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Hydrologic Data Development System

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ABSTRACT

Hydrologic Data Development System

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The Hydrologic Data Development System (HDDS) is a package of spatial data and menu-driven programs that allows user-interactive determination of hydrologic parameters and estimation of flood frequency relationships for the design of highway drainage structures. The program employs Arc/Info, a commercial geographic information system.

A data base was developed to cover the extent of Texas at a scale of 1:2,000,000 and a smaller sample area of Northeast Texas at a scale of 1:250,000. The data include digital elevation models, major highways, soil characteristics, design rainfall depth/frequency/duration, land use, stream gauge sites, and other themes. New tables were developed to spatially relate soil characteristics and land use to runoff coefficients used in the Soil Conservation Service Runoff Curve Number method.

Spatial analysis techniques were employed to define watershed outlets and determine important hydrologic parameters. The system delineates drainage boundaries and flow paths using relevant digital elevation data, and overlays other data layers to determine parameters such as average watershed slope, time of concentration, area-weighted runoff curve numbers, and area-weighted design rainfall. Input files can be established and submitted to THYSYS, the Texas Department of Transportation hydraulic program, to determine flood frequency relationships. The results can then be used for the design of drainage structures.

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1. Introduction

The Texas Department of Transportation (TxDOT) is responsible for the design, construction and maintenance of more than 40,000 waterway bridges and culverts, and thousands of miles of storm drains on the highway system in Texas. The provision of cost-effective, safe hydraulic structures is paramount.

For TxDOT and other highway agencies, a continuing concern is the need to apply current engineering hydrologic and hydraulic design and analysis procedures that balance simplicity with accuracy. Most hydrologic and hydraulic calculation procedures are now available in computer programs, the use of which has substantially reduced the mathematical effort involved. However, a substantial effort is required to establish and manipulate the data required for input into computer programs.

The estimation of hydrologic runoff parameters is currently performed manually. For example, the delineation and measurement of drainage area may require piecing together several topographic maps on which a designer must establish drainage boundaries by interpreting the elevation contours. Measurement of area involves the use of planimeters or digitization on computer-aided design systems. Other required parameters include:

- land use/cover characteristics,
- soil types and properties,
- design rainfall characteristics, and
- watershed slope.

Hydrologic parameters vary spatially and require interpretation of maps which often vary in scale and accuracy. Data requirements can be extensive, and acquisition and manipulation of the data are time-consuming. Generally, to avoid an extensive data collection effort, simplified hydrologic and hydraulic mathematical models are employed, sometimes at the expense of accuracy.

State-of-the-art photogrammetry, surveys using global positioning systems, and total station surveys provide means of developing extensive spatial data sets. Furthermore, the emergence and continued development of geographic information systems and digital terrain modeling offer the potential to automate much of the spatial data manipulation. Federal agencies such as the United States Geological Survey and the Soil Conservation Service are developing and providing a wealth of spatial data which have direct application for hydrologic and hydraulic analysis procedures.

Geographic information systems (GIS) are specifically designed to manage and analyze spatial data. They offer the capability to relate the location and geometric aspects of a feature to the feature's properties, and as such they offer significant potential for hydrologic analysis. Several GIS software packages are currently available which differ in complexity. Arc/Info (ESRI, 1994) is an extensive package of GIS tools which is used in this research.

1.1 Hydrologic Data Development System (HDDS)

The focus of this research is on the design and programming of an integrated set of Arc/Info programs and associated data called the Hydrologic Data Development System (HDDS). This system provides a user with the capability of establishing some of the most important hydrologic parameters used in hydrologic analysis methods. HDDS incorporates a menu-driven system within which a user can identify a highway stream crossing or other site and determine the following:

- drainage basin boundaries, areas and subareas,
- maximum flow path length,
- estimated travel time,
- watershed average slope,
- hydrologic soil group,
- design rainfall,
- weighted runoff coefficients, and
- other hydrologic parameters.

The data may be passed automatically from the system to THYSYS, the Texas Department of Transportation hydrologic and hydraulic computer program to calculate design flood frequency relationships. The resulting data may then be manipulated easily to create drainage area maps, tables and other documentation using ARCVIEW, a GIS data query and visualization package.

The system is a prototype and is intended to demonstrate potential capabilities of using a GIS for highway-based hydrologic data development and analysis. Though the programming described here is specific to Arc/Info, the data are transferable and the general methodologies should be applicable to any GIS package that has similar capabilities.

1.2 Outline

This thesis documents the concepts, data requirements, data processing procedures, development and application of HDDS. The reader is initially provided with an introduction to GIS-based concepts. The primary goal is to demonstrate the potential speed and precision with which GIS may help develop important hydrologic parameters for flood frequency determination, especially those used by highway agencies such as TxDOT for hydraulic design.

A literature review and results of a nationwide questionnaire on the use of GIS in state highway agencies appear in Section 2. A discussion of some relevant GIS application to surface hydrology and hydraulics analysis is followed by an appraisal of the state of the practice in use of GIS within highway agencies for drainage feature design. Section 3 discusses concepts that are considered important to the successful use of systems such as HDDS. These include spatial data modeling methods used in GIS, elements of geodesy such as georeferencing systems and map projections, and hydrologic methods commonly used by TxDOT for which data can be derived in HDDS.

Section 4 details the data requirements, data development methods for the HDDS spatial database, and the methods employed by HDDS during execution of the system. Section 5 provides a guide to the steps necessary to perform an analysis using HDDS. Included is a sample application on a study area of the North Sulphur River Basin in Northeast Texas above State Highway 24 (SH 24). Hydrologic parameters are established for determination of discharge versus frequency relations using the hydrologic methods discussed in Section 3. Additionally, a discussion is provided on the way in which HDDS was employed to use several stream gauge sites in the Trinity River basin in Texas as outfall locations for drainage boundary delineation. Results of these are presented in Section 6. Section 7 provides an assessment, a discussion of future potential and general conclusions.

2. Literature Review and Questionnaire

Geographic information systems have been implemented mostly by large entities such as Federal, State, and local government agencies. The predominant use is for mapping and management of spatial data. However, there is increasing interest in the potential application of GIS in engineering design and analysis, especially in hydrology and hydraulics. The goal of this work is to establish and demonstrate a means by which GIS can be used to support the determination of flood frequency relationships for use in the hydraulic design of highway drainage structures, especially for bridges and culverts draining large, mostly rural areas.

Several pioneers are worthy of note for their foresight and work in the development of hydrology-related application of GIS for engineering applications. The initial focus seems to have been on the delineation of drainage boundaries and runoff flow paths using digital terrain data. Jensen and Domingue (1988) and Jensen (1991) outlined a grid scheme to delineate watershed boundaries and stream networks to defined outfalls (pour points). The scheme uses digital elevation data to determine the hypothetical direction of flow from each cell in a grid to one of its eight neighboring cells. The cells contributing flow to the pour point can be counted, representing area, and the cells having no contributing flow define drainage boundaries. Cells having a flow accumulation in excess of a threshold establish stream network cells. Tarboton et al. (1991) computed stream slopes and stream lengths using a similar grid system. Jones et al. (1990) employed a triangulation scheme on digital elevation data to determine watershed boundaries and flow paths.

Other investigators have focused attention on employing processes that are unique to GIS. That is, the ability to relate spatial features to their properties and perform overlays of different spatial hydrologic themes. Ragan (1991) developed a personal computer-based GIS named GIS-HYDRO. This allows a user to assemble predetermined land use, soil and slope data clipped within a user-defined boundary. A digitizer is used to delineate the watershed boundary, flow paths, and define land use changes. GIS-HYDRO provides basic file setup for use in the computer program TR 20 (1986). Maidment (1993) provided an intellectual basis for linkage between GIS and hydrologic modeling: a scope within which GIS could be employed for determining parameters for lumped surface hydrologic models, groundwater flow, storm water pollutant and sediment transport, and urban storm drain systems. Additionally, he indicates the potential for development of new spatial hydrologic models, the use of which would not be contemplated without GIS capability. Of specific relevance to this thesis is Maidment's recommendation for development of a new look-up table for using land use types classified by the Anderson system to establish runoff curve numbers for the US Department of Agriculture Soil Conservation Service hydrologic methods. This project provides such tables using existing Anderson Level II codes and by developing new, more detailed level codes that are related to runoff curve numbers based on hydrologic soil groups.

Maidment (1993) outlines a conceptual grid model that incorporates flow direction and a runoff velocity field to develop unit hydrographs from isochrones (areas of equal time of travel to a pour point). This employs the concept of a linear rainfall-runoff response system in which the runoff velocity field is spatially variable but non-temporal and discharge-invariant. Maidment is currently pursuing development and implementation of such a method. Additionally, he is employing GIS to link atmospheric data, surface hydrologic characteristics and subsurface characteristics to create water balance models (Maidment, personal communication, 1994). This may prove to be invaluable for assessing water resources, especially in developing countries.

The work of the aforementioned people and others has encouraged the inclusion of hydrologic tools in GIS software. For example, Arc/Info (ESRI, 1991) incorporates a gridded scheme similar to that described above for delineating drainage boundaries and stream networks. Such features provide the basis for this work.

The dates of the above citations are indicative of the infancy of the hydrologic GIS field. As might be expected, the practicing engineering community has had only limited exposure to such capabilities. As part of this project, a survey was sent out to the fifty state highway agencies to assess the current use (state of the practice) and expected use of GIS for hydraulics-related highway work. Appendix C presents the questions and responses.

Thirty-two states responded to the questionnaire. It is evident from the responses that those state highway agencies who have implemented GIS (10 states) are using it for mapping and data management. Most recognize the potential of GIS for engineering analysis but only one state, Maryland, has implemented a system that supports hydrologic analysis. They employ GIS-HYDRO which was mentioned earlier. To some, the distinction between GIS and Computer Aided Design (CAD) seems to be blurred. GEOPAK, for example, is listed by one responder as a GIS, but is a roadway design CAD package which has digital elevation model capability. However, there is a trend towards integration of CAD and GIS systems. For example, ESRI (1995) is pursuing integrating Arc/Info capabilities with AutoCAD, a commercial CAD package.

Several agencies cite the lack of accurate data and capable software as hindering application of GIS to hydrologic and hydraulic analysis. The Hydrologic Data Development System was developed to demonstrate the potential application of GIS for determining flood frequency relationships and other hydrologic parameters that are used for design of highway drainage facilities. The system employs data that are now widely available or will become more prevalent.

3. Basic Concepts

3.1 Geographic Information Systems

The goal of this work is to use GIS to reduce the effort required for map manipulation, table referencing, and repetitious computations for the determination of hydrologic parameters. The intent is not to replace the need for hydrologists but to increase the ability of the hydrologist to make responsible decisions based on the most detailed data available. Hydrologic analyses must still rely in part on judgement and experience. Use of GIS can allow a designer to accommodate more detailed appraisal of the spatial variations in hydrologic parameters than would be feasible using manual procedures. However, first, the hydrologist must obtain some knowledge in the field of GIS. This section provides an introduction to the concepts that are applicable to the Hydrologic Data Development System as well as to GIS in general.

Geographic information systems have been described as computer-assisted systems for the capture, storage, retrieval, analysis, and display of spatial data (Clarke, 1986). A definition that is more appropriate to the applications contained herein is a collection of interactive computer hardware and software tools and data that allow translation of spatially referenced (georeferenced) data into quantitative information which can aid in decision making. Originally developed as a cartographic tool, GIS offers capability for spatial data management. A GIS is characterized by the unique ability of a user to overlay data layers and perform spatial queries to create new information, the results of which are automatically mapped and tabulated. Graphical elements describing the location and shape of features are dynamically linked to databases which describe the properties of the features.

The goal of a GIS is to take observations of the real world and simplify and scale the data into graphical elements to which are related descriptive features termed attributes. The attributes are maintained in a database management system (DBMS) while the graphical elements are described in one of two general types of spatial structure: vector and tessellation. Vector structures are those in which discrete elements, points, lines, and polygons, are represented digitally by a series of two-dimensional coordinates (x and y) which imply magnitude and direction. Tessellation refers to the representation of spatial data with a network (or mesh) of elements. Many types of tessellation are possible including rectangles, squares, equilateral triangles, irregular triangles, and hexagons.

Generally, vector methods are suitable for mapping and performing spatial queries, while tessellation is used to represent continuous surfaces such as topography. Rectangular tessellation may be used for modeling involving mathematical functions and logical operators. The following discusses two structures, vector and square tessellation (grid), which are employed by Arc/Info, a widely used commercial package of GIS software.

3.1.1 Arc/Info Vector Modelling

Three basic elements, a point, a line, and a polygon, can be used to describe discrete features: a point is defined by one set of Cartesian coordinates (x and y). A line, termed an arc in Arc/Info, is defined by a string of Cartesian coordinates in which the beginning and end points are defined as nodes, and intermediate points along the line are defined as vertices. A straight line can be defined by two nodes and no vertices. A curve is defined by two nodes and a multitude of vertices. A polygon is defined by an arc or a series of arcs in which the terminal nodes join to create an enclosed area.

Spatial relationships between features (termed topology) are defined using three basic parameters - connectivity, area definition, and contiguity. Connectivity is established using arc-node topology in which each arc has a unique numerical identifier, a beginning identifier (from-node), and an end identifier (to-node). Joining arcs share a common node. Polygon-arc topology defines areas by assigning a unique numerical identifier to the series of arc identifiers that make up a polygon. In doing so, an arc identifier may appear in more than one polygon (where two or more areas abut each other), however, the coordinates defining the arc require definition only once. This minimizes storage requirements and avoids overlapping of polygon boundaries.

Contiguity is established by the combination of arc direction (described by the from and to-nodes) and by identifying the polygon on either side of the arc. This is termed left-right topology. The area outside the defined features but within the map boundary is identified as a universal polygon (ESRI, 1994).

In typical computer-aided design, specific feature types are established as individual graphical layers which are displayed simultaneously. Similarly, in GIS, topologically-defined feature types are organized in layers or themes of information which are often termed coverages. Features are described in database tables which are linked to the topological data using the feature numerical identifier. Three table types are of particular relevance to HDDS: arc attribute tables (AAT's), polygon attribute tables (PAT's), and

INFO tables. Descriptive data that apply to lines (arcs) in a theme are assigned to an arc attribute table and include the following:

- from-node
- to-node
- arc length
- internal arc numerical identifier
- user-defined or default arc numerical identifier, and
- user supplied feature descriptions (attributes).

Area features are described in polygon attribute tables which include:

- area,
- perimeter,
- internal polygon numerical identifier,
- user-defined or default polygon numerical identifier, and
- user supplied feature descriptions (attributes).

A Point feature is described using a PAT in which no area is defined.

In HDDS, and for many other applications, the majority of attribute data can be assigned to PAT's or AAT's. However, for conditions in which one-to-many or many-to-one relationships exist, definition of all attributes in a PAT or AAT can require repetition. Use of INFO database tables can eliminate redundancy by assigning attributes to a table which is index-linked to the PAT or AAT.

Geographic Analysis

The power of vector processing is the ability to perform geographic analyses using overlays of different coverages and applying conditions to establish new information with new topology and attributes. The most common processes include:

- creation of buffer zones,
- intersection of coverage features,
- joining of maps, and
- clipping of one coverage using another coverage.

Figure 3-1 indicates the general nature of these processes. Other variations of these basic processes exist but are not detailed here.

Tabular Analysis

The functionality of most database systems are applicable to attribute tables and other INFO tables. Since attribute tables are linked to graphical features, conditional queries may be applied to the data. The features meeting the specified conditions can then be displayed and used for subsequent geographic analysis. Some of the basic tabular operations employed in HDDS are (1) selection of a subset of active data with user-specified conditions, (2) adding of data to subsets with user-specified conditions, and (3) assignment of new values to a specified item calculated from a user-defined function of existing attributes.

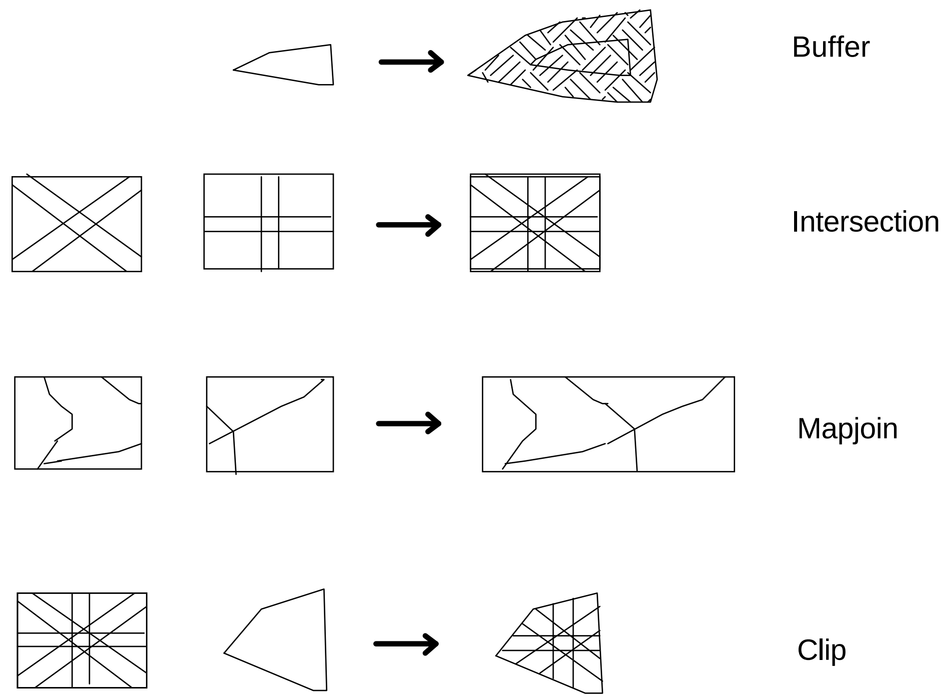


Figure 3-1： Basic vector processes

3.1.2 Cell-Based Processing with GRID

This section provides an introduction to some basic features of GRID, a cell-based geoprocessing facility that operates within Arc/Info versions 6 and 7. Cell-based, or raster, processing is the mainstay of HDDS so specific attention to GRID processes is warranted.

Generally, cell-based geographic information systems employ a grid data structure in which a rectangular domain is divided into an array of uniformly-sized, square cells. Each cell is assigned a value which defines the condition of any desired spatially-varied quantity. This contrasts with vector coverages in which map features are represented using a vector topological model and thematic attributes are represented in tabular data. GRID provides an extensive set of functions and operators, collectively termed Map Algebra Language, which allow manipulation of existing gridded data to produce new data.

GRID Data Model and Structure

A grid database consists of a set of grids each of which represents a spatial variable or theme. Rows and columns are defined in a Cartesian coordinate system which may have an associated map projection. (The map projections available to Arc coverages are also applicable to GRID). Values assigned to each cell may be integer or floating point numbers representing nominal, ordinal, interval, or ratio measurements. Null data, such as would exist outside the domain of valid cell values, are assigned NODATA.

If the grid is defined as an integer grid, a Value Attribute Table (VAT) is assigned. Primarily, this comprises a record number, the cell value, and the number of such values in the grid. Each value in the grid corresponds to one record in the VAT. Additionally, the VAT may contain supplemental attributes the use of which may be compared to an Arc Attribute Table (AAT) or a Polygon Attribute Table (PAT). Supplemental items are not limited to integer values. Grid operations may be performed using a defined item in the VAT but the default item is the cell value. The supplemental attributes must be added to the VAT using standard Arc/Info tabular database procedures: they cannot be added directly from GRID functions. GRID functions assign data to the value and count items of the VAT.

As long as grids are spatially registered, they may be considered as layers between which or on which mathematical or logical operations may be formed. Spatial registration implies that all grids must be in the same map projection. Each grid contains registration information that includes the map projection as well as the location of the grid within the Cartesian coordinate system. Summary statistics are also contained in the registration data.

Representation of Geographic Features in GRID

A grid may represent a continuous surface such as topography or discrete elements such as points lines and polygons and regions. In reality, a grid does not differentiate between continuous or discrete data. A point, for example, is merely represented by a single cell having a unique value. A line is represented as a string of cells containing the same value. A polygon is represented by a contiguous block of cells each with the same value. A zone in GRID is defined as the collection of cells containing identical cell values. As such, a zone is not necessarily contiguous. Since a zone need not be contiguous but all cells within a zone have the same cell value, a GRID zone may represent a region. GRID has specific features that allow conversion of vector coverages into grid coverages and vice versa. These are:

- POINTGRID - converts points to grid cells,
- LINEGRID - converts lines to grid cells,
- POLYGRID - converts polygons to grid cells,
- GRIDPOINT - converts grid cells to points,
- GRIDLINE - converts grid cells to lines, and
- GRIDPOLY - converts grid cells to polygons.

Map Algebra Language

The structural framework within which grid processing operations are organized is termed map algebra. The following four classes of operations are identified and available in GRID:

- local or per-cell,
- focal or per-neighborhood,
- zonal or per-zone, and
- global or per-layer.

Local Operators and Functions

Local operators and functions perform on each cell individually. That is, the function or operation is performed on a cell and the resulting value is assigned to the same cell location in an output grid and the same process is performed on all cells in the grid as indicated in **Figure 3-2**. Input grid cells with NODATA will yield output grid cells with NODATA unless the operation specifically defines how to manipulate NODATA. Local operators include arithmetic, Boolean, relational, bitwise, logical and assignment operators. Local functions include trigonometric, exponential, logarithmic, tabular reclassification, selection, statistical and conditional evaluation functions. Decision making and iteration capabilities are provided using a DOCELL feature in which cell by cell computations may be performed within a loop while or until specific conditions are satisfied.

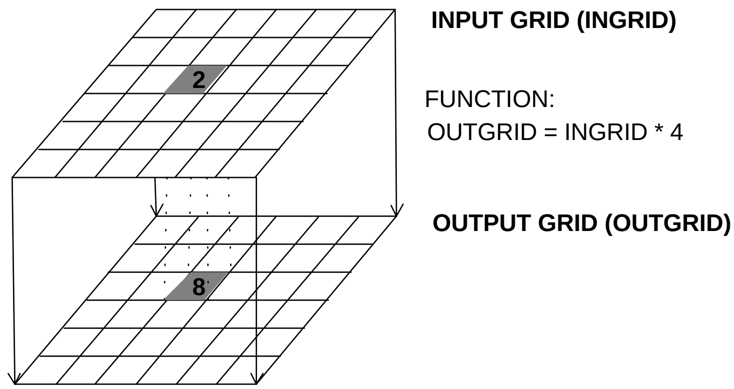


Figure 3-2: Example of a local function

Focal Functions

The value of an output grid cell may be derived as a function of the cells in a defined neighborhood. A neighborhood could consist of the eight cells abutting the cell or defined shapes such as rectangular, circular, annular, wedged shaped or a user-defined shape. **Figure 3-3** shows a focal function in which the output cell is the sum of the cells in a 3-cell by 3-cell neighborhood.

