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Extracting Hydrologic Parameters from Open Source Digital Spatial Data for HMS Modeling

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ABSTRACT

A methodology is presented for extracting topographic, topologic, and hydrologic information, from the digital spatial data of a hydrologic system, for hydrologic modelling with HMS. Methods for stream and watershed delineation from digital elevation models are presented. After vectorising raster-based stream segments and watersheds, navigation fields are added to their tables to support topologic analysis based entirely on the information stored in the tables of the spatial datasets. Algorithms for calculation for calculation of stream segment and watershed hydrologic parameters also discussed. These parameters are Curve Number, area, and lag-time for the watersheds, and routing model and travel time for the stream segments. Once the hydrologic parameters and topology are defined, a basin model that summarizes all the information and which can be used as input for HMS is created. Using this methodology, the determination of the spatial parameters for HMS is an automatic process that accelerates the setting up of a hydrologic model and leads to reproducible results.

Keywords : Modeling, watershed, Muskingum, Node, Flow direction, Digital Elevation Model

I. INTRODUCTION

Rainfall runoff modelling and flood discharge estimation have always been a foremost task in hydrologic sciences and Engineering. Flood flow estimation, in particular, has been given special attention because of the impact that accurate forecasts have in the management of flood- related emergency programs. Probably more than other concerns in hydrology, estimation of flood discharge is oriented towards saving human lives and protecting people's property.

This paper presents a Geographic Information Systems (GIS)-based methodology for extracting relevant information from digital spatial data for hydrologic modelling using the hydrologic modelling system (HMS) developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE). Although, to a certain extent, the paper focuses on the current capabilities of CRWR-PrePro [1], [2] an application develop at the Centre for Research in Water Resources (CRWR) of the university of Texas at Austin for supporting

HMS-based hydrologic modelling. Focus is sharpened on the general principles and methodology behind this application, which in the writer's understanding will last after the software becomes obsolete. Significant changes in the software platform used in CRWR-PrePro motivated the isolation of concepts from computer code, and this was to ease in the future the development of new analysis tools based on this model.

Hydrologic Modeling System (HMS) is a software system designed to simulate the complete hydrologic Precipitation-Runoff processes of dendritic watershed systems. The HMS software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing in a watershed or region, and it supersedes the HEC program HEC-1 flood Hydro graph package (Hydrologic Modeling 2000) [3]. Although applicable to different Rainfall runoff processes, use of HEC-1 and HMS has been traditionally oriented toward the estimation of flood hydrographs. HMS requires three input components: (1) the Basin Model, which describes the different elements of the hydrologic system (i.e subbasins, reaches, junctions, sources, sinks,reservoirs and diversions) including their hydrologic parameters and topology; (2) the meteorological model, which describes-in space and time-the precipitation event to be modelled as well as the evapotranspiration processes; and (3) the control specifications, which define the time window for the simulation. HMS is a very flexible application that allows the user to select among different loss rate, routing, and base flow models for the subbasins, as well as different routing models for the reaches. However, some of these models depend on hydrologic parameters that controls the extracted from spatial data, and this paper will discuss only those based on parameters that can be extracted.

Because of the significance of spatial analysis in the definition of the basin model, GIS constitutes a powerful modeling tool, thus, how t take advantage of its capabilities to generate the basin model is explained here. Using the methods presented in this paper, the determination of a basin model for HMS is an automatic process that saves analysis time and leads to reproducible results.

II. PREVIOUS RESEARCH WORK

Digital Elevation Models (DEM) are arrays of elevation values at equally spaced points of the terrain. Because of their matrix nature, DEMs are stored in grid or raster format, which is a data structure composed of square cells or pixels of equal size arranged in rows and columns. The suitability of DEM-based modelling of gravity-driven flow has been addressed in the literature. Consequently, raster-based algorithms for hydrologic analysis have been developed [4],[5], and functions to delineate streams and watersheds based on them are included in commercially available GIS software. Likewise, DEMs have been developed for different parts of the world at different resolutions [6],[7] and further developments of these data are aimed toward improving its resolution.

