IMPORTANCE OF DIGITAL ELEVATION MODEL IN URBAN STORM WATER MODELLING

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ABSTRACT

Surfaces, such as the surface of the earth, are continuous phenomena (fields) rather than discrete objects. To fully model the surface, would need an infinite amount of points. There are various ways of representing continuous surfaces in digital form using a finite amount of storage. A Digital Elevation Model (DEM) of a catchment is a basic source of information that has multiple applications in hydrologic modelling. The term digital elevation model or DEM is frequently used to refer to any digital representation of a topographic surface. However, most often it is used to refer specifically to a raster or regular grid of spot heights. This is the definition that is used here. Digital terrain model or DTM may actually be a more generic term for any digital representation of a topographic surface, but it is not so widely used. The DEM is the simplest form of digital representation of topography and the most common. A variety of DEMs are available, including coverage of much of the US from the US Geological Survey. The resolution, or the distance between adjacent grid points, is a critical parameter. The best resolution commonly available is 30 m, with a vertical resolution of 1 m. Coverages of the entire globe, including the ocean floor, can be obtained at various resolutions. At 30m resolution there are approximately 10^{12} points required to cover the globe. The different derivatives of a DEM which are found to be useful include slope, aspect, watershed boundary, drainage network and channel ordering etc. In addition, some variables may be derived from combinations of the variables. These variables are referred as compound variables, and include wetness index, stream power and sediment index. The advent of relatively high map resolution DEMs allow a greater variety of variable to be derived with higher precision. To illustrate the derivation of above parameters, selected

characteristics have been derived for a catchment. In this lecture, DEM derivation and its applications in urban storm water modelling have been presented.

WHAT IS DEM?

A Digital Elevation Model (DEM) is the numeric or digital representation of the topography of an area with respect to its geographic location. A DEM is not a model in the sense this term is used in hydrology. Actually, it stores the information about a terrain using which its topographic attributes can be characterised. Normally it consists of elevations sampled at discrete points although in some cases the average elevation over a specified region of the landscape may be used. DEMs are a subset of digital terrain models (DTMs), which can be defined as ordered arrays of numbers that represent the spatial distribution of terrain attributes, not just elevation. Whether called DEMs, DTMs, or Digital Ground Models (DGMs), these data sets exist in many forms.

The DEM provides a base data set from which topographic is digitally generated. The raster grid structure lends itself well to neighborhood calculations which are frequently used to derive these parameters. Primary surface derivatives such as slope, aspect and curvature provide the basis for characterization of landform. These terrain attributes are used extensively in hydrologically-based environmental applications and are derived directly from the DEM. The routing of water over a surface is closely tied to surface form. Flow direction is derived from slope and aspect. From flow direction, the upslope area that contributes flow to a cell can be calculated, and from these maps, drainage networks, ridges and watershed boundaries can be identified. Topographic, stream power, radiation, and temperature indices are all secondary attributes computed from DEM data. Wilson and Gallant (2000) provide a detailed review of the DEM-derived primary and secondary topographic attributes. Primary topographic attributes can be calculated directly from elevation data and a hydrologically related application as adapted by Moore et al. (1991) from Speight (1974, 1980) is presented in Table 1.

DEM RESOLUTION AND SCALE

There are three principal ways of structuring a network of elevation data for its acquisition and analysis: 1. Contour 2. Raster 3. Triangular Irregular Network (TIN).
Contour-based methods of representing the land surface elevations or other attributes have important advantages for hydrologic modeling because the structure of their elemental areas is based on the way in which water flows over the land surface. The raster data structure is perhaps one of the more familiar data structures in hydrology. Many types of data are often measured and stored in raster format. Raster of pixels is also a useful format for representing geographical data, particularly remotely sensed data, which in its native format is a raster of pixels. Raster data is also referred to as grids. Raster DEMs are one of the most widely used data structures because of the ease with which computer algorithms are implemented.

The raster GIS grid cell data structure makes it possible to represent locations as highly defined discrete areas. The size of a grid cell is commonly referred to as the grid cell's resolution, with a smaller grid cell indicating a higher resolution. The grid cell size imposes a scale on raster GIS analyses. DEM accuracy has been shown to decrease with coarser resolutions that average elevation within the support (Li, 1992). Smaller grid cell sizes allow better representation of complex topography and these high resolution DEMs are better able to faithfully represent the characteristics of undulating topography. This has led many DEM users to seek the highest DEM resolutions possible, increasing the costs associated with both data acquisition and processing. The hydrologic literature has established that the grid cell size of a raster DEM significantly affects derived terrain attributes (Kienzle, 2004).