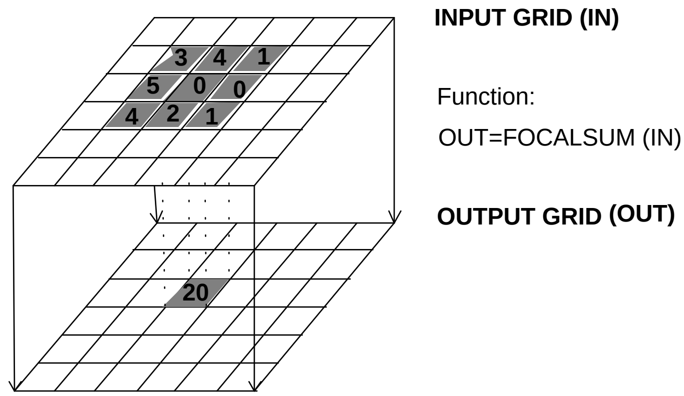


Figure 3-3: Example of a focal function

Zonal Functions

A zonal function returns the value of an output grid cell as a function of the values in a source input grid that are identified as zones by an input zone grid. An example is shown in **Figure 3-4**.

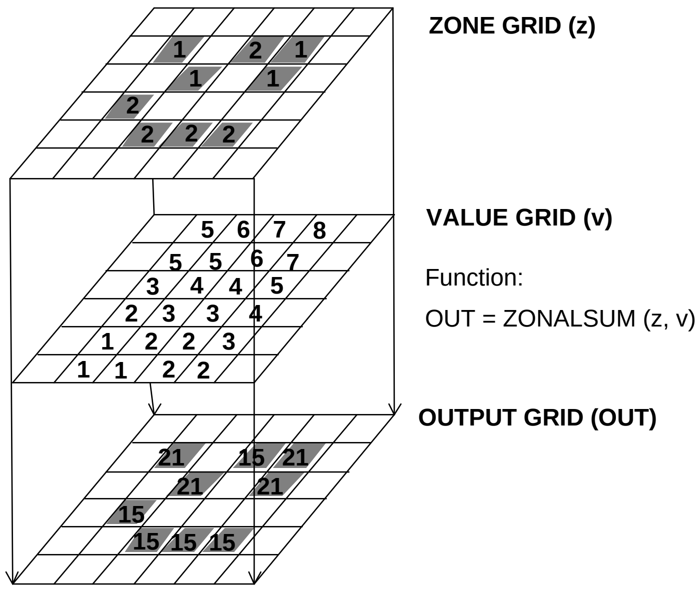


Figure 3-4: Example of a zonal function

Global Functions

Global functions, see **Figure 3-5**, operate on input grids to produce output grids in which the value in each cell may possibly be a function of all the cells in the input grids. Such functions include, but may not be limited to:

- euclidean distance measurement,
- cost distance measurement,
- shortest path,
- nearest neighbor,
- grouping of zones into connected regions,
- geometric transformations,
- raster to vector conversion, and
- interpolation.

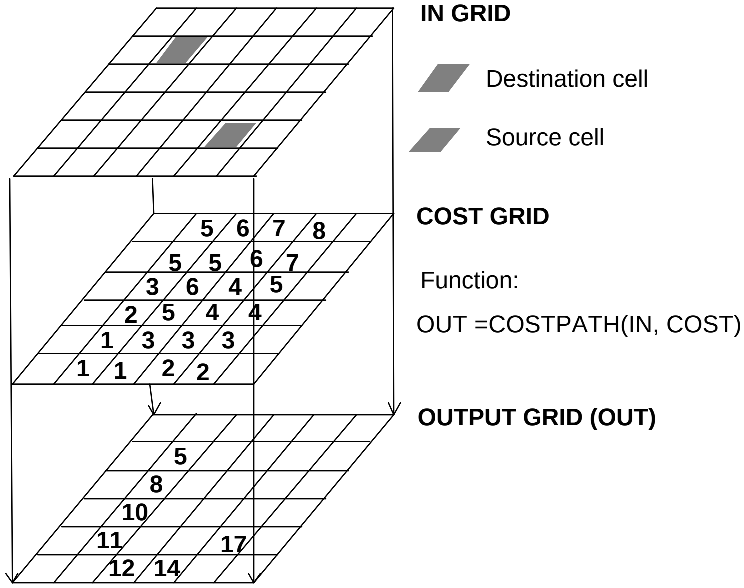


Figure 3-5: Example of a global function

DOCELL Blocks

GRID provides an impressive array of pre-defined functionality, however, this may not suffice. DOCELL blocks allow user-defined functionality similar to "DO" loops in FORTRAN. As the name implies, a DOCELL performs a user-defined operation on a cell-by-cell basis. In this respect, it is similar to a local function. The primary difference is that mathematical, logical, and conditional operators can be incorporated so that operations may differ by cell as opposed to the same operation being performed on every cell in a grid. Such differential treatment of spatial data is not available in vector-based processing. HDDS makes extensive use of such capability.

3.1.3 Vector Analysis versus Cell-based Processing

Figure 3-6 contrasts the ways in which vector and grid schemes represent features. The arc-node topology system and associated attribute database in Arc/Info produce new information (coverages and attributes) by computation on the records resulting from Boolean queries. The same operation is performed on all selected records. It is difficult to perform operations on individual records in such a way as to combine both the location and descriptive attributes of a feature. The GRID map algebra language and cell-based representation of features allow almost limitless manipulation in a relatively efficient manner.

Attribute data representation can be more efficient in a vector system than a raster system. For example, the value code for a contiguous zone of land use must appear in every cell within the zone of a grid. The same zone is represented in a vector system by one polygon and one value code. On the other hand, a grid system is easily represented geographically: in addition to the projection parameters, a grid can be completely defined by a point of origin, the cell dimensions, and array size. A vector element can require extensive strings of coordinates.

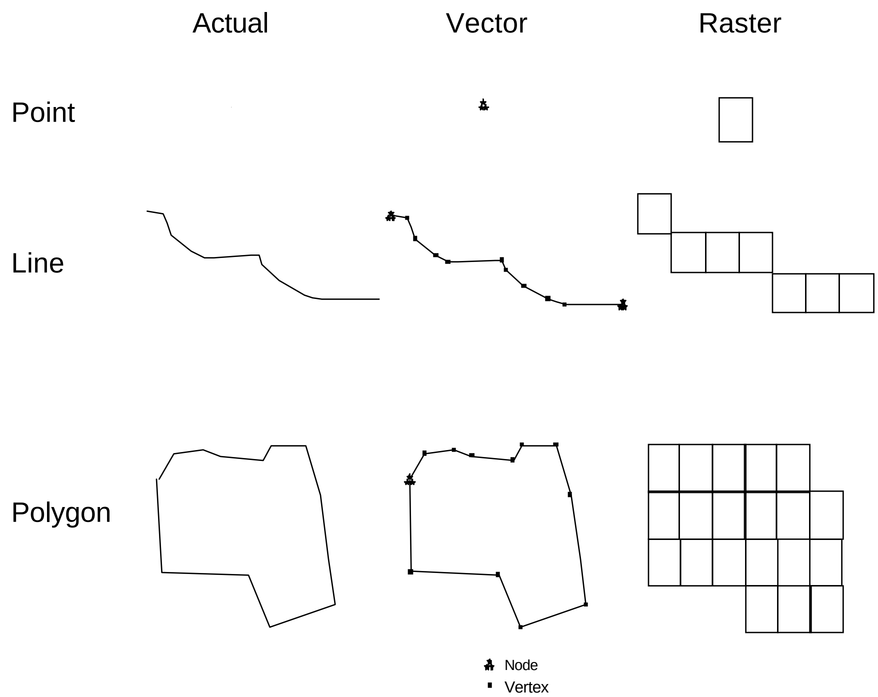


Figure 3-6: Representation of features in ARC and GRID

3.1.4 Triangular Irregular Networks (TIN)

A triangular irregular network is a tessellation scheme in which a continuous surface is represented by a mesh of triangles which need not be regular. This type of system is not employed in HDDS.

3.1.5 Arc Macro Language (AML) and Interface Programming

Arc/Info is command-line driven. That is, commands are typed in by the user to which the software responds. This may seem archaic, however, a high-level programming language, Arc Macro Language (AML), is available with which a user can automate command sequences, establish conditional statements and looping routines, request user input, create menu-driven interfaces, read and write files, and run external programs.

All vector processing, GRID expressions and DOCELL blocks may be embedded in scripts using AML. AML allows:

- variable substitution,
- control of flow,
- iteration,
- development of user interface menus and slider bars, and
- access to external programs.

Use of AML's becomes essential for building complex applications and repetitive processes. HDDS comprises an extensive set of AML routines which incorporate vector analysis and cell-based processing. One initially confusing issue when using AML is that the syntax for mathematical operations in AML differs from the GRID Map Algebra Language, but MAL may be incorporated in AML.

The simplest use of AML is to link a string of commands that would usually be entered individually. Such an AML is a file containing the same commands in the same order that they would have been issued manually. The provision of a wide array of special commands (termed directives) specific functions, and menus allows much more complex programming than basic command sequence repetition. Macro routines can invoke menus and other macro routines, and menus can invoke macro routines and other menus. HDDS is dependent on this capability.

User input via keyboard, mouse, or other devices can be requested to establish variables. Also, data can be read from existing attribute and information tables to be set as variables for subsequent use. Variables can be integer number, real number, character, or Boolean. They may be assigned as global or local: local variables are active only within the routine in which the variables were set, whereas global variables remain active from initiation until the particular Arc session is ended. HDDS employs local variables wherever the variables are not needed in subsequent routines to save random access memory. Global variables are used extensively where needed between routines and to save processing time. (Data could be written to files or tables and subsequently read when needed, but this increases processing time, though memory use would be reduced).

The above provides only a brief discussion of AML. For detail, the user is referred to ESRI (1993).

3.2 Elements of Geodesy

A particular point on the Earth's surface is defined by its geographic coordinates of latitude (ϕ) and longitude (λ), and elevation (z) above mean sea level. Latitude and longitude are angles measured in degrees, minutes, and seconds on a reference geometric model of the curved Earth surface. Elevation is measured in feet or meters above a surface which is defined by a gravitational model of the Earth.

Most engineering computation is done on a simplified Cartesian system with mutually perpendicular axes (x, y, and z). In fluid mechanics, it is customary to identify a "datum" which is drawn as a horizontal line but in fact is a curved line following a constant gravitational potential.

Translation from a geographic coordinate system to a Cartesian system is a complex process involving consideration of the shape of the Earth and its gravitational field.

By definition, a GIS relies on the ability to define position and spatial relationships accurately. Generally, GIS is two-dimensional, representing the horizontal plane referenced to a horizontal datum. A horizontal datum is a mathematical representation of the Earth, usually a sphere or an ellipsoid. Elevations are referenced to a vertical datum and may be represented in GIS as attributes of spatial elements. Geodesy is the subject in which the definition of location and elevation are addressed. This subject is no discussed.

Guralnik (1982) provides the following definition of geodesy.

The branch of applied mathematics concerned with measuring , or determining the shape of, the Earth or a large part of its surface, or with locating exactly points on its surface.

Traditionally, there has been no distinction made between geodesy and surveying but today, many consider surveying to be the practice of positioning while geodesy provides the theoretical foundation for surveying. The National Research Council of Canada (NRC, 1973) employs the following definition.

Geodesy is the discipline that deals with the measurement and representations of the Earth, including its gravity field, in a three-dimensional time varying space.

3.2.1 Geometry of the Earth's Shape

There is a common misconception that the Earth was considered flat until Copernicus angered the church by contradicting its Earth-centered universe tenet with the theory of a spherical Earth in orbit around the sun.

As early as 600 BC, Thales of Miletus hypothesized a spherical Earth and by 550 BC, the School of Pythagoras believed in a spherical Earth. Eratosthenes (270-195 BC) is credited with being the founder of geodesy having made the first recorded estimate of the Earth's radius at approximately 7,350 km versus today's estimates of about 6,370 km (Dragomir et al., 1982).

In 1660, on behalf of the Academy of Sciences in Paris, Jean Picard determined the length of quarter of a meridian to be 10,009 km (which is equivalent to a radius of 6372 km) the methods and accuracy of which are deemed comparable to present results.

Until the 17th century, consideration of the Earth's shape had focused on geometrical attributes. In 1687, Newton set forth his theory of universal attraction from which he deduced that the Earth must be an oblate spheroid flattened at the poles. Measurements made by the Paris Academy of Sciences between 1735 and 1744 supported Newton's concept (Dragomir et al, 1982). Newton deduced that mean gravity increases from the Equator to the poles.

Contemporary knowledge is that the Earth is an irregular shape, the description of which presents severe difficulties when performing mathematical calculations on its surface. Therefore, it is necessary to define a regular solid figure that most nearly fits the topography of the Earth. To date, the most practical shape considered has been the oblate spheroid or ellipsoid. Though there are several estimates in use today, the major axis is in the plane of the Equator with a radius of about 6378 km and the minor axis is in the plane of the polar axis with a radius of about 6357 km.

Ellipsoid vs. Spheroid

The terms ellipsoid and spheroid are often used interchangeably: a spheroid may be generated by rotating an ellipse about either its major axis or its minor axis. A solid in which all plane sections through one axis are ellipses and through the other axis are ellipses or circles is defined as an ellipsoid. If two of the axes of an ellipsoid are equal, the shape can be described as spheroidal but is also described as an ellipsoid of revolution. Of course, if all three axes are equal, the shape is a sphere. If an ellipse is rotated about its minor axis it is described as being oblate. Prolate refers to an ellipse rotated about its major axis.

The term biaxial ellipsoid is also used to refer to a spheroid. A further refinement of the geometrical shape of the Earth would be a triaxial ellipsoid in which none of the axes is equal. i.e. a section through the Earth at the Equator would be an ellipse also. Though the deformation would only be of the order of 20 m. While such a shape would provide a better fit of the Earth's shape, the added mathematical complexity has limited its use.

The geometrical parameters of a reference ellipsoid are as follows and refer to **Figure 3-7**.

a = semi-major axis

b = semi-minor axis

f = (a-b)/a = geometrical flattening (approximately 1/300)

$$e = \sqrt{\frac{a^2 - b^2}{a^2}} = \text{numerical eccentricity} \qquad \textbf{(3-1)}$$

The eccentricity may be determined as a function of the flattening as:

$$e^2 = 2f - f^2 \qquad \textbf{(3-2)}$$

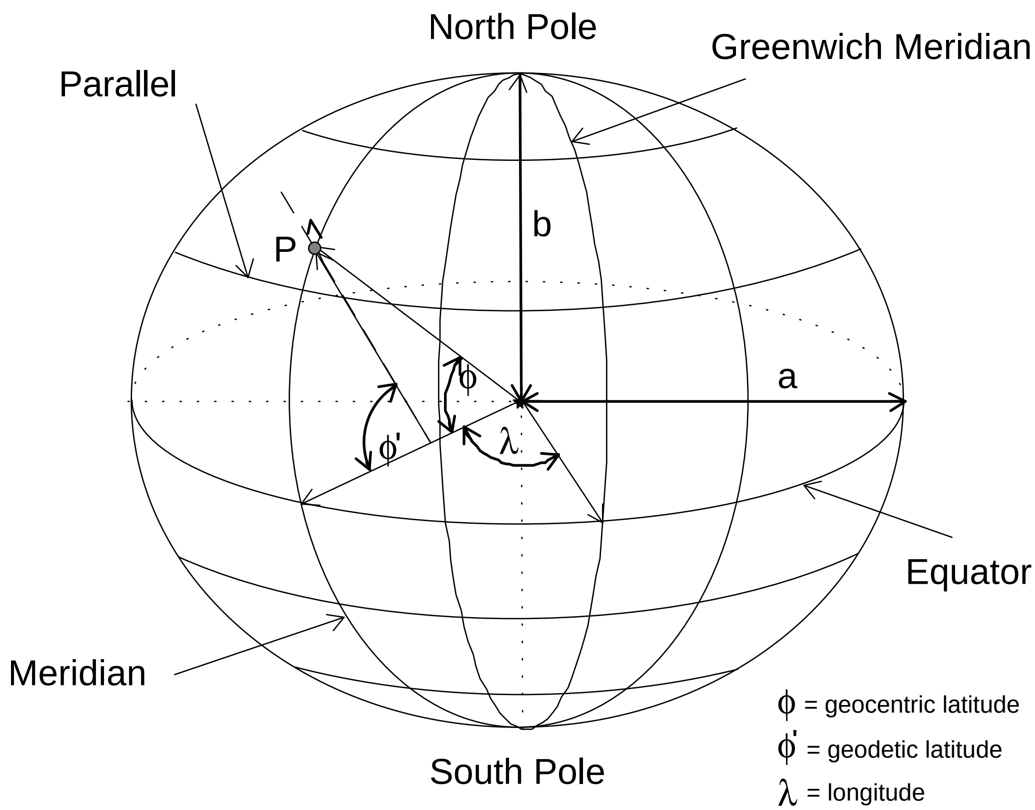


Figure 3-7: The graticule and parameters of the ellipsoid

3.2.2 Gravity and the Geoid

To date, the instruments with which the land has been surveyed are gravity dependent e.g. levels and theodolites, electronic distance measurement devices and total station instruments. Even global positioning system (GPS), which employ radio signals emitted from artificial satellites, rely on gravity since the orbit of each satellite is a function of Earth's gravity.

Initially, it may appear that, by defining a reference ellipsoid that reasonably well represents the shape of the Earth the information should be available to define spatial relationships. Analysts are used to dealing with Cartesian coordinates and linear orthogonal planes in which a level surface is considered to be parallel to the horizontal plane. However, in terrestrial terms, a level surface is neither linear nor is it necessarily parallel to the reference surface (ellipsoid). A level surface is a function of the Earth's gravity potential. That is, a level surface represents the locus of points having the same value of gravity potential and as such is also called an equipotential surface. (Dragomir et al., 1982, pp. 63) The physical surface that most closely approximates any terrestrial equipotential surface is the sea surface: although sea level varies temporally, its mean level provides a suitable reference. In geodesy, the equipotential surface which best approximates mean sea level over the whole Earth is called the geoid (Vanicek et al., 1986, pp. 87).

Gravity Field

Gravity (force) is the sum of gravitational and centrifugal forces. Newton's law of universal gravitation states that a body of mass (M) attracts another body of mass (m) by a force (F) whose magnitude is proportional to the product of the two masses and inversely proportional to the square of their separation distance (r):

$$F = \frac{GmM}{r^2} \qquad \textbf{(3-3)}$$

G is described as the gravitational constant and represents the ratio between the behavior of mass as a source of gravitation and behavior of the same mass as a responder to gravitation. Its value is determined to be 6.672 E-11 $kg^{-1}\ m^3\ s^{-2}$ (Vanicek, 1988, p71).

The dimensions of the Earth cannot be considered as negligible. Also, the distribution of mass within the Earth is not uniform. Since gravitational forces are additive, the force exerted by an Earth of nonuniform density can be obtained by considering the Earth as a series of infinitesimally small volumes of a particular density distribution and integrating over the body of the Earth. However, the distribution of density of the Earth is only approximately defined at present such as to negate any benefit of performing an integration.

Considering the mean radius of the Earth to be 6371.009 km and GM to be 3.986005E20 $cm^3\ s^{-2}$, **Eq. (3-3)** yields a mean value of gravitational attraction on the surface of the Earth of F = 9.82022 [ms^{-2}] x m, or g = 9.82022 ms^{-2}.

Since the distribution of density is both radially varied and laterally irregular and the Earth is not spherical, the gravitational field is not perfectly radial. Additionally, the Earth's density distribution varies with time. Conventional treatment of the Earth's gravitational field ignores these variations.

The centrifugal component of Earth's gravity is a result of the rotation of the Earth about the polar axis. The magnitude of the centrifugal force acting on an Earthbound body is quantified by **Eq. (3-4)**:

$$f = pw^2m \tag{3-4}$$

where:

p is the perpendicular distance of the body to the spin axis,

w is the Earth's angular velocity of spin, and

m is the mass of the particle.

Using a radius at the Equator of 6378.137 km and w = 72.92115 E-6 rad s^{-1} , the centrifugal force is:

$$f = 3.392\ [\text{cm s}^{-2}] \times m$$

This is about 0.35 % of the gravitational force. At the poles, the force will be zero. The angular velocity varies temporally thus inducing variations in the magnitude of centrifugal force. Furthermore, a phenomenon described as the wobble of the Earth affects the direction of centrifugal force.

The gravity force, then, is a vector quantity that is the resultant of the gravitational force and centrifugal force. The resulting force is:

$$F_R = F_{B-A} + f_a = [GM / r^2 + p_A w^2]m \tag{3-5}$$

It is more convenient to work in terms of accelerations rather than forces. From Newton's second law, F_R = ma, the term in brackets can be described as the vector of acceleration denoted as g. Thus, in order to determine the geometrical properties of the gravity force field, it is sufficient to focus on the acceleration (g). The units of the magnitude of g are gal (after Galileo) where 1 gal = 1E-2 m/s^2. The mean value of g is of the order of 980.3 Gal (Vanicek et al., 1986, pp. 75). Since the component forces vary spatially, the magnitude and direction of gravity varies spatially and temporally. Generally, the direction of gravity is neither towards the mass centroid of the Earth nor perpendicular to the reference ellipsoid.

The geoid is an irregular surface that is only approximated by a reference ellipsoid. The distance between the geoid and the reference ellipsoid is termed the geoid undulation (N) and is measured perpendicular to the ellipsoid surface.

Gravity Potential

The gravity force, by definition is a vector property. Therefore, the gravity field is a vector field. It is also an irrotational field and thus can be represented by a scalar field so requiring only one value at each location rather than a triplet of numbers. The gravity field can then be expressed by **(3-6)**.

$$F = mg = \nabla V = m\nabla W \text{ or } g = \nabla W \qquad \textbf{(3-6)}$$

W is called the gravity potential and V is the potential energy. Since the differential operator (∇) is a linear operator, the gravity potential W can be evaluated as the sum of the gravitational potential W_g and the centrifugal potential W_c:

$$g = g_g + g_c = \nabla W_g + \nabla W_c = \nabla(W_g + W_c) = GM/r + 0.5\, pw^2 \qquad \textbf{(3-7)}$$

From **Eq. (3-7)**, it can be seen that W_g decreases above the Earth while W_c increases **(**Vanicek et al., 1986, pp. 83). Though W_c only applies while the mass of interest is Earthbound.

By defining specific values of gravity potential, equipotential surfaces can be defined. Lines of force can be described as being the curves to which the gradient of the potential is tangent at every point. These lines are known as plumb lines. Since the distribution of density and angular velocity vary with location the equipotential surfaces undulate and are not parallel.

Sections through equipotential surfaces closely resemble series of concentric ellipsoids. By definition, the magnitude of gravity is directly related to the spacing of equipotential surfaces. Close spacing represents a stronger gravity field. Since the gravity potential is constant over an equipotential surface, and in the absence of any other external forces, there can be experienced no work on a particle along the surface.

The above discussion on geodesy allows one to realize that the surface of an homogeneous fluid in equilibrium coincides with an equipotential surface. Only minor deviations exist due to nonhomogeneity of the water in addition to external forces such as wind and thermal gradients. Thus when considering a static sea of uniform density, the surface would coincide with an equipotential surface. Mean sea level, then, represents the equipotential surface termed the geoid, at least to an approximation of a few meters. Static waters at levels other than sea level, such as tarn lakes, retention pools etc., approximate the shape of other equipotential surfaces.

In order for water to flow, external energy must be applied to the water. The primary source of such energy is gravity. (Wind and the Coreolis effect are minor). The existence of gravimetric potential difference between two points provides the potential energy. However, in order for the potential energy imparted to water to be converted into kinetic energy, the Earth's topography must provide unobstructed pathways between higher and lower equipotential surfaces.

