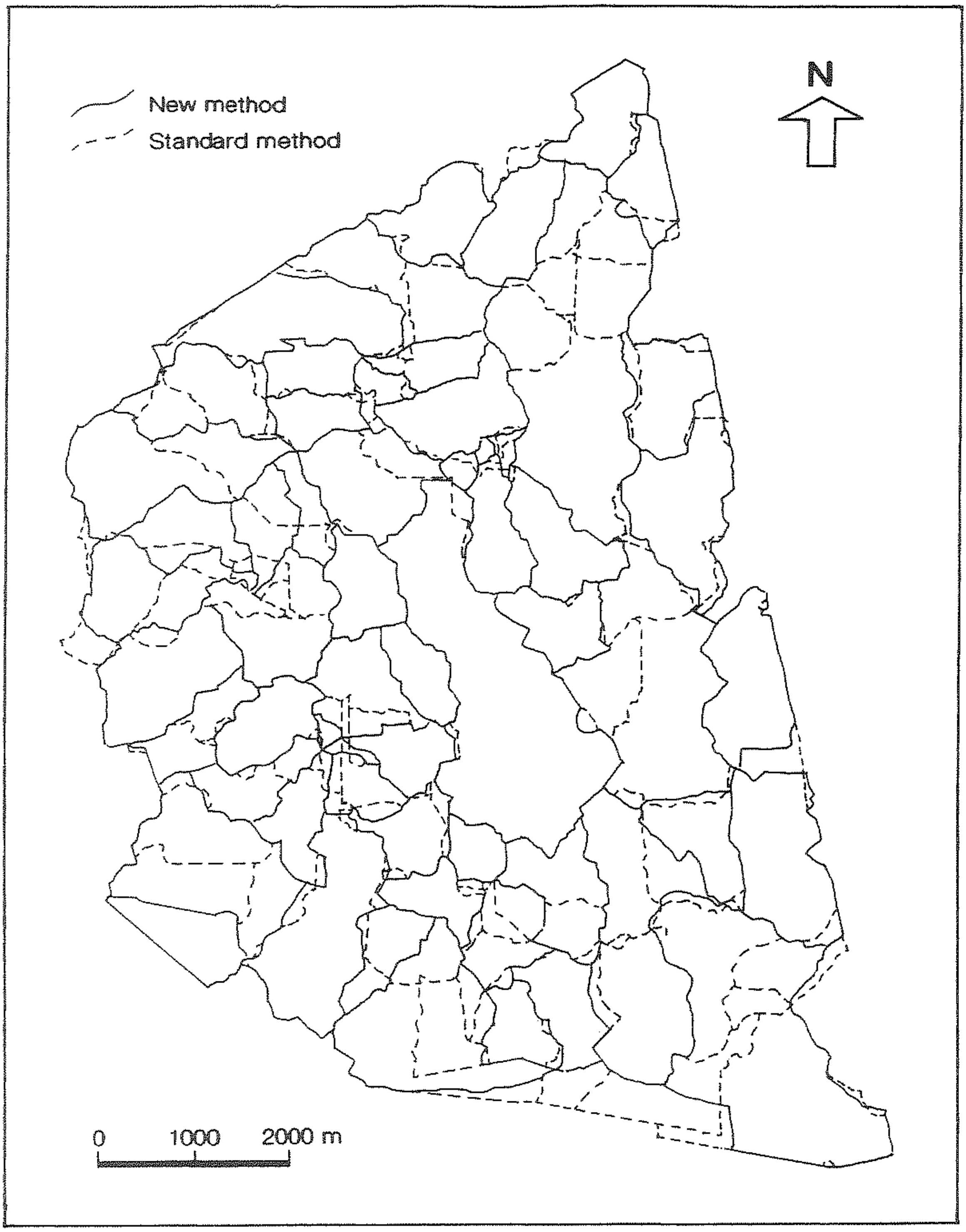

Figure 5. Comparison of conventional and new method of watershed delineation.