This paper summarizes the methodologies used in some of the applications developed over the last years at the CRWR and the Environmental Systems Research Institute (ESRI) for DEM-based stream and watershed delineation, hydrologic parameter estimation and linkage to HMS for hydrologic modeling. Among these applications, the following are worth mention:

- Watershed delineator [8],[9], developed by ESRI for the Texas Natural ResourcesConservation Commission (TNRCC), which can be used to delineate the drainage area of a point, line segment or polygon selected interactively by the user from the map.

- Flood flow calculator [10], developed by the CRWR for the Texas Department of Transportation (TxDOT), which can be used to estimate watershed hydrologic parameters and flood peak discharges according to regional regression equations developed for Texas [6]. All hydrologic parameters required by these equations, such as drainage area, watershed shape factor, and slope of the longest flow-path are extracted automatically from the spatial data.

- HECPREPRO [11], developed by the CRWR for the HEC, which can be used to establish the topology of hydrologic elements described by watershed polygons and stream lines and to write an input ASCII file readable by HMS with all information.

- CRWR-PrePro[2],developed by the CRWR for the TxDOT, which combines the terrain analysis capabilities of the watershed delineator with the hydrologic parameter calculation capabilities of the Flood Flow Calculator and the topologic analysis capabilities of HECPREPRO to produce a hydrologic modelling tool that prepares the basin model for HMS.

Rather than walking the user over step-by-step case study tutorial, this paper stresses the methodology behind the applications, the algorithms used, and the hydrologic meaning of the information extracted from the spatial data.

III. METHODOLOGY

The process of generating input data for the basin components of HMS has been divided into seven analysis steps: (1) raster-based terrain analysis; (2) raster-based watershed and stream network delineation; (3) vectorization of watersheds and stream segments; (4) topologic analysis; (5) computation of hydrologic parameters of the watersheds; (6) computation of hydrologic parameters of the stream segments; and (7) writing of an HMS basin model.

Accuracy of the resulting delineated watersheds and stream network, as well as of the calculated hydrologic parameters, depends on the accuracy of the input data. In general, the spatial accuracy of geographic datasets is defined by the scale of the map to which they compare, and one should expect the same spatial accuracy for the results as per the input datasets. For instance, [12] compared the areas of delineated watersheds with those values published by the U.S. Geological survey for specific points of the Guadalupe and San Antonio basins in Texas, and found a significant improvement in matching the USGS values when increasing the spatial resolution of the spatial data. Accuracy of the numerical values in the in the input dataset tables or raster data also affects the accuracy of the results.

A. *Raster-Based Terrain Analysis*

Raster-based terrain analysis for hydrologic purposes used [4] algorithms. These algorithms can be used to determine flow directions, drainage area, and watersheds from a DEM. For each terrain cell, the flow direction grid of a DEM stores a code number that refers to its downstream cell out of its eight neighbour cells. This downstream cell is selected so that the descent slope from the cell is the steepest. Therefore, a unique downstream path from each cell can be determined by connecting the cell to its downstream cell, and so forth. This process produces a stream network, with the shape of a spanning tree, that represents the paths of the watershed flow system.

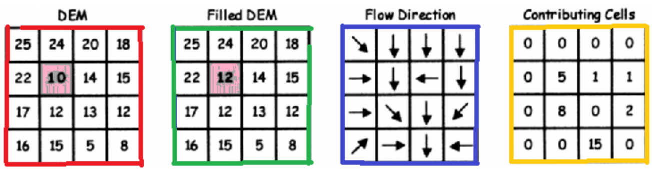

Fig.1: DEM, Filled DEM, Flow Direction and contributing Cells Grids (Shaded Cell in DEM Grid corresponding to Terrain pit

A cell can flow to a cell that does not store any value-called here NODATA cell-if the elevation of its other surrounding cells define that flow direction. NODATA cells, though, do not have flow direction, and therefore do not allow water flow through them. Because of this property of the NODATA cells, they are used to represent the ocean or the lowest points of natural depressions. In general, raster functions applied on NODATA cells generate, again, NODATA cells. Because a flow direction cannot be determined for cells that are lower than their surrounding neighbour cells, a process of filling the terrain depressions is necessary before determining flow directions [13]. Real terrain depressions, however, should not be filled and be kept as part of landscape description. In such a case, to avoid filling, drainage to the depression pour point should be allowed by assigning a NODATA cell at its lowest point. After assigning NODATA cell to depression pour points, the DEM can be filled producing the filled DEM grid for which the flow directions can be determined [2]. Based on the flow direction grid, the contributing cells of each cell can be identified. The contributing cells grid stores the number of cells located upstream of each cell, which, if multiplied by the cell area, equals the drainage area.