Although it is feasible to define locations on the Earth as sets of three-dimensional geometric coordinates, any hydrologic study must incorporate both the spatial relations of topographical features and the gravimetric features as indicated by height.

Gravity Anomaly

Equation (3-5) allows computation of the theoretical value of gravity assuming the Earth to be a regular surface without undulations, or without variations in rock densities or crust thickness. Actual measurements of gravity often vary from theoretical values. The differences are termed anomalies.

3.2.3 Horizontal Positioning and Horizontal Datum

The North and South poles approximate the ends of an axis about which the Earth revolves. An imaginary circle, halfway between the poles is called the Equator. A network of imaginary lines of latitude and longitude (graticule) is used to define locations on the Earth's surface. Lines of latitude, or parallels, are formed by equally-spaced circles surrounding the Earth parallel to the Equator. The spacing is one degree such that there are ninety spaces from the Equator to each pole, numbered from 0 at the Equator to 90 at the poles. North is considered positive and the South referenced as negative. For a spherical Earth model, the arc length of one degree of latitude is invariant. The length of one degree of latitude increases toward the poles of an ellipsoidal Earth model.

Lines of longitude, or meridians, are formed as half circles or half ellipses about a polar axis and which are orthogonal to the Equator. The Equator is divided into 360 spaces such that there are 360 meridians at one degree spacing. The meridian passing through Greenwich, England was established internationally as the Prime Meridian (0 degrees) in 1884

(Snyder, 1987, pp. 9). The convention is to measure eastward locations as positive up to 180 degrees from the Greenwich Meridian, and westward locations as negative. The length of a degree of longitude decreases with increasing latitude since the radius of a line of latitude decreases towards the poles.

A typical horizontal datum of the Earth comprises longitude and latitude of an initial point (origin), an azimuth, the semi-major radius, the flattening, and the geoid separation at the origin. Horizontal datums based on artificial satellite data use the center of mass of the Earth as origin. Several horizontal datums are in use in the United States:

- North American Datum of 1927 (NAD 27),
- North American Datum of 1983 (NAD 83),
- World Geodetic System of 1972 (WGS 72), and
- World Geodetic System of 1984 (WGS 84).

The North American Datums are civilian systems while the World Geodetic Systems were developed by the military but are now being used by civilian entities. Consideration of the datum employed is of paramount importance because the location of origin, axes of rotation and other defining parameters differ from one system to the next. As a result, the latitude and longitude of any point on the Earth's surface changes when moving from one datum to another. Most GIS and other mapping software accommodate translation of data from one datum to another.

North American Datum of 1927

Early reference ellipsoids relied on terrestrial measurements and astronomic observations necessitating use of locations on the Earth's surface to define an origin. NAD 27 is defined with an initial point at Meades Ranch, Kansas, (lat 39°13'26.686", long 261°27'29.494") and employs the Clarke 1866 ellipsoid, the parameters of which are shown in **Table 3-1**. The Clarke 1866 ellipsoid is not Earth-centered and its minor axis does not coincide with the polar axis, though it is considered to be parallel to the polar axis. This datum was established to minimize error in representation of locations in North America and so does not represent the best global fit.

North American Datum of 1983

NAD 83 was derived from measurements using modern geodetic, gravimetric, astrodynamic, and astronomic instruments. It is an Earth-centered datum and uses the Geodetic Reference System 1980 (GRS 80) ellipsoid, the parameters of which appear in **Table 3-1**. The minor axis approximates the polar axis and the major axis is parallel to the Equator. As a result, the NAD 83 surface deviates from the NAD 27 surface.

World Geodetic System of 1972

WGS 72 was based on satellite, surface gravity, and astrogeodetic data available through 1972. It was established by the Defense Mapping Agency (DMA) for the Department of Defense's navigation and weapon system guidance requirements. The system provided a reference frame within a geometric figure and gravimetric model of the Earth. The coordinate system is Earth-centered and Earth-fixed and provides a means of relating positions described in various local geodetic systems to be represented in one contiguous system. Reference ellipsoid data appears in **Table 3-1**.

World Geodetic System of 1984

The WGS 84 is a conventional terrestrial coordinate system that was developed by the DMA as a replacement for WGS 72 as a result of newer, more accurate instrumentation and more comprehensive control networks. The WGS Earth Gravitational Model and geoid were replaced with more accurate models based on new and more extensive data sets and improved software. Improvements were made to the accuracy of datum shifts from other geodetic systems errors. The WGS 84 establishes specific ellipsoid parameters, which appear in **Table 3-1**, however, for practical purposes, they can be considered the same as those defined by GRS 80 (DMA, 1988 pp. 3-9). Of note is that GRS 80 does not have an associated Earth gravitation model whereas WGS 84 does.

WGS 84 is the reference system now employed by TxDOT and is especially important for collection of data using Global Positioning Systems.

Table 3-1: Reference Ellipsoid Parameters

Ellipsoid	semi-major axis (m)	flattening ratio	Gravitation Constant (GM) m^3s^{-2}	Angular Velocity (rad s^{-1})
Clarke 1866	6378206.4	1:294.9786982	-	-
GRS 80	6378137	1:298.257222101	-	-
WGS 72	6378135	1:298.26	-	-
WGS 84	6378137	1:298.257223563	3986001.5E8	7292115E-11

Abstracted from DMA (1988, pp. 7-12).

3.2.4 Vertical Positioning and Vertical Datum

The height above mean sea level (h) of a point on the Earth's surface is the difference between the orthometric height (H) and the geoid undulation (N):

$$h = H - N \qquad \textbf{(3-8)}$$

The orthometric height is the distance between the geoid surface and the Earth's surface. Positive undulations are those in which the geoid appears above the reference ellipsoid surface.

Elevations are referred the geoid. For the US, the National Geodetic Vertical Datum of 1929 (NGVD 29), was established by the U.S. Coast and Geodetic Survey from about 75,000 km of U.S. level-line data and about 35,000 km of Canadian level-line data. Mean sea level was held fixed at 26 tide gauges that were spaced along the east and west coast of North America and along the Gulf of Mexico. This datum was originally named "Mean Sea Level Datum of 1929" and was changed to NGVD 29 in 1973 to eliminate reference to "sea level" in the title.

Since the 1929 adjustment, new leveling has been established and continued efforts have shown increasing discrepancies with NGVD 29. Some phenomena to which such disagreements are attributed include (1) vertical movement due to Earthquake activity, postglacial rebound, and ground subsidence, (2) disturbed or destroyed benchmarks due to highway maintenance, building, and other construction projects, and (3) more accurate instrumentation, procedures, and computations.

The North American Vertical Datum of 1988 is beginning to replace NGVD 29, however, the preponderance of data are referred to NGVD 29. In any event, it is essential to ensure that vertical datum differences between data sets are accommodated.

Effect of Elevation

The reference sphere or ellipsoid represents a mathematical approximation of the Earth at mean sea level. As one increases in altitude, the distance from the origin increases. For a fixed angular displacement, the distance represented on the surface of the sphere or ellipsoid is less than the actual distance at an altitude that is higher than mean sea level as indicated by **Figure 3-8**. Similarly, areas would appear smaller at mean sea level than altitudes higher than mean sea level. This may appear worrisome: land platting and construction of extensive features such as highways may warrant adjustment for average elevation. For example, at an elevation of 1000 m above mean sea level the error in arc length measurement of a 1° arc would be of the order of 17 m (about 0.02%). HDDS does not provide computational adjustments for elevation differences.

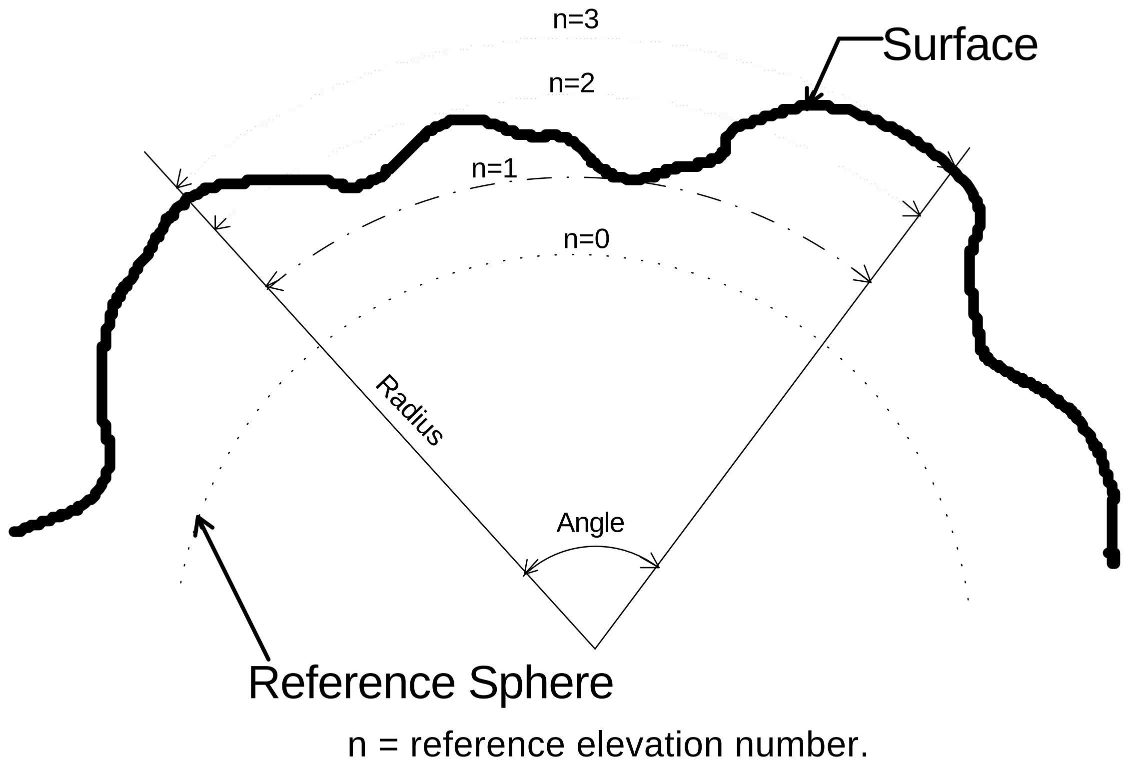


Figure 3-8: Effect of elevation on scale

3.2.5 Coordinate Systems and Map Projections

Traditionally, most visual representations of the Earth and its land masses have been two-dimensional. That is, maps are presented on paper or computer screen both of which are two-dimensional media. The previous sections discussed the three-dimensional features of the Earth, which is described as an oblate spheroid. Three-dimensional scaled representations of the whole Earth are available as globes but large-scale, 3-dimensional representations of specific areas of land are not practical for most uses. In order to represent the Earth or parts of it on a piece of paper, it is necessary to scale and project the desired area of the globe using mathematical or geometric transformations. There are many ways in which the Earth can be represented in two dimensions. It is not expected that the hydraulic engineer will wish to become an expert in map projections; however, a basic understanding of map projection concepts is necessary for any person wishing to make the transition into GIS. Therefore, this section presents some insight into the field of map projections insofar as the need is anticipated for most highway hydrology-related applications of GIS.

The most common system employed to define positions on the globe is the geographic coordinate system. This is not a projection: true positions are represented by longitude (λ) and latitude (ϕ) referenced to either a sphere or an ellipsoid. By definition, positions referenced to a sphere are geocentric, that is, angles are measured from the center of the reference sphere. For an ellipsoidal datum, the coordinates could be either geocentric or geodetic. For geodetic coordinates, angles of longitude are measured from the center of the ellipsoid in the Equatorial plane and angles of latitude (ϕ‘) are measured from a line that extends from the major axis to the point of interest and orthogonal to the surface of the reference ellipsoid as shown in **Figure 3-7**. Since geographic coordinates represent location by angular displacements, dimensions such as distance and area cannot be inferred directly. Spherical or ellipsoidal geometry may be applied to calculate such dimensions but this is not convenient for most mapping uses. Instead, other coordinate systems may be employed which involve projections.

It is impossible to represent the three-dimensional features of the Earth on a two-dimensional medium without either incurring significant discontinuities or some kind of distortion. One feature that is preserved in all standard projections is location. Various projection types have been devised to minimize specific distortions such as shape, area, direction, or distance. Unfortunately, the features of interest to a hydraulic engineer such as area, slope, direction and distance cannot all be preserved simultaneously.

Three basic projection surfaces exist: cylindrical, conic, and plane. **Figure 3-9** shows the simplest general forms of these projection surfaces which can be visualized by considering light rays radiating from either a point or linear source through points on the globe on to a projection surface. Many possibilities exist for each basic type. Projections that preserve direction are termed conformal (or orthomorphic) while those preserving area are termed equal area (or equivalent), and those preserving scale (or distance) a referred to as equidistant. Three of the most common projection methods used in the U.S. are Universal Transverse Mercator, Lambert Conformal Conic, and Albers Equal Area. These are introduced below but a more detailed review of standard projection types is provided by Snyder (1987).

Universal Transverse Mercator

It is difficult to discuss the Universal Transverse Mercator (UTM) projection without first discussing the Mercator and Transverse Mercator projections from which the UTM is derived. The Mercator projection is probably the most familiar name to the layperson. Traditional maps of the world often employ the Mercator projection. It is a cylindrical, conformal projection in which the axis of the cylinder is coincident with the polar axis and the surface is tangential to the Equator. The projection process can be visualized initially as shown in **Figure 3-9** for a typical cylindrical projection. The graticule would be represented by equally spaced vertical lines (meridians) and perpendicular straight lines of equal length (latitude). This results in the poles being out in infinity and the upper latitudes grossly exaggerated. To establish conformality, the spacing of lines of latitude are adjusted by the same ratio as the exaggeration ratio of the length of lines of latitude. Areas and lengths still become exaggerated away from the Equator, but direction and shape are preserved. Dimensions within a 30° band centered around the Equator can be considered true for most practical purposes.

Instead of using the Equator as the line of tangency, the Transverse Mercator uses a meridian such that the axis of the cylinder is perpendicular to the polar axis and in the plane of the Equator. The meridians and parallels are represented by complex curves with the exception of the Equator, the central meridian, and each meridian 90° away from the central meridian. Scale is true only along the central meridian since the reference sphere or ellipsoid is tangential to the cylinder only along the central meridian. Areal enlargement increases away from the line of tangency.

The Universal Transverse Mercator projection (UTM) is a specific application and modification of the Transverse Mercator in which a reference ellipsoid is employed and specific parameters, such as central meridians, have been established. Also, instead of a tangential cylinder, a secant cylinder is used: a cylinder with a radius slightly smaller than the Equatorial radius so as to create a wedding ring-like band (zone) of the Earth outside the cylinder and parallel to the central meridian. Dimension errors are minimized within the band but become excessive elsewhere. Sixty zones cover the Earth between latitudes 84°N and 80° S mostly at a spacing of 6° longitude, a few exceptions exist but not over the USA. The zones are numbered from 1 to 60 beginning at the 180th meridian and proceeding east. A grid is established by dividing each zone with lines of latitude at a spacing of 8° for the USA, though variations exist at the higher (North and South) latitudes. For each zone, the resulting quadrangles are designated by single letters from South to North. All divisions occur at integer values of latitude and longitude. Each quadrangle is subdivided into 100,000 meter squares and are designated with double letters. The boundaries may be represented by partial cells.

Locations are defined in a two-dimensional Cartesian system established for each zone: the central meridian is established half way between the bounding meridians and, for civilian application in the Northern Hemisphere, the intersection of the Equator and the central meridian define the origin with an x coordinate of 500,000 meters and y coordinate of 0 meters.

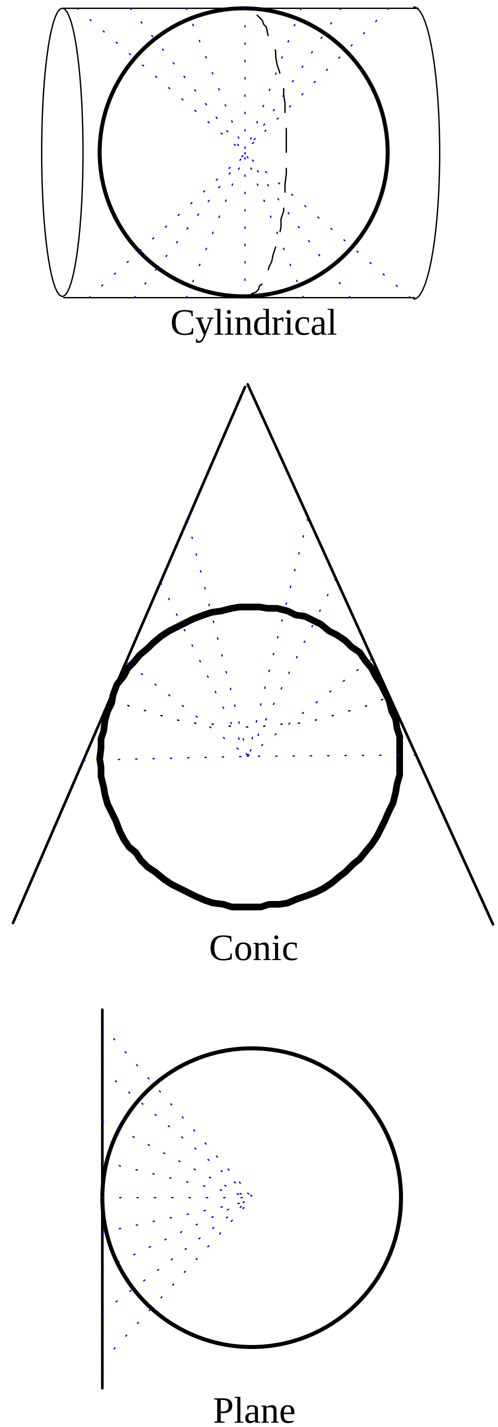


Figure 3-9: Projection surfaces

Lambert Conformal Conic

A tangential cone is represented in **Figure 3-9**. The Lambert Conformal conic projection is based on a secant cone in which a zone between two defined parallels (standard parallels) appears outside the cone. Parallels are represented by unequally spaced, concentric arcs, more closely spaced near the center of the map (between the standard parallels). Meridians are equally spaced radii perpendicular to the parallels. The pole near the apex of the cone is represented by a point.

With reference to **Figure 3-10**, it can be seen that scale in all directions within the standard parallels is compressed. Outside the standard parallels, scale is exaggerated. The scale is constant along any given parallel and true scale is represented only along standard parallels.

Albers Equal Area

Albers Equal Area is a conic projection in which a conceptual secant cone has an apex vertically above the pole, an axis which is coincident with the polar axis, and cuts through the globe at two latitudes (two standard parallels). Like the Lambert Conformal, the projection results in concentric arcs for parallels and equally spaced radii as meridians which are perpendicular to the parallels. Unlike the Lambert Conformal Conic, the parallels decrease in spacing away from the standard parallels. The pole towards the apex of the cone is represented by an arc which is concentric with the parallels. The other pole is not represented (out in infinity).

Scale is preserved only along the standard parallels. As with the Lambert Conformal Conic, scale along the parallels between the standard parallels is compressed. Outside the standard parallels, dimensions along parallels are exaggerated. The converse is true for dimensions along meridians. In fact, for the Albers Equal Area projection, the scale factor along the meridians is the reciprocal of the scale factor along parallels such as to maintain equal area. Only the standard parallels are free from angular distortion.

Since areas are represented true to scale (not necessarily true shape), the Albers Equal Area projection is suitable for drainage area determination. the Albers Equal Area is the projection of choice for HDDS. The HDDS projection parameters appear in **Table 3-2**. False eastings and northings refer to situations in which the coordinates are adjusted usually to avoid negative values of x and y respectively. These adjustments are convenient for hand computations but are not really needed for computer applications.

As long as a projection can be described mathematically, at least two potential options exist for minimizing errors associated with the Earth's curvature: the most common practice is to create a site-specific projection - one in which the projection type, origin, and standard parallels are established to minimize the distortions within the region of interest but which may incur gross errors outside the region. Many GIS packages allow such a capability. The main drawback is that the larger the region, the higher the order of error. Furthermore, if there is the need to merge data from several projects, each with its own projection, each data set would have to be transposed into a common projection prior to merging.

An alternative that previously would not have been practical, is the potential of computing scale factors necessary to adjust dimensions from those measured in a projection to those that would be represented on the surface of the ellipsoid. HDDS establishes one means by which this can be accomplished, the components of which are discussed in this section and in Section 4.2.2.

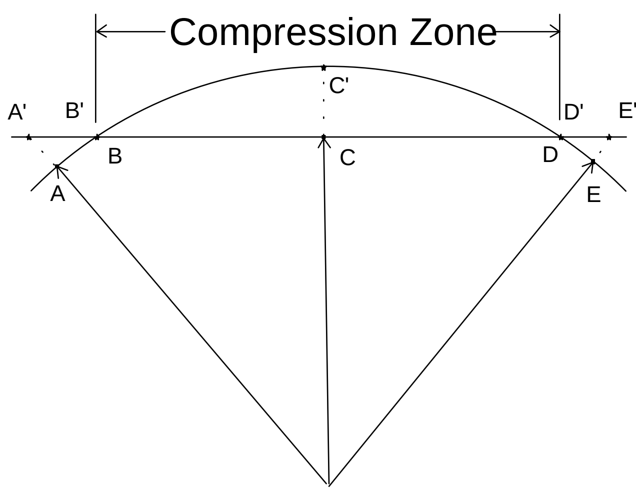


Figure 3-10: Distortion of scale in Lambert Conformal Conic projection

State Plane and Texas Statewide Mapping System

The Texas State Plane coordinate system employs the Lambert Conformal Conic projection. Five zones exist, each of which is a separate projection. While this system incurs smaller scaling errors than would ensue from use of only one statewide projection, there is no match between boundaries of zones.

The Texas State GIS Standards Committee established the Texas Statewide Mapping System to minimize scaling errors while allowing continuous representation of the whole state of Texas. **Table 3-2** includes projection parameters for the Texas State Plane Coordinate System and the Texas Statewide Mapping System. Though HDDS employs neither of these projections, they are important for consistent mapping of data. Any data created in HDDS may be transposed in Arc/Info by using the appropriate projection parameters.

Map Projection Scale Factors

The projections discussed above consist of transformations that can be described mathematically. As such, there exists the potential to measure distances and areas on the map and calculate scale factors by which these measurements can be adjusted to determine the equivalent dimensions on the surface of the sphere or ellipsoid.

HDDS employs the Albers Equal Area projection using GRS 1980 ellipsoid as the basis for all spatial data. The following details equations abstracted from Snyder (1987, pp. 15 - 102) and rearranged to allow calculation of longitudinal and latitudinal distance scale factors for a reference ellipsoid. By definition, no areal scale factors are required for an equal area projection.

