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9.4.2 Geographic Information Systems

The function of a GIS in hydrologic modeling is to improve the efficiency and/or quality by reducing the labor intensity of the map manipulations, table look-ups, and repetitious computations required to define input parameters; enable data collection and analysis within variable geographic constructs; and produce more meaningful data outputs in terms of maps, tables, and reports. By reducing the time required to define the input parameters, a larger portion of the project time is available to interpret results and explore alternative design strategies. Although a GIS will allow a hydrologist to be more productive, it cannot replace judgment and experience. Indeed, a well-designed GIS must allow the hydrologist to easily add special conditions to the database and modify pre-programmed procedures when unusual watershed conditions are encountered.

As an illustration of the GIS approach, assume that the SCS procedures described in earlier are to produce subwatershed hydrographs that will be routed through a channel network to generate the peak flow rates and runoff hydrographs required for the design of a bridge. After the input parameters have been defined, the computational tasks will be executed on a computer. The watershed will have to be modeled for both existing and proposed future conditions. After the land cover and hydrologic soil type databases for the jurisdiction have been stored and any needed field data have been obtained from the watershed, a well-designed hydrologic GIS will allow the modeling tasks to be accomplished with the following scenario:

> The hydrologist sits at a desktop workstation and defines a watershed of interest by selecting subwatershed boundaries that were generated automatically from properly scaled digital elevation models (DEMs). The GIS then uses the vector

coordinates of these boundary polygons to access the jurisdiction-wide database and assemble the land cover, land use, and soil data that define the existing conditions in the watershed. The hydrologist inputs any special conditions that have been observed in the field and digitizes the locations of land cover changes that will represent the future condition of the watershed. The digital elevation model is used to identify the location and slopes of the main stream network, minor tributaries, and overland flow planes. Representative channel cross-sections and roughness coefficients for existing and future watershed conditions are defined for specific stream reaches. All the data overlays and other required manipulations are automatically performed to define the parameters and create the software input data. The computer program then produces the existing and proposed condition hydrographs and supporting software provides the array of maps, graphs and tables needed to interpret the analyses.

9.4.2.1 Overview of GIS

Many definitions of geographic information systems technology have evolved, each influenced by the application of interest to its author. A definition that is appropriate for the field of hydrologic modeling is: "A geographic information system is a set of interactive hardware/software tools that integrate and quantify spatially referenced data into quantitative information required for decision-making."

An example of an application of this definition in hydrology would be to use rainfall, watershed land cover, soil, and topographic data as inputs to a model that provides information in the form of a runoff hydrograph required for a design project.

A GIS integrates data from various sources in disparate scales and differing reference systems and stores this information in a geographically registered database. These data may include a number of layers such as land cover, soil type, and topography. Data can be retrieved, analyzed, and used to produce quantitative information needed to support the decision to be made. The system can be used to reformat geospatial data into formats such as maps, tables, graphs, and text and machine-readable code for input into hydrographic modeling systems that optimize the use and interpretation of information.

Figure 9.20 is a schematic showing the major components of a geographic information system. GIS systems are scalable with reference to data storage, software functionality, and throughput capacity. The current overview of GIS operations in hydrologic modeling concentrates on systems that can be served by a single desktop work station.

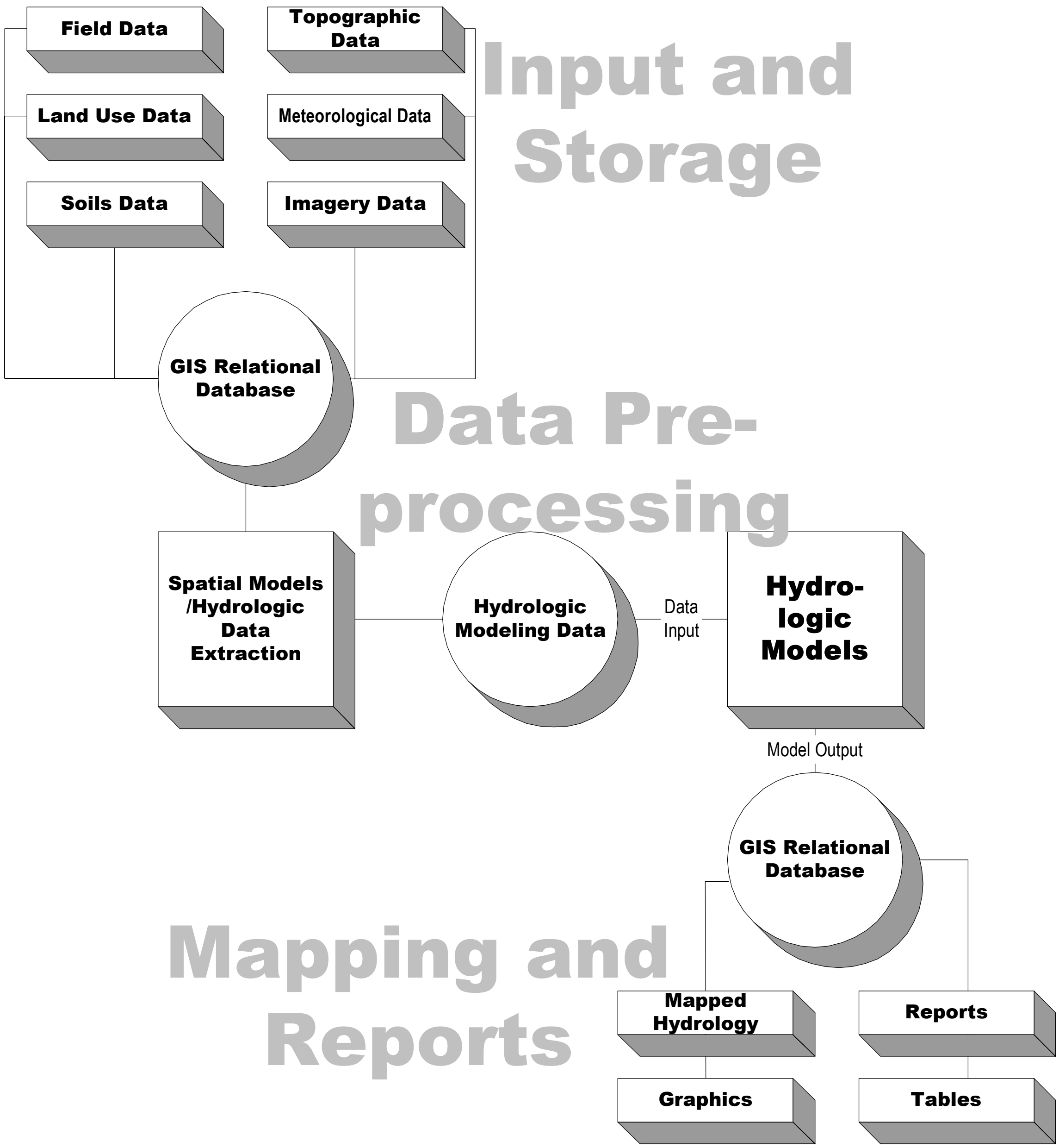


Figure 9.20. Major components of a geographic system integrated with hydrologic modeling.