Fig.1 shows the filled DEM, flow direction, and contributing cells grids for a given DEM. The shaded cell on the DEM grid constitutes a pit, which has been filled by adding a2 to its value, as can be seen on the filled DEM grid.

B. *Raster-Based Watershed and Stream Network Delineation*

The DEM cells that form the stream network are the union of two sets of grid cells. The first set consists of all cells whose drainage area is greater than a user-defined threshold value. Since flow depends on other variables that are not related exclusively to topography, this set identifies the streams with the largest drainage area but not necessarily the largest flow. The cells that form part of this first set are selected based on their number of contributing cells. The second set consists of the cells located on streams the user wishes to include in the network, but whose drainage area is less than the threshold value used previously. To assure consistency with the flow direction grid, each of these streams is defined only by its most upstream cell (i.e a point where a stream forms) while the remaining downstream cells are selected automatically based on the flow direction grid. By including this second set of cells, the user can select particular streams-regardless of how small their drainage area is (low number of contributing cells)-without having to lower the threshold value for the first set of cells and defining unnecessarily a denser network for the entire system. The network grid stores the value one at the stream network cells and has NODATA cells elsewhere. On the stream network, stream segments are defined as the flow-paths that connect two consecutive junctions. Stream segments are elementary modeling units in which the hydrologic parameters (i.e. slope, cross section, roughness) are uniform and the flow is considered to vary gradually (i.e no tributaries flow to the stream segments). Stream segments are randomly assigned a unique identification number for modeling purposes.

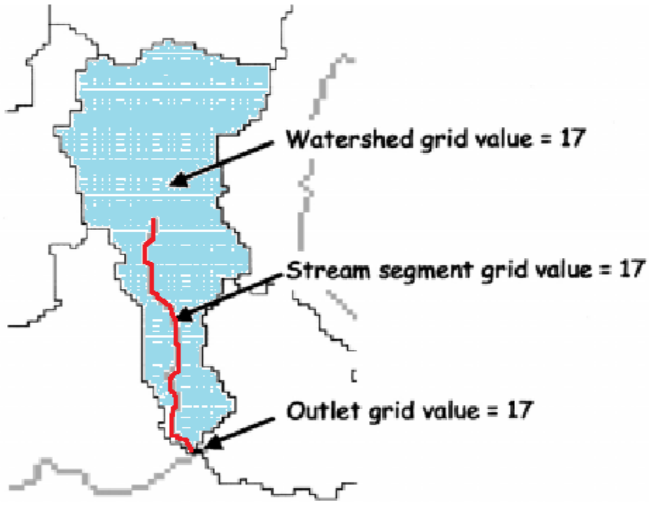

Fig.2: After delineation in the Raster domain, the watershed grid, segment grid, and outlet grid store the same values for each set of watershed, segment and outlet

The segments grid stores the segment identification number in the stream cells and has NODATA cells elsewhere. However, if the hydrologic parameters change significantly at certain points of a segment, it should be sub-divided into two or more uniform stream segments. Reservoirs, flow gauges, and other control points also constitute points at which segments should be sub divided. Although these point do not refer to changes in the hydrologic parameters, they constitute calibration points and, as such, it is convenient to identify them separately. reservoirs, in particular, can be recognized by HMS and modelled as uncontrolled water bodies, for which there is a monotonically increasing relationship between storage and outflow [3]. After identifying the cells at which segments are to be subdivided, all cells of the segments with a number of contributing cells greater than that of the subdivision cell are assigned a new segment identification number. To avoid duplication, it is convenient to make this number equal to the original segment number plus the highest segment number of the entire system. Is a segment is to be subdivide into three or more parts, it is better to do so by first subdividing it into two parts and then repeating the process.

Watershed outlets are then identified at the most downstream cell of each segment. Thus, watershed outlets are either the cells located just upstream of junctions or the cells at which segments were subdivided. At the junctions. two outlet cells are identified, one for each of the upstream branches. The system outlet is also identified as a watershed outlet. The outlet grid stores the outlet identification number, which by definition is equal to the number of its corresponding segment.