First, the following constant parameters are defined with values based on the GRS 1980 reference ellipsoid (**Table 3-1**) and HDDS projection parameters (**Table 3-2**):

a = semi-major axis of ellipsoid = 6378137 m

e = eccentricity of ellipsoid = 0.081819221

ϕ_0 = latitude of origin of projection coordinate system = 23° = 0.4012 radians

ϕ_1 = first standard parallel = 29.5° = 0.5146 radians

ϕ_2 = second standard parallel = 45.5° = 0.7941 radians

λ_0 = longitude of central meridian = -96.0° = 1.6755 radians

n = cone constant as calculated using **Eq. (3-9)**. All angles are in radians.

$$n = \frac{(m_1^2 - m_2^2)}{(q_2 - q_1)} \qquad \textbf{(3-9)}$$

where,

$$m_n = \frac{\cos\phi_n}{(1 - e^2 \sin^2\phi_n)^{1/2}} \qquad \textbf{(3-10)}$$

and,

$$q_n = (1-e^2)\left(\frac{\sin\phi_n}{1-e^2\sin^2\phi_n} - \frac{1}{2e}\ln\left[\frac{1-e\sin\phi_n}{1+e\sin\phi_n}\right]\right) \quad \textbf{(3-11)}$$

Using **Eq. (3-10)**, m_1 = 0.871062964 and m_2 = 0.702105833.

Using **Eq. (3-11)**, q_0 = 0.77670266, q_1 = 0.979314365 and q_2 = 1.4201783

Substituting for m_1, m_2, q_1, and q_2 in **Eq. (3-9)** gives n = 0.602902769.

The radius of latitude of the origin, ρ_0, is calculated from **Eq. (3-12)**:

$$\rho_0 = \frac{a(C-nq_0)^{1/2}}{n} \quad \textbf{(3-12)}$$

where,

$$C = m_1^{\ 2} + nq_1 \ = \ 1.34918203 \quad \textbf{(3-13)}$$

so that ρ_0 = 9928937.007

All of the above values are constant for the given reference ellipsoid and projection parameters. For any given location using the projection coordinates (x and y), the polar coordinates (ρ and θ) must be computed. All angles are in radians.

Equation (3-14) determines the radius at the latitude of a given point x, y:

$$\rho = \left[x^2 + (\rho_0 - y)^2\right]^{1/2} \quad \textbf{(3-14)}$$

and the angular displacement is given by **Eq. (3-15)** as

$$\theta = \arctan\left[\frac{x}{(\rho_0 - y)}\right] \quad \textbf{(3-15)}$$

The latitude, ϕ, of the point may be calculated from **Eq. (3-16)**

$$\phi = \beta + \left(\frac{e^2}{3} + \frac{31e^4}{180} + \frac{517e^6}{5040}\right)\sin 2\beta + \left(\frac{23e^4}{360} + \frac{251e^6}{3780}\right)\sin 4\beta + \frac{761e^6}{45360}\sin 6\beta$$

(3-16)

where,

$$\beta = \arcsin\left(\frac{q}{\left\{1 - \left[\frac{(1-e^2)}{2e}\right]\ln\left[\frac{(1-e)}{(1+e)}\right]\right\}}\right) \quad \textbf{(3-17)}$$

and,

$$q = \frac{C - \frac{\rho^2 n^2}{a^2}}{n} \qquad \textbf{(3-18)}$$

Then the scale factors along a parallel (k) and a meridian (h) may be determined using **Eq. (3-19)** and **Eq. (3-20)** respectively.

$$h = \frac{\cos\phi}{\left(C - 2n\sin\phi\right)^{1/2}} \qquad \textbf{(3-19)}$$

$$k = 1/h \qquad \textbf{(3-20)}$$

The scale factors h and k apply to distances measured along the meridian and parallel, respectively, only in the vicinity of the point for which the factors are calculated. The factors vary with location. Section 4.2.2 includes an outline of the development of a cell-based scheme by which the above equations may be used to determine point-to-point distances using **Equations (3-9)** to **(3-20)** inclusive.

Table 3-2: Projection Parameters

Parameter	HDDS	Texas State Plane	Texas Statewide
Horizontal Datum	NAD 83	NAD 27	NAD 83
Reference Ellipsoid	GRS 80	Clarke 1866	GRS 80
Projection Type	Albers Equal Area	Lambert Conformal Conic	Lambert Conformal Conic
Central Meridian	96° 00'W	-	100° W
1st standard parallel	29° 30'N	North - 34° 39'N N. Central - 32° 08'N Central - 30° 07'N S. Central - 28° 23'N South - 26° 10'N	27°25' N
2nd standard parallel	45° 30'N	North - 36° 11'N N. Central - 33° 58'N Central - 31° 53'N S. Central - 30° 17'N South - 27° 50'N	34°55' N
Longitude of Origin	96° 00'W	North - 101° 30'W N. Central - 97° 30'W Central - 100° 20'W S. Central - 99° 00'W South - 98° 30'W	100° W
Latitude of Origin	23° 00'N	North - 34° 00'N N. Central - 31° 40'N Central - 29° 40'N S. Central - 27° 50'N South - 25° 40'N	31° 10'N
False Northing	0	0	1,000,000 m
False Easting	0	0	1,000,000 m

3.3 HYDROLOGIC METHODS

During the design of highway drainage facilities, estimates of peak discharge and sometimes runoff hydrographs are essential. Discharge can be considered as hydraulic load as it directly affects the design size of a drainage structure. Generally, it is not economically feasible to design for the most extreme possible floods. Therefore, either a risk analysis approach is employed or standard practice may establish design frequencies. In either case, it is necessary to establish a relationship between discharge and frequency of occurrence.

This project addresses the data requirements and procedures for three commonly used methods for determining peak flow rates: rural regression equations, statistical analysis of stream gauge records, and the Soil Conservation Service (SCS) runoff curve number method. These are outlined in order to clarify the use of parameters that are determined in HDDS. In each of the methods, discharge versus frequency relationships may be established using six flow frequencies: 2 year, 5 year, 10 year, 25 year, 50 year, and 100 year.

3.3.1 Regional Regression Equations

Regional regression equation methods are widely accepted for establishing peak flow versus frequency relationships at ungauged sites or sites with insufficient data for a statistical flood frequency derivation. A study by the U.S. Geological Survey (Schroeder and Massey, 1977) resulted in regression equations for six hydrologic regions in Texas.

Figure 3-11 presents the designated hydrologic regions for Texas and **Table 3-3** presents the equations developed for each region. Regression equations were not developed for some areas in South Texas, the Trans-Pecos region due to a paucity of data, and the High Plains due to the presence of playa lakes.

Figure 3-11
Hydrologic regions in Texas for regional regression equations
Shaded areas are undefined.
Adapted from TxDOT (1985, pp. 2-12)

Table 3-3: Rural Regression Equations for Texas Hydrologic Regions

Region 1	**Region 2**	**Region 3**
$Q_2 = 89.9\ A^{0.629}\ S^{0.130}$	$Q_2 = 216\ A^{0.574}\ S^{0.125}$	$Q_2 = 175\ A^{0.540}$
$Q_5 = 117\ A^{0.685}\ S^{0.254}$	$Q_5 = 322\ A^{0.620}\ S^{0.184}$	$Q_5 = 363\ A^{0.580}$
$Q_{10} = 131\ A^{0.714}\ S^{0.317}$	$Q_{10} = 389\ A^{0.646}\ S^{0.214}$	$Q_{10} = 521\ A^{0.599}$
$Q_{25} = 144\ A^{0.747}\ S^{0.386}$	$Q_{25} = 485\ A^{0.668}\ S^{0.236}$	$Q_{25} = 759\ A^{0.616}$
$Q_{50} = 152\ A^{0.769}\ S^{0.431}$	$Q_{50} = 555\ A^{0.682}\ S^{0.250}$	$Q_{50} = 957\ A^{0.627}$
$Q_{100} = 157\ A^{0.788}\ S^{0.469}$	$Q_{100} = 628\ A^{0.694}\ S^{0.261}$	$Q_{100} = 1175\ A^{0.638}$
Region 4	**Region 5**	**Region 6**
$Q_2 = 13.3\ A^{0.676}\ S^{0.694}$	$Q_2 = 4.82\ A^{0.799}\ S^{0.966}$	$Q_2 = 49.8\ A^{0.602}\ (P-7)^{0.447}$
$Q_5 = 42.7\ A^{0.630}\ S^{0.641}$	$Q_5 = 36.4\ A^{0.776}\ S^{0.706}$	$Q_5 = 84.5\ A^{0.643}\ (P-7)^{0.533}$
$Q_{10} = 80.7\ A^{0.604}\ S^{0.596}$	$Q_{10} = 82.6\ A^{0.776}\ S^{0.622}$	$Q_{10} = 111\ A^{0.666}\ (P-7)^{0.573}$
$Q_{25} = 163\ A^{0.576}\ S^{0.535}$	$Q_{25} = 180\ A^{0.776}\ S^{0.554}$	$Q_{25} = 150\ A^{0.692}\ (P-7)^{0.608}$
$Q_{50} = 248\ A^{0.562}\ S^{0.497}$	$Q_{50} = 278\ A^{0.778}\ S^{0.522}$	$Q_{50} = 182\ A^{0.709}\ (P-7)^{0.630}$
$Q_{100} = 397\ A^{0.540}\ S^{0.442}$	$Q_{100} = 399\ A^{0.782}\ S^{0.497}$	$Q_{100} = 216\ A^{0.725}\ (P-7)^{0.647}$

Adapted from TxDOT (1985, pp. 2-11)

Variable definitions are as follows:

A = Watershed area in square miles.

S = Average watershed slope, in feet per mile, measured as the slope of the stream bed between points 10 per cent and 85 per cent of the distance along the main stream channel from the outfall to the basin divide

P = Mean annual precipitation in inches, if needed.

The equations apply neither to urban watersheds nor to streams that are regulated by physical controls such as water resource and flood control projects, irrigation systems, or major channel improvements. In Region 6, the equations do not apply to areas with an elevation more than 4,000 feet above mean sea level due to insufficient data. **Table 3-4** shows the range of watershed areas and slopes within which the regression equations are considered valid.

Table 3-4: Regression Equation Limitations

Flood frequency region	Drainage area (square miles)	Slope (feet/mile)
1	0.39 - 4,839	0.85 - 206.2
2	0.33 - 4,233	1.16 - 108.1
3	2.38 - 4,097	-
4	1.09 - 3,988	2.33 - 74.8
5	1.08 - 1,947	9.15 - 76.8
6	0.32 - 2,730	-

Texas Hydraulics System

The Texas Hydraulics System computer program (THYSYS, 1977) is a package of hydrologic and hydraulic analysis routines. One subsystem employs the regional regression equations as outlined above. For determination of flood frequency using the regression equations for Texas, an ASCII input data file is required which specifies the following:

- hydrologic method (regression equations),
- hydrologic region number,
- watershed area,
- average watershed slope (if applicable), and
- mean annual precipitation (if applicable).

Additional Regression Parameters

The aforementioned regression equations were published in 1977. Standard errors were estimated to be of the order of 50%. Now, longer records and more stream gauge sites are available for analysis. The Texas Department of Transportation is sponsoring a six-year study to develop new regression analysis procedures for Texas. Preliminary indications are that the following parameters are significant:

- watershed area*,
- average watershed slope*,
- average annual precipitation*,
- Watershed shape factor, defined as area divided by square of length of mainstream)*, and
- Drainage density, defined as area divided by square of total length of streams in the watershed.

These parameters are spatially varying in which case GIS is an appropriate means of deriving them. HDDS currently demonstrates derivation of the parameters indicated above by an asterisk.

3.3.2 Estimation of Peak Discharge from Stream Gauge Data

Stream gauges recording annual peak discharges have been established at 936 stations around Texas (Slade, personal communication, 1995). If the gauging record covers a sufficient period (typically, at least 8 years), it is possible to develop a peak-discharge versus frequency relationship by statistical analysis of the observed data.

For the equations to be valid, the urbanization character of the watershed must not change enough to affect the characteristics of peak flows within the total time of observed annual peaks and no significant flow regulation must exist. The record of observed data must be consistent in that no significant changes in the channel or basin should have taken place during the period of record. If any of these changes occur, the resulting peak-stream flow frequency relation could be flawed.

For peak-stream flow frequency analyses, the Interagency Advisory Committee on Water Data (Bulletin 17 B, 1982), formerly known as the U.S. Water Resources Council, recommends the Log-Pearson Type III statistical distribution procedure which uses a series of annual-peak discharges for the subject gauge station. This method employs the three most important statistical parameters: mean value, standard deviation, and coefficient of skew.

The mean value is calculated using **Eq. (3-21)**.

$$\overline{Q}_L = \frac{\sum x}{N} \tag{3-21}$$

where,

x is the logarithm of the annual peak discharge, and

N is the number of annual peak measurements.

The standard deviation of the log values is determined using:

$$s_L = \sqrt{\frac{\sum x^2 - \left(\sum x\right)^2 / N}{N-1}} \tag{3-22}$$

and the coefficient of skew is:

$$Cs = \frac{N^2 \sum x^3 - 3N \sum x \sum x^2 + 2\left(\sum x\right)^3}{N(N-1)(N-2)s^3} \tag{3-23}$$

The flood magnitude versus frequency can then be calculated using:

$$\log Q = \overline{Q}_L + KS_L \tag{3-24}$$

where K is a frequency factor dependent on coefficient of skew and return period. Bulletin 17 B (1982, pp. 3-1) presents tables of skew coefficients (K values). The discharge can be computed for a range of frequencies for which K coefficients exist.

The skew represents the form of curvature of the plotted curve as shown in **Figure 3-12**. For a negative skew, the flood-frequency curve is concave downward and for a positive skew, the curve is concave upward. If the skew is zero, the plotted relation forms a straight line, the logarithm of the distribution is defined as normally distributed, and the standard deviation becomes the slope of that straight line.

The erratic nature of flooding in the State of Texas can result in records in which some of the observed annual-peak discharge rates do not seem to belong to the population of the series. These may be extremely large or extremely small with respect to the rest of the series of observations. Such values may be "outliers" which possibly should be excluded from the set of data to be analyzed. Bulletin 17 B (1982, pp. 17) outlines statistical checks for outliers.

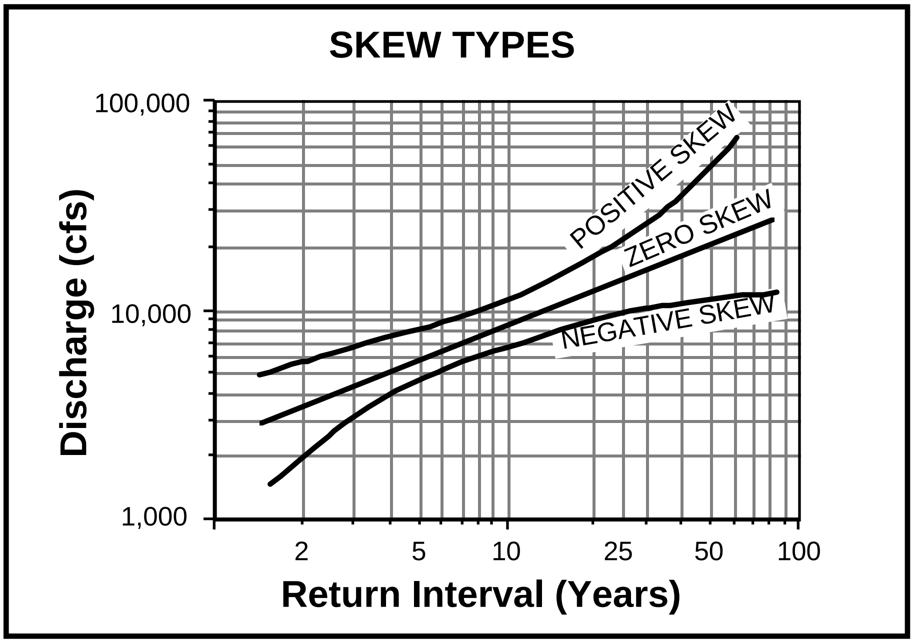


Figure 3-12: Typical discharge versus frequency curves
Adapted from Reagan and Smith (1993)

HDDS assists in application of this method by identifying which (if any) stream gauge records apply to streams within a delineated watershed.

3.3.3 Soil Conservation Service Runoff Curve Number Method (SCS)

The National Engineering Handbook (SCS, 1985) outlines peak discharge and runoff hydrograph determination by a rainfall-runoff method commonly referred to as the SCS Runoff Curve Number Method. This section discusses the most basic components of the method which may be used to determine peak discharges and runoff hydrographs from uncontrolled watersheds using a dimensionless unit hydrograph as shown in **Figure 3-13.**

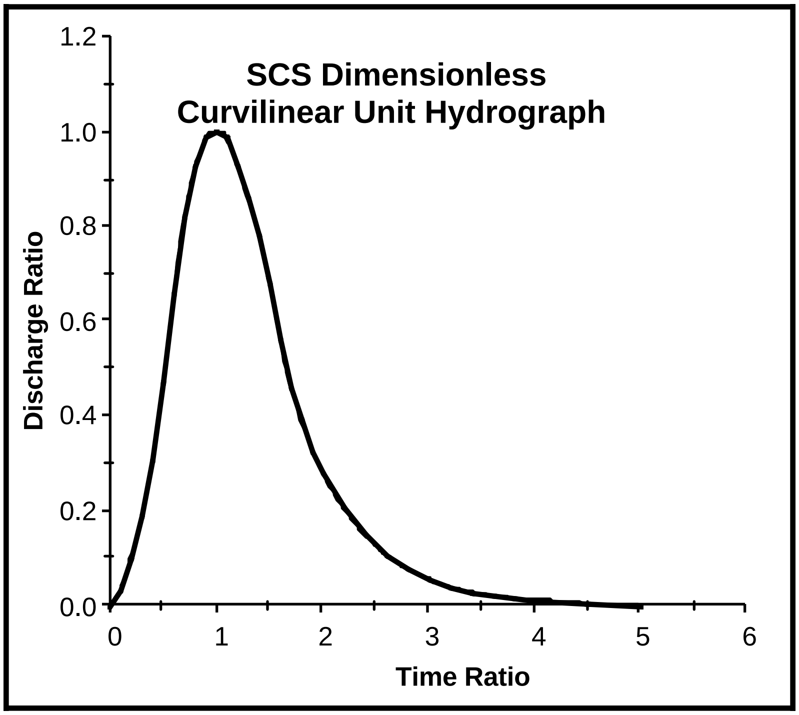


Figure 3-13: SCS dimensionless unit hydrograph
Adapted from SCS (1985, pp. 16.3)

The primary input variables are:

- drainage area size (A) in sq.mi.,
- time of concentration (T_c) in hours,
- weighted runoff curve number (RCN),
- rainfall distribution (SCS Type II or III for Texas), and
- total design rainfall (P) in inches.

HDDS is designed to develop these parameters with the exception of rainfall distribution type.

Rainfall-Runoff Equation

Equation (3-25) represents a relationship between accumulated rainfall and accumulated runoff. This was derived by the SCS from experimental plots for numerous soils and vegetative cover conditions. Data for land treatment measures, such as contouring and terracing, from experimental watersheds were included.

$$R = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \textbf{(3-25)}$$

where: R = accumulated direct runoff, inches

P = accumulated rainfall (potential maximum runoff), inches

I_a = initial abstraction including surface storage, interception, and infiltration prior to runoff, inches

S = potential maximum retention, inches

The potential maximum retention (S) may be computed as

$$S = \frac{1000}{RCN} - 10 \qquad \textbf{(3-26)}$$

which is valid if S < (P-R).

Where RCN is the runoff curve number described below.

Equation (3-25) was developed mainly for small watersheds from recorded storm data that included total rainfall amount in a calendar day, but not its distribution with respect to time. Therefore, this method is appropriate for estimating direct runoff from 24-hour or 1-day storm rainfall.

Generally, I_a may be estimated as:

$$I_a = 0.2S \cdot \qquad \textbf{(3-27)}$$

which, when substituted in **Eq. (3-25)** gives:

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \textbf{(3-28)}$$

Accumulated Rainfall (P)

For most highway drainage design purposes, the accumulated rainfall may be abstracted from Technical Paper 40 (NWS, 1961) for a 24 hour duration storm for the relevant frequency. The 24 hour 2, 5, 10, 25, 50, and 100 year frequency for Texas counties are presented in the **Table 3-5**.

Rainfall Distribution

The SCS (TR 55, 1986) presents two design dimensionless rainfall distribution types that are valid for Texas; Type II and Type III which are shown in **Figure 3-14**. The differences between Type II and Type III are minimal and as such, no effort has been expended here to differentiate the two in HDDS.

Soil Groups

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. The SCS (1985) has divides soils into four hydrologic soil groups based on infiltration rates, groups A, B, C, and D which are described as follows.

Group A Soils having a low runoff potential due to high infiltration rates even when saturated (0.30 - 0.45 in/hr). These soils consist primarily of deep sands, deep loess and aggregated silts.

Group B Soils having a moderately low runoff potential due to moderate infiltration rates when saturated (0.15 - 0.30 in/hr). These soils consist primarily of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (shallow loess, sandy loam).

Group C Soils having a moderately high runoff potential due to slow infiltration rates (0.05 - 0.15 in/hr if saturated). These soils consist primarily of soils in which a layer near the surface impedes the downward movement of water or soils with moderately fine to fine texture (clay loams, shallow sandy loams, soils low in organic content, and soils usually high in clay).

Group D Soils having a high runoff potential due to very slow infiltration rates (less than 0.05 in/hr if saturated). These soils consist primarily of clays with:

- high swelling potential
- soils with permanently high water tables
- soils with a claypan or clay layer at or near the surface
- shallow soils over nearly impervious parent material (soils that swell significantly when wet, heavy plastic clays, and certain saline soils).

Runoff Curve Number (RCN)

Rainfall infiltration losses primarily are dependent on soil characteristics and land use (surface cover). The SCS method uses a combination of soil conditions and land use to assign runoff factors known as runoff curve numbers. These represent the runoff potential of an area when the soil is not frozen. The higher the RCN, the higher the runoff potential. **Tables 3-6 through 3-9** provide an extensive list of suggested runoff curve numbers. The assigned land use codes are discussed in Section 4.2 and have been established as part of this thesis. The RCN values assume medium antecedent moisture conditions. Chow et al. (1988, pp. 149) provide equations to adjust the RCN for wet and dry antecedent moisture conditions. **Equation (3-29)** adjusts values for expected dry soil conditions (antecedent moisture condition I). **Equation (3-30)** should be used to accommodate wet soils (antecedent moisture condition III). **Table 3-10** assists the determination of which moisture condition applies.

$$RCN(I) = \frac{4.2RCN(II)}{10 - 0.058RCN(II)} \quad \textbf{(3-29)}$$

$$RCN(III) = \frac{23RCN(II)}{10 + 0.13RCN(II)} \quad \textbf{(3-30)}$$

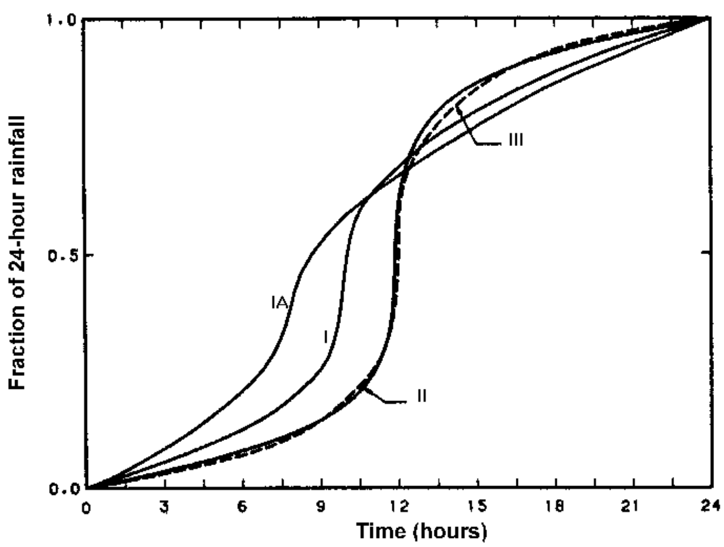


Figure 3-14: Soil Conservation Service 24-hour rainfall distributions
Adapted from TR55 (1986, pp. B-1)

Time of Concentration

The time of concentration (T_C) is the time required for water to travel from the most hydraulically distant point in a watershed to its outlet. In general, the time of concentration is equal to the distance of runoff along the watercourse divided by the average velocity of runoff: however, surface flow velocities vary considerably with topography, surface cover, and cross-section characteristics. Therefore, it is advisable to divide the watercourse into segments of overland and channel flows and determine flow velocities for each segment. The time of travel for each segment can be computed as the quotient of length and velocity. The sum of times of travel along each segment in series yields the total travel time.