9.4.2.2 Manual Approach to Input Parameter Generation

This section presents an example to define GIS requirements for hydrologic modeling and to explain some of the concepts of file structure and operation. The example begins by reviewing a manual-based approach to defining model parameters for a small watershed. The objective of the example problem is to use maps and tables to define several parameters that will be inputs to a computer model that generates a design hydrograph. A later section introduces the relevant elements of GIS structure and operations by explaining how the manual operations with the tables and maps are translated into digital procedures, thereby demonstrating the applicability and value of GIS.

In this scenario the hydrologist uses a computer to run a model to generate design hydrographs. Maps and tables are used to define the watershed area, percent of imperviousness, weighted curve number, and the time of concentration. The hydrologist then uses the computer keyboard to type the input parameters into the format required by the model.

The SCS curve number approach is applied in this illustration. A number of widely used hydrologic models use the curve number (CN) to compute the rainfall excess. The CN approach is simple enough to be easily understood. At the same time, the manual overlaying of the spatially distributed land covers and soil types to define a weighted watershed CN are sufficiently difficult to indicate the advantage of computer assistance when the drainage areas are large and diverse. Further, the manual operations with the paper maps and tables listing land cover and soil characteristics provide a good base for understanding the structure and operations with GIS files that are introduced later.

Figure 9.21 illustrates minimum resources needed to define the parameters listed above. Figure 9.21A shows the watershed boundary and the flow network needed to define the area and time of concentration. Figure 9.21B is a plot of the "typical bank-full" stream cross-section that will be used to estimate the velocity in the stream as part of the time of concentration. Figures 9.20C and 9.20D are maps showing the land cover and SCS Hydrologic Soil Groups for an area of 3,660 m (12,000 ft) by 2,130 m (7,000 ft) that surrounds the watershed. The land cover map could have been developed by overlaying a thin paper onto an aerial photograph and drawing polygons around areas having a given land cover. The map of hydrologic soils would have been developed using the county soil maps available from the SCS. Table 9.12 lists symbols that can be used to represent each land cover category that might be found in the vicinity of the watershed, the CN for each soil type and the percent of imperviousness. Table 9.13 is a list of symbols that can be used to represent each of the four hydrologic soil groups.

Historically, a mechanical planimeter or other manual method would be used to determine the area of each land cover category or soil group within each of the polygons of Figures 9.20C and 9.20D. An expedient approach is to overlay a grid as illustrated in Figures 9.21A and 9.21B and assign the symbols of Tables 9.12 and 9.13 to represent the dominant category within each cell. The number of cells in each category is then counted. The smaller the cell size, the closer will be the agreement with the areas obtained using the more accurate, but more time consuming, planimetric approach. Both the planimeter and grid cell processes assume that the soils map, landcover map, and watershed definition are in the same map projection, use the same coordinate system, and are derived from the same scale.

The grid cell representation provides a relatively easy way to develop information required to model the watershed of Figure 9.21A. The grid cell representation of the watershed is illustrated by Figures 9.22A and 9.22B. First, the number of cells within each land cover and soil category inside the watershed are counted and the resulting areas are presented in Tables 9.14 and 9.15. The basin area is 501 hectares (1,240 acres) and the distributions provide an inventory for environmental impact analyses, etc.