A map of topography can be shown at any scale within a GIS. Once data is digitized and represented electronically in a GIS, resolution finer than that at which it was compiled is lost. Subsequent resampling to a coarser or finer resolution obscures the inherent information content captured in the original map. A small-scale map is one in which features appear small, have few details, and cover large areas. An example of a small-scale map is one with a scale of 1: 1000000. Conversely, large-scale maps have features that appear large and cover small areas. An example of a large-scale map is one with a scale of 1:2000. A map compiled at 1:1000000 can easily be displayed in a GIS at a 1:2000 scale, giving the false impression that the map contains more information than it really does. Because GIS provides the ability to easily display data at any scale, we must distinguish between the compilation or native scale and the user- selected scale. The scale and resolution at which the data is collected or measured is termed the native scale or resolution. If the spot or point elevations are surveyed in the field on a grid of 100 m, this is its native resolution. Once contours are interpolated between the points and plotted on a paper map at a scale of, for example, 1:25000, we have introduced a scale to the data. Once the paper map is digitized, there will be little more information contained at a scale larger than 1:25000; enlarging to 1: 1000 would make little sense. The importance to hydrology is that variations in landform, slope or topography may not be adequately captured at resolutions that are too coarse. Further, to claim that we have a 1:1000 scale map simply because we can set the scale in the GIS is misleading, because the small variations that may have been present were lost when the contours were compiled at 1 :25000. The hydrologist must decide what scale will best represent hydrologic processes controlled by the topography.

A variety of algorithms have been used to compute topographic slope from grid-DEMs using various grid cell resolutions. In general as the DEM resolution becomes finer, the calculated maximum slope becomes larger. This effect is related to the topography's complexity. If the topography is complex, greater discrepancies can be expected between grid cells.

The choice of resolution has an important impact on the hydrologic simulation. Choosing a coarse resolution DEM, deriving slope, and using this in a surface runoff model has two principal effects. One is to shorten the drainage length, because many of the natural meanders or crookedness of the drainage network is short-circuited by connecting raster grid cells together by way of the principal slope. The other effect is a flattening of the slope due to a sampling of the hills and valleys at too coarse resolution. These effects together may have compensating effects on the resulting hydrograph response. A shortened drainage length decreases the time taken by runoff from the point of generation to the outlet. A flattened slope will increase the time.

Grid resolution has been shown to impact the accuracy of hydrologic derivatives in the following applications: topographic index, drainage properties such as channel networks and flow extracted from DEMs, the spatial prediction of soil attributes, computation of geomorphic measures such as area-slope relationships, cumulative area distribution and Strahler stream orders (Hancock, 2005), flow direction calculations, modeling processing of erosion and sedimentation, computation of soil water content, and output from the popular rainfall-runoff model TOPMODEL. DEM resolution has also been shown to directly impact hydrologic model predictions from the TOPMODEL, the SWAT model, and the Agricultural Nonpoint Source Pollution (AGNPS). The Water Erosion Prediction Project (WEPP) model, however, was not sensitive to coarser resolution DEMs unless the resolution compromised watershed delineation.

Research has demonstrated that higher resolution is not necessarily better when it comes to the computation of DEM derived topographic parameters. Higher resolution DEMs generates larger slope values. This can be attributed to the nature of the slope algorithm in which the grid cell resolution is effectively the “run” in the rise-over-run formula. Smaller grid cells, therefore, compute larger slope values. Research to determine an appropriate grid cell resolution for particular analyses has also been undertaken. However, selection of an appropriate resolution depends on characteristics of the study area and nature of the analysis. The repeated outcomes of the effects of grid cell resolution in various hydrologic applications suggest that grid cell resolution will remain an important factor in understanding, assessment and quantification of the propagation of DEM errors to hydrologic standing, parameters and resulting uncertainty in related modeling applications.