An inordinate number of paths may be possible for the time of concentration. It is necessary to identify the path of runoff within the watershed which will define the longest travel time. Manual methods require trial and error estimates. The designer might choose what appears to be the longest distance from the watershed boundary to the outfall, but the topography and surface roughness could be such that the longest time results from a different travel path. HDDS has been designed to determine the time of concentration based on the longest travel time. This is detailed in Section 4.2.

The Texas Department of Transportation (TxDOT, 1985) recommends use of **Figure 3-15** for estimating velocity of runoff for overland flow and shallow swale flow. Since the subject watershed component may not have exactly the definition as shown on the chart, it may be necessary to interpolate between lines with identification similar to the subject watershed characteristics.

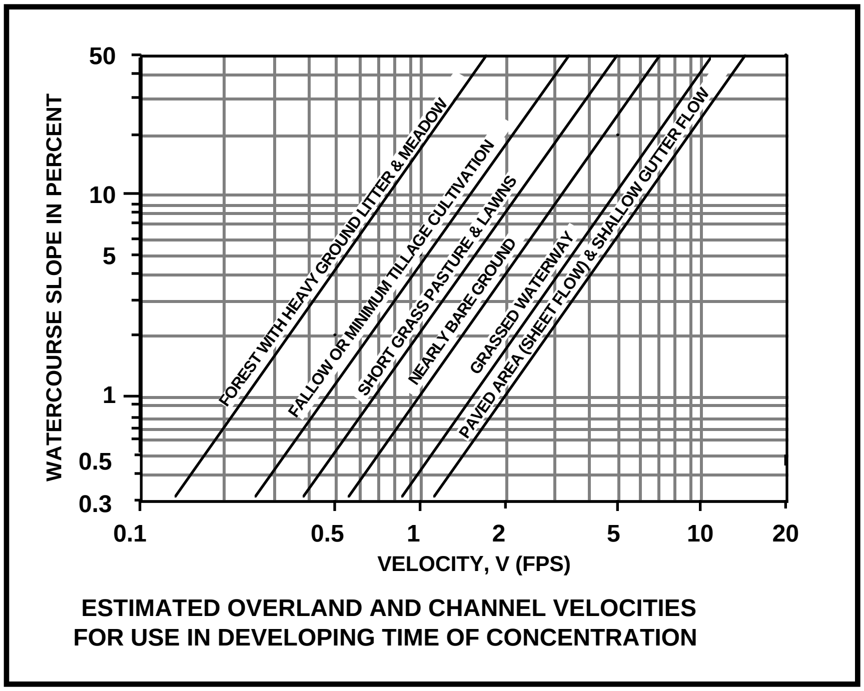


Figure 3-15: Velocities for estimating time of concentration
Adapted from NEH (1985, pp. 15-8)

Generally, the travel time along concentrated flow reaches such as streams should be estimated using channel analysis techniques. Oftentimes, Manning's Equation, **Eq. (3-31)**, is used assuming bank full flow. Currently, HDDS does not incorporate development of channel analysis parameters, however, flow velocities can be specified from which times can be calculated. See Section 4.2.

$$V = \frac{1.49AR^{2/3}S^{1/2}}{n} \quad \textbf{(3-31)}$$

where,

V = average flow velocity (fps),

A = channel section area (ft^2),

R = hydraulic radius = area/wetted perimeter (ft),

S = water surface slope which is approximated by channel bed slope (ft/ft), and

n = Manning's roughness coefficient.

Peak Flow and Runoff Hydrograph Determination

Much like other rainfall runoff methods, it is necessary to perform the following:

- determine cumulative rainfall,
- determine cumulative and incremental excess rainfall,
- establish a unit hydrograph for the specific watershed, and
- determine runoff hydrograph by convolution of excess rainfall and unit hydrograph.

The following briefly outlines how this may be accomplished for the SCS method:

1. Derive a cumulative rainfall table by multiplying each ordinate of the standard rainfall distribution (**Figure 3-14**) by the total design rainfall (P) as determined from **Table 3-5**.
2. Determine the duration of unit excess rainfall (runoff), D, using **Eq. (3-32)**. For convenience, D may be rounded such that the duration of precipitation is a whole number times D.

   $$D = 0.133T_c \qquad \textbf{(3-32)}$$

   where T_c = time of concentration (hours).
3. Calculate the peak discharge (q_p)for the unit hydrograph using **Eq. (3-33)**.

   $$q_p = \frac{484AQ}{T_p} \qquad \textbf{(3-33)}$$

   where,

   A = drainage area (sq. mi.),

   T_p = time to peak of the unit hydrograph (U.H.) = 0.67 T_c (for rural watersheds)

   Q = volume of runoff per unit area during time interval (= 1 in for the U.H.)
4. Develop the unit hydrograph ordinates using the dimensionless hydrograph from **Figure 3-14**. For each time step, $D \times \frac{t}{T_p}$, $q = q_p \times \frac{q}{Q}$.

   A plot of all the ordinates represents the runoff resulting from 1.0 inch of rainfall excess occurring during a time of D hours.
5. Using the cumulative rainfall table from Step 1, calculate the accumulated runoff and incremental runoff using a time increment of D, the estimated RCN, **Eq. (3-26),** and **Eq. (3-28)**. If, for any time interval, P - 0.2 S = 0, then R = 0.

6. Compute the hydrographs resulting from each increment of runoff by multiplying the ordinates of the unit hydrograph by the increment of runoff. This will result in as many hydrographs as there are increments of runoff, each of which should be displaced by the duration time from the previous hydrograph. At each time step, summate the runoff values to yield the composite runoff hydrograph.

The aforementioned process describes appropriate steps for the simplest analysis in which no consideration is given to the effect of spatial distribution of rainfall and individual runoff hydrographs resulting from tributaries within the watershed. By dividing the watershed into subareas and employing channel routing techniques, the SCS runoff curve number method may be employed to better accommodate differences in subarea characteristics. HDDS aids the process by delineating subareas, estimating subarea times of concentration and flow path, and weighting design rainfall and runoff curve numbers by subarea.

Computer programs such as TR 20 (1986) and THYSYS (TxDOT, 1977) are available to perform the hydrologic computations. HDDS is designed to develop the data required as input for such programs as discussed in **Section 4.2**.

Table 3-5: Design 24-Hour Rainfall in Inches for Texas Counties

CNTY_NAME	24hr Design Rainfall (inches) by Frequency (F years)					
	F2_24	F5_24	F10_24	F25_24	F50_24	F100_24
Anderson	4.40	6.00	7.00	8.40	9.50	10.50
Andrews	2.60	3.50	4.30	5.00	5.60	6.50
Angelina	4.80	6.50	7.70	9.20	10.50	11.50
Aransas	4.50	6.30	7.50	9.00	10.30	11.80
Archer	3.65	4.90	5.70	6.80	7.70	8.70
Armstrong	2.80	3.80	4.60	5.30	5.90	6.70
Atascosa	4.00	5.50	6.70	7.80	8.80	10.00
Austin	4.65	6.35	7.75	9.10	10.40	11.80
Bailey	2.60	3.40	4.20	4.70	5.80	6.20
Bandera	3.80	5.20	6.20	7.40	8.30	9.40
Bastrop	4.20	5.70	6.80	8.00	9.00	10.10
Baylor	3.55	4.80	5.40	6.60	7.50	8.40
Bee	4.25	6.00	7.10	8.50	9.50	11.00
Bell	4.10	5.50	6.70	7.80	8.80	9.90
Bexar	3.80	5.30	6.50	7.80	8.70	9.90
Blanco	3.80	5.30	6.50	7.60	8.60	9.70
Borden	2.90	4.10	4.75	5.70	6.40	7.20
Bosque	4.00	5.40	6.50	7.50	8.50	9.50
Bowie	4.40	5.75	6.85	7.85	8.80	9.85
Brazoria	5.10	7.00	8.50	10.00	11.50	13.00
Brazos	4.50	6.13	7.30	8.75	9.75	11.00
Brewster	2.60	3.40	4.30	5.00	5.70	6.50
Briscoe	2.90	3.95	4.70	5.45	6.10	6.80
Brooks	4.25	6.00	7.10	8.40	9.50	11.00
Brown	3.70	5.10	6.10	7.10	8.10	9.10
Burleson	4.45	6.10	7.25	8.75	9.65	10.95
Burnet	3.80	5.30	6.30	7.50	8.50	9.50
Caldwell	4.10	5.60	6.70	7.90	8.90	10.00
Calhoun	4.60	6.40	7.80	9.30	10.50	12.00
Callahan	3.60	4.90	5.70	6.80	7.80	8.80
Cameron	4.60	6.30	7.40	9.00	10.00	11.50
Camp	4.40	5.80	6.85	7.95	8.90	9.90
Carson	2.80	3.70	4.50	5.20	5.80	6.60
Cass	4.45	5.80	6.85	7.90	8.90	9.90
Castro	2.65	3.60	4.30	4.90	5.50	6.30
Chambers	5.50	7.30	8.80	10.10	11.70	13.10
Cherokee	4.50	6.10	7.20	8.50	9.50	10.30
Childress	3.20	4.30	5.00	5.90	6.90	7.50
Clay	3.70	5.10	5.80	7.00	7.90	8.90
Cochran	2.55	3.40	4.20	4.75	5.30	6.20
Coke	3.30	4.50	5.30	6.40	7.20	8.20
Coleman	3.60	5.00	5.80	6.90	7.80	8.90
Collin	4.00	5.40	6.40	7.60	8.60	9.60
Collingsworth	3.10	4.20	4.90	5.80	6.70	7.30
Colorado	4.60	6.30	7.60	9.00	10.20	11.60
Comal	3.80	5.30	6.30	7.50	8.50	9.50
Comanche	3.80	5.20	6.20	7.20	8.20	9.20
Concho	3.60	4.80	5.70	6.80	7.70	8.80
Cooke	3.80	5.20	6.20	7.30	8.20	9.30
Coryell	4.00	5.40	6.40	7.60	8.60	9.65
Cottle	3.20	4.40	5.10	6.00	7.00	7.70
Crane	2.60	3.60	4.40	5.00	5.80	6.50

CNTY_NAME	F2_24	F5_24	F10_24	F25_24	F50_24	F100_24
Crockett	3.00	4.30	5.10	6.10	6.90	7.80
Crosby	2.90	3.80	4.75	5.55	6.35	7.00
Culberson	2.00	2.70	3.40	4.10	4.50	5.10
Dallam	2.40	3.20	3.90	4.50	5.20	5.80
Dallas	4.00	5.40	6.50	7.60	8.60	9.60
Dawson	2.80	3.90	4.70	5.30	6.00	6.80
Deaf Smith	2.60	3.50	4.20	4.80	5.40	6.20
Delta	4.15	5.60	6.80	7.80	8.80	9.80
Denton	3.90	5.30	6.30	7.40	8.40	9.40
De Witt	4.30	6.00	7.20	8.50	9.60	11.00
Dickens	3.10	4.25	5.00	5.90	6.75	7.45
Dimmit	3.70	5.20	6.20	7.40	8.30	9.50
Donley	2.90	4.00	4.80	5.60	6.30	6.90
Duval	4.10	5.75	6.90	8.10	9.10	10.50
Eastland	3.70	5.10	6.00	7.00	8.00	9.00
Ector	2.60	3.60	4.40	5.00	5.80	6.50
Edwards	3.50	4.80	5.70	6.80	7.80	8.80
El Paso	1.50	2.30	2.80	3.20	3.60	3.80
Ellis	4.10	5.40	6.60	7.70	8.70	9.80
Erath	3.80	5.20	6.30	7.30	8.30	9.30
Falls	4.20	5.70	6.80	8.00	9.00	10.10
Fannin	4.05	5.45	6.50	7.60	8.60	9.60
Fayette	4.50	6.10	7.30	8.60	9.70	11.00
Fisher	3.25	4.50	5.25	6.30	7.10	8.10
Floyd	2.90	4.00	4.75	5.50	6.25	6.90
Foard	3.40	4.60	5.20	6.20	7.20	8.10
Fort Bend	4.90	6.70	8.20	9.55	11.00	12.45
Franklin	4.25	5.70	6.85	7.85	8.90	9.90
Freestone	4.33	5.90	6.90	8.20	9.25	10.30
Frio	3.80	5.30	6.30	7.60	8.50	10.00
Gaines	2.60	3.50	4.25	4.90	5.60	6.40
Galveston	5.30	7.20	8.60	10.10	11.60	13.10
Garza	2.90	4.10	4.80	5.70	6.50	7.10
Gillespie	3.80	5.20	6.20	7.40	8.30	9.40
Glasscock	2.90	4.10	4.80	5.75	6.50	7.30
Goliad	4.30	6.10	7.20	8.50	9.70	11.10
Gonzales	4.20	5.90	7.00	8.40	9.50	10.70
Gray	2.90	3.90	4.70	5.50	6.20	6.70
Grayson	3.90	5.40	6.40	7.40	8.40	9.40
Gregg	4.50	5.95	7.00	8.10	9.20	10.20
Grimes	4.62	6.30	7.55	9.00	10.00	11.50
Guadalupe	4.10	5.60	6.70	7.90	8.90	10.00
Hale	2.75	3.75	4.55	5.25	5.85	6.70
Hall	3.00	4.20	4.80	5.75	6.50	7.20
Hamilton	3.90	5.30	6.40	7.40	8.50	9.50
Hansford	2.70	3.60	4.30	5.00	5.70	6.30
Hardeman	3.30	4.50	5.20	6.20	7.20	8.10
Hardin	5.25	7.20	8.45	10.00	11.10	12.65
Harris	5.00	6.80	8.30	9.60	11.00	12.50
Harrison	4.55	6.00	7.00	8.20	9.20	10.20
Hartley	2.50	3.30	4.00	4.70	5.20	6.00
Haskell	3.50	4.70	5.40	6.40	7.40	8.30
Hays	4.00	5.40	6.50	7.70	8.70	9.80
Hemphill	2.90	4.00	4.80	5.50	6.30	6.90
Henderson	4.30	5.80	6.90	8.00	9.10	9.90

CNTY_NAME	F2_24	F5_24	F10_24	F25_24	F50_24	F100_24
Hidalgo	4.30	6.10	7.20	8.50	9.60	11.10
Hill	4.00	5.40	6.60	7.80	8.80	9.80
Hockley	2.65	3.60	4.40	5.00	5.65	6.45
Hood	3.90	5.20	6.40	7.40	8.40	9.40
Hopkins	4.20	5.65	6.85	7.85	8.85	9.90
Houston	4.60	6.25	7.50	8.80	9.95	11.20
Howard	2.90	4.10	4.80	5.70	6.50	7.30
Hudspeth	1.70	2.50	3.00	3.50	4.00	4.40
Hunt	4.10	5.50	6.60	7.80	8.70	9.70
Hutchinson	2.70	3.70	4.40	5.10	5.70	6.50
Irion	3.20	4.40	5.20	6.30	7.00	8.00
Jack	3.75	5.20	6.00	7.10	8.00	9.10
Jackson	4.60	6.40	7.80	9.20	10.50	12.00
Jasper	5.00	7.00	8.25	9.60	10.60	12.50
Jeff Davis	2.10	2.90	3.60	4.20	4.80	5.50
Jefferson	5.50	7.50	8.80	10.20	11.80	13.10
Jim Hogg	4.10	5.75	6.80	8.10	9.10	10.50
Jim Wells	3.90	5.90	7.10	8.30	9.50	10.90
Johnson	4.00	5.30	6.40	7.50	8.50	9.50
Jones	3.50	4.60	5.40	6.50	7.30	8.30
Karnes	4.20	5.80	7.00	8.30	9.30	10.70
Kaufman	4.20	5.60	6.70	7.80	8.80	9.80
Kendall	3.80	5.30	6.40	7.60	8.50	9.50
Kenedy	4.40	6.25	7.30	8.70	10.00	11.30
Kent	3.20	4.25	5.05	6.00	6.80	7.55
Kerr	3.80	5.20	6.20	7.30	8.30	9.30
Kimble	3.70	4.90	5.90	7.10	8.00	9.10
King	3.00	4.50	5.10	6.10	7.10	8.00
Kinney	3.50	4.80	5.70	7.00	8.00	9.00
Kleberg	4.30	6.20	7.30	8.60	9.90	11.30
Knox	3.40	4.60	5.30	6.40	7.30	8.20
La Salle	3.85	5.40	6.50	7.70	8.60	9.90
Lamar	4.20	5.55	6.80	7.80	8.75	9.75
Lamb	2.65	3.60	4.40	4.90	5.55	6.40
Lampasas	3.80	5.30	6.30	7.50	8.50	9.50
Lavaca	4.50	6.30	7.50	8.80	10.00	11.20
Lee	4.40	5.95	7.10	8.45	9.50	10.70
Leon	4.40	6.05	7.20	8.50	9.55	10.75
Liberty	5.25	7.00	8.50	9.90	11.10	12.60
Limestone	4.30	5.70	6.80	8.00	9.10	10.10
Lipscomb	2.90	3.90	4.60	5.40	6.10	6.80
Live Oak	4.20	5.75	7.00	8.20	9.10	10.60
Llano	3.90	5.20	6.30	7.50	8.40	9.50
Loving	2.30	3.00	3.80	4.40	4.90	5.60
Lubbock	2.80	3.80	4.60	5.30	6.00	6.80
Lynn	2.80	3.85	4.70	5.30	6.00	6.80
Madison	4.60	6.20	7.50	8.80	9.80	11.10
Marion	4.50	5.90	6.95	8.00	8.90	10.00
Martin	2.80	3.90	4.70	5.30	6.10	6.80
Mason	3.80	5.10	6.10	7.20	8.20	9.30
Matagorda	4.90	6.80	8.30	9.60	11.20	12.50
Maverick	3.50	5.00	5.80	7.00	8.00	9.00
McCulloch	3.70	5.00	5.90	7.10	8.00	9.10
McLennan	4.10	5.50	6.60	7.80	8.80	9.80
McMullen	4.00	5.55	6.70	8.00	9.00	10.30

CNTY_NAME	F2_24	F5_24	F10_24	F25_24	F50_24	F100_24
Medina	3.80	5.30	6.20	7.50	8.50	9.50
Menard	3.80	4.90	5.80	6.90	7.80	8.90
Midland	2.80	3.90	4.70	5.30	6.20	6.80
Milam	4.20	5.70	6.80	8.00	9.00	10.10
Mills	3.80	5.20	6.30	7.30	8.30	9.30
Mitchell	3.10	4.25	5.10	6.10	6.70	7.80
Montague	3.80	5.10	6.00	7.20	8.00	9.10
Montgomery	4.85	6.60	8.10	9.30	10.60	12.20
Moore	2.60	3.60	4.30	4.90	5.50	6.30
Morris	4.40	5.75	6.85	7.90	9.00	9.90
Motley	3.05	4.20	4.90	5.80	6.60	7.25
Nacogdoches	4.70	6.20	7.50	8.80	10.00	11.00
Navarro	4.20	5.60	6.80	7.90	9.00	9.80
Newton	5.10	7.00	8.25	9.60	10.60	12.50
Nolan	3.25	4.50	5.25	6.30	7.10	8.10
Nueces	4.30	6.10	7.30	8.60	10.00	11.30
Ochiltree	2.80	3.70	4.50	5.20	5.90	6.50
Oldham	2.60	3.30	4.10	4.70	5.30	6.10
Orange	5.50	7.40	8.80	10.10	11.60	13.00
Palo Pinto	3.80	5.10	6.20	7.20	8.20	9.20
Panola	4.60	6.20	7.20	8.50	9.50	10.60
Parker	3.90	5.20	6.30	7.30	8.30	9.30
Parmer	2.60	3.40	4.20	4.75	5.20	6.20
Pecos	2.70	3.70	4.50	5.20	6.00	6.80
Polk	4.85	6.60	8.00	9.40	10.50	12.00
Potter	2.70	3.60	4.40	5.00	5.60	6.40
Presidio	2.10	2.90	3.70	4.20	4.80	5.50
Rains	4.20	5.70	6.85	7.85	8.90	9.95
Randall	2.70	3.70	4.40	5.10	5.70	6.50
Reagan	3.00	4.10	4.90	5.90	6.70	7.50
Real	3.60	5.00	5.80	7.10	8.00	9.00
Red River	4.30	5.65	6.80	7.85	8.80	9.80
Reeves	2.30	3.10	3.90	4.50	5.00	5.70
Refugio	4.50	6.20	7.50	9.00	10.10	11.50
Roberts	2.80	3.80	4.60	5.30	6.00	6.70
Robertson	4.40	5.90	7.00	8.40	9.40	10.60
Rockwall	4.10	5.40	6.60	7.70	8.70	9.70
Runnels	3.60	4.80	5.60	6.70	7.50	8.60
Rusk	4.55	6.10	7.25	8.50	9.50	10.20
Sabine	4.87	6.60	7.90	9.10	9.75	11.50
San Augustine	4.80	6.50	7.75	9.05	10.00	11.50
San Jacinto	4.85	6.50	8.05	9.40	10.50	11.50
San Patricio	4.30	6.20	7.30	8.60	10.00	11.30
San Saba	3.80	5.20	6.20	7.30	8.30	9.40
Schleicher	3.40	4.60	5.50	6.50	7.40	8.40
Scurry	3.10	4.25	5.10	6.00	6.70	7.60
Shackelford	3.60	4.80	5.60	6.70	7.70	8.70
Shelby	4.75	6.30	7.60	8.70	9.95	11.00
Sherman	2.60	3.50	4.20	4.80	5.40	6.10
Smith	4.45	5.90	7.00	8.15	9.20	10.20
Somervell	3.90	5.30	6.40	7.40	8.40	9.40
Starr	4.10	5.50	6.90	8.20	9.30	10.60
Stephens	3.70	5.00	6.00	7.00	8.00	9.00
Sterling	3.10	4.25	5.10	6.10	6.80	7.80
Stonewall	3.00	4.50	5.20	6.30	7.10	8.10

