Hydraulics Research
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VARIABLE GRIDDED TIDAL MODEL

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SUMMARY

The numerical modeller concerned with water flows in estuaries is often faced with the dilemma of choosing a coarser grid than is ideally needed to resolve the details of his problem or accepting the higher computing costs demanded by a finer gridded model. The difficulties are alleviated if some flexibility can be introduced in the grid sizes to provide fine grid where local detail is required and a coarser grid further away to enable the boundary conditions to be prescribed outside the sphere of influence of the works being studied. Hydraulics Research currently use two methods for doing this - patching and locally distorted grids near boundaries - and this report describes another method which has been devised to extend the latter to give local grid distortion within the model area. In particular this will improve the resolution of low water channels and the edges of inter tidal areas.

This report describes the philosophy of the new method which is based on tables of flow areas, widths and depths, and cell volumes and surface areas in terms of the water level. In order to set up the large data base required to generate these tables it was necessary to have an automatic scheme for digitising original charts. For this purpose we adapted the Digital Terrain Model system developed at Wallingford for setting up models of river flood plains.

A new computer program TABLES has been written to process the raw depths into tabular form. However, it has not been possible to check the efficacy of the new method within the current research programme because there was no survey data available from a suitable site for testing purposes, and therefore the benefits of variable gridding cannot yet be quantified.

Program TABLES is part of the HR tidal flow modelling system called TIDEWAY. The full TIDEWAY system is available for application at Wallingford to a wide range of engineering problems in ports, harbours, estuaries and coastal areas and subsets of the system can be implemented on external computers.

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1 INTRODUCTION

For modelling water flows in estuaries there is a need for flexibility in grid sizes within computer models to provide local detail. Hydraulics Research Limited (HR) has two methods available for achieving this - patching and locally distorted grids near boundaries and it would be useful to extend the latter to give local distortion near the waterline as the tide falls and in particular to resolve low water channels in the middle of model areas.

Design factors

The appropriate equations for studying water movements in tidal areas are the 2-D, depth-averaged, shallow water-wave equations. Finite difference approximation to them can be made as accurate as required by suitably refining the finite difference grid. On the other hand it is usually advantageous to have the open boundary conditions of a model as far from the area of interest as possible i.e. beyond the range of influence of the works being studied. A uniform grid over the whole area, fine enough to give the required resolution in the area of interest, would lead to unacceptable computing requirements and so models have been developed at Wallingford in which the grid size could be changed from one area to another - the grid size being constant within each area. This allows larger grid sizes to be used away from the area of interest. Grid sizes (length of sides of grid squares) are increased by factors of three from one area to the next because this gives the most natural matching at the patch line (Ref 1).

Resolution in 2-D models

It often happens that, because of constraints on computing times or costs, a minimum grid size has been determined which does not resolve narrow channels or rapidly varying coastlines as well as one would wish. While the preferred method for overcoming this difficulty is always to use a smaller grid in practice one is forced to accept a compromise.

For some time Hydraulics Research has employed a locally distorted grid around the no flow boundaries of the model (Ref 1). In this approach the width of a cell side is no longer taken as Δx but as Δx times a width factor (generally less than 1.0 but can be greater). For narrow channels, reducing the width rather than artificially making the depth shallow to get the correct cross-section has the advantage of keeping the correct depth for the friction calculation, and may avoid incorrect drying in shallow areas. This has the effect of reducing the formal accuracy of the finite difference scheme because the differences become off centred. However, this is not of any practical significance because the actual accuracy of a centred scheme would also be reduced in the vicinity of stepped boundaries which are inevitable on a rigid grid system. Indeed the flow is expected to be represented more accurately when a locally distorted grid is used.

Resolution in 1-D channels and rivers

If lateral variations are not important the shallow water wave equations are integrated over the cross section of the region to be modelled to give 1-D equations for the bulk flow. HR has a complete suite of computer programs named TIDEWAY-1D based on this principle for studying problems in water movements and transport processes. These employ look-up tables for the width, area and hydraulic radius for each model section. Unfortunately, this system cannot be combined readily with the analogous TIDEWAY-2D depth integrated system. There are too many possible configurations to have a general, all purpose system combining TIDEWAY-1D and TIDEWAY-2D. There are numerical difficulties in joining an implicit 2-D model to an implicit 1-D model in the case of a wide river because this gives too much coupling. Also it is not feasible to allow the facility for a river join at any point in the 2-D model and so combining 1-D and 2-D models has in the past been a time consuming and costly exercise with each application being treated as a special case.