CATCHMENT HYDROLOGIC PROPERTIES

The DEM provides a base data set from which topographic attributes are digitally generated. Raw DEM data frequently requires pre-processing like pit removal etc. which are described as follows:

Surface modification for hydrologic analyses

Depressions in DEMs have been recognized as one of the major problems in hydrological applications, since they hinder flow routing. A depression is defined as a point or an area lower than all immediately surrounding points. Each depression has its own catchment area. The outlet of a depression is defined as a point through which water could leave the depression; normally the lowest point along the border of the depression catchment DEMs often contain depressions which are the areas that have no drainage. These are often referred to as sinks or pits. These depressions disrupt the drainage surface, which preclude routing of flow over the surface. Sinks arise when neighbouring cells of higher elevation surround a cell, or when two cells flow into each other resulting in a flow loop, or the inability for flow to exit a cell and be routed through the grid. Derivation of hydrologic parameters from DEMs, such as flow accumulation, flow direction and upslope contributing area, require that sinks be removed. According to Burrough and McDonnell (1998) and Rieger (1998) removal of sinks is a "necessary evil". Sinks, however, can be real feature of the surface. With the advent of high resolution DEMs, it is likely that sink filling operations will be costly not only in processing time, but in removing naturally occurring features of the terrain surface. Naturally occurring sinks in elevation data with a grid cell size of $100m^2$ or larger are rare, although they could occur in glaciated or karst topography (Mark, 1988; Tarboton et al., 1993).

A number of methods have been described for eliminating depressions in DEMs. GIS packages such as the ESRI use a sink filling approach based on the D8 single flow direction flow routing method first described by Jenson and Domingue (1988) and Jenson (1991). This sink filling approach raises the sink elevation to that which enables flow linkage. This approach has the disadvantage of assuming that all depressions are due to an underestimation of elevation in the sink, rather than the overestimation of surrounding cells, and flow routing is based on the D8 single-direction flow algorithm.

The first step in eliminating a depression is to define the outlet point, usually the lowest point along the edge of the catchment border. Most of the available algorithms then raise the inner region of the depression. The following methods of achieving this have been reported in Rieger, W., 1998.

1. Raising the inner area to the elevation of the outlet point. The method has the great disadvantage that all form information within the depression is completely lost. Thus topographical principles (rather than elevation information) are needed to define flow paths through the depression.
2. Rerouting the flow direction data set such that flow paths are defined. The principle is the same as in point 1 above, if routing is done merely topographically.
3. Raising the inner area and retaining the form of the depression. The inner area of the depression is raised between the elevations of the outlet point and its lowest outer neighbour, retaining the height relationships between the points. The flow path is then lowered from the depression to the outlet point. The advantage of the method is that the form is retained, so that there no necessity to define flow directions arbitrarily within the depression.
4. Smoothing has sometimes been used to eliminate many small depressions. This is, however, problematic since it flattens all curvature in a land scape and systematically shifts hillslopes.

Some pit removal algorithms incorporate the multiple flow path approach that more adequately addresses the nature of depressions. While research has focused on the development of sink filling methods, little attention has been paid to either the appropriateness of a particular sink filling algorithm or to the impact of the sink filling operation on DEMs and derived parameters. Wechsler (2000) investigated the impact of DEM errors and the sink filling procedure on representation of elevation and derived parameters using a Monte Carlo simulation technique. The effect of sink filling was directly quantified for elevation and slope and indirectly for the topographic index (TI). While there was no significant difference between elevation from filled and unfilled DEMs, a significant bias was observed in the slope parameter. The sink filling procedure raised the elevation of cells where sinks were found, increasing elevations in these areas, resulting in a larger positive bias for elevation. Raising these elevations in turn decreased slope estimators in these areas, leading to negative bias for slope. Sink filling did not appear to have a significant impact on the calculation of TI. These findings have implications for watershed studies conducted in lower lying, flatter areas such as agricultural watersheds.

FOUR PRIMARY DEM PRODUCTS

The four data or products which, alone or in certain combinations, are the key instruments in deriving most of the important properties for hydrologic modelling are described below.

I. ELEVATION

The most common method of acquiring elevation data in digital raster format is often the least accurate one, namely digitizing contours from a topographic map and applying an interpolation method to transform the contour data into a DEM.

II. SLOPE

After obtaining an interpolated raster DEM; other terrain properties can be extracted using filtering techniques. First, gradients in X and Y direction are derived, transforming the scalar into vector field. Each pixel becomes a vector with two components the partial derivatives in X and Y direction. After creating gradients say, GX and GY, the absolute gradients can be used as a slope map.

Slope is a widely used topographic measurement that describes the nature of the land surface and, more importantly, influences the flow rates of water. Numerous algorithms exist for calculating topographic parameters. For example, slope is calculated for the center cell of a 3×3 matrix from values in the surrounding eight cells. Algorithms differ in the way the surrounding values are selected to compute change in elevation. Different algorithms produce different results for the same derived parameter and their suitability in representing slope in varied terrain types may differ.