CNTY_NAME	F2_24	F5_24	F10_24	F25_24	F50_24	F100_24
Sutton	3.40	4.70	5.50	6.60	7.50	8.50
Swisher	2.75	3.75	4.50	5.20	5.80	6.60
Tarrant	3.90	5.30	6.40	7.40	8.40	9.50
Taylor	3.50	4.60	5.50	6.50	7.50	8.40
Terrell	2.90	3.90	4.80	5.60	6.50	7.30
Terry	2.65	3.65	4.40	5.00	5.70	6.50
Throckmorton	3.60	4.80	5.60	6.60	7.60	8.50
Titus	4.30	5.75	6.85	7.90	8.90	9.90
Tom Green	3.40	4.60	5.50	6.50	7.30	8.40
Travis	4.10	5.60	6.70	7.90	8.90	10.00
Trinity	4.75	6.45	7.75	9.10	10.20	11.50
Tyler	4.80	6.50	7.75	9.50	10.55	12.10
Upshur	4.40	5.80	6.90	8.00	9.00	10.00
Upton	2.80	3.90	4.70	5.50	6.30	7.00
Uvalde	3.70	5.00	6.00	7.20	8.20	9.20
Val Verde	3.20	4.40	5.30	6.50	7.00	8.50
Van Zandt	4.20	5.80	6.80	7.90	9.00	9.90
Victoria	4.50	6.20	7.50	9.00	10.10	11.50
Walker	4.70	6.40	7.80	9.10	10.20	11.60
Waller	4.75	6.45	8.00	9.25	10.50	12.00
Ward	2.40	3.30	4.20	4.70	5.30	6.10
Washington	4.60	6.25	7.50	8.95	10.00	11.45
Webb	3.80	5.30	6.50	7.60	8.60	10.00
Wharton	4.80	6.50	8.00	9.40	10.70	12.00
Wheeler	3.00	4.10	4.80	5.70	6.50	7.10
Wichita	3.65	4.80	5.60	6.70	7.60	8.60
Wilbarger	3.55	4.70	5.40	6.50	7.40	8.30
Willacy	4.50	6.25	7.30	8.80	10.00	11.40
Williamson	4.10	5.60	6.70	7.90	8.90	10.00
Wilson	4.10	5.60	6.80	8.00	9.00	10.40
Winkler	2.40	3.30	4.20	4.70	5.30	6.10
Wise	3.80	5.20	6.20	7.30	8.20	9.30
Wood	4.25	5.75	6.90	7.90	8.95	10.00
Yoakum	2.55	3.40	4.20	4.75	5.40	6.20
Young	3.70	5.00	5.80	6.90	7.80	8.80
Zapata	3.90	5.50	6.70	7.80	8.90	10.20
Zavala	3.70	5.20	6.00	7.30	8.20	9.50

Table 3-6: Runoff Curve Numbers for Urban Areas

Cover Description			Curve numbers(RCN) for hydrologic soil groups			
Assigned lucode(s)	Cover type and hydrologic condition	Average % impervious area	A	B	C	D
18 & 181	Open space (lawns, parks, golf courses, cemeteries, etc.) Poor condition (grass cover <50%)		68	79	86	89
182	Fair condition (grass cover 50% to 75%)		49	69	79	84
183	Good condition (grass cover > 75%)		39	61	74	80
141	Impervious areas: Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
14 & 142	Streets and roads: Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
143	Paved; open ditches (including right-of-way)		83	89	92	93
144	Gravel (including right-of-way)		76	85	89	91
145	Dirt (including right-of-way)		72	82	87	89
171	Western desert urban areas: Natural desert landscaping (pervious areas only)		63	77	85	88
172	Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
	Urban districts:					
12	Commercial and business	85	89	92	94	95
13	Industrial	72	81	88	91	93
	Residential districts by average lot size:					
11 & 111	1/8 acre or less (town houses)	65	77	85	90	92
112	1/4 acre	38	61	75	83	87
113	1/3 acre	30	57	72	81	86
114	1/2 acre	25	54	70	80	85
115	1 acre	20	51	68	79	84
116	2 acres	12	46	65	77	82
	Developing urban areas					
173	Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

Table 3-7: Runoff Curve Numbers for Cultivated Agricultural Land

Cover description				Curve numbers for hydrologic soil group			
Assigned lucode	Cover type	Treatment	Hydrologic condition	A	B	C	D
21 & 2111	Fallow	Bare soil	-	77	86	91	94
2112		Crop residue	Poor	76	85	90	93
2113		cover (CR)	Good	74	83	88	90
2114	Row	Straight row (SR)	Poor	72	81	88	91
2115	Crops		Good	67	78	85	89
2116		SR + CR	Poor	71	80	87	90
2117			Good	64	75	82	85
2118		Contoured (C)	Poor	70	79	84	88
2119			Good	65	75	82	86
2120		C + CR	Poor	69	78	83	87
2121			Good	64	74	81	85
2122		Contoured &	Poor	66	74	80	82
2123		terraced (C & T)	Good	62	71	78	81
2124		C&T + CR	Poor	65	73	79	81
2125			Good	61	70	77	80
2126		Small grain SR	Poor	65	76	84	88
2128			Good	63	75	83	87
2129		SR + CR	Poor	64	75	83	86
2130			Good	60	72	80	84
2131		C	Poor	63	74	82	85
2132			Good	61	73	81	84
2133		C + CR	Poor	62	73	81	84
2134			Good	60	72	80	83
2135		C&T	Poor	61	72	79	82
2136			Good	59	70	78	81
2137		C&T + CR	Poor	60	71	78	81
2138			Good	58	69	77	80
220		Close-seeded SR	Poor	66	77	85	89
222		or broadcast	Good	58	72	81	85
244		Legumes or C	Poor	64	75	83	85
245		Rotation	Good	55	69	78	83
246		Meadow C&T	Poor	63	73	80	83
247			Good	51	67	76	80

Table 3-8: Runoff Curve Numbers for Other Agricultural Lands

Cover description			Curve numbers for hydrologic soil group			
Assigned lucode	Cover type	Hydrologic condition	A	B	C	D
24 & 241	Pasture, grassland, or range-	Poor	68	79	86	89
242	continuous forage for grazing	Fair	49	69	79	84
243		Good	39	61	74	80
248	Meadow--continuous grass, protected from grazing and generally mowed for hay	--	30	58	71	78
33 & 331	Brush--brush-weed-grass	Poor	48	67	77	83
332	mixture, with	Fair	35	56	70	77
333	brush the major element	Good	30	48	65	73
43 & 431	Woods--grass combination	Poor	57	73	82	86
432	(orchard or	Fair	43	65	76	82
433	tree farm)	Good	32	58	72	79
434	Woods	Poor	45	66	77	83
435		Fair	36	60	73	79
436		Good	30	55	70	77
23	Farmsteads--buildings, lanes, driveways, and surrounding lots	--	59	74	82	86

Table 3-9: Runoff Curve Numbers for Arid and Semiarid Rangelands

Assigned lucode	Cover type	Hydrologic condition	A	B	C	D
31 & 311	Herbaceous--mixture of grass,	Poor		80	87	93
312	weeds, and low-growing brush,	Fair		71	81	89
313	with brush the minor element	Good		62	74	85
41 & 411	Oak-aspen--mountain brush	Poor		66	74	79
412	mixture of oak brush, aspen,	Fair		48	57	63
413	mountain mahogany, bitter brush, maple, and other brush	Good		30	41	48
42 & 421	Pinyon-juniper--pinyon, juniper,	Poor		75	85	89
422	or both; grass understory	Fair		58	73	80
423		Good		41	61	71
32 & 321	Sagebrush with grass understory	Poor		67	80	85
322		Fair		51	63	70
323		Good		35	47	55
324	Desert shrub--major plants	Poor	63	77	85	88
325	include saltbush, greasewood,	Fair	55	72	81	86
326	creosote-bush, blackbrush, bursage, palo verde, mesquite, and cactus	Good	49	68	79	84

Data for Tables 3-6 to 3-9 were abstracted from TR-55 (1986) considering average runoff conditions and initial abstraction, $I_a = 0.2S$. Detailed notes are provided on their use in the aforementioned reference. Assigned land use codes (lucodes) are discussed in Section 4.2.

Table 3-10: Rainfall Groups For Antecedent Soil Moisture Conditions During Growing And Dormant Seasons

Antecedent Condition	Conditions Description	Growing Season Five-Day Antecedent Rainfall	Dormant Season Five-Day Antecedent Rainfall
Dry Condition I	An optimum condition of watershed soils, where soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes place	Less than 1.4 inches	Less than 0.5 inches
Average Condition II	The average case for annual floods	1.4 to 2.1 inches	0.5 to 1.1 inches
Wet Condition III	When a heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm	Over 2.1 inches	Over 1.1 inches

4. Methods

4.1 Data Acquisition and Development

The success of any hydrologic analysis is dependent on the availability, quality, and application of relevant data. In highway drainage facility design, the hydrologic data, especially peak flood flow rates, are the primary factors that affect the size of a facility. Failure to use adequate and appropriate data can lead to damage of the facility and interruption of traffic from possible undersizing, or excessive construction costs due to oversizing.

The first steps in the design of a drainage facility are to:

- locate the site,
- identify the types of data required,
- determine sources of data, and
- acquire and manipulate the data.

This section outlines the data needs for typical hydrologic analyses for the design of highway drainage facilities, discusses potential data sources, and details the methods of establishing digital data for use in HDDS.

Data Needs

Section 3.3 outlines several hydrologic methods which have specific data requirements. That is, data requirements are dependent on the intended hydrologic method. In design, the availability and reliability of data affect the choice of hydrologic method. The most prevalent hydrologic parameters include:

- drainage area size and shape,
- topography,
- soil type,
- land use/land cover,
- rainfall characteristics,

- stream size, shape, and roughness, and
- storage volumes.

HDDS accommodates the first five items, and are discussed here. The last two items are by no means unimportant, but are beyond the current scope of this work.

Generally, the process of establishing parameters for use in hydrologic is manual: drainage area size and shape, watershed slopes and stream geometry still are established by interpretation of topographical maps, field survey data, and aerial photographs. Aerial photographs, land use maps, and vegetation maps are used to determine land use and land cover within a watershed. Soil information is acquired from county soil maps and soil reports. Design rainfall data is usually acquired by interpolation of rainfall depth-duration-frequency maps or tabular data.

The digital data requirements for hydrologic analyses are similar to those required using manual methods. **Table 4-1** presents a comparison of paper sources with digital data sources for hydrologic parameter development. An important consideration for spatial data is that of geospatial reference information including projection parameters, horizontal datum, and, if applicable, vertical datum. These were discussed in Section 3.2. All spatial data for a particular analysis must use the same geospatial reference parameters. The spatial data contained in HDDS have been set up in an Albers Equal Area projection, heretofore referred as the HDDS projection, with the parameters shown below.

Horizontal units: meters

Vertical units: meters

Spheroid: GRS 1980

Datum: NAD 83

First standard parallel: 29 30 00

Second standard parallel: 45 30 00

Longitude of origin: -96 0 00

Latitude of origin: 23 0 00

False Northing: 0.0

False Easting: 0.0

These parameters are used to represent data covering the contiguous United States, although most existing data uses NAD 27 as the horizontal datum. If a system such as HDDS was to be implemented for Texas, it would be preferable to set up all data using the Texas Statewide Mapping System projection parameters. This has not be done here for the following reasons:

1. Much of the source data were already in the nationwide projection.
2. By minimizing the amount of projection transformations, it was expected that projection errors would be minimized.
3. The main goal of this work is to demonstrate the potential of using a system such as HDDS for development of hydrologic data, not necessarily to have a version that is to be implemented.
4. If this type of system is to be used for nationwide analysis, the current projection parameters would be appropriate.
5. The possible application of scale factor adjustment techniques such as those discussed in Sections 3.2 and 4.2.2 could help negate or reduce the need for different projections for analysis at different locations. (Output generation would still employ the most appropriate projection).

Table 4-1: Comparison of Sources of Paper Data and Digital Data

Parameter	Paper Format	Digital Format
Location	Texas County maps (TxDOT), USGS topographical maps (1:250 K and 1:24 K scale)	Digitized highways, county boundaries, major cities.
Drainage area	USGS topographical maps, field survey data	Digital elevation models, digitized aerial photogrammetric data
Path Length and slope	As above	As above
Soil type	SCS County soil maps and reports	STATSGO (SCS)
Land use	Aerial photos, vegetation maps	GIRAS land use/cover
Rainfall depth	Rainfall depth-duration-frequency maps (e.g. TP 40)	Digitized spatial data by county

Data Sources

Table 4-2 presents a list of the existing data types, their sources, and original formats that have been used in HDDS.

Table 4-2: Data Sources for HDDS

Data	Source	Source Format	Georeferenced
15 arc second DEM	USGS - Oklahoma	ASCII	Yes
3 arc second DEM	USGS - Internet	ASCII	Yes
30 m DEM	USGS - Sioux Falls	ASCII	Yes
1:2 M highways	USGS - Internet	Digital Line Graph	Yes
1:2 M streams	USGS- Internet	Digital Line Graph	Yes
1:250 K land Use	USGS - Internet	Arc/Info - polygon	Yes
1:2 M drainage basins	USGS - Internet	Arc/Info - polygon	Yes
Hydrologic soil group	SCS STATSGO	Arc/Info - polygon	Yes
Stream gauge records	USGS-Austin	Tabular - ASCII	No
Stream gauge sites	USGS - Austin	Arc/Info - point	Yes
TP 40 24 hour rainfall	National Weather Service	Paper Contour Map	No
Texas county boundaries	USGS CDROM	Arc/Info - Polygon	Yes
1:250 K quadrangle index	USGS CDROM	Arc/Info - Polygon	Yes
1:24 K quadrangle index	USGS CDROM	Arc/Info - Polygon	Yes
Hydrologic regions	TxDOT	Paper map	No
Hydrologic Region boundaries	USGS - AUSTIN	Arc/Info - line	Yes
Rational Method rainfall coefficients	Texas Department of Transportation	Paper Tables	No
Texas state boundary	ArcUSA CDROM	Arc/Info - line	Yes

Data Development

Several data sets have been created which have been compiled into two packages, a large and a small set. For the large package, three data sets exist. One is based on 1:2000,000 (1:2 M) scale data, covers the whole of Texas and is entitled “tx”. The second is based on 1:250,000 (1:250 K) scale data covering an area of Northeast Texas near Paris and is entitled

”g”. The third set is named “s” and comprises processed 1:24 K data which covers two tributaries of the North Sulphur River. Short names are used to help minimize file name sizes. For the small package, the same named sets exist, but the data set “tx” covers the same geographic extent of Northeast Texas as set “g” at a 1:2 M scale. The set “g” is identical to the large package. The data was split up this way because the large package was difficult to transfer to other systems for testing and demonstration. Obviously, the larger package would be preferable for statewide implementation.

Table 4-3: Database Coverages

Data name	Feature type	Description	Primary attributes
raingrd	GRID	Design rainfall data	Rational method coefficients & 24-hour rainfall
txacc *	GRID	Flow accumulation	Cell value = no. of cells accumulated
txfil *	GRID	Filled DEM	Cell value = elevation
txstrms *	GRID	DEM-based streams	Cell value = 1
txrdgrd *	GRID	DEM-based roads	Cell value = txrds-id
txbas *	GRID	Drainage basins	Cell value = zone id
txslnk *	GRID	Stream links	Cell value = txsarc-id
txdir *	GRID	Flow direction	Cell value = direction
txslope *	GRID	Cell slope	Cell value = percent slope
arcbasns	POLYGON	Major Texas drainage basins	basin#, basinname
gsrgns	POLYGON	Hydrologic regions	Region#
statsgo	POLYGON	Soil data - soil names and percent hydrologic group	muid, muname, a-pct, b-pct, c-pct, d-pct
txcnty	POLYGON	Texas county boundaries	State_fips, state_name, cnty_fips, cnty_name
txlus	POLYGON	Texas land use	Anderson level II landuse code
tx24ndx	POLYGON	Index of 1:24 K quadrangles	Quadrangle name
tx250ndx	POLYGON	Index of 1:250 K quadrangles	Quadrangle name
txpoly	POLYGON	Texas state boundary	state_fips, state_name
txsarc *	LINE	Vector coverage of streams (txslnk)	txsarc-id = txslnk cell value
txrds *	LINE	major Texas (&OK) highways	txrds-id , hwy_name
txgages	POINT	Stream gauge sites	txgages_id, area, discharge

* also available at 1:250 K scale with prefix “g” instead of “tx” and 1:24 K scale with prefix “s”.

The large package data set “tx” was established manually, using the procedures outlined below. The sets “g” and “s”, and the small package set “tx” were created using the data preprocessor within HDDS (which is described in Section 4.2.2).

Table 4-3 presents a list of the digital data employed in this system and the relevant attributes. The following sections discuss the creation of the components of the aforementioned data sets.

Digital Elevation Model Data

Digital Elevation Models (DEM’s) are files that contain a uniform grid of ground elevations. This type of data can be used for a wide variety of applications, including watershed delineation, which require digital description of the topography. The elevation assigned to a cell within the grid represents the ground elevation at the centroid of the cell. Digital elevation data are available from the United States Geological Survey at 1:2 M and 1:250 K scales for the whole US, and limited 1:24 K data are available.

The DEM data are crucial to the success of HDDS: a majority of the procedures rely on the digital elevation data. These are discussed in Section 4.2.

The 1:2 M (15 arc second) elevation data, which cover the contiguous United States, are experimental (unpublished) and were acquired from the USGS (Rea, 1994). The elevation sampling was at 500 m intervals. The original data are in Albers equal area projection, using the nationwide parameters discussed above, and the elevations are referenced to NGVD 1929.

For use in HDDS, the original 1:2 M scale data were converted to from an image format to an Arc/Info GRID format by Mizgalewicz (1994). Then, a window was set around the original data to create a data set which covered the whole of Texas and the approximate extent of all drainage basins that enter Texas.

The DEM data often contain artificial sinks and peaks (see discussion of problems) which may be eliminated using the GRID command **FILL**. This command allows the user to specify a limit within which peaks or sinks will be removed, however, it is unlikely that one threshold would be applicable to all instances, making an iterative approach necessary.

The 1:250 K DEM data are available from the USGS in 1 degree by 1 degree blocks (quadrants). The data are in geographic coordinates, horizontally referenced to the WGS 84 datum. Elevation data are in meters, vertically referenced to NGVD 1929 and sample spacing is 3 arc seconds (USGS, 1993, pp. 5). Individual quadrants are retrievable by binary file transfer protocol (ftp) from the following World Wide Web site:

http://edcww.cr.usgs.gov/glis/hyper/guide/l_dgr_demfig/ni14.html.

Two adjacent quadrants, Sherman East and Texarkana West, in Northeast Texas, were downloaded for use in HDDS. After downloading, it was necessary to delimit each file using the following UNIX command:

dd if=infile of=outfile ibs=4096 cbs=1024 conv=unblock

The resulting files were then imported into Arc/Info as a lattice using :

DEMLATTICE <infile> <outfile>

The above command must be issued from the ARC prompt, even though the resulting file is a grid coverage.

Since the original 1:250 K DEM data are in geographic coordinates, subsequent operations such as determining flow directions, cell slopes, and watershed areas, would be completely meaningless unless the data is projected. The subject quadrants were projected into the HDDS projection (Albers Equal Area). In addition to normal rounding errors, this process introduces sampling errors since the centroids of the cells in the projected file do not conform with the spacing of the original geographic data. The resulting spacing for the projected files was about 93 m. (This would vary with latitude for other data sets).

The two blocks of data (Sherman East and Texarkana West) were then merged to create a contiguous grid covering the extent of the North Sulphur River.

Once the data were in GRID format, projected and merged, the operations on the 1:250 K data and the procedures were the same as those described for the 1:2 M data.

As indicated earlier, only limited 1:24 K scale DEM coverage of Texas is available. The 1:24 K scale data consist of rectangular arrays of elevations horizontally referenced in the

UTM coordinate system using NAD 27. They are set up in 7.5-minute quadrangles. The sample spacing is 30 m, the elevations are in meters and are vertically referenced to NGVD 1929 (USGS, 1993, pp. 2&3).

Two quadrangle data files, Ladonia and Honey Grove, were obtained from the USGS (Dunn, 1995). These two adjacent quadrangles cover about one fifth of the geographic extent of the aforementioned 1:250 K data. The procedures for creating an Arc/Info GRID of the 1:24 K data are similar to those described for the 1:250 K.

An important issue for all scales of DEM data is whether the projecting of individual grids should precede the merging process. Without doubt, if the data are in UTM and extend across different UTM zones, the DEM's should be projected individually before merging into one grid. This is recommended here because the boundaries of adjacent blocks of data do not match. The process of transforming into a consistent projection should create matching boundaries (accuracy limitations notwithstanding). For DEM data in geographic coordinates, the order may not be so important, though it may be preferable to merge the individual blocks prior to projecting the data. This should reduce processing time and potential projection errors. In geographic coordinates, adjacent blocks of data should join without any erroneous gaps.

Potential Problems Related to DEMS

The most common problem results from errors in the sampling process which incur either false elevations, no data or artificial peaks and sinks. A sink is a topographical condition in which water collects to a point which has no outfall. For hydrologic analysis, artificial sinks are more worrisome than peaks because they could reduce the number of cells that should be contributing to the drainage area. In this project, all sinks, whether natural or artificial have been eliminated. It is recognized that for detailed analysis, it is necessary to differentiate between the natural sinks and artificial ones.

The GRID documentation (ESRI, 1991, pp. 1-14) leads the user through an involved process to identify sinks using the command **SINKS**. This process can be precluded by subtracting the original DEM from the filled DEM. All the cell locations that have not been filled will result in a value of zero, while those that have been filled will have values that represent the depth of the original sink. If the user has topographic maps or a knowledge of the terrain, the user may decide which, if any sinks are natural. There are means by which the user can then add the natural sinks back into the filled grid, or refill the original grid using an appropriate threshold.

Flat surfaces such as lakes and reservoirs pose potential problems similar to those associated with artificial sinks. The cells representing the water surface may be lower than any cell surrounding the water body, creating a sink. In reality, water may be released through gates at a much lower elevation. The elevation sampling accommodates only surface elevations.

Generally, sea level is represented by the value zero in the USGS DEM data. When issuing the **FLOWDIRECTION** command, the expanse of zero values associated with the sea results in meaningless flow directions which affect subsequent analysis. To avoid this problem, the **SETNULL** command may be used on the filled DEM prior to performing a flow direction analysis. This assigns all cells having a specified value (e.g. zero) as NODATA. The disadvantage is that any ground elevations of zero will also be eliminated.

Land Use Data

The USGS has land use/land cover data available mostly at the 1:250 K scale and some 1:100 K scale. The information contains georeferenced polygons in GIRAS format with land use codes assigned as attributes.

Originally, several 1:250 K quadrangles were downloaded from the Internet from the following FTP site:

http://sun1.cr.usgs.gov/glis/hyper/guide/1_250lulcfig/states/TX.html.

Table 4-4: Anderson Level I and Level II Land Use Codes

Level I		Level II	
Code	Description	Code	Description
1	Urban or Built up Land	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation, Communications and Utilities
		15	Industrial and Commercial Complexes
		16	Mixed Urban or Built-up land
		17	Other Urban or Built-up land
2	Agricultural Land	21	Cropland and Pasture
		22	Orchards, Groves, Nurseries, and Ornamental Horticultural Areas
		23	Confined Feeding operations
		24	Other Agricultural Land
3	Rangeland	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	Forest Land	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	Water	51	Streams and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
6	Wetland	61	Forested Wetland
		62	Nonforested Wetland
7	Barren Land	71	Dry Salt Flats
		72	Beaches
		73	Sandy Areas Other than Beaches
		74	Bare Exposed Rock
		75	Strip Mines, Quarries, and Gravel Pits
		76	Transitional Areas
		77	Mixed Barren Land

Abstracted from USGS (1986, pp. 4)
Note: Codes for Tundra and snow or ice cover were omitted.