Combined model of channels and 2D areas

In the present context we are more interested in the case where the 1-D part of an estuary is only needed to provide tidal storage to produce the correct flow in an adjacent part of the 2-D part of the estuary.

The main drawback of representing the 1-D sections by a fixed 2-D grid is the failure to resolve low water channels when there are drying banks within individual grid squares. The consequences of this on model friction are described in Ref 2. These difficulties could sometimes be overcome by using a finer grid, however, this would increase computing requirements out of proportion to the benefits obtained. A locally distorted grid is only useful for situations where the width of the channel decreases along the channel but does not change significantly during the tide (Ref 1).

The logical conclusion is to extend the 1-D principle of using look up tables to the 2-D system. This would enable both low water channels to be resolved in the middle of 2-D model areas and rivers to be handled in the 2-D model and also would have the advantage that the full 2-D system of processing and computer plotting programs would become available for the whole model including the 1-D sections.

Such an approach could not be contemplated in the past because of the large computer storage involved but is now well within the capacity of modern machines such as the ICL DAP.

2 SETTING UP UNIFORM GRIDDED MODELS

The original procedure for setting up uniform gridded models at Wallingford is described in Ref 3. The first stage was manual and involved dropping a uniform mesh on to the base chart and taking off depths at spacings of the model grid or one third of this spacing if greater accuracy was needed or if there was a possibility of an extra level of patching being required later. The data was input to the computer and processed through a series of steps (Fig 1). The system had optional stages where depths and flags could be edited manually and where model contours could be output graphically for checking. The setting up of locally distorted grid models followed the same procedure, but was more time consuming. The mechanics of setting up models in this way could be carried over to variable gridded models, but it would prove even more time consuming because grid intersections would also have to be recorded. This emphasised the need for an automatic method of setting up models.

Meanwhile, another group of workers at HR had been developing an automatic system called the Digital Terrain Model (DTM) for use in setting up models of river flood plains (Ref 4). The DTM works from data files containing contour strings and random spot heights which may be input by a digitiser (Fig 2). The DTM system already contained much of the processing required for setting up 2-D tidal models and consequently it was decided to adapt the DTM for this purpose. Some modifications were required to implement the DTM for TIDEWAY models. The DTM system was originally based on 1km by 2km map units at a fixed scale of 1:2500 corresponding to the standard Ordnance Survey plans. A typical application of the DTM to a flood problem required many map units to cover the model area and the system was designed to cope with these when there were only a few model elements per map unit. By contrast charts for TIDEWAY model geometries come in all shapes and sizes and are usually at much smaller scales. A TIDEWAY model would normally be contained on one or two charts but it is not uncommon for several thousand TIDEWAY model elements to be required.

Scale differences were readily overcome using scale factors. It was not found feasible to sub-divide the charts into many map units when there were a large number of model elements because the paging of map units which this entailed produced unacceptably long computer processing times. The solution was to increase the limit on the quantity of data which could be handled in a map unit so each chart was treated as just one or two map units. A few further amendments were also required so that the DTM system produced files compatible with the TIDEWAY modelling system (Fig 1).

The first stage was to test and implement the DTM on setting up a uniform gridded model. This was achieved without any serious difficulties working from data files comprising contour strings. Some further adjustments were needed to get the system to work from data files containing a significant proportion of spot heights. This was necessary because DTM had been designed as a contour dominated system. Any contours crossing section lines were used in calculating the flow area but spot heights were only taken into account if they lay close to the nodes of the section line. This difficulty was overcome by the simple artifice of specifying superfluous nodes at intermediate positions along the section lines so that these were automatically included in the DTM processing. Some guidelines to follow when using the DTM to set up models are given in Appendix 1.

3 SETTING UP GRIDS WITH VARIABLE GEOMETRY

The objective is to set up geometry files to give a better description of sub grid detail when the model grid cell is partly dried out.

The geometry in a uniform gridded model is specified using water surface Z(k) and bed levels HU(k) and HV(k) on the east and south sides of cell (Fig 3) and these are combined with the cell dimensions DX and DY to form the basic quantities:

AU(k)	= HU(k)xDY	(Flow area of E side of cell k)
AV(k)	= HV(k)xDX	(Flow area of S side of cell k)
AZ(k)	= DXxDY	(Wetted surface area of cell k)
VOL(k)	= AZ(k)xDMAX(k)	(Volume of water in cell k)

where DMAX(k) is Z(k) + the maximum bed level of the fours sides of cell k.