Based on the flow direction grid, watersheds are delineated for each outlet. The process of delineating watersheds consists of assigning to the outlet the terrain cells whose downstream flow-path passes through the outlet. In case of cell whose flow-path passes through more than one outlet, it is assigned to the immediately next downstream outlet. The watershed grid stores the watershed identification number, which again by definition is equal to the number of their corresponding outlet and segment.

As can be seen in Fig.2, a one-to-one relation between segments, outlets, and watersheds has been established, in which the three share the sane identification number.

C. *Vectorization of Watersheds and Stream Segments*

Because HMS applies lumped models to each hydrologic element, hydrologic parameters have to be calculated for the watersheds and stream segments, and not for the individual grid cells. Thus, the spatially variable hydrologic system is represented by a network of uniform hydrologic elements, where the spatial variability is captured by the different hydrologic parameters of the elements.

After the stream segments and their corresponding watersheds have been delineated in the raster domain, a vectorization process follows, which consists of creating a polygon dataset of watersheds and a line dataset of stream segments by using raster-to-vector conversion functions. When doing so, the watershed and segment identification numbers are transferred to the watersheds table and the segments table of the vector datasets, thus preserving the link between watersheds and segments. Further vector processing (i.e. merging of dangling watershed polygon) might be necessary to ensure that each watershed is represented by a single polygon, and that the one-to-one watershed/segment relation established in the raster domain is preserved in the vector domain [1].

The one-to-one watershed/segment relation, through, could be relaxed by merging adjustment watershed polygons, so that a watershed contains more than one stream segment. note that for merging two watersheds, one has to drain toward the other or both share the same outlet. When merging watershed polygons, the identification number of the one downstream prevails in the watersheds table; however, if the polygons share their outlet, one identification number is selected randomly. Additionally, besides storing the segment identification number in the segments table, it is convenient to store the identification number of the watershed in which the segment is located after merging the polygons. Note that the option of one segment flowing through multiple watersheds is not supported in this model.

Finally, line topology should be built for the stream network, so that for each line a from-node (i.e. upstream node) and a to-node (i.e. downstream node) are identified. Identification numbers are assigned consecutively and randomly to all nodes in the network. After a topologic analysis, from-node and to-node fields in the segments table are populated with the corresponding node identification numbers. These from-nodes and to-nodes are defined in such a way that the to-node of a segment is the from-node of the immediate downstream segment.

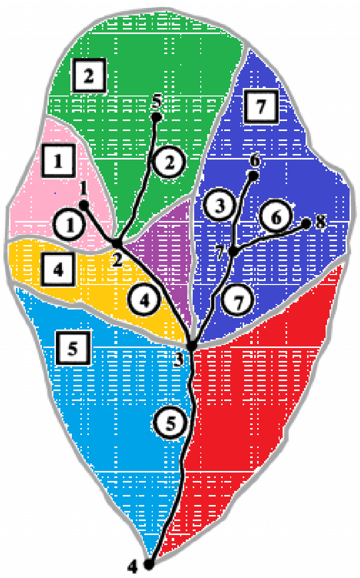

Fig. 3: Number of square boxes refer to watershed identification numbers, numbers in circle to segment identification numbers and plain numbers to node identification numbers.

Note that, because of the methodology used to delineate streams. segments can share their to-node but not their from-node.

Fig.3 shows watersheds, segments and nodes labelled by their identification number. Note that watershed No.7 contains segment No.3, No. 6, and No. 7, as a consequence of having merged watershed polygons No.3, No.6 and no.7 into a single polygon. Notice also that this resulting polygon has the identification number of the downstream segment No.7.

Table 1 shows the segment identification number, from-node, to-node, and watershed identification number for the seven segments of Fig.3. The fact that watershed No.7 contains segments No.3, No.6 and No. 7 is shown in the watershed identification number column at the right-hand side of Table.1

Table 1: Stream segmentation after vectorization

Segment Identification Number	From-node	To-node	Watershed identification number
1	1	2	1
2	5	2	2
3	6	7	7
4	2	3	4
5	3	4	5
6	8	7	7
7	7	3	7

table 2 lists the watersheds after merging polygons Table 1 and 2 do include other columns. However, only those relevant for the topologic analysis have been displayed.