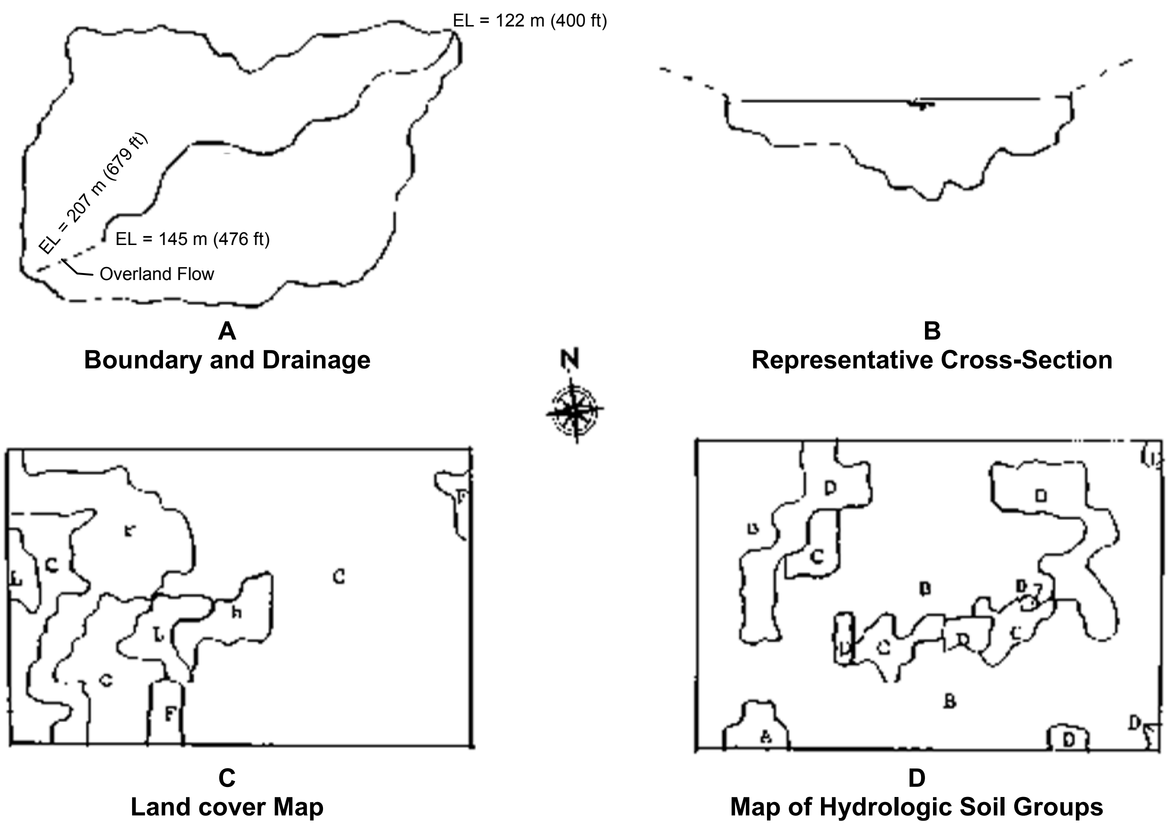


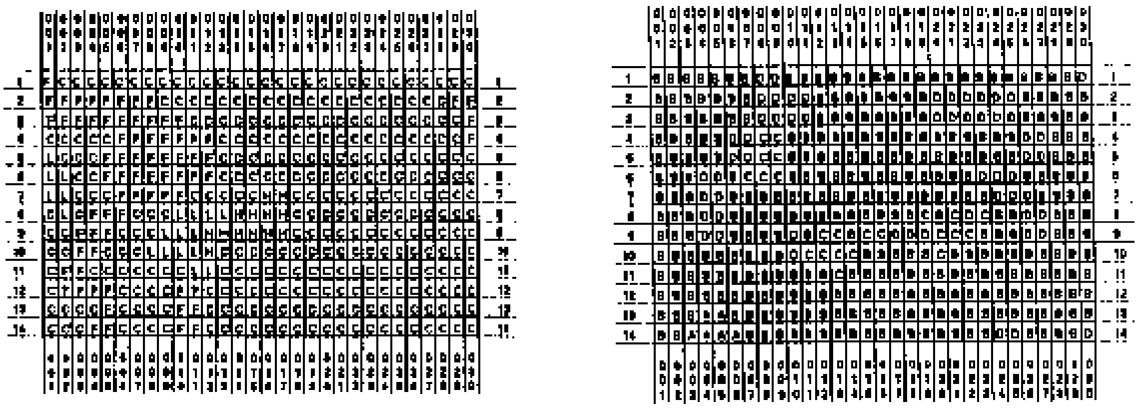
Figure 9.21. Minimum information requirements to run an SCS model

Table 9.12. Characteristics of Land Cover in Area of Interest

				Curve Number				
Line	Category	Sym.	%Imp.	A	B	C	D	Color
1	RESID(low density)	L	25	54	70	80	85	14
2	RESID(medium density)	M	38	61	75	83	87	12
3	RESID(high density)	H	65	77	85	90	92	6
4	COMM/INDUSTRIAL	A	85	89	92	94	95	4
5	INSTITUTIONAL	I	72	81	88	91	93	5
6	FOREST	F	0	36	60	73	79	2
7	BRUSH	B	0	35	56	70	77	8
8	WATER	W	0	100	100	100	100	1
9	WETLANDS	X	0	100	100	100	100	9
10	BARE SOIL	U	0	77	86	91	94	15
11	CROPLAND	C	0	72	81	88	91	3
12	GRASS	G	0	49	69	79	84	10
13	SURFACE MINING	E	0	77	86	91	94	11
14	CROPLAND-B	@	0	77	86	91	94	7
15	R-30	#	90	90	94	95	97	6
16	RT-12%	%	70	78	88	93	94	5
17	C-2	$	90	88	92	95	96	4

Table 9.13. SCS Hydrologic Soil Groups

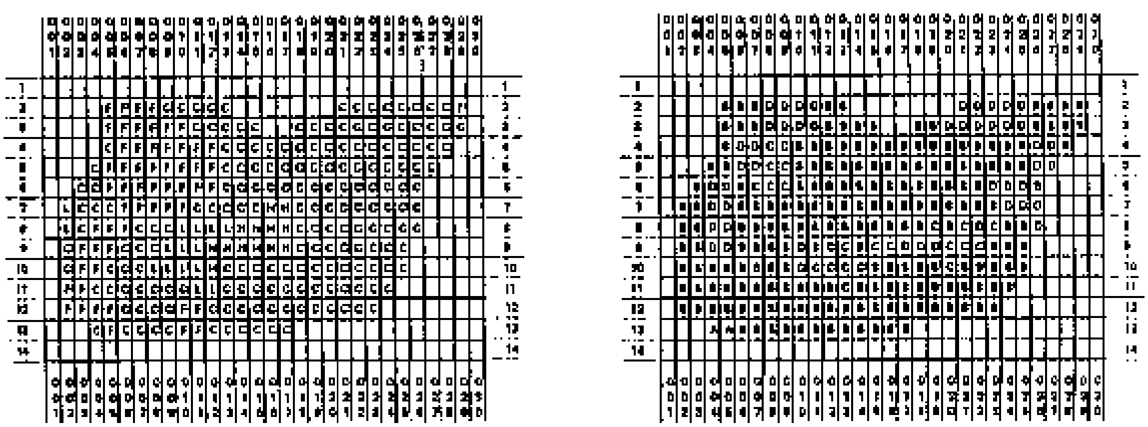
Category	Symbol	Color
Group A	A	14
Group B	B	2
Group C	C	4
Group D	D	8



Land Cover
A

Soils
B

Figure 9.22. Grid cell representation of the spatial distribution of land cover and hydrologic soil groups



Land Cover
A

Soils
B

Figure 9.23. Grid cell representation of land cover and hydrologic soils groups within a watershed

Table 9.14. Summary of Land Cover Distribution in Watershed of Figure 9.21

Symbol	Category	Number of Cells	Area (ha)	Area (ac)	Percent
L	RESID (low density)	15	27.82	68.7	5.56
H	RESID (high density)	13	24.11	59.6	4.81
F	FOREST	58	107.56	265.8	21.48
C	CROPLAND	184	341.20	843.1	68.15
Total		270	500.69	1237.2	100.00

Table 9.15. Summary of Hydrologic Soil Group Distribution in Watershed of Figure 9.21

Sym.	Category	Number of Cells	Area (ha)	Area (ac)	Percent
A	GROUP A	2	3.71	9.2	0.74
B	GROUP B	197	365.32	902.7	72.96
C	GROUP C	23	42.65	105.4	8.52
D	GROUP D	48	89.01	219.9	17.78
	Total	270	500.69	1237.2	100.00

The distribution of the cells shown in Figures 9.22A and 9.22B are used in conjunction with Tables 9.12 and 9.13 to define the composite runoff curve numbers required by the SCS models. For example, Table 9.12 shows that the "F" representing the dominant land cover in cell (8,2) of Figure 9.23A is "Forest". Figure 9.23B shows the corresponding soil cell to be in the D hydrologic group. Table 9.12 is then used to show that cell (8,2), an area of "Forest" on a "D Hydrologic Soil", has a curve number of 79. This overlay/ table look-up process is extended for all cells within the boundary to estimate an average or "weighted" curve number for the watershed. Table 9.16 illustrates one approach that can be used to manage the cell counting process and Table 9.17 shows the computations to define the average curve number and percent of imperviousness.