In the first instance, the raw data for tide varying geometry will be presented to the preprocessor in the form of 16 spot depths per basic model cell (as used by TRILINE in Ref 1). This will be processed on the basis that each raw depth is the average depth over the rectangular sub area DX/3 by DY/3 around the spot depth. Volume and area calculations are weighted by:

unity for interior spot depths
half for middle edge spot depths

quarter for corner spot depths

and based on the 2-D histogram idealisation shown in Fig 4. These geometry functions could be improved later once the principles have been established.

In any event, the preprocessing yields the following tables for use by the TIDEWAY models.

HUMAX(k), HVMAX(k) -
are the maximum (deepest) of the four spot heights along the u and v faces of the continuity cell k (Fig 1)

HUMIN(k), HVMIN(k) -
are the minimum (shallowest) of the 4 spot heights along the u and v faces (Fig 1)

HMAX(k), HMIN(k) -
are the maximum of the four face maxima (ie. of HUMAX(k), HUMAX(kw), HVMAX(k), HVMAX(kn)) and the minimum of the four face minima. These could be calculated when required rather than stored as array variables if problems with storage.

The above extremes are used to define the intermediate levels for which cell volumes, mean depths and flow areas are to be tabulated. The number of tabulated values is called LEVELS.

VKL(k,j) -
are the cell volumes below the jth intermediate level. ZL = -HMAX(k) + j*(HMAX(k) - HMIN(k))/LEVELS for j = 1, LEVELS

HU(k,j) and HV(k,j) -
are the mean depths of the wet part of the u and v faces of the continuity cell, below the jth intermediate levels

ZUL(k,j) = -HUMAX(k) + jx(HUMAX(k) - HUMIN(k))/LEVELS
ZVL(k,j) = -HVMAX(k) + jx(HVMAX(k) - HVMIN(k))/LEVEL

AU(k,j) and AV(k,j) -
are the u and v flow areas below the jth levels ZUL and ZVL for j = 1, LEVELS. Alternatively it may be more convenient to store mean widths WU(k,j) = AU/HU and WV(k,j).

AZ(k,j) -
is the wetted surface area at the jth level ZL for j = 1, LEVELS

The intermediate table levels ZL, ZUL and ZVL could also be stored in tables to avoid recalculation if there was adequate space.

User instructions for routine TABLES which sets up the tables is given in Appendix 2.

Use of Tables in the flow program

Volume will be summed up for each cell and used to define the water level on the variable geometry. The new volume, VOL(k) will be obtained from the continuity calculation, then the water level calculated as:

$$Z(k) = -HMAX + VOL(k)/(DX \times DX) \text{ for } VOL(K) > VKL(k,LEVELS)$$

$$= -HMAX + DELZ \times \{j - 1 + (VOL(k) - VKL(j-1)\}/\{VKL(j) - VKL(j-1)\}$$

for

$$VKL(j-1) < VOL(k) < VKL(j)$$

$$= -HMAX + DELZ + VOL(k)/VKL(1) \text{ for } VOL(k) < VKL(k,1)$$

where DX is model grid and DELZ = (HMAX - HMIN)/LEVELS

NOTE 1 that last case could be combined with second case if extra volume entry VOL = 0 put into table

NOTE 2 Surface areas are not needed in the flow model but when they are needed (eg transport models) they would be calculated in an analogous manner.

Mean depths for flow will be calculated in the following manner. Note that the present program uses the acceleration form of the momentum equation so the flow area not required directly but it is needed to calculate total discharges for subsequent transport calculations.

The level at a u-face, ZU is the average of Z(k) and Z(ke). The depth for friction (and later for continuity) is defined as:

$$DU(K) = ZU + HU(k,LEVELS) \text{ for } ZU > -HUMIN$$

$$= HU(k,j-1) + (ZU - ZULM1) \times \{HU((k,j) - HU(k,j-1)\}/DELZ$$ for surface in slices 2 to LEVELS

$$= (ZU + HUMAX) \times HU(k,j)/DELZ$$ for surface in the bottom slice (No 1)

where ZULM1 is elevation of bottom of slice j and DELZ = (HUMAX - HUMIN)/LEVELS

V-depths and U and V-flow areas would be interpolated in a similar manner.

4 CONCLUSIONS AND RECOMMENDATIONS

A new method has been devised to provide a better description of flow geometry within the model area, and automatic methods have been produced to generate the appropriate data bases. The final checking of the variable gridded models will be quite costly and it has been decided that this phase will need to be delayed until we find a suitable site with survey data for testing purposes.

5 REFERENCES

1. Hydraulics Research Station. HRS Tidal Modelling System - tidal flow programs detailed description. Report No IT 238, 1982.