Table 2: Watershed after vectorization

Watershed identification number
1
2
4
5
7

D. *Topologic Analysis*

Establishing the topology of the hydrologic system consists in determining the element located downstream of each element. Since the HMS hydrologic schematic allows only one downstream element, no ambiguity is introduced in this process. The seven hydrologic elements considered in the HMS model are subbasins, reaches, junctions, reservoirs, sources, sinks, and diversions. The topology presented here supports only four of them. Subbasins, reaches, junctions, and sinks. Reservoirs, sources, and diversions can be added to the model in the HMS environment.

To facilitate hydrologic navigation, the segment table and watersheds table include specific fields, whose significance has been discussed above. The segments table includes the fields segment identification number, from-node and to-node, while the watersheds table includes field watershed identification number. Recall that the watershed identification number is equal to the segmentation identification number of its corresponding segment. If the watershed includes more than one segment, the one most downstream is considered.

In accordance with the HMS basin model, spurious segments are those that do no convey flow from upstream elements and, therefore, do not form part of the flow network. before establishing the topology, spurious segments have to be removed from the flow network. Two processes for removing these segments are necessary one to remove segments from watersheds with more than one segment, and another to remove headwater segments. for the first process, in the segment table, the from-node value of each segment is searched in the to-node column and, if not found, the segment is removed, unless it is the only segment in the watershed.

After removing spurious segments, the topology is established by observing the following rules:

- Junctions are identified at the from-node of the segments.
- Sinks are identified at the nodes that are to-nodes but not from-nodes.
- Subbasins are identified at the watershed polygons.
- Reaches are identified at the (not spurious) segment lines.

In the topologic analysis, a point dataset of junctions and sinks, a line dataset of reaches, and a polygon dataset of sub-basins are created, the last two based on the segments and watersheds datasets. A hydrologic element identification number is then assigned consecutively to all elements regardless of their type (i.e. junction, sink, reach, or subbasin), and a field is added to the three-dataset tables to store the elementidentification number of the downstream element. The downstream element field for the sinks is populated with a predefined value (e.g.0) that is not the identification number of any element.The downstream-element field for the junctions is populated with the identification number of the reach of which the junction is from-node. The downstream–element field for the subbasins is populated with the identification number of the junction that corresponds to the to-node of the segment with the same identification number (regardless of whether it is a spurious segment or not). The downstream-element field for the reaches is populated with the identification number of the junction that coincides with their to-node. note that the topologic analysis is based only on data stored in the tables and not on spatial analysis.,which has proved to be more complex and ambiguous in some cases. Tables 3-5 present the results of the topologic analysis of the system shown in Fig.3. It can be noted that the records (and corresponding lines of the network) associated to the spurious segments 1, 2, 3, 6, and 7 have been removed. Segments 3 and 6 were identified as spurious because they are located in watershed 7, which has more than one segment, and their from-nodes 6 and 8 were not listed in the to-node column of Table1. After removing segments 3 and 6, segment 1,2. and 7 were identified as spurious because their from-nodes 1, 5, and 7 were not listed in the to-node column of Table 1.

Table 3: Reaches after Topologic analysis

Node number	Hydrologic element identification number	Downstream element
2	8	1
3	9	2
4	10	0

Table 4: Subbasins after topologic analysis

Watershed identification number	Hydrologic element identification number	Downstream element
1	3	8
2	4	8
4	5	9
5	6	10
7	7	9

The tables display the hydrologic element identification number" and the "downstream element" for each sub basin, reach, junction, and sink. For example, runoff generated in hydrologic element No.5 (subbasin No.40, drains to element No.9 (junction No.3) element No.2 (reach No.5), and element No.10 (sink No.4). The value 0 in the "downstream element" column of Table 5 differentiate sinks from junctions.

E. *Computation of Hydrologic Parameters of Subbasins*

Among the different options supported by HMS for runoff calculation and subbasin routing (i.e unit hydrograph model), the curve number method for calculation of abstractions and the dimensionless

Table 5: Junctions/sinks after Topologic analysis

Segment identification number		From node	To-node	Watershed identification number	Hydrologic element identification number	Down-stream element
4		2	3	4	1	9
5		3	4	5	2	10

synthetic unit hydrograph (SCS 1972) are discussed in this paper. The discussion is centred on the automatic implementation of these methods within a GIS environment. For implementing the curve number method for calculation of abstractions, the only parameter needed is the subbasin average curve number, while for implementing the dimensionless synthetic unit hydrograph, the parameters needed are the subbasin area and lag-time. Methods are presented for automated extraction of the above-mentioned hydrologic parameters, their values are appended to the subbasin table.