Table 9.16. Example of Type of Tabulation Used to Define Cell Counts for Curve Number Computation

Land Cover Category	Cells in Soil Group				Total Cells
	A	B	C	D	
RESID(low density)	0	12	1	2	15
RESID(high density)	0	7	5	1	13
FOREST	1	37	7	13	58
CROPLAND	1	141	10	32	184
Total	2	197	23	48	270

Table 9.17. Example of Weighted Curve Number Computation

Land Cover Category	Cells x Curve Number					Product
	A	B	C	D		
RESID(low density)		12(70) +	1(80) +	2(85)	=	1,090
RESID(high density)		7(85) +	5(90) +	1(92)	=	1,137
FOREST	1(36) +	37(60) +	7(73) +	13(79)	=	3,794
CROPLAND	1(72) +	141(81) +	10(88) +	32(91)	=	15,285
Total						21,306

Weighted Curve Number = 21,306/270 = 79
Percent Imperviousness 15(25) + 13(38) = 869/270 = 3.2%

The first step in determining the time of concentration is to consider the main stream. The watershed time of concentration is the sum of travel times through the stream network and overland flow. These equations require that the hydrologist have information on the slope and cross-sectional characteristics of the main stream and overland flow, as is the case with most physically-based models.

The next step is to arrange the watershed area, weighted curve number, time of concentration, and the precipitation of interest into the required format for keyboard input to the model. Even this task can be frustrating because the format requirements of many models are quite cumbersome.

These are the steps used to model the watershed under existing conditions. With increasing frequency, the hydrologist must develop hydrographs for some proposed condition where no streamflow data exist or where land covers have changed on parts of the watershed and all or some of the drainage network has been modified. If proposed conditions have to be modeled, the changes would be made on Figures 9.20A, 9.20B, 9.20C, and 9.22A, and all the above steps repeated with little gain in efficiency over the existing condition analysis.

9.4.2.3 Translation of Manual Approach into GIS Procedures

The map-based steps used to define the area, curve number, and time of concentration are tedious even for this small watershed. Through GIS technologies, the manuaul steps described previously can be translated into equivalent digital procedures that can be executed in a fraction of the time required by conventional approaches. Some of the pertinent GIS concepts will now be explored by translating the map-based approaches described above into generic GIS operations.

In the example, the spatial distributions of the land cover and soil databases were represented and analyzed as the arrays of grid cells shown in Figure 9.22A and 9.22B. When this grid cell representation is translated into a digital format for use in a GIS, it is termed a "raster data structure" or a raster file. Data can be entered into the GIS system using any number of data entry techniques in which the symbol is translated into a digital number for each cell. Each symbol would represent the dominant land cover or soil category in the rectangular area located at the indicated column/row. If data are provided by reputable distributors, e.g., USGS and NRCS, the data will most commonly be georeferenced. Map coordinates, physical cell size, map projection, map coordinate system, and levels of precision are recorded and transmitted as Metadata with each data set. This process enables the hydrologist to store information that crosses jurisdictional lines and extract data based upon a geographical description of the watershed.

In performing the tasks involving Figures 9.22A and 9.22B, the first step was to note the symbol for each cell. Tables 9.12 and 9.13 were then used to determine the category the cell represented and to assign percent imperviousness and a curve number. In a GIS, the digital equivalents of Tables 9.12 and 9.13 are called "attribute tables" and are related to the digital value of each cell. As in the manual example, attribute tables assign properties to digital values in the raster database. For example, if the symbol "H" is accessed in the land cover raster database, the attribute file of the form of Table 9.12 is accessed to identify the land use in the cell as "RESID(high density)" with an imperviousness of 65 percent.

In the context of this example, the hydrologic GIS is designed to duplicate the steps that would have traditionally been performed manually, but with much more speed, reproducibility, and quality control. One of the major capabilities of a GIS system is the ability to model spatially related data to perform data extraction (spatial queries) and data analysis by applying mathematical operations to data. A simple example would be, column 8 on row 2 of the raster equivalent of Figure 9.23A is overlaid onto the corresponding location on the equivalent file of Figure 9.23B. The match is "F" land cover on a "D" soil. The attribute file representing Table 9.12 is then accessed to assign a CN=79 to the cell in the same manner as described in the manual approach.

It is important to note that the raster format is only one approach to representing the spatial distribution of the land cover and soil categories in Figures 9.20C and 9.20D. Most GIS systems integrate raster and vector (line and point data) into unified systems. Neither format is inherently “better” or “more powerful” than the other. Current GIS systems use the two formats to complement one another to expedite processing and maximize quality.

In the manual approach, the watershed boundary was drawn and visual inspection selected the cells that were inside. In the GIS environment, a polygon representing the boundary is created in geographic space. The boundary is used to query and extract all coincident data available within the selected polygon.

In the manual approach, the lengths of the stream and overland flow plane were measured on Figure 9.21A. A hydrologic GIS delineates stream reaches and stores lengths of streams and overland flow segments based upon digital topographic relationships. The elevations required for the slopes are extracted from digital elevation models.

After these inputs are provided by the hydrologist, the GIS software places the watershed area, weighted curve number, and time of concentration into a file formatted for entry into the hydrologic model being supported. Similar steps are followed by GIS software when the hydrologist selects methods other than the SCS curve number approach.

Data used throughout hydrologic analysis can also be used to support parallel issues such as environmental impact studies, sediment control programs, economic impacts, etc.

9.4.2.4 GIS Requirements for the Modeling of a Complex Watershed

A more complex case study is considered in this section. Figure 9.21A is Subwatershed 8 in the larger basin represented by Figure 9.24A. The drainage area of the watershed shown in Figure 9.24A is 131 km^2 (50.6 mi^2). In a watershed of this size, travel time, nonhomogeneous conditions, and floodplain storage in the stream network will have a major impact on the hydrograph at the watershed outlet. The stream system is simulated by combining and routing the hydrographs from each subwatershed through the dendritic network shown in Figure 9.24B using one of the routing techniques presented in an earlier chapter. As stated earlier, the computational intensity of these tasks lead hydrologists to rely on computer programs. The use of GIS to support the hydrologic modeling of complex watersheds, such as the example in this section, is discussed by Ragan (1991).

As an additional requirement, assume that the watershed of Figure 9.24 has to be modeled for both the existing and proposed land cover distributions shown in Figure 9.25. When an organization is using a GIS to support the modeling of watersheds, the land cover/curve number attribute table is probably more like Table 5.4 than Table 9.12. Two situations typically occur in hydrologic modeling. First, field investigations may reveal that there are areas in the watershed that are different from any of the categories in the attribute table that has been prepared for general use. Second, modeling future conditions is frequently based on local zoning designations rather than the names of land cover categories that appear in the attribute files. Thus, the GIS must allow the attribute files, digital equivalents of Table 9.12 or Table 5.4, to be easily edited so that new land cover and zoning categories can be added or deleted for use on a particular watershed. In the case illustrated by Figures 9.25A and 9.25B, a "CROPLAND-B" has been to be added to improve the representation of the existing land cover, and three zoning designations have been added to describe the anticipated future development.