III. FLOW (DRAINAGE) DIRECTION

The routing of flow over a surface is an integral component to the derivation of subsequent topographic parameters such as watershed boundaries and channel networks. Many different algorithms have been developed to compute flow direction from gridded DEM data and are referred to as single or multiple flow path algorithms. The single flow path method computes flow direction based on the direction of steepest descent in one of the 8 directions from a center cell of a 3×3 window, a method referred to as D8. The D8 algorithm is the flow direction algorithm that is provided within mainstream GIS software packages (such as ESRI GIS). However, the users in the hydrologic community recognize that the D8 approach oversimplifies the flow process and is insufficient in its characterization of flow from grid cells. In response, researchers have developed multiple flow path methods that distribute flow in all possible down-slope directions, rather than just one; see for example. Multiple flow path methods attempt to approximate flow on the sub-grid scale. Multiple flow path functions are currently not part of standard GIS packages and are, therefore, not readily available to DEM users. Desmet and Govers (1996) compared six flow routing algorithms and determined that single and multiple flow path algorithms produce significantly different results. Thus any analysis of contributing areas such as watersheds or stream networks will be greatly affected by the algorithm implemented. Other approaches to deriving channel networks and watershed boundaries have been developed such as those that incorporate additional environmental characteristics. Unfortunately, GIS packages do not differentiate between rough and smooth surfaces when applying a slope or provide users with an option when it comes to derivation of terrain parameters. Users cannot choose a particular method; only one algorithm for derivation of parameters such as slope, aspect and flow direction is embedded in a particular GIS software package. This lack of flexibility in software capability introduces the likelihood of further error transferred to derived topographic parameters. Additional research on the appropriateness of certain algorithms for various terrain types is needed.

The flow direction operation determines the neighbouring pixel into which any water in a central pixel will flow. To determine this, the steepest slope method has been applied as follows:

- For each block of 3x3 input pixels, this operation calculates the height difference between the central pixel (CP) and each of the 8 neighbour pixels.
- If, for a neighbour, the height difference is positive (i.e. central pixel has larger value than the specific neighbour), then:
    - for corner neighbours, height differences are divided by (distance) 1.4
    - for horizontal neighbours, height differences are divided by (distance) 1

  This determines the steepness between the central pixel and its neigbours.

- Now the (position of the) neighbour with the largest 'steepness' value is the output flow direction for the current central pixel.

In addition to the above, the following rules are also applied:

- Pixels along the edges of the input map (margins and corners) will always return the undefined value in the output map.
- If all neighbouring pixels of a central pixel have a larger value than the central pixel itself (i.e. a sink or pit), the undefined value will be returned in the output map.
- When a central pixel has the undefined value, undefined will be returned in the output map.
- Neighbour pixels that have the undefined value are ignored during the calculation.
- If from eight neighbour pixels considered, three adjacent neighbour pixels in a single row or column are found to have the same steepest slope or the same smallest height value, then the position of the neighbour pixel that is in the middle of those three neighbours is used.
- If from eight neighbour pixels considered, two neighbour pixels are found to have the same steepest slope or smallest height value, then the position of one of these two neighbour pixels is used arbitrarily.

IV. FLOW ACCUMULATION

A flow accumulation function was defined by O'Callaghan and Mark (1984) as "an operator which, given the drainage direction matrix and a weight matrix, determines a resulting matrix such that each element represents the sum of the weights of all elements in the matrix which drain to the outlet".

If the weight matrix is set to one, the flow accumulation matrix will contain the contributing drainage area of every cell. For example, the value of the flow accumulation matrix at the catchment outlet will represent the catchment area. Cells having a flow accumulation value of one, which means no inflow, will correspond to ridges or hilltops.

A cell with a value higher than a certain threshold will form a connected drainage network provided that the DTM has no pits or depressions without outlet. The flow accumulation operation performs a cumulative count of the number of pixels that naturally drain into outlets. The operation can be used to find the drainage pattern of a terrain. The accumulated flow value for each pixel is calculated using a recursive function.

When a pixel has neighboring pixels pointing to itself, the values of these neighbours are accumulated, including the value of the pixel itself.