2. Miles, G V and Weare, T J. On the representation of friction in 2-D numerical models. Proc. of Int. Conf. on Numerical Methods in Fluid Dynamics. Univ. of Southampton, 1973.

3. Hydraulics Research Station. HRS Tidal Modelling System - preliminary and tidal flow programs user manual. Report No IT 239, 1982.

4. Samuels P G, Price R K, Wilde J S and Cormack W J. A Digital Model of River Valley Topography. Adv. Eng. Software, 1982, Vol. 4 No. 2 pp 58 to 63.

APPENDIX 1

GUIDELINES FOR APPLYING DTM TO TIDEWAY SYSTEMS

Digitising your chart

Firstly, the area of interest must be divided into map units or half map units with dimensions of 2 x 1, or 1 x 1 units. It is wise to use as few map units as possible when covering your area. Always make sure that the map units cover an area slightly bigger than the intended model area. This ensures that the model does not waste time searching for information outside a map unit. Having decided where your map units are, record the equivalent coordinates of the map units, in real terms and in map unit terms.

Choose the size of the map units with sensible dimensions, so that it is easy to relate map unit distances to actual distances on the ground eg a 2 x 1 map unit may be equivalent to a 10 x 5km area on the ground. This is particularly useful when checking your database, as the DTM will produce a plot which can be overlaid on the original to check for errors. Remember that only blocks for 1 x 1 map units may be reproduced by this method, so make sure that they will actually fit onto the graph plotter.

The DTM system was designed for use with 1/2500 scale Ordnance Survey (OS) plans with respect to the grid origin SV0000 at the extreme South west corner. For TIDEWAY applications it is necessary to imagine the model area superimposed on the OS grid and it is convenient to place the bottom left hand corner of the chart at the OS grid origin SV0000. The bottom left hand map unit is then referenced as SV0000, the one butting on to the east is SV0200, the one butting on to the north is SV0001, and the one touching the north east corner is SV0201, etc.

Hints on what and how to digitise the information

1. Aim for a uniform distribution of contours without "empty" spaces.

2. Fill in the land with contour values also.

3. Whenever possible leave a contour very close to the edge of map units.

4. Position the DTM on a round number of the national grid.

5. Add an open contour along channels to avoid a flat bottomed channel in the database.

6. Omit unnecessary detail when digitising a contour if the cell spacing would be such as to lose the information anyway.

7. Where there is a dense packing of contours (say at a steep slope) it is best to digitise every other contour so that "crossing" errors would be reduced.

APPENDIX 2

PROGRAM TABLES - USER INSTRUCTIONS

Function

The main user manual for the HR tidal modelling system (Ref 1) describes the preliminary programs used to set up an array of averaged depths applied to the cell faces used in computing the water flows. The great increase in computer power available, especially where parallel array processing facilities are used, makes it feasible to use a more detailed representation of the bed geometry. This appendix describes a method of supplying such a detailed representation based on a simple extension of the histogram method used in the earlier reports.

Method

Since this process requires the use of four depth values for each cell face, the new program TABLES replaces TRILINE in the setting up process. For this reason, the two-dimensional plan array is still present in the output and the active variables of flow areas, mean depth and volume are three- dimensional.

As a further means to assist subsequent checking and editing the tabulation subscript is the first in the bracket. This will require that a further program be written to invert the array for efficient use of the output with parallel processing.

The depth data supplied to the program must be in the form of the output generated by INLINE. The information supplied to the flow computation programs is presented as a number (LEVELS) of tabulated values, and the upper and lower limits of tabulation are set by the maxima and minima of the depths along the south and east faces of the cell, when values equal to the control variable DRY are ignored.

Similarly the contained volume and wetted surface area are tabulated betwen the maxima and minima of the four face limits. This concept is illustrated in Figure 4.

The tabulation levels (ZUL, ZVL and ZL) are measured positively upwards from the reference plane and form an arithmetic progression between the relevant maximum and minimum. The flow areas (AU and AV) are the areas of the histograms in square metres and the mean depths (HU and HV) are calculated as AU or AV divided by the relevant width. As in the earlier program a U in the variable name indicates that the variable applies on the eastern face. Similarly, the occurrence of a V denotes the southern face.

The cell wetted surface (AZ) generates numbers too large for the field widths currently in use so this has been expressed as the fraction of the cell area wetted. In the same way the cell volume (VKL) is expressed as the true cell volume divided by total cell area.

The cell is designated active or inactive by means of an integer flag, FLAGZ. This has the value 0 for inactive, and 1 for active cells. In TABLES, a cell is active if its wetted area is greater than one ninth of the cell area.