A representative subbasin curve number (i.e. area-weighted average) can be estimated from a curve number map. In turn, a curve number map-in vector or raster format-can be estimated using soils and land-use spatial data as inputs, and relating this information to a curve number lookup table.

The SCS (1972) has published curve number lookup tables, which consist of recommended curve number values for unique combinations of hydrologic soil group (i.e. A, B, C, or D) and land use. The hydrologic soil group is a soil classification based on illustration rate, so that A is more permeable and D is less permeable. Spatial soil data for the United States can be obtained for example, from the natural ResourcesConservation Service (NRSC) [14],[15]. the state Soil Geographic (STATSGO) database, in particular, is consistent with 1:250000 scale map, and the Soil Survey Geographic (SSURGO) datasets with 1:12000 to 1:63360 scale maps. In both datasets, the terrain is subdivided into map units represented by polygons in the map. map units, in turn, consist of soil components, which are soil portions that have unique combinations of soil properties. The spatial locations of soil components within the map units, though, is unknown, so that the resolution of the dataset is that of the map unit. In India, soil toposheets are available from National Bureau of Soil Survey and Landuse Planning (NBSS&LUP)-Indian Council of Agricultural Research [16].Among the properties available in the hydrologic soil groups of the soil components and their percentage within the map units are included. Thus, it is possible to determine the percentage of each hydrologic soil group within each map unit polygon. Spatial landuse data can be obtained from different sources. For the Indian states a Landuse-Landcover map has been developed by BHUVAN-ISRO-Geoportal, gateway to Indian earth observation, providing visualization services and earth observation data to users in public domain [17]. In urban area, municipalities usually update their land-use maps regularly. In rural areas, though, it is more difficult to find updated land-use data.

Soil polygons intersected with land-use polygons create a map in which each resulting polygon is related to a unique combination of soil and land use(fig.4)

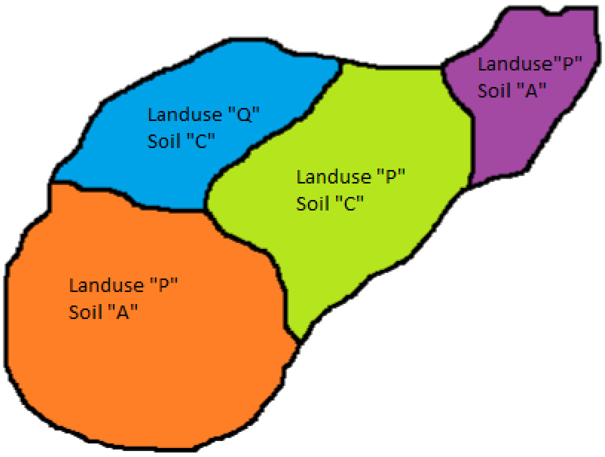

Fig. 4: After intersecting soil and land-use polygons with soil polygons each resulting polygons is a combination of land use and soil and a curve number can be calculated.

Combination of soil and land use for each polygon, the Curve Number is obtained as a weighted combination of curve numbers based on the percentage of each hydrologic soil group in the polygon. After assigning curve number values to each polygon, the map can be rasterized if needed. Average curve number values for each subbasin are then calculated. If using a vector curve number map, the curve number polygons and the subbasin polygons have to be intersected prior to averaging. if using a raster map, the averaging process is based on the value of the cells within the subbasin polygon.