- The calculation is initialized by calling the recursive function for the outlet pixel.
- The function then recursively calls itself for all pixels that flow to the outlet pixel.
- The recursion stops when a pixel is reached that has no more neighbour pixels that flow into it.

The distance to the outlet is calculated as the overall distance from each cell to the nearest channel it flows into, and the continuation down to the channel outlet network to the basin outlet.

HYDROLOGIC CATCHMENT PROPERTIES

DEM can be put in use in variety of applications. After the four important primary products have been obtained from a DEM, a number of hydrologic catchment characteristics can be derived. Considerable research has been carried out in the field of drainage network extraction and watershed boundary delineation by hydrologists and geologists. In general, there are two major types of analysis that may be undertaken:

1. Delineation of drainage network;
2. Derivation of drainage basins, and

1. DELINEATION OF DRAINAGE NETWORK

Drainage network extraction

A drainage network can be extracted from a DEM with an arbitrary drainage density or resolution. Numerous algorithms for this have been proposed. The one used most commonly was developed by Jenson and Domingue (1988) and is based on calculating the flow that accumulates at each point on the land scale-pixels with flow above a chosen threshold are then identified as 'channel' pixels

2. DELINEATION OF DRAINAGE BASIN

Raster or Triangulated irregular network (TIN) DEMs are the primary data structures used in the delineation of watershed boundaries. O'Callaghan and Mark (1984) and Jenson (1987) proposed algorithms to produce depressionless DEMs from regularly spaced grid elevation data. Numerical filling of depressions, whether from artifacts or natural depressions, facilitates the automatic delineation of watersheds. Smoothing of the DEM can improve the success of delineation but can have deleterious effects on derived slopes. If the depressions are hydrologically significant, their volume can be calculated. Jenson and Dominique (1988) used the depression less DEM as a first step in assigning flow directions. Their procedure is based on the hydrologically realistic algorithm discussed by O'Callaghan and Mark (1984), but it is capable of determining flow paths iteratively where there is more than one possible receiving cell and where flow must be routed across flat areas.

Recent development in the integration of remote sensing and GIS with hydrology

Many types of hydrological analysis are limited by a lack of spatial data, since traditionally hydrological data are point measurements. Remote sensing data are fundamentally different, they incorporate spatial information. The rapidly developing GIS technology is a powerful tool to organize, process and visualize spatial data. Thus, RS and GIS can complement each other and enable hydrological models to be more physically based and more efficient. It is only during the last five years that an integration of RS and GIS with hydrological models became technically feasible (Baumgartner et al 1997). For hydrological modeling, the integration of RS and GIS was weak (Shih 1996). However, in 1998 Esri and ERDAS together released the Image Analysis tool for ArcView GIS, which directly linked some basic functions in RS and GIS.

GIS has provided a new environment to develop distributed hydrological models. These models take into account and predict the values of the studied phenomena at any point within the watershed (Mitas and Mitasova 1998). Zhang (1997) developed a framework integrating a stochastic space-time rainfall model and a distributed hydrologic simulation with GIS. Recently, Hellweger and Maidment (1999) implemented an automatic tool in ARC/INFO and ArcView to define and connect the hydrological units, then linking them to the HEC-HMS for the lumped hydrological model.

RS and GIS have become increasingly important in hydrology. However, the current use of RS information in the field of planning, design and operation of water resources systems still falls far below its potential (Schultz 1997). GIS technologies are relatively new and still near the lower end of the growth curve in terms of applications (Goodchild 1996).

Valuable urban spaces and resources require precise stormwater management and flood control. Stormwater runoff estimation is a fundamental problem for both urban planning and urban water resource management.

The framework of integration RS and GIS with Urban hydrology

To best preserve the functionality of each software package in RS, GIS and distributed hydrologic simulation, coupling their inputs / outputs can be one approach for integration, since those software have been widely applied and extensively tested. The data exchange might be complex, but the computation in each subsystem has been proven to be reliable. Figure 1 details the functional integration of RS and GIS with urban hydrologic simulation in support of urban stormwater management (adapted from Zhang et al 1999). The functionality and coupling will be discussed.