Input

Channel 1 : card reader
Card 1 : ICONV equals 0 for no conversion of depths
equals 1 for depths in fathoms and feet
Card 2 : LEVELS The number of levels used in the tables
Format (I6) for both cards
Channel 3 : card reader (Generally this is the file produced by INLINE) Card 1 : determines size of model
(i) M Number of depths east-west
(ii) N Number of depths north-south
(iii) DX Depth spacing (m) east-west
(iv) DY Depth spacing (m) north-south
(v) DRYIN Code for land
Format (2I6, 3F8.2)
Cards 2, 3 : ignored (These contained text and column information if produced by INLINE)
Following N cards : depths (positive downwards)
The depths are to be supplied in 'strips', 10 wide, each covering the complete north-south extent of model, first card being the northern most.
Format (A10,10F7.2)

The first 10 columns of each card are ignored. This is because if the file was produced by INLINE, the columns would hold the row numbers. The last (N + 2) cards are then repeated for the remaining 10 depth wide strips until the grid has been covered. Depths for the easternmost strip need only be given for positions within the grid. For example, if M were 15, the second (and last) strip need only contain 5 columns of depths.

Output

Channel 2 : Line printer. Listing of FLAGZ. The values are printed in strips 100 columns wide, with no spacing between the 0's and 1's. This gives a simple graphic description of the estuary.

Channel 4 : Formatted card punch file. In addition to using a similar storage manner to that of INLINE, (grid size information and FLAGZ), this file contains tabulated values of all the depth varying variables.

Card 1 : M, N, DX, DY, DRY
Format (2I6, 3F8.2)
Card 2 : LEVELS
Format (I6)

Listing of FLAGZ as in channel 2
Listing of cell heading and tabulated values for each cell
First card cell column and row number
Second card column headings
Next LEVELS cards tabulated values of all the variables for each level
One tabulation level per card containing

- ZUL jth tabulation level for u-point
- HU mean depth below jth level ZUL
- AU u-flow area below jth level ZUL
- ZVL jth tabulation level for v-point
- HV mean depth below jth level ZVL
- AV v-flow area below jth level ZVL
- ZL jth tabulation level for z-point
- AZ surface area at jth level ZL
- VKL cell volume at jth level ZL

Format (1X, I5, 4X, 2F7.2, F7.1, 2F7.2, F7.1, 3F7.2)

These last LEVELS + 2 cards are repeated for each model cell.