The subbasin area is calculated automatically when vectorising the watersheds. The subbasin lag-time, measured from the centroid of the hyetograph to peak time of the hydrograph, is calculated with the following formula (SCS 1972).

$$t_p = L_w^{0.8}\left[\frac{\left(\frac{1000}{CN}-9\right)^{0.7}}{(31.675)^{0.5}}\right] \qquad \text{.................................(1)}$$

where t_p = subbasin lag-time (min), L_w = length of the subbasin longest flow-path (ft), S = slope of the subbasin longest flow-path (%), and CN= average Curve Number in the subbasin. However,to assure that the unit hydrograph comprises a minimum number of analysis time-steps (i.e. 17 time steps), the lag-time has to be greater than 3.5 time-steps [18]. Therefore

$$t_p = \max\left(\frac{L_w^{0.8}[(1000/CN)-9]^{0.7}}{31.675^{0.5}}, 3.5\Delta_t\right) \text{.....................(2)}$$

where Δ_t = analysis time-step (min). In (2), the average curve number CN is calculated following the procedure described above, and the analysis time-step is set by the user. How to calculate the length and slope of the longest flow path L_w and S is explained below.

The longest-flow path is identified as the set of cells of the subbasin for which the sum of the "downstream flow-length to the sub-basin outlet' plus the "upstream flow length to the sub-basin boundary" is a maximum [19]. to understand the physical meaning of these two flow lengths, the "downstream flow length" and "upstream flow length" are discussed first.

The downstream flow length grid (Fig.5) stores the distance along downstream paths that comprise the flow direction grid-from a grid cell to a NODATA cell or to the border of the analysis window (whichever is found first). On the contrary, the upstream flow length grid stores the distance along upstream paths that comprises the flow direction grid-from a grid cell to its most upstream cell within the analysis window (i.e drainage divide), or to the border of the analysis window, or to a NODATA cell (whichever is found first). Functions to calculate these two flow lengthsare included in commercially available GIS software that operates on raster datasets. Based on these two distance grids, the "downstream flow length to the sub-basin outlet" and the "upstream flow length to the sub-basin boundary" are evaluated as shown below.

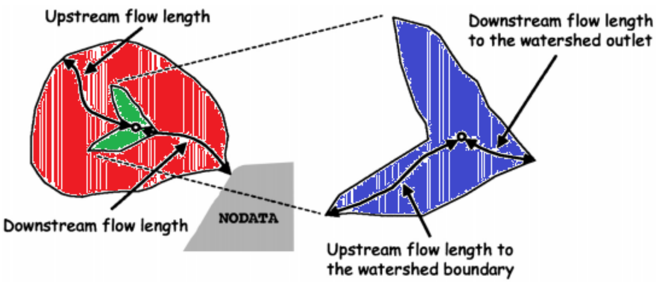

Fig.5 : "Downstream flow length" and "upstream flow length" apply to entire Hydrologic system, "downstream flow length to the sub-basin boundary" apply within each subbasin

The downstream flow length to the subbasin outlet grid (fig.5) stores the distance – along downstream paths that comprise the flow direction grid – from a grid cell to the outlet cell of its corresponding subbasin. The "downstream flow length to the sub-basin outlet" is calculated as the "downstream flow length" of the cell minus the "downstream flow length" of its corresponding outlet cell.

The upstream flow length to the subbasin boundary grid (Fig.5) stores the distance–along upstream paths that comprise the flow direction grid – from a grid cell to the most upstream cell within its subbasin (i.e. drainage divide), and does not necessarily follow the main channel. The "upstream flow length to the sub-basin boundary" is calculated as the "upstream flow length" based on a modified flow direction grid, in which NODATA cells are assigned at the subbasin outlets. NODATA cells are assigned at the subbasin outlets to keep the "upstream flow length" algorithm from searching for longer paths in the upstream subbasins [1].

The length of longest flow path is equal to the maximum value of the "downstream flow length to the sub-basin outlet" grid or of the "upstream flow length to the sub-basin boundary" grid, which are equal.

The slope of the longest-flow path is determined as the elevation drop between two user-defined points of the longest flow-path, divided by their distance along the flow-path. these two user –defined points are located at fixed distances from the subbasin outlet, expressed as percentages of the total flow-path length. For instance, percentages of 10% and 85% refer to that 75% (i.e. 85% - 10%) middle portion of the flow path located 10%ofthe channel length upstream of the subbasin outlet. The location of these two points along the flow-path is determined using the flow length grids.