In defining the input parameters needed to model the watershed of Figure 9.24, the steps described in Section 9.4.2.3 are followed to determine the drainage area, curve number, and time of concentration for each of the 13 subwatersheds for both existing and proposed conditions. To accomplish this, each specific data layer can be initially input in the form of Figure 9.23 to reflect current conditions and then edited to reflect anticipated changes. For example, after developing the existing condition model, the area to be changed to "CROPLAND-B" for future conditions is edited. All other areas that are being rezoned for future development are also edited. A second database that stores the land cover distribution of Figure 9.25B is then generated to support the definition of the watershed under future conditions.

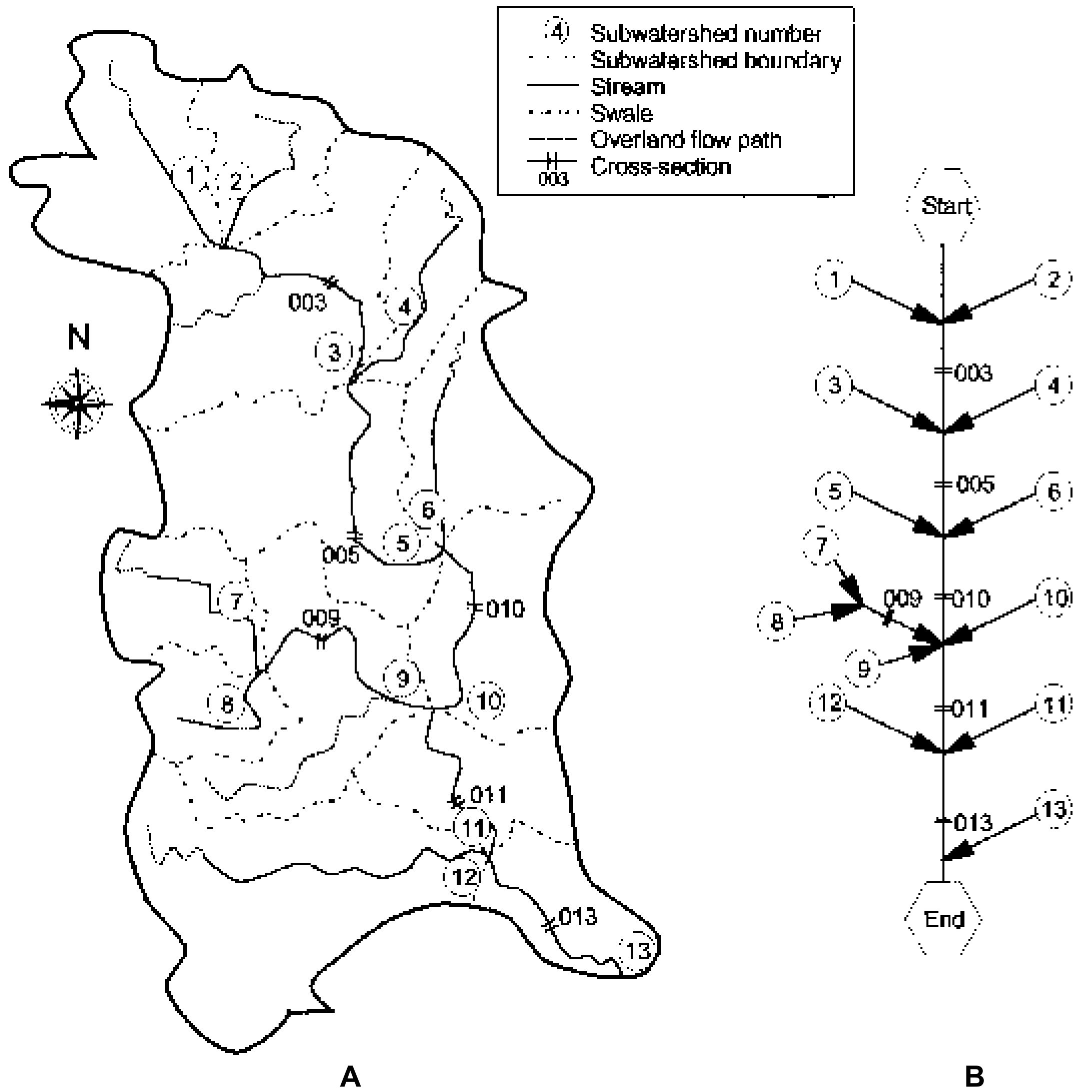


Figure 9.24. Distribution of subwatersheds and network representation of a complex river basin

The next step is for the GIS to assist in setting up the data that define the stream network that will control the hydrograph combining and routing. The stream junctions will correspond to the outlet locations of the subwatersheds and represent points where subwatershed hydrographs will be combined before being routed.

Bank-full stream cross-sections and a Manning roughness coefficient are used to determine the velocities needed for calculating the time of concentration and routing parameters. Some flood routing models require complete cross-sections along with main channel, left overbank, and right overbank roughness coefficients. The GIS can be configured to accept the cross-sections from survey notes, plots, or through interpolation along digitized contours. In the example of

Figure 9.24, some routing techniques require the cross-section data to be translated into some form of stage-discharge tables for cross-sections 003, 005, 009, 010, 011, and 013.

When modeling a watershed of the complexity of Figure 9.24, the computation and merging of the subwatershed hydrographs and routing through the stream network usually involves the use of computer programs. The input file required by the model must not only define the model parameters, but also, the linking and routing processes illustrated by Figure 9.24B. The well-designed GIS should incorporate "network analysis" that uses the digitized stream segments and junctions to automatically set up the input file that will cause the model to be executed in accordance with the watershed schematic of Figure 9.24B.