A Diagram of Functional Integration of RS and GIS with Urban Hydrology

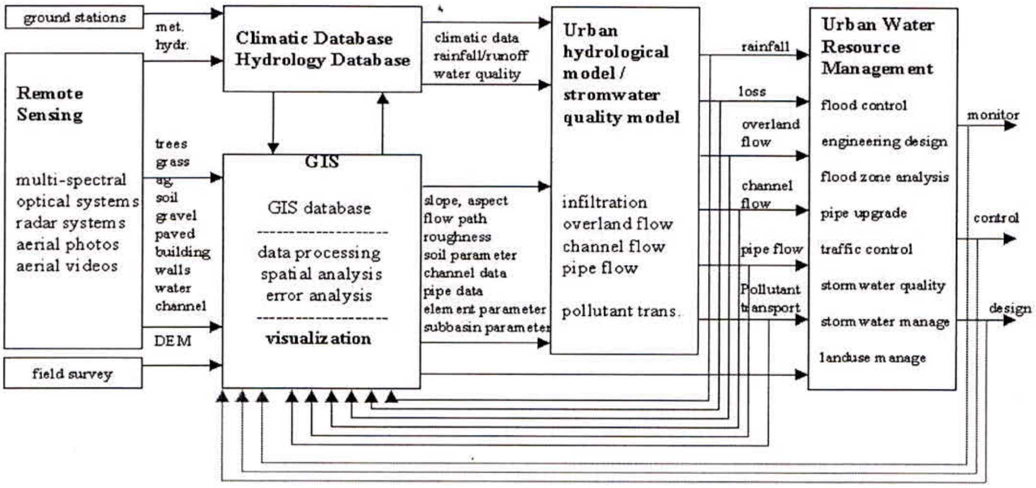


Figure 1. A Funtional Intergration Diagram

The integrated system consists of four subsystems. These sub-systems are RS, GIS, hydrologic simulation and decision support. It is necessary to develop an information management system to handle the data exchange. A RS tool provides the spatial information on both land use (from optical RS systems) and rainfall information (by radar systems). GIS performs the spatial analysis at the multiple scales from multiple data sources. It also prepares the input files for hydrologic simulation. The simulated results will be stored, retrieved and visualized by GIS. These results provide support for decision making in urban resource management. A real application based on this framework will be introduced in the next section.

Integrate RS and GIS with urban stormwater management: An Example

In 1997, an attempt to integrate RS and GIS with urban stormwater management was made by a research group in The University of Arizona. It was initialized from a research project supported by NASA and The City of Scottsdale, Arizona. The study site was a highly developed urban area, Basin 9 in the City of Scottsdale, Arizona. Its area is about 6.69 square kilometers and is predominantly mixed residential with some industrial and commercial areas. The remote sensing data consisted of images from Landsat TM, SPOT, NS001 (which is a TM simulator with the same 7 spectral bands as TM but a 2.9 m spatial resolution) and aerial photography. The high-resolution (1ft grid size) digital elevation map (DEM) was acquired from the field survey. The GIS database included the data for streets, underground pipes, flow paths, soils, etc.. The distributed hydrologic modeling and simulation were carried out by using HEC-1 (it is now updated as HEC-HMS). GIS/Avenue, an ArcView programming language, was used to customize the information management system. This integrated system provided a new environment for both research and application.

Processing Remotely Sensed Data

Three remotely sensed images, Landsat, SPOT and NS001 were processed by supervised classification, then geo-registered and rectified with reference to aerial photography and street map. The identified categories were residential buildings, industrial buildings, asphalt, concrete, trees, grass, bare soil, water, and agriculture land. The processed images were spot-checked by the field observation in an adaptive sampling approach. NS001 show the best classification, since its sensor has best spectral resolution and highest spatial resolution of those three systems. Landsat TM has a more accurate classification of the paved area than SPOT, due to its higher spectral resolution. The impact of RS data resolution to hydrologic simulation were investigated in detail, the results will be introduced later.

Digital Elevation Modeling the Urban Watershed

A high-resolution DEM with 1-foot grid size was provided by the City of Scottsdale, together with a basin boundary map. The research team made field surveys to improve the GIS database, especially with regard to data on channels and flow paths. The field surveys showed that, in this area, it is necessary to model walled boundaries to delineate the sub-basins, since a mile-long wall can physically change flow direction. These walls could not be identified from the three RS images, and it was not in DEM either. Field investigations of flow paths were performed on some streets and large parking lots that were relatively flat, the flow paths were field investigated. Data were also collected along the channels. Data for detention ponds were collected in industrial areas. These field data greatly improved the GIS data quality. Using these data, the basin was partitioned by GIS hydrologic functions, based on pre-selected outlet points. The TOPOGRID function in ARC/INFO GRID was used to perform the hydrologic corrections. Figure 2 compares the basin partition with hydrologic corrections (based on the feedback from the field data) to the original one, using the same set of outlet points. In the hydrological corrected DEM model, in contrast to the original one, the streets no longer served as sub-basin boundaries, since the streets in this area have a shallow V shape.