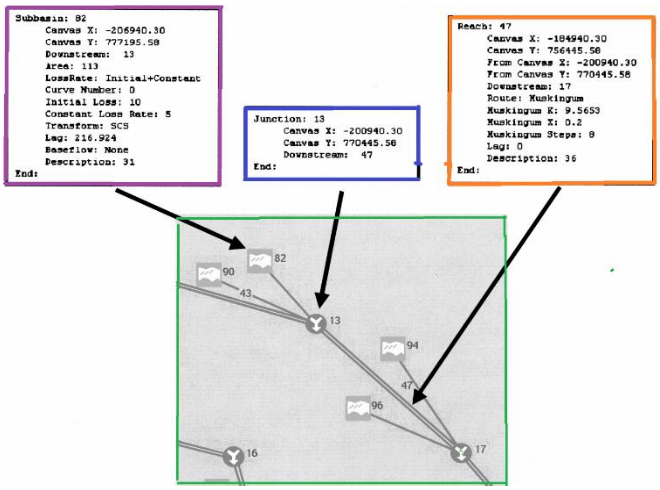

Fig. 6: HMS schematic of hydrologic system built from basin model text file

F. *Computation of Hydrologic Parameters of Reaches*

Among the different options supported by HMS for reach routing, the Muskingum and pure lag models are discussed here. Again, the discussion is centered on the automatic implementation of these methods within a GIS environment. The Muskingum model is a reach routing algorithm that account for mass translation and peak flow attenuation, while the pure lag model accounts only for translation. Procedures are presented for automated selection of the routing model for each reach and evaluation of the required parameters. The reach parameters calculated are the length, travel time, and – in case the Muskingum model is selected – the number of sub-reaches into which the reach should be subdivided. After determining the reach hydrologic parameters, their values are appended to the reaches table.

The reach length 'L' is determined automatically in the process of stream segment vectorization.

The travel time 'K' is calculated as K= L/v, where 'v' is the flow velocity in the reach. Note that the flow velocity 'v' cannot be extracted from available spatial data, should be an input to the model.

In the Muskingum model, to avoid numerical instability, the relation between the travel time 'K' and the analysis time-step 'Δt'has to satisfy the condition $2XK < \Delta_t < K$, where 'X' is a parameter of the Muskingum model. As with the velocity 'X' cannot be extracted from available spatial data and should be an input to the model. In a long reach (i.e. where $2XK < \Delta_t$ is not satisfied), numerical instability is avoided by subdividing the reach into shorter equal-length sub-reaches that satisfy the condition $2Xk < \Delta_t$, where 'k' is the sub-reach travel time. Since the travel time in the sub-reaches is equal to k= K/n = (L/v)/n, where 'n' (an integer value greater than zero) is the number of sub-reaches, it follows $n > 2X(L/v)/\Delta_t$. In short reaches (i.e. where $\Delta_t < K$ is not satisfied), numerical instability is avoided by using the pure lag model with a lag-time equal to the travel time 'K'. In all other reaches (i.e where $\Delta_t < K < \Delta_t/2X$ is satisfied), the Muskingum routing model should be used without reach subdivision and with travel time 'K'.

G. *Writing of HMS Basin Model*

At this point, the subbasins table, the reaches table, and the junctions/sinks table are populated with the downstream element identification number and the hydrologic parameters required by HMS for hydrologic modeling, creating an HMS basin model consists in transferring the information stored in the tables to an ASCII file according to a specific format. This ASCII file constitutes the basin model of HMS, and when opened with HMS, generates a topologically correct schematic network of hydrologic elements.

Fig.6 shows portions of an HMS basin model that correspond to a subbasin, junction, and reach. Note that these portions list the element number (right next to the element type on the first line), the downstream element number (right next to the word "downstream"). and the hydrologic parameters

IV. CONCLUSIONS

A methodology for connecting GIS datasets describing a hydrologic system and Hydrologic Modeling System (HMS) has been developed. Using this methodology, the extraction of topographic, topologic, and hydrologic information from digital spatial data for HMS is an automatic process that accelerates the setting up of a model and leads to reproducible results.

The methodology presented in this paper discusses algorithms for stream and watershed delineation that set the base for further topologic analysis using, exclusively, information stored in the dataset tables. Moreover, the methodology supports the calculation of hydrologic parameters for the SCS curve number method for loss rate calculations, the SCS unit hydrograph model for watershed routing for which the lag-time is calculated with the SCS lag-time formula, and the Muskingum and pure lag models for flowrouting I stream segments. Finally, based on the information stored in the dataset tables, a basin model for HMS is created.

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