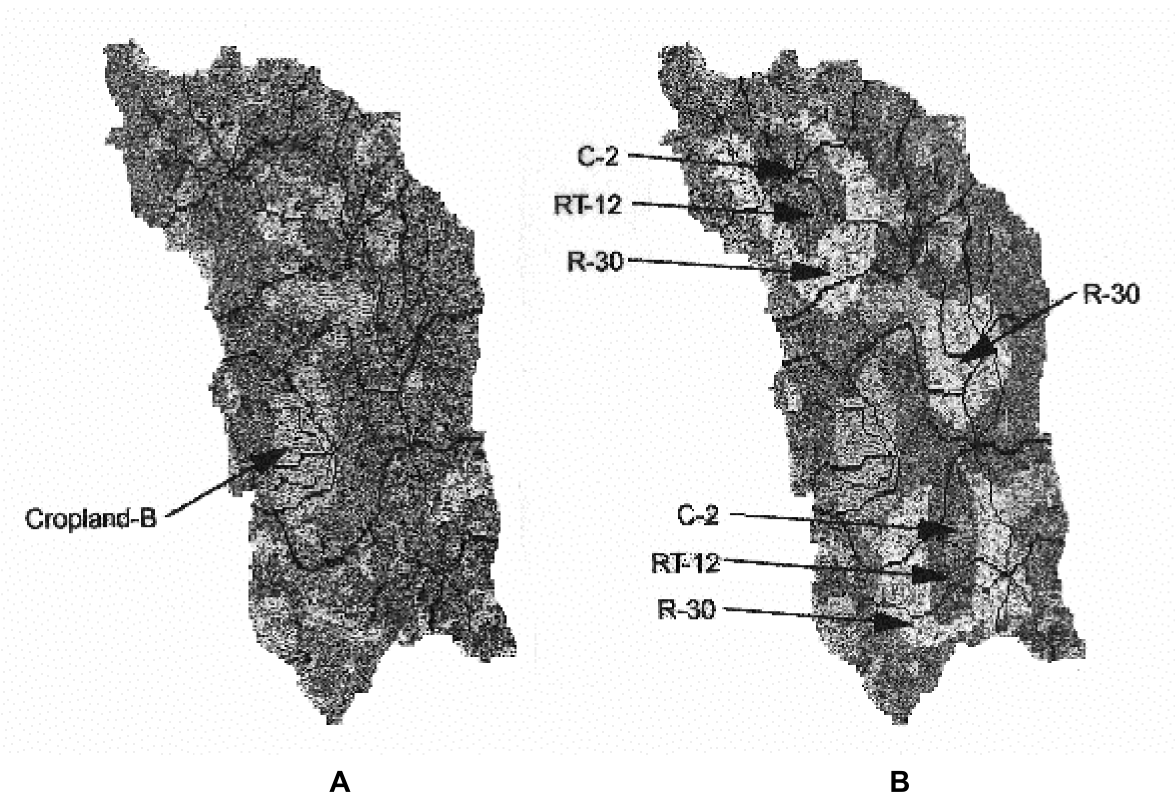


Figure 9.25. Existing and ultimate development land cover distributions in a complex watershed

9.4.3 GIS Implementation Issues

9.4.3.1 Storage and Resolution

A state or county highway department may conduct modeling studies such as those described earlier many times during a year. One project may be in one part of the jurisdiction while the next will be in another area. If the watershed sizes are above some minimum value and the objectives of the modeling efforts are similar from one project to the next, the optimal approach is to develop a jurisdiction-wide database that will be maintained and immediately available on the hard disk of the workstation. In a traditional hard-copy map-based approach, the hydrologist goes to storage cabinets to obtain the topographic maps, aerial photos or land cover maps and the soil maps. With the data available from sources available on the system network, the hydrologist would simply use the mouse to point to the data to be retrieved.

The hydrologic database can be very large, especially if it is to support a GIS that will be used anywhere in a state. Even with the efficiencies of today's workstations, a large database must be properly structured if it is to be quickly accessed and easily maintained. Network access to data from local, state, federal, and private sources have been enabled through the internet. Baseline data collected for one hydrologic study may have applicability to another hydrologic model. Therefore, sound database and network design are critical to being able to store, retrieve, and update geospatial data sets.

Data sharing among state, local, and federal agencies is active and growing as of this writing. It is not necessary for the individual highway department to create and store all of the data required for hydrologic studies, only to request access to the data stores of other agencies. It is critical that the hydrologist understand the nature or level of detail stored in each dataset. Modeling very small watersheds with a high quality model can require the location of each building, road, parking lot and storm sewer along with a detailed description of the soil distribution. The hydrologist must match the scale, level of detail, and currentness of the data to the scale of the hydrologic study.

Modeling watersheds when their areas are larger than around 60 ha (150 ac) can be accomplished with the more general land cover categories such as those in Table 9.12 stored as an array of 1.86 ha (4.60 ac) cells in a raster format (Ragan, 1991). Four-acre cells are considered to be quite coarse with modern systems. National Land Cover Data (USGS) are available in 30m cell sizes, 0.2 ac per cell. Thus, a practical approach is to select a lower limit on the size of a watershed to be modeled and build a jurisdiction-wide, on-line database to support that task. The GIS is then designed to allow the hydrologist to develop optimal resolution. Local databases to support the modeling on special projects, such as the watershed illustrated by Figure 9.26, can be developed on a case by case basis.

It is not necessary to store land cover in cells that represent an area of 1 ha (2.5 ac) if the area is homogeneous and the data can be stored in 5 ha (12.5 ac) cells without changing a parameter beyond some acceptable, predetermined limit. In general, relatively large cells can be used to represent the spatial distribution of land cover in the agricultural fields of the great plains, but, much smaller cells would have to be used to adequately describe a suburban or urban area. The GIS system can provide accurate tabular results to be included in the hydrologic models from either scenario. Each layer can be independent of other layers, e.g., county level soils data can be used in its native level of precision along with statewide land use data. Sensitivity studies would normally be conducted to gain insight into the consequences of changing the size of the data cell.