Hydrologic Parameterization by RS and GIS

Each processed image was converted to a grid. The spatial land use information was organized and processed with GIS tools. Using a rule base, the GIS determined the pixel hydrologic parameters based on the surface feature (soil type, vegetation type, ...) combined with other GIS data (natural channel, residential area, ...). The typical pixel hydrologic parameters derived mainly from RS are the surface resistance factor, N, and SCS Runoff Curve Number, CN. The parameters for modeling overland-flow elements were the area, average flow length, slope, roughness, and CN. For modeling flow routing along a channel or pipe, the GIS provided cross-section data, roughness and slope. Figure 3 shows the geo-reference connected RS and GIS with hydrologic parameterization together.

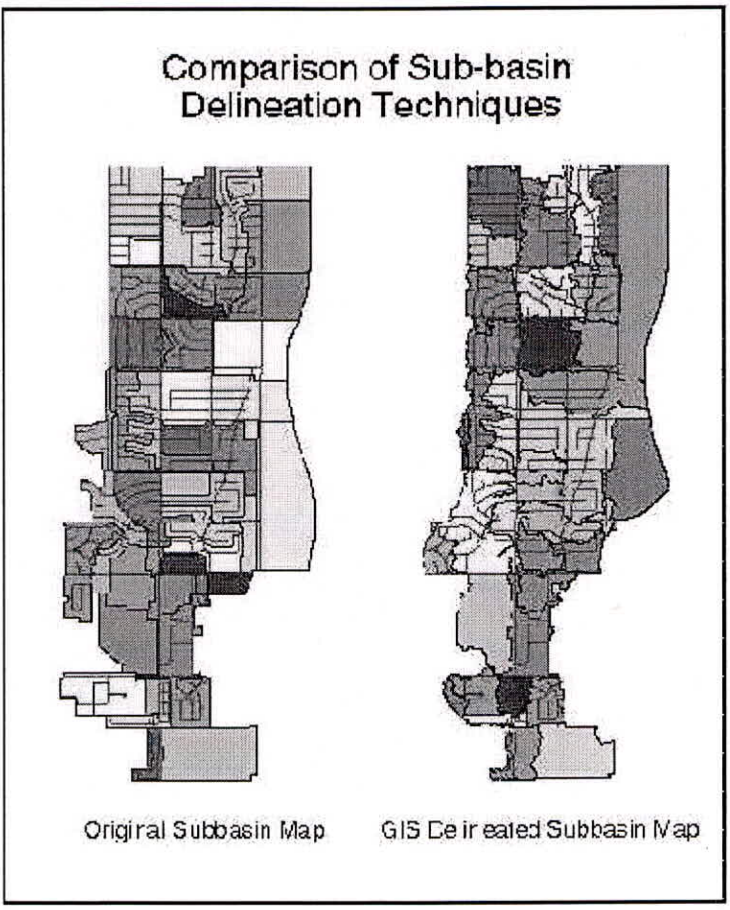
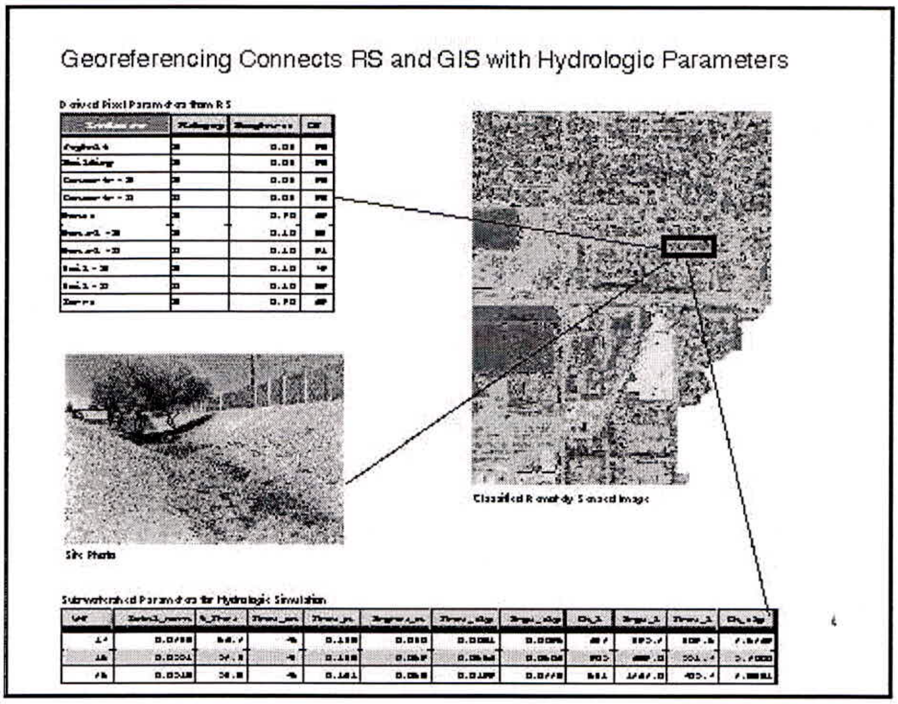