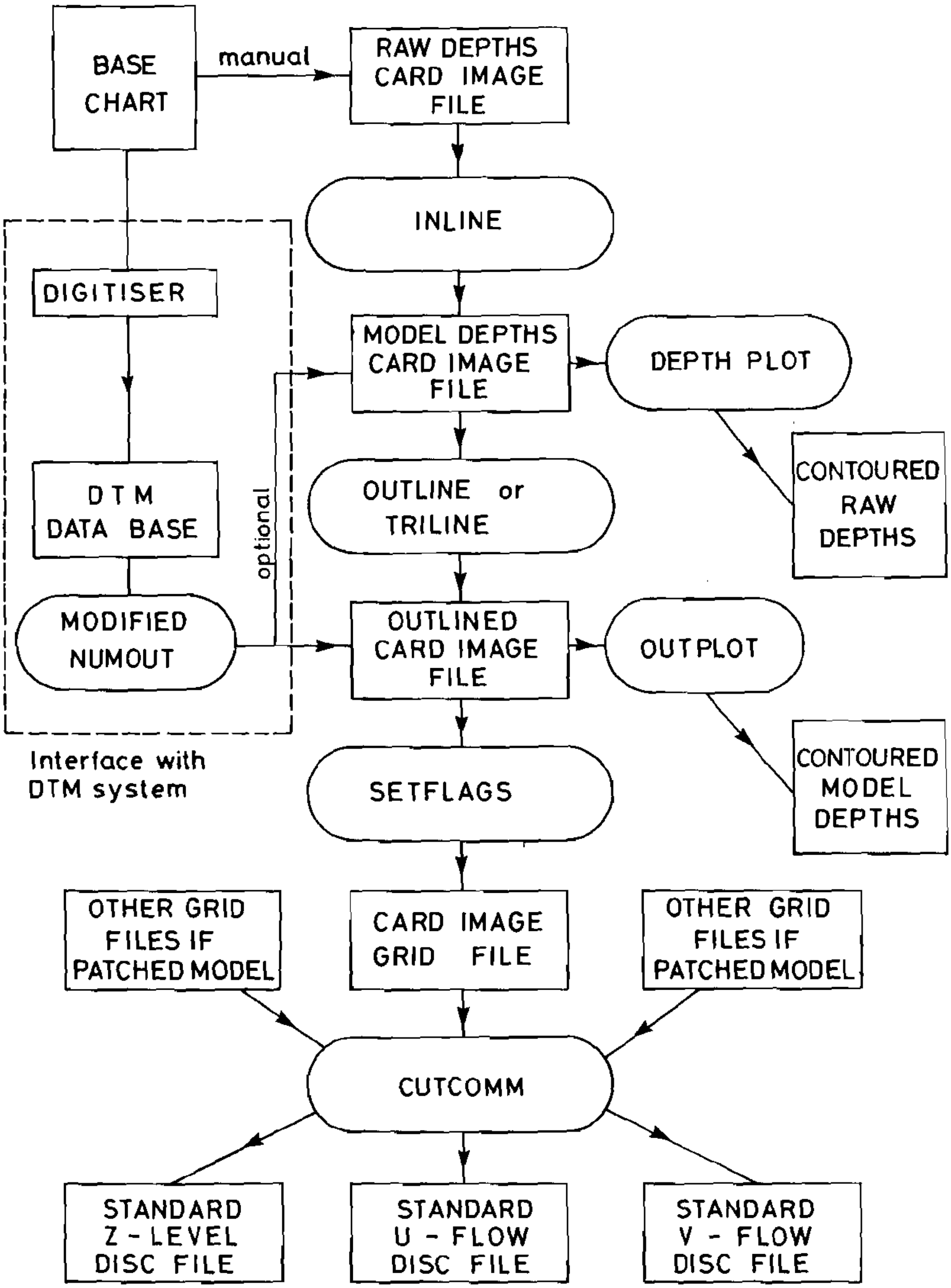

Fig 1 2-D Model setting up system

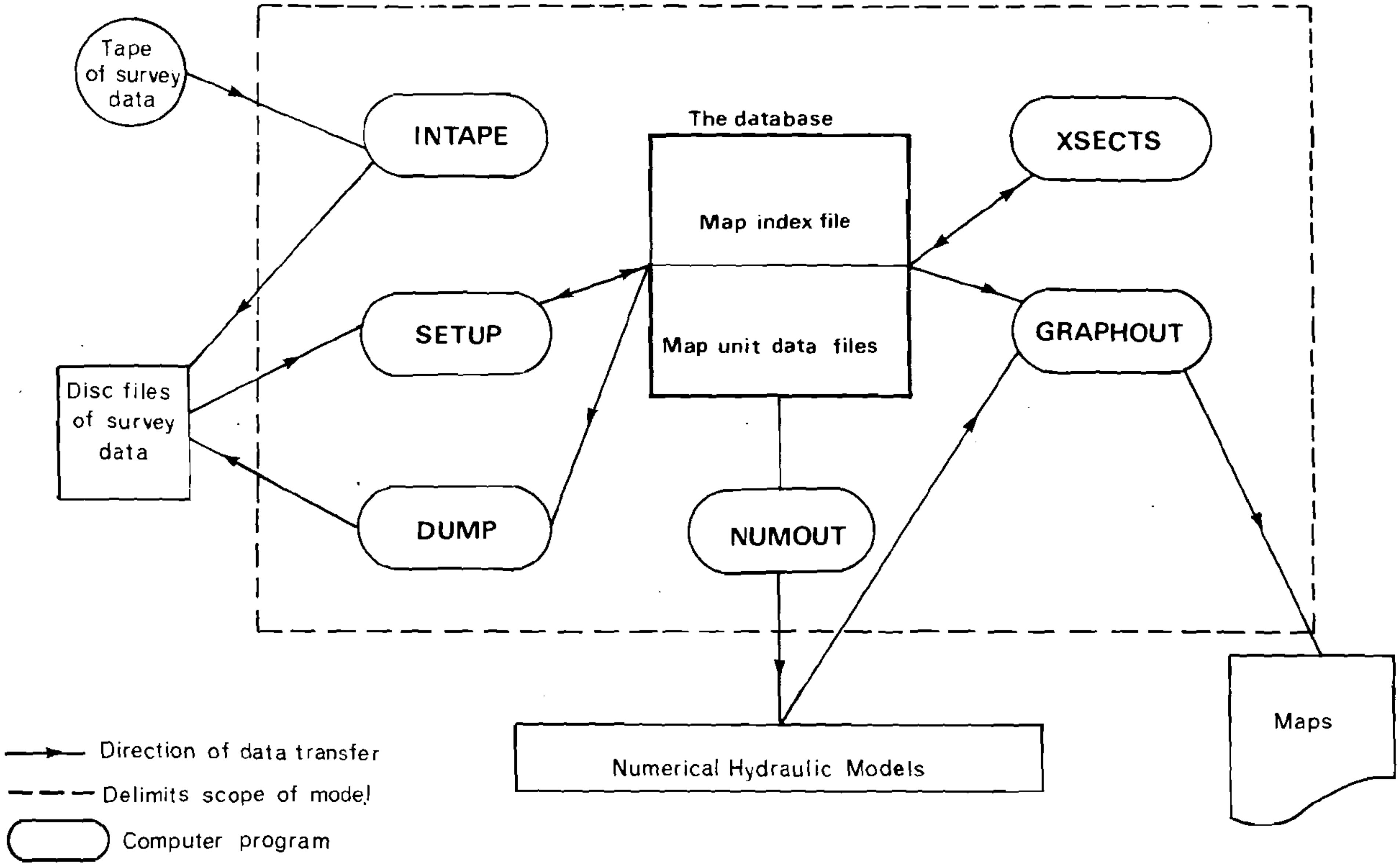