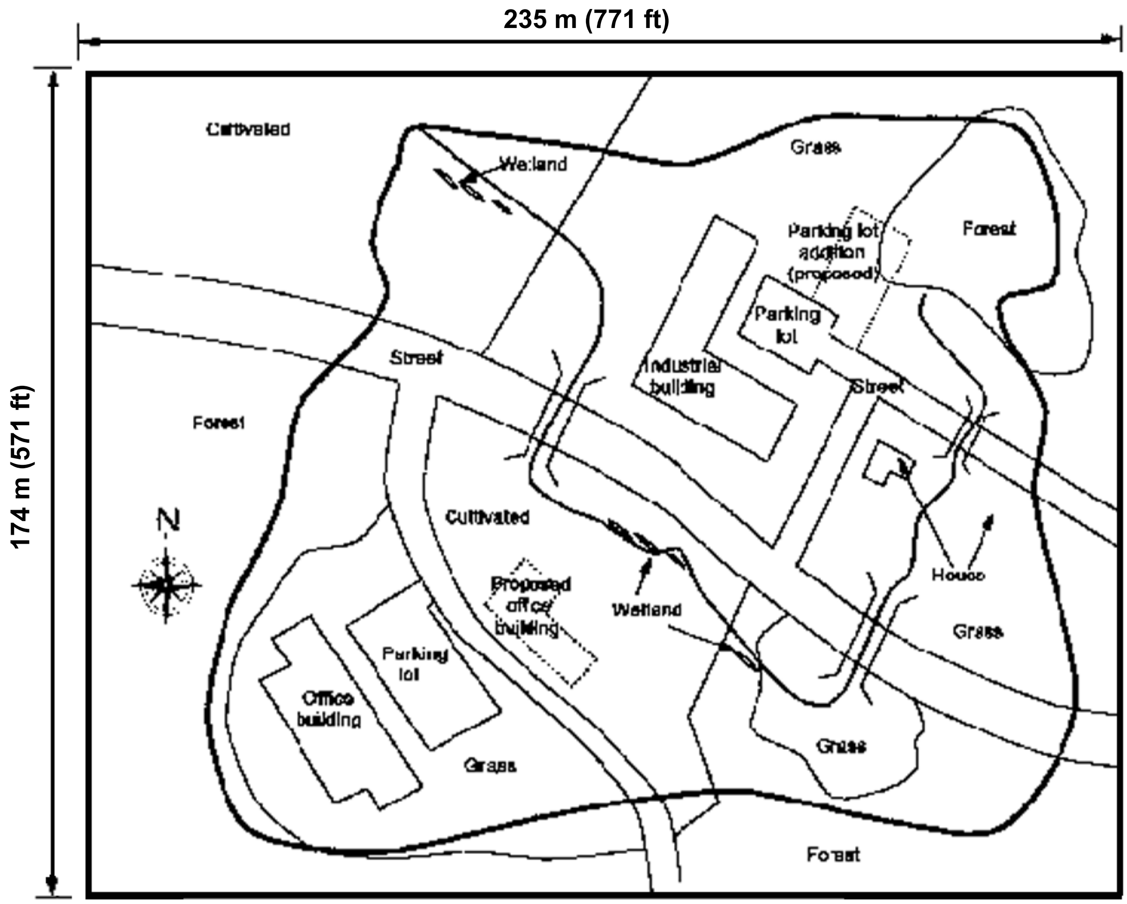


Figure 9.26. Example of a detailed land cover distribution required for the modeling of a very small watershed

Figure 9.27 indicates how a sensitivity study could be conducted. The ordinate in each of the plots is the percent change in the estimate of CN with the most detailed resolution (30 m resolution) as the reference point. Each of the curves in each plot is labled with the resolution of the comparative data, e.g. 60 m and 120 m. The alternative distributions represent three different land/soil complexes. Though not described here, the land cover distributions I, II, and III increase in complexity. The problem is to define how much a curve number is changed as the size of the data cells is increased from 30 to 60 to 120 to 210 to 300 m (100 to 200 to 400 to 700 to 1,000 ft). If the study area is quite large and the time and resources are restrictive, it may be beneficial to use the largest possible cell size to minimize database development and operation costs. If the database covers an area having a land cover distribution similar to Distribution I, then the data cell could be increased from 30 m to 210 m (100 ft to 700 ft) and only change the curve number by 5 percent for a watershed of 1.5 km² (0.6 mi²). If land cover distribution II were involved, 210-m (700-ft) data cells would give curve numbers for a 1.5 km² (0.6 mi²) watershed that differed from that obtained with a 30-meter cell by approximately 12 percent. For Distribution III, the difference would be about 23 percent.

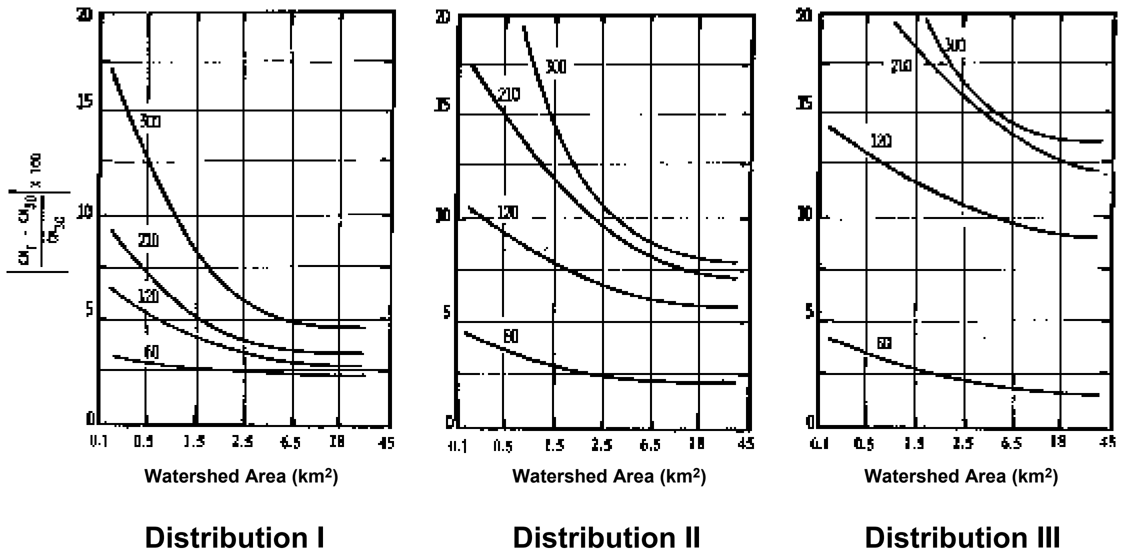


Figure 9.27. Change in estimated curve number for increasing grid cell size for three land cover soil complexes

If the data are to be stored in a vector rather than a raster format, a similar sensitivity study is required. Instead of testing for the minimum cell size, the quest is for the "minimum mapping unit", the smallest polygon storing data. The minimum mapping unit is important because many county land cover maps and government-distributed databases are specified in terms of this unit. The minimum mapping unit is identified within the metadata of each dataset.

The hydrologist needs the results of the sensitivity studies to make a decision that balances the requirements of the parameter estimates with the economics of database development and processing. If the modeling objectives can be met with a 120-m (400-ft) database, the hydrologist will be developing and working with one-sixteenth the data that would be involved with a 30-m (100-ft) database.

9.4.3.2 Sources of Digital Format Geographic Data

If the hydrologist chooses to develop a GIS database to meet the requirements of hydrologic modeling, there are a number of digital format data products that can be used. The Federal Government can be an excellent source of digital format data that can be integrated into a GIS. This section discusses some of the most widely used digital format data.

Generally, the most expedient approach to the development of a GIS database is to obtain data that are already in a map referenced digital format. Thus, a first step in the development of a database should be to contact agencies in the region to determine where hydrologic data of the appropriate level of detail can be obtained. The first search mechanism can be the internet. Most local, state, and federal agencies distribute hydrologic data in transportable GIS format.