The data were imported into Arc/Info using the ARC command GIRASARC, however, on attempting to join adjacent quadrangles, it was noticed that an excessive non-conformal overlap was occurring. It is the author's belief that, although the original data are reported to be in UTM projections, the x and y shifts (origins) differ from quadrangle to quadrangle with no recorded information about these parameters. This problem could have been overcome by measuring the overlap and projecting each quadrangle using the measured overlaps as false eastings and false northings. However, existing land use coverages by drainage basin were acquired from the USGS (Tan, 1995). These coverages were then merged, projected into the HDDS projection, and cleaned to create coverage of the State of Texas. The original files contained only the Anderson Level II land use codes which appear in **Table 4-4**.

Hydrologic Soil Group Data

The Soil Conservation Service provides a spatial database of soil characteristics called the State Soil Geographic Data Base (STATSGO). STATSGO contains georeferenced polygon data of soil types which are available for the whole United States and are based on a generalization of detailed soil report and are mapped on U.S. Geological Survey 1:250 K scale topographic quadrangle maps. The data contain an extensive array of soil attributes contained in several cross-referenced tables. The data are available in Arc/Info format but some considerable processing was involved to link appropriate data and eliminate unwanted data. For this project, the soil names and percentages of occurrence of soils in each of four hydrologic soil groups (A, B, C, and D) were considered to be sufficient. A sample of the soils and hydrologic groups appears in **Table 4-5**: the complete data set consists of more than four thousand soil names and so is not shown here. Group A represents the best draining soils such as dry sands, while Group D represents soils of poor drainage quality such as heavy clays as discussed in Section 3.3.3.

Table 4-5: Sample of Hydrologic Soil Group Data

STATSGO ID	MUID	MUNAME	A PCT	B PCT	C PCT	D PCT
488	TX530	SPURLOCK-GRUVER-TEXLINE (TX530)	0	76	15	9
489	TX213	GRUVER-DUMAS-SUNRAY (TX213)	0	64	29	7
490	TX049	CONLEN-BERTHOUD-PASTURA (TX049)	2	62	0	36
491	TX213	GRUVER-DUMAS-SUNRAY (TX213)	0	64	29	7
492	TX108	CONLEN-SUNRAY-SPURLOCK (TX108)	0	88	4	8
493	TX124	DALLAM-DALHART-DUMAS (TX124)	1	98	1	0
494	TX049	CONLEN-BERTHOUD-PASTURA (TX049)	2	62	0	36
495	TX213	GRUVER-DUMAS-SUNRAY (TX213)	0	64	29	7

Hydrologic Regions

The hydrologic calculations employed in HDDS need a pre-defined hydrologic region as an input variable. For GIS analysis, a polygon coverage of regions is required. No polygon coverage was found, however, digitized line coverage of the boundaries between regions was acquired from the USGS (Ulery, 1995). A polygon coverage was created by placing a polygon of the Texas state boundary in the arc coverage of hydrologic regions. The hydrologic region arcs were then edited to ensure intersection with the Texas boundary using ARCEDIT and the polygons were built using **CLEAN**. (Note: CLEAN creates nodes at any intersection prior to attempting to build polygons. BUILD does not). The name (numerical id) of each region was then added to the polygon attribute table (PAT) using **ADDITEM** and **ADD** in the TABLES subsystem. The hydrologic regions are used to identify regression equations from which can be derived discharge versus frequency relationships as discussed in Section 3.3.1. **Figure 4-1** shows the coverage of hydrologic regions employed in HDDS.

Political

County boundaries and the Texas State boundary were abstracted from the ArcUSA 1:2 M compact disk using the **RESELECT** command within ARCPLOT. Items named FIPS_1, FIPS_2, FIPS_3 and FIPS_4 were used to isolate those arcs whose attributes contained the Texas code of 48. County boundaries were abstracted by reselecting arcs whose FIPS item contained the Texas code (48).

Design Rainfall Data

One of the hydrologic methods used here, the SCS runoff curve number method (discussed in Section 3.3.3), uses 24 hour duration design rainfall as appears in the National Weather Service Technical Paper 40 (1961). This publication includes maps with isohyetal lines for rainfall frequencies of 1 year, 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years. For HDDS, ASCII format tables were created containing the TP 40 rainfall for the 2 through 100 year frequencies abstracted by county (**Table 3-5**). The rain tables were imported into Arc/Info and joined to the ArcUSA 1:2 M county polygon coverages using the county name as the relate item. The unwanted attributes were removed and the remaining coverage was converted into a grid using POLYGRID. The polygon identifier was used to establish the cell values. The 2 through 100 year frequency rainfall items of the vector coverage were then joined to the VAT of the grid coverage. This was accomplished by adding the polygon id name as an alternate name for the cell value in the grid using the TABLES command ALTER. Then the vector coverage PAT and the grid VAT were joined using the polygon id as the relate item. This resulted in a grid with a VAT containing the design TP 40 rainfall values. **Figure 4-2** shows the distribution across Texas of the design 24-hour, 100 year rainfall.

In anticipation of incorporating the Rational method into HDDS, the rainfall intensity coefficients for all Texas counties were added as attributes in the same manner as that described for the TP 40 data. HDDS has not been set up to use this data at the moment since recommended use of the Rational method is limited to about 200 acres or less (TxDOT, 1985, pp. 2-14). The author considers the resolution of the DEM data currently available for use in HDDS to be too coarse for determining such small areas.

Highways and Streams

The USGS publishes 1:2 M scale Digital Line Graphs (DLG) of hypsography and transportation features (USGS, 1990) and are available from the following Internet address:

http://sun1.cr.usgs.gov/glis/hyper/guide/2milfig/mapindex

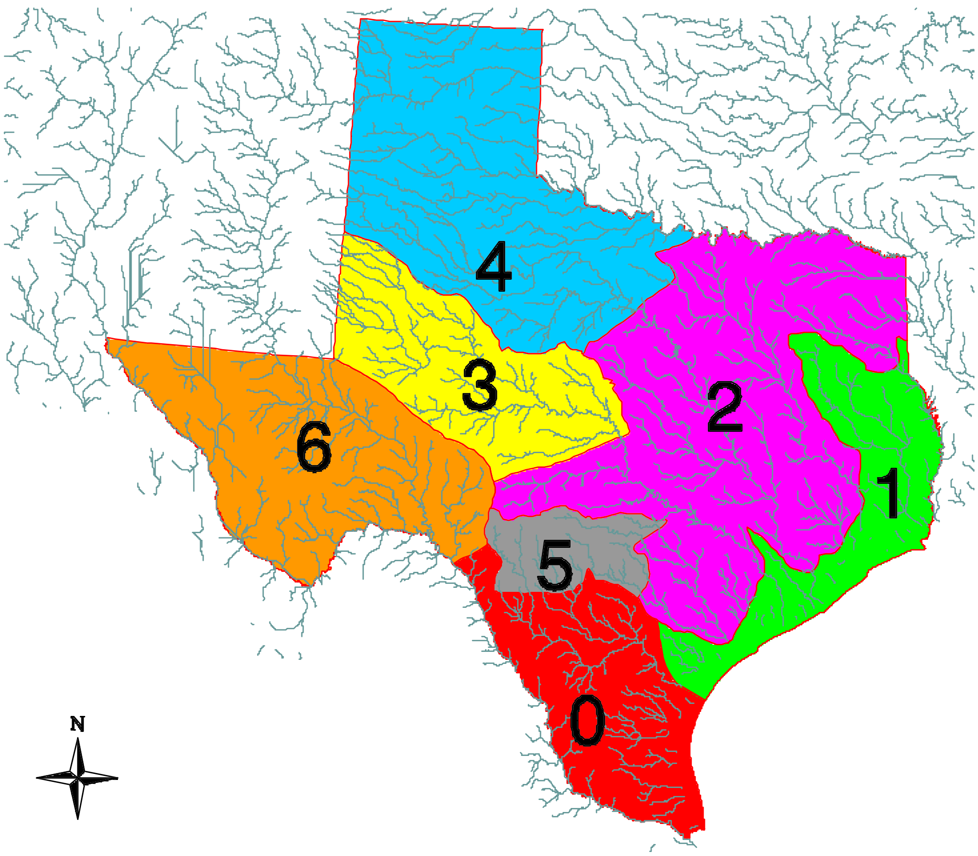


Figure 4-1:
HDDS coverage of hydrologic regions in Texas for regional regression equations
Number 0 represents undefined area.

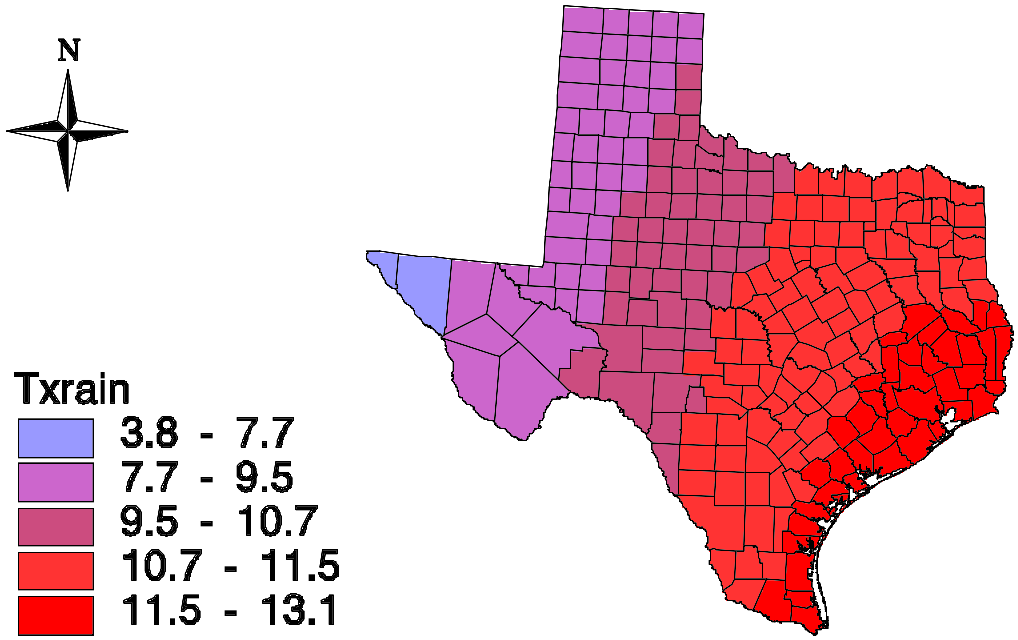


Figure 4-2:
Distribution of design 24-hour 100-year rainfall in Texas

Texas is covered by two portions (North and South). Two file types exist: standard and optional. It does not matter which is selected since Arc/Info seems to be able to use either. For highways, only major roads (e.g. Interstate and State highways) are presented. The attributes include items such as class but no highway names are included. Similarly, no names are available for the stream coverages. The following procedure was employed to convert the data into Arc/Info coverages. The optional file format was selected.

1. The downloaded file was delimited using the UNIX command

   dd if=<input> of=<output> ibs=8000 cbs=80 conv=unblock

2. The files were imported into Arc/Info using the ARC command

   DLGARC OPTIONAL <infile> <outcover> # ATTRIBUTED

3. Topology was established using the ARC command

   BUILD <incover> lines

4. Highway names were added as attributes of the highway vector coverage (txrds). Time constraints precluded attributing more than a few stretches of highway:

   In ARC Tables,

   ADDITEM txrds.aat hwy_name 7 7 C

   This specifies a data width of 7 characters, an output data width of 7 characters and the item type is alphanumeric (character)

5. Still in ARC Tables, the AAT for the highway coverage was opened: **SELECT txrds.aat**

6. The highway name was then added using **ADD** and following the prompts.

   Using the same approach other attribute data can be appended to the following:

   - Arc Attribute tables
   - Polygon attribute tables
   - Grid value attribute tables
   - Info lookup/relate tables.

No attributes were added to the streams at this stage, since the digital elevation model was used to delineate streams as discussed below. **Figure 4-3** shows the extent of highways and stream coverage at the 1:2 M scale.

Preprocessed Data

One objective of this project was to identify the procedures that are common to all hydrologic analyses and perform such procedures up front to minimize real-time processing. Several procedures were identified as being required for all sites, most of which involve sequential processing of the digital elevation data as follows:

1. Remove all sinks from the DEM using the GRID command **FILL**.
2. Compute flow directions using the GRID command **FLOWDIRECTION**.
3. Compute flow accumulation (number of cells contributing to a cell - not actual flow volume or rate) using the GRID command **FLOWACCUMULATION**.
4. Establish streams as being those cells with a flow accumulation in excess of some defined threshold using the GRID command **CON**.
5. Subdivide delineated streams into links with unique id's using the GRID command **STREAMLINK**.
6. Convert the links into a vector coverage using the GRID command **STREAMLINE**.
7. Determine general drainage basins (not individual drainage areas) using the GRID command **BASIN**.
8. Calculate the slope of each cell using the GRID command **SLOPE**.
9. Convert vector coverage of highways into grid using the GRID command **LINEGRID**.

The filling process was described earlier. **Figure 4-4** indicates the processing involved in steps (2) through (6). Since all cells in a grid, except boundary cells, have eight adjacent cells, there are eight possible directions in which flow may proceed from one cell to the next. Arc/Info uses a binary geometric series to define the directions: 1 = East, 2 = Southeast, 4 = South, 8 = Southwest, 16 = West, 32 = Northwest, 64 = North, and 128 = Northeast. The flow direction assigned is based on the steepest calculated slope between adjacent cells. Problems may arise where two or more directions yield the same "steepest" slope, in which case a unique direction would not exist. This problem is most likely to occur in flat terrain with coarse cell resolution. In such instances, the flow direction value in the cell reflects the sum of the individual flow direction codes. This allows identification of the problem cells.

The flow accumulation process counts the number of cells that contribute flow to a cell using the flow direction grid. At any given cell, the drainage area to the cell (but not including the cell) is the product of the flow accumulation value and the cell area.

The stream grid is determined subjectively as those cells whose flow accumulation value exceeds a threshold value. For HDDS, a threshold of 500 cells for the 1:2 M scale data and 1000 cells for the 1:250 K scale data were considered reasonable. Recent unpublished work suggests that a better threshold may be determined as a function of area and annual rainfall (Olivera, 1995, personal communication). However, for HDDS, and certainly for demonstration purposes, the threshold is not critical as long as it is low enough to include most highway stream crossings yet not so small as to create an inordinately excessive stream network and mislead a user into believing that a stream exists when in fact it does not. As an aside, it is worthwhile to note that, apparently, there has been no consistent method applied to the delineation of streams on the USGS 1:24,000 topographical maps. The use of drainage area, average annual rainfall, and possibly section geometry, in a GIS environment may be a suitable means of standardizing a method to designate streams.

Step (7) is similar to the watershed delineation process which is discussed in Section 4.2.2. However, instead of using user-specified pour points, the process considers any boundary cell or sink as a pour point.

The aforementioned procedures are time-consuming, yet perfunctory. They have been performed for each DEM data set and the resulting data have been added to the "permanent" database. Appendix A includes a preprocessing AML named preproc.aml which performs the above steps and may be applied to data for other areas. The preprocessor is discussed in Section 4.2.

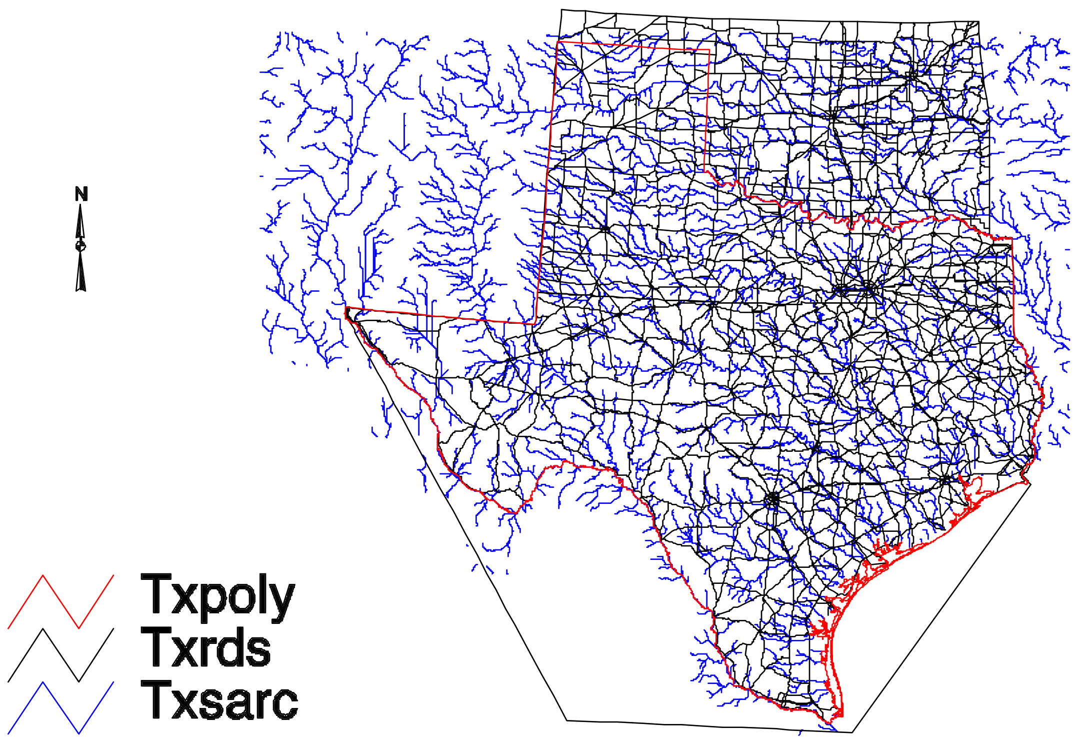


Figure 4-3: Extent of 1:2 M scale data

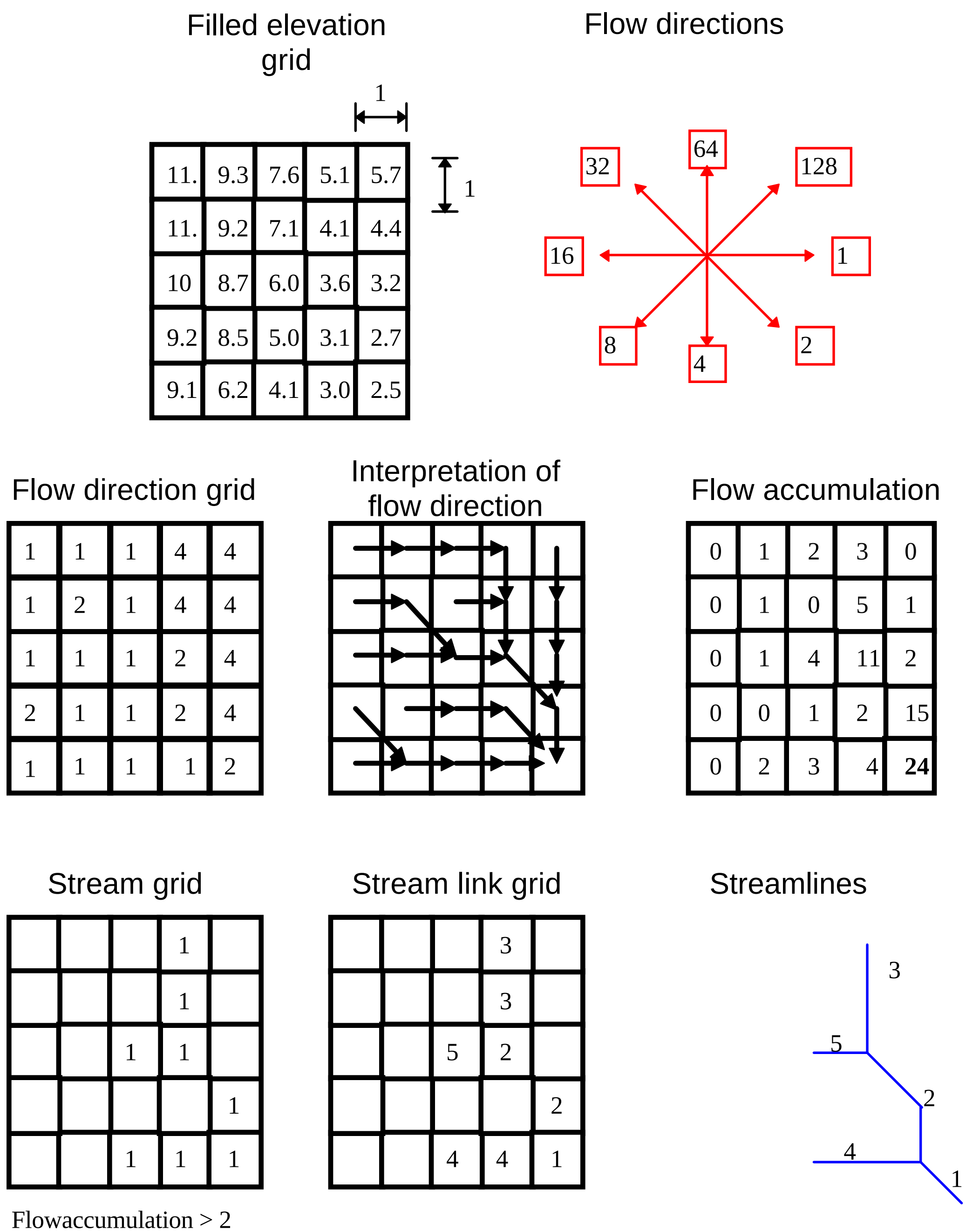


Figure 4-4: Processing the DEM grid

Relating Land Use and Soil Group to SCS Runoff Curve Number By Lookup Table

HDDS contains procedures which estimate Soil Conservation Service runoff curve numbers and times of concentration as discussed in Section 3.3.3. The curve numbers can be estimated by referencing tables which relate land use/land cover and hydrologic soil group to runoff curve numbers (**Tables 3-6, Table 3-7, Table 3-8, and Table 3-9**). A designer can establish a runoff curve number for a defined area by identifying land surface use/cover, determining which description best fits the surface cover and selecting the suggested RCN for the appropriate hydrologic soil group. A similar approach is employed in HDDS and is described in Section 4.3.3. Since the existing land use data (**Table 4-4**) are limited to sgeneral land use categories, and the SCS runoff curve number tables do not contain land use codes, a means of relating these with suggested runoff curve numbers was needed. **Table 4-6** was developed as an INFO table to relate hydrologic soil group and existing Anderson Level II codes and additional, more detailed codes to runoff curve number. As can be seen from **Table 4-4**, the Anderson Level II codes provide only general descriptions. These may be appropriate for small scale analysis or where more accurate description is not warranted. Surface descriptions appearing in **Tables 3-6 to Table 3-9** were grouped into appropriate Anderson Level II categories. The most conservative range of RCN's was taken to relate the Level II code to hydrologic soil group. For example, the Level II code 11 represents residential use. **Table 3-6** includes curve numbers for six different residential average lot sizes, for which the most conservative (highest values) is the range for 1/8 acre lots. The runoff curve numbers for soil groups A, B, C, and D are 77, 85, 90, and 92 respectively. These values were assigned to the Level II code 11. Since HDDS is intended for design, the author deems it appropriate to assign the most conservative values. However, on average, lower values may be reasonable. The detailed level codes were established by assigning numbers in which the first two digits relate to the assigned Level II group and the remaining digits are unique and sequential identifiers for the cover description. HDDS provides the capability of reassigning curve numbers to existing land use codes (see Section 5).