Fig 2 Overall structure of the DTM

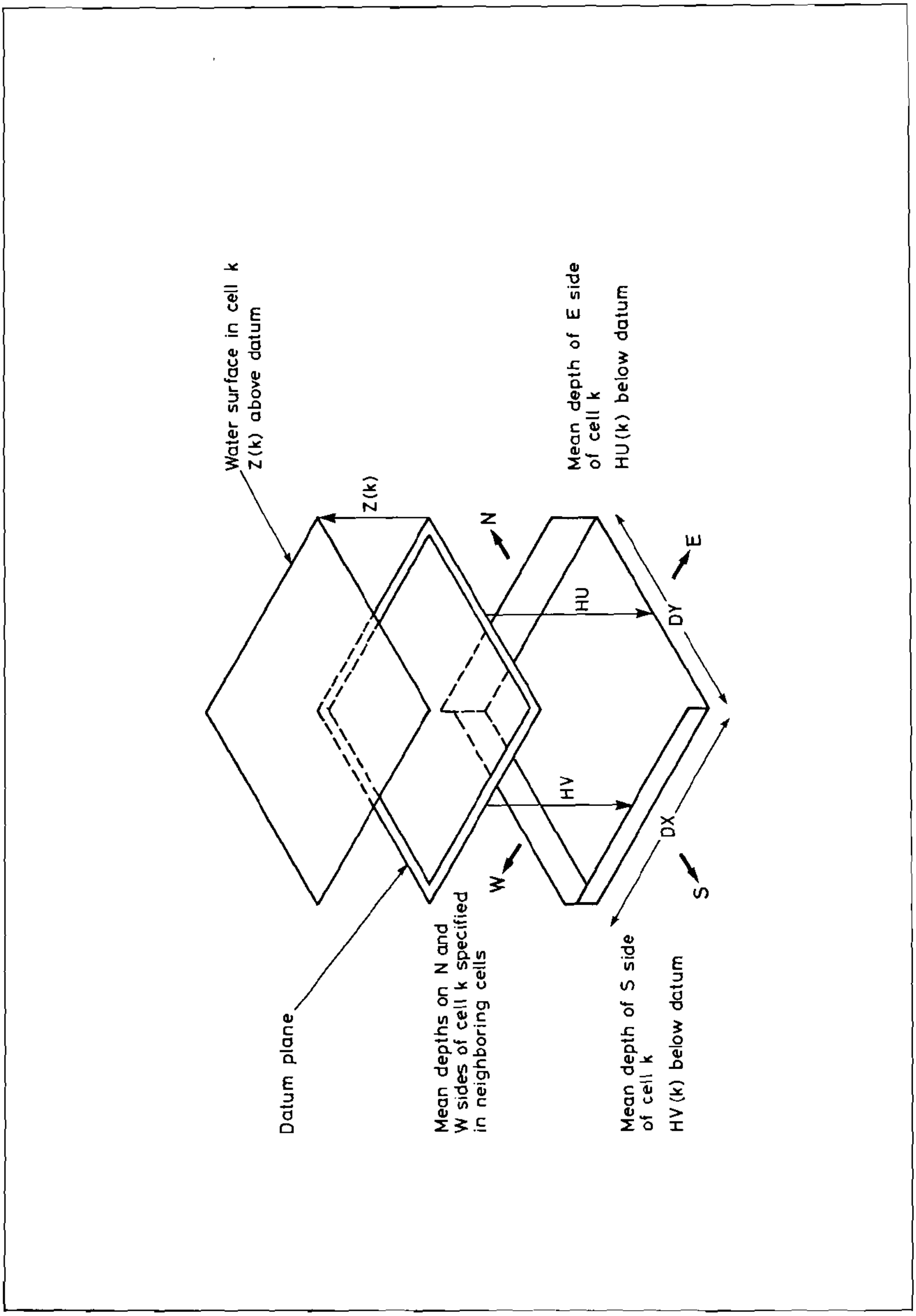

Fig 3 Representation