The hydrologist should be aware of differing map projection, e.g., Albers Equal Area, Lambert Conformal Conic; coordinate systems, e.g., State Plane Coordinates, UTM; and datum references, e.g., NAD27, NAD83, GRS80. Failure to identify map projection issues can result in significant data offset and misalignment. Most modern GIS systems perform “projection on the fly” which will properly align data automatically. The hydrologist may choose to reproject all GIS data into a standard projection and coordinate system to minimize the chance of misalignment errors.

The USGS distributes digital land cover and land use at scales of 1:100,000 or 1:250,000 and 30 m resolution National Land Cover Data (NLCD). There are 37 land use and land cover categories stored as polygons as small as 4 ha (10 ac) - the minimum mapping unit for digital land cover land use. Most of the land cover information for the US was defined in the mid-1970s. The metadata for each dataset identifies the date of acquisition. The files also contain political boundaries, hydrologic units, and federal/state land ownership information. There are 21 land cover classes in NLCD. These data were created from satellite imagery in the early to mid 1990s and are updated periodically.

Satellite imagery and aerial photography is an important resource for the development of a land cover database. The satellite industry is changing rapidly, providing higher resolution (0.6 m panchromatic data at this writing) with more frequent re-visit times. Data costs are highly variable depending upon the level of detail requested and the timeliness of the data. Imagery from satellites are available in either photographic or digital formats. Photographic reproductions of satellite imagery are often a realistic approach to define land cover distributions. If digital format satellite imagery is to be the source, the hydrologist must ensure that the supplier of the land cover data is experienced and well-equipped for image processing. The hydrologist needs to ensure that any imagery requested match the map coordinates and projection system used for the rest of the study, especially if photo products are acquired.

The USGS also distributes Digital Ortho Quarter Quadrangle (DOQQ) data either through the State or through the NRCS. DOQQs are orthogonal to the surface of the earth and are available in color or B&W in 1 m spatial resolution. The metadata provide the creation date of a DOQQ.

The USGS digital elevation model (DEM) data, an array of regularly spaced elevations, has found increasing applications in hydrologic modeling. DEM data in 7.5-minute units are spaced at 30 m (100 ft), and in some cases 10 m (30 ft) spacing, while the 1-degree units are spaced at 3 arc seconds. Care must be exercised when using the watershed definition capabilities of a GIS system using a DEM. The accuracy of automatic watershed delineation with a DEM decays significantly as the number of elevation points inside a watershed boundary decrease. Also, the hydrologist must be sure that the level of precision of the DEM is sufficient for the watershed being studied and that the elevations are current. If the study area is in a rapidly developing area, the DEM may not reflect current conditions. The metadata provide the creation date of a DEM.

The USGS also distributes Digital Raster Graphics (DRG), which are georeferenced scanned quad maps. These maps are available for 1:24,000, 1:100,000, 1:250,000, and 1:1,000,000 scale maps for the entire US. These data can be used as standard map backdrops to ensure the spatial accuracy of hydrologic studies.

The USGS digital line graph (DLG) data are digital representations of the cartographic information on topographic quadrangle maps. DLG data are available in nine categories that provide digital representations of features such as streams, watershed boundaries, roads, vegetative cover, buildings, and transportation networks. The metadata provide the creation date and the level of precision of DLG data.

The National Wildlife Service is the primary producer and distributor for National Wetland Inventory (NWI) data. The data can be obtained in either 1:24,000 or 1:100,000 scale for points, linear features, and polygons. The metadata provide the creation date of NWI data.

The NRCS of the U.S. Department of Agriculture is the primary source of data concerning soils. The NRCS has developed computerized databases to integrate soil map information with other data in geographic information systems for most of the US. These digital format databases are being developed at three levels of detail with the Soil Survey Geographic Database (SSURGO) being the most appropriate for hydrologic modeling associated with highway drainage structures. SSURGO is not available for all counties in the United States. The availability of SSURGO and other levels of NRCS digital soil data within a region of interest can be determined by contacting the respective NRCS state office or the NRCS internet distribution site for a status map of SSURGO data. STATSGO soil association data are available for virtually all of the US in digital format. These data may be appropriate for large watershed studies or if SSURGO data are unavailable for a specific region.

The U.S. Bureau of the Census provides several digital products that can be of value in a hydrologic GIS. The TIGER/Line files (Topological Integrated Geographically Encoding and Referencing) can be used to plot streams and roads. The TIGER files used in conjunction with the Bureau's socio-economic data can provide important information for hydrologic modeling on urbanizing watersheds. The hydrologist should be aware that the positional accuracy of pre-2004 TIGER data is derived from 1:250,000 scale USGS DLG data. After 2004, the positional data will be derived from 1:24,000 DLG data, a much more precise dataset. Logical accuracy, e.g., the population of a town, is quite good, however.

FEMA distributes some floodplain maps in digital format. FEMA is also embarking on several programs for digitizing floodplain maps around the country.

Nearly all of the federal digital format data products, such as the USGS land use/land cover, can be downloaded through the Internet. There are also a number of "value added" companies that sell geographic databases that cover a state, county, or other political unit. The nucleus of these databases is typically one of the federal products described in this section. The company may add data to better reflect existing local conditions, reformat files for easier use, provide software to improve access to the data, and provide technical assistance.

State, local, and private sources may have higher level of detail data available for low or no costs. Highly detailed elevation models are sometimes derived from aerial photography, radar (IFSAR), or Light Detection and Ranging (LIDAR) data. These data may be obtained on contract for FEMA flood studies or other funded research. Several vendors provide these services. Small watersheds can be defined within ± 2” of actual elevations using these technologies.

9.4.3.3 Digitizing Paper Format Data Sources

The plethora of readily available digital data reduces the necessity of using paper format maps. However, if the source of some specialized data is paper format, there are two approaches to translating the data into a digital format.

Areas, lines, and points can be translated into digital format with either a digitizing tablet or an optical scanner. The digitizing tablet has been the "standard" for many years. In this approach, the technician traces lines with the cursor. Software then translates the digitizer inputs into the required GIS formats. In a scanner approach, the paper product is placed on a glass stage and a light source transfers the image into a computer workstation. A technician interacts through screen prompts with software that translates the image into the GIS formats. The scanner is generally faster than the digitizing table and less subject to operator error. A discussion of the issues that defined these two approaches is presented by Ragan (1991).

The county soil maps published by the U.S. Department of Agriculture NRCS are available in paper format source of soil data if SSURGO data are not available. These maps can usually be obtained from the state offices of the NRCS.