Figure 2. Comparison of Basin Patition

In summary, GIS tools played a central role for parameterization. Geo-referencing connected RS and GIS with hydrologic parameterization together. Here, the parameters were directly observed and then automatically derived from each pixel, which is significantly different from the traditional approach where the parameters were interpolated from the point measurements. It would be very difficult to apply the traditional interpolation approach in the highly developed urban area, where land use conditions change rapidly.



Georeferencing Connects RS and GIS with Hydrologic Parameters

Derived Pixel Parameters from RS

Classified Remotely Sensed Image

Site Photo

Subwatershed Parameters for Hydrologic Simulation

Figure 3. Georeferencing Connects RS and GIS with Hydrologic Parameters

CONCLUSIONS

Topographic data are one of the key inputs required for natural resource management, and in the form of particularly larger scale DEMs, are currently set to assume an even more important place in GIS. Grid-type DEMs are often used as a source of topographic data for distributed watershed models. However, as with most data, DEM have shortcomings and limitations that must be understood before using the data in water resources modeling applications. DEM quality and resolution are two important characteristics that can impact application results. DEM quality and resolution must be consistent with the scale of the application and of the processes that are modeled, the size of the land surface features that are to be resolved, the type of watershed model (physical process, empirical, lumped, etc), and the study objectives. The user must insure that relevant and important topographic features are accurately resolved by the selected DEM. DEM are often processed by GIS packages to define the configuration of the channel network, location of drainage divides, channel length and slope, and subcatchment properties. Basin areas, maximum length of flow and time-area graphs to produce instantaneous unit hydrographs are promising because their derivation is not as critical, and because of their direct application in hydrologic modelling.

The automated derivation of such information from DEM is faster, less subjective and provides more reproducible measurements than traditional manual evaluation of maps. Past trends and developments, the increasing quality and resolution of new DEM products, new raster processing methodologies, as well as the expanding capabilities of GIS and linkage with traditional watershed models, lead us to believe that the use of DEM to derive topographic and drainage data for water resources investigations will continue to increase.

Table 1: Primary topographic attributes (Moore et al 1991 from Speight (1974, 1980)

Attribute	Definition	Hydrological significance
Altitude	Elevation	Climate, vegetation type, potential energy
Upslope height	Mean height of slope area	Potential energy
Aspect	Slope azimuth	Solar irradiation
Slope	Gradient	Overland/subsurface flow velocity and runoff rate
Upslope	Mean of upslope area	Runoff velocity
Dispersal slope	Mean slope of dispersal area	Rate of soil drainage
Catchment slope	Average slope over the catchment	Time of concentration
Upslope area	Catchment area above short length of contour	Runoff vol., steady-state runoff rate
Dispersal area	Area downslope from a short length of contour	Soil drainage rate
Catchment area	Area draining to catchment outlet	Runoff volume
Specific catchment area	Upslope area per unit width of contour	Runoff vol., steady-state runoff rate
Flow path length	Maximum distance of water flow to a point in the catchment	Erosion rates, sediment yield, time of concentration
Upslope length	Mean length of flow paths to a point in the catchment	Flow acceleration, erosion rates
Dispersal length	Distance from a point in the catchment to the outlet	Impedance of soil drainage
Catchment length	Distance from highest point to outlet	Overland flow attenuation
Profile curvature	Slope profile curvature	Flow acceleration, erosion/deposition rate
Plan curvature	Contour curvature	Converging/diverging flow. Soil water content

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