of uniform grid geometry

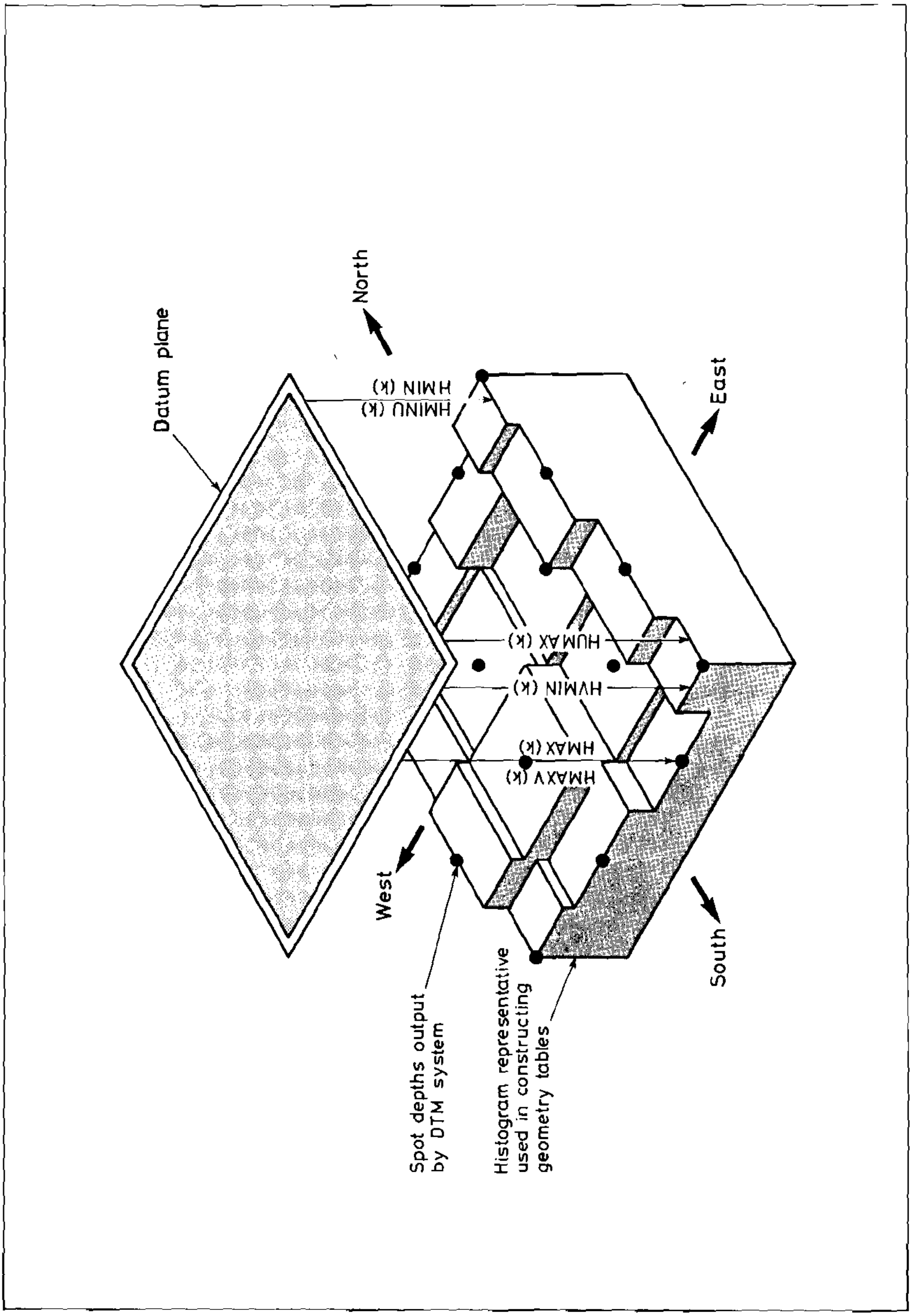

Fig 4 Representation of sub-grid geometry