Some analyses will require a more refined description of land use than the Anderson Level II descriptions allow. A third level of description was established here by assigning land use codes (lucode) to **Tables 3-6**, **Table 3-7**, **Table 3-8**, **and Table 3-9**. These tables show the assigned codes for clarity, but the actual data used in HDDS appear in **Table 4-6**. This table is entitled “rcns.dat” in HDDS. The general steps employed to create this table follow:

1. An ASCII format table was prepared containing all the desired data without headers.
2. The INFO command **DEFINE** was used to establish an INFO data file frame in which the item names, field widths and data type were established. The items were named to conform with named items in appropriate coverage attribute tables. i.e. “lucode” is as appears in the polygon attribute table of the land use coverage “txlus”, and “hyd-a”, “hyd-b”, “hyd-c”, and “hyd-d” appear in the polygon attribute table of soil coverage “statsgo”.
3. The ASCII file was incorporated into the defined INFO file using the command **ADD FROM**.

By creating cross-referenceable items between the INFO table and coverage attribute tables, a “look up” capability results, the use of which is discussed in Section 4.2.

Table 4-6 also contains velocity coefficients, the use of which are described later. The values were estimated on the assumption that surface roughness characteristics can be related to land use/ land cover: Section 3.3.3 describes the relationship between velocity coefficient and surface cover description. The curves appearing in **Figure 3-16** can be described by **Eq.(4-1)**.

$$v = b \cdot S^{0.5} \qquad \textbf{(4-1)}$$

where,

v is the surface flow velocity (m/s),

S is the average topographical slope (m/m), and

b is a coefficient dependent on surface cover herein named velocity coefficient.

Table 4-7 presents calculated values of velocity coefficient for each cover description.

The velocity coefficients assigned in **Table 4-6** are subjective interpolations of the aforementioned curves: they were determined by the author on the basis of his judgement and experience of estimating velocities for computing time of concentration. HDDS provides the capability of reassigning these values as discussed in Section 5.

Table 4-6: Estimated Runoff Curve Numbers (RCN) and Velocity Coefficients

	Description		RCN by Hydrologic Soil Group				
LUCODE	DES_A	DES_B	HYD_A	HYD_B	HYD_C	HYD_D	VCOEFF
0	Incase-of-zero data		100	100	100	100	5.00000
11	Residential	Level_2	77	85	90	92	4.62000
111	Residential	1/8_acre	77	85	90	92	4.62000
112	Residential	1/4_acre	61	75	83	87	3.66000
113	Residential	1/3_acre	57	72	81	86	3.42000
114	Residential	1/2_acre	54	70	80	85	3.24000
115	Residential	1_acre	51	68	79	84	3.06000
116	Residential	2_acre	46	65	77	82	2.76000
12	Urban_85%_imperv	Comm_&_business	89	92	94	95	5.34000
13	Urban_72%_imperv	Industrial	81	88	91	93	4.86000
14	Streets_&_roads	Level_2	98	98	98	98	5.88000
141	Paved	parking_lots-roofs	98	98	98	98	5.88000
142	Streets_&_roads	Paved-curbs/gutter	98	98	98	98	5.88000
143	Streets_&_roads	Paved-open-ditches(w	83	89	92	93	4.98000
144	Streets_&_roads	Gravel(w/ROW)	76	85	89	91	4.56000
145	Streets_&_roads	Dirt(w/ROW)	72	82	87	89	4.32000
16	Mixed_Urban		80	86	89	92	4.50000
17	Other_urban	Level_2	89	92	94	96	5.34000
171	Western_Desert_Urban	Natural_desert	63	77	85	88	3.78000
172	Western-Desert-Urban	landscaping	96	96	96	96	5.76000
173	DEVELOPING-URBAN	Newly-graded-area	77	86	91	94	4.62000
18	Urban-Open-space	General	68	79	86	89	4.08000
181	Urban-Open-space	grass<50%	68	79	86	89	4.08000
182	Urban-Open-space	grass50%-75%	49	69	79	84	2.94000
183	Urban-Open-space	grass>75%	39	61	74	80	2.34000
21	AGRICULTURAL	Level_2	77	86	91	94	4.62000
2111	Fallow	Bare-soil	77	86	91	94	4.62000
2112	Fallow	CR-poor	76	85	90	93	4.56000
2113	Fallow	CR-good	74	83	88	90	4.44000
2114	Row-crops	SR-poor	72	81	88	91	4.32000
2115	Row-crops	SR-good	67	78	85	89	4.02000
2116	Row-crops	SR+CRpoor	71	80	87	90	4.26000
2117	Row-crops	SR+CR-good	64	75	82	85	3.84000
2118	Row-crops	C-poor	70	79	84	88	4.20000
2119	Row-crops	C-good	65	75	82	86	3.90000
2120	Row-crops	C+CR-poor	69	78	83	87	4.14000
2121	Row-crops	C+CR-good	64	74	81	85	3.84000
2122	Row-crops	C&T-poor	66	74	80	82	3.96000
2123	Row-crops	C&T-good	62	71	78	81	3.72000
2124	Row-crops	C&T+CR	65	73	79	81	3.90000
2126	Small-grain	SR-poor	65	76	84	88	3.90000
2125	Row-crops	C&T+CR-good	61	70	77	80	3.66000
2128	Small-grain	SR-good	63	75	83	87	3.78000
2129	Small-grain	SR+CR-poor	64	75	83	86	3.84000
213 0	Small-grain	SR+CR-good	60	72	80	84	3.60000

Table 4-6(cont.)

LUCODE	DES_A	DES_B	HYD_A	HYD_B	HYD_C	HYD_D	VCOEFF
2131	Small-grain	C-poor	63	74	82	85	3.78000
2132	Small-grain	C-good	61	73	81	84	3.66000
2133	Small-grain	C+CR-poor	62	73	81	84	3.72000
2134	Small-grain	C+CR-good	60	72	80	83	3.60000
2135	Small-grain	C&T-poor	61	72	79	82	3.66000
2136	Small-grain	C&T-good	59	70	78	81	3.54000
2137	Small-grain	C&T+CR-poor	60	71	78	81	3.60000
2138	Small-grain	C&T+CR-good	58	69	77	80	3.48000
220	Close-seeded	SR	66	77	85	89	3.96000
222	legumes	SR	58	72	81	85	3.48000
23	Farmsteads	Level_2	59	74	82	86	3.54000
24	OTHER-AG	General	68	79	86	89	4.08000
241	Grass	poor	68	79	86	89	4.08000
242	Grass	fair	49	69	79	84	2.94000
243	Grass	good	39	61	74	80	2.34000
244	Rotation	C-poor	64	75	83	85	3.84000
245	Meadow	C-good	55	69	78	83	3.30000
246	Meadow	C&T-poor	63	73	80	83	3.78000
247	Meadow	C&T-good	51	67	76	80	3.06000
248	Meadow	Non-grazed	30	58	71	78	1.80000
31	Herbaceous	Level_2	70	80	87	93	4.20000
311	ARID-SEMIARID-RANGE	Herbaceous-poor	70	80	87	93	4.20000
312	ARID-SEMIARID-RANGE	Herbaceous-poor	60	71	81	89	3.60000
313	ARID-SEMIARID-RANGE	Herbaceous-poor	50	62	74	85	3.00000
32	Shrub-and-Brush	Level_2	55	67	80	85	3.30000
321	Sagebrush	poor	55	67	80	85	3.30000
322	Sagebrush	fair	40	51	63	70	2.40000
323	Sagebrush	good	25	35	47	55	1.50000
324	Desert-shrub	poor	63	77	85	88	3.78000
325	Desert-shrub	fair	55	72	81	86	3.30000
326	Desert-shrub	good	49	68	79	84	2.94000
33	Mixed-Rangeland	Level_2	48	67	77	83	2.88000
331	Brush_mix	poor	48	67	77	83	2.88000
332	Brush_mix	fair	35	56	70	77	2.10000
333	Brush_mix	good	30	48	65	73	1.80000
41	Deciduous_Forest	Level_2	55	66	74	79	3.30000
411	Oak-aspen	poor	55	66	74	79	3.30000
412	Oak-aspen	fair	37	48	57	63	2.22000
413	Oak-aspen	good	25	30	41	48	1.50000
42	Evergreen-Forest	Level_2	60	75	85	89	3.60000
421	Pinyon-juniper	poor	60	75	85	89	3.60000
422	Pinyon-juniper	fair	45	58	73	80	2.70000
423	Pinyon-juniper	good	25	41	61	71	1.50000
43	Mixed-Forest	Level_2	57	73	82	86	3.42000
431	Woods-grass	poor	57	73	82	86	3.42000
432	Woods-grass	fair	43	65	76	82	2.58000

Table 4-6 (cont.)

LUCODE	DES_A	DES_B	HYD_A	HYD_B	HYD_C	HYD_D	VCOEFF
433	Woods-grass	good	32	58	72	79	1.92000
434	Woods	poor	45	66	77	83	2.70000
435	Woods	fair	36	60	73	79	2.16000
436	Woods	good	30	55	70	77	1.80000
51	Streams-&-Channels		100	100	100	100	6.00000
52	Lakes		100	100	100	100	6.00000
53	Reservoirs		100	100	100	100	6.00000
54	Bays-&-Estuaries		100	100	100	100	6.00000
61	Forested-wetland		100	100	100	100	6.00000
62	Nonforested-wetland		100	100	100	100	6.00000
71	Dry_salt_flats		25	25	25	25	5.00000
72	Beaches		25	25	25	25	2.00000
73	Non_beach_sand		25	25	25	25	2.00000
74	Bare_rock		98	98	98	98	5.88000
75	Quarries-gravel_pits		0	0	0	0	0.01000
76	Transitional_areas		75	80	85	90	3.00000
77	Mixed_Barren_land		75	80	85	90	3.00000

Table 4-7: Calculated velocity coefficients

Cover Description	Velocity Coefficient (b)
Forest	0.7495
Fallow	1.4158
Short Grass	2.0821
Bare Ground	2.9147
Grassed waterway	4.5804
Paved	5.4138

4.2 HDDS Technical Procedures

4.2.1 Database Design

Figure 4-5 shows the directory layout for HDDS. The system consists of a main directory, and four sub-directories as follows:

1. The previous section outlined the digital data employed in this project. These data layers were established as the permanent database from which hydrologic analyses could be performed within the geographical extent of the data.
2. The macros, menus and message files were grouped together. For larger systems it may be desirable to provide separate sub-directories for each type, however, grouping these allowed easier programming.
3. Only one lookup table is currently present, rcns.dat, described earlier.
4. A user could choose to establish a workspace in any location. This example includes the workspace as a sub-directory of HDDS.

Once a database has been established an almost limitless number of possibilities exist for subsequent analysis. A system of menus, macros, and text files were established to perform the following "on-the-fly" analyses or functions:

- selection of database,
- creation of workspace,
- preprocessing of DEM data and highway coverage,
- viewing of basins, highways, streams coverages, and user-selected data,
- identification of watershed outlet (outfall) by intersecting stream and road, or user-identified cell or polygon,
- selection and relocation of stream gauges
- drainage area delineation and measurement,
- longest flow path delineation and measurement and ellipsoidal scale factor adjustment,

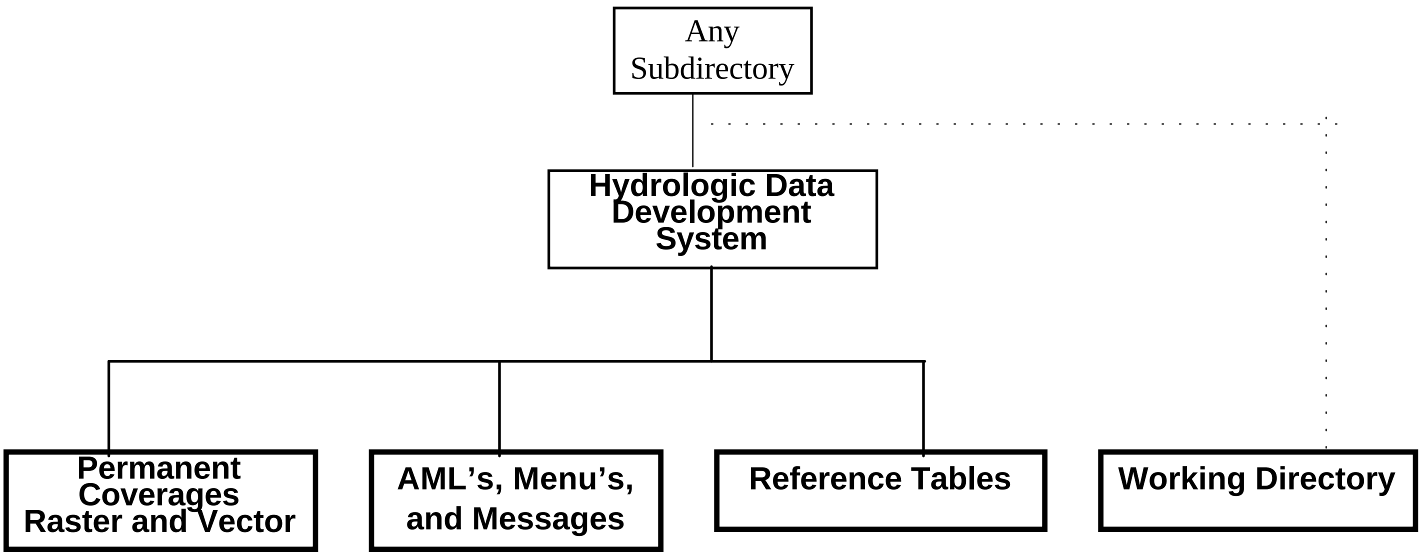


Figure 4-5:
Database layout for the Hydrologic Data Development System

- average watershed slope determination,
- watershed shape factor,
- subarea delineation and measurement,
- land use code designation/modification,
- weighted SCS runoff curve numbers by watershed or subarea,
- designation of overland and in-stream flow velocities,
- calculation of watershed and subarea times of concentration,
- hydrologic region designation,
- determination of required higher resolution quadrangles (1:250 K and 1:24 K DEM),
- execution of external hydrologic program (THYSYS),
- clipping of watershed hydrologic soil group data,
- clipping of watershed location data (political), and
- cleaning up of workspace.

Analyses may be performed in any user-created workspace.

4.2.2 Program Components

This section discusses the significant steps incorporated in HDDS. Flow diagrams of main menu routines and sub-menus are presented in **Figures 4-6**, **Figures 4-7**, **and Figures 4-8**. Annotated menus and routines are provided in Appendix A.

HDDS employs a combination of Arc/Info vector processing (ARC), raster or cell-based processing (GRID) and Arc Macro Language (AML) to determine hydrologic parameters. In general, vector coverages of features are overlaid upon a raster (GRID) image of major drainage basins. The drainage basin grid is used primarily as a visual aid. That is, a backdrop for other data such as streams and highways to be displayed. Vector coverages are used for visual aid, identification of features, clipping of data, and storage of hydrologic parameters determined within HDDS. The majority of hydrologic parameters are determined using cell-based processing. All hydrologic parameters determined by HDDS are

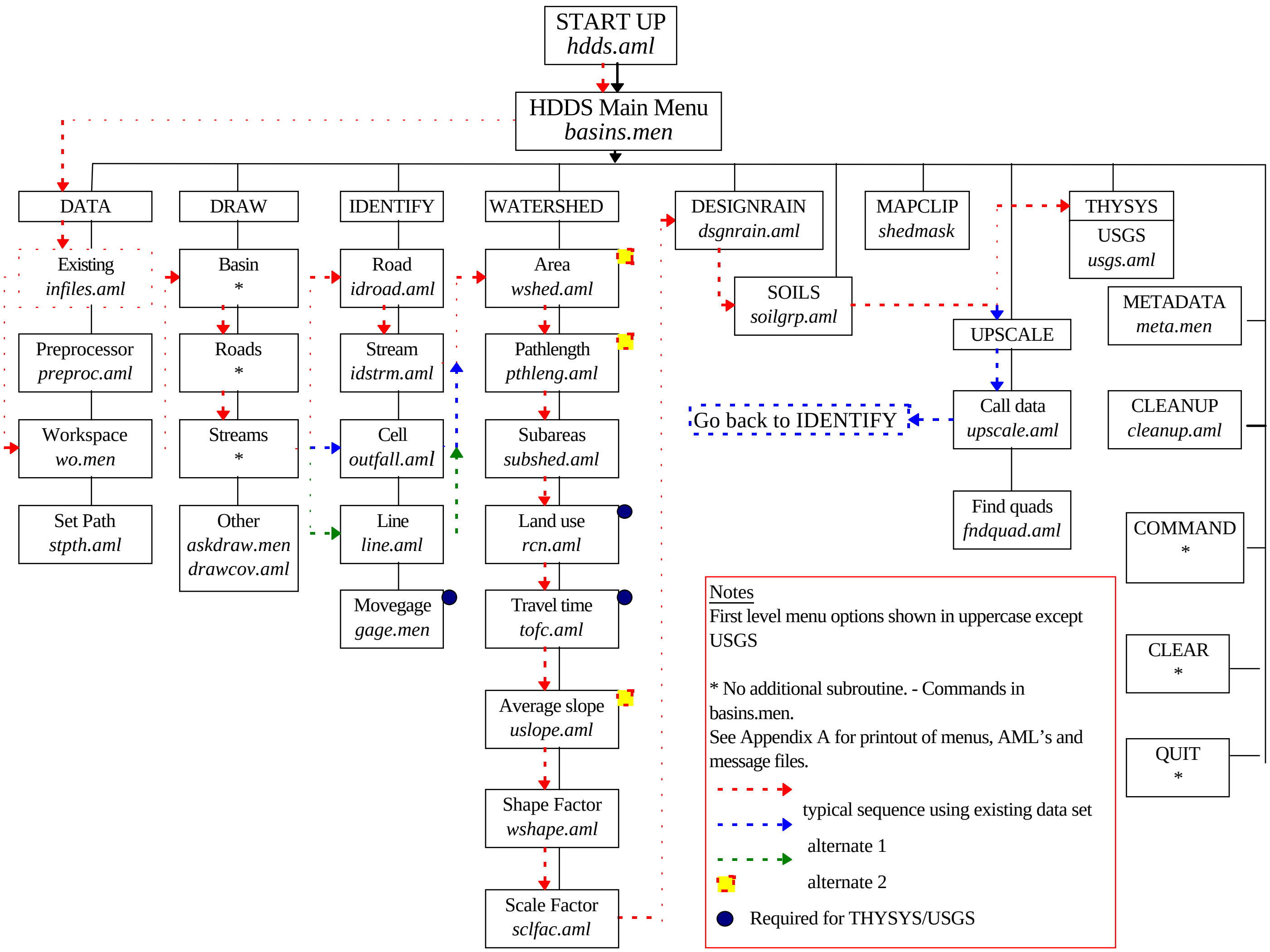


Figure 4-6: HDDS Main Menu Options

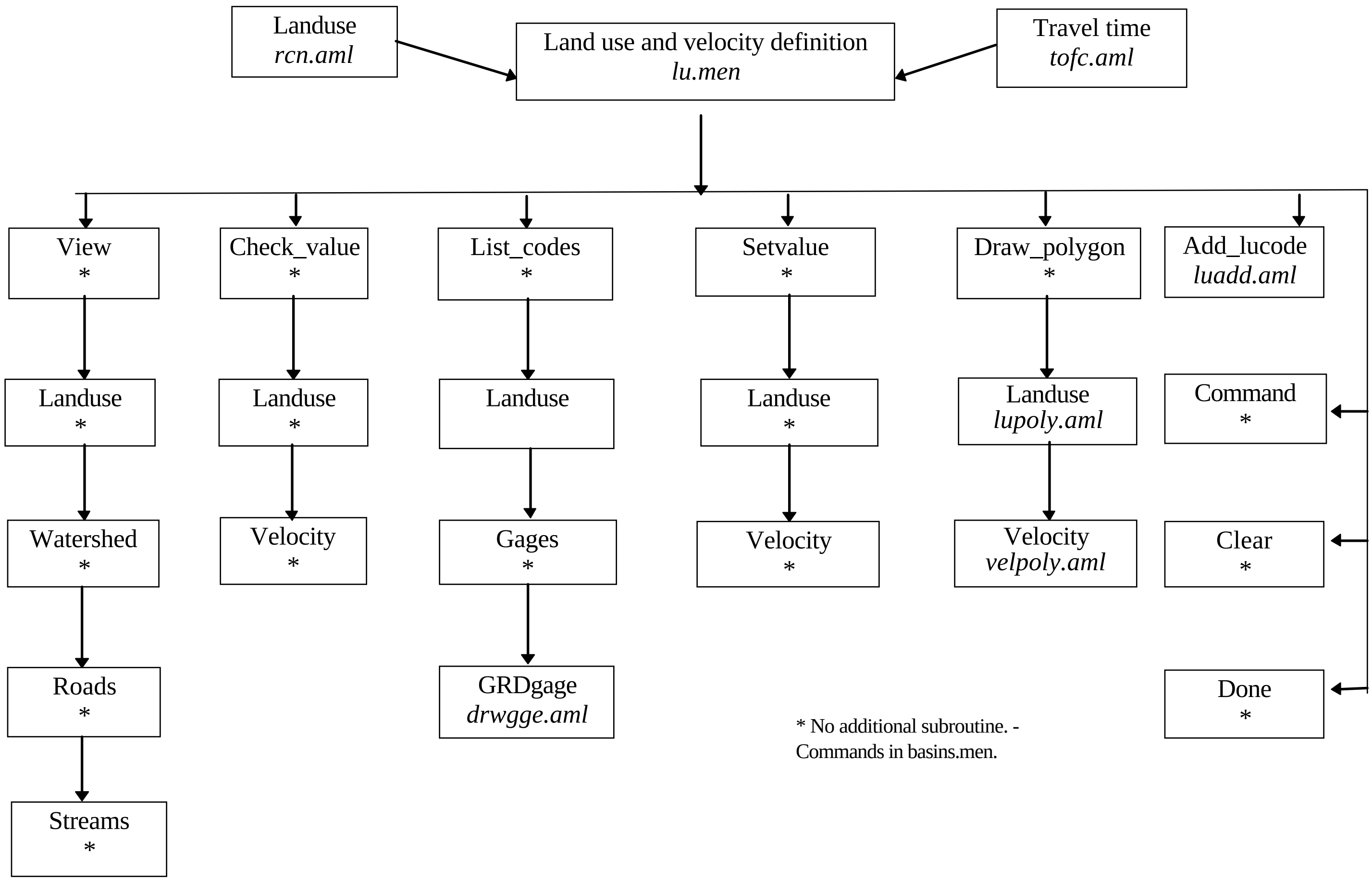


Figure 4-7
Menu layout for defining land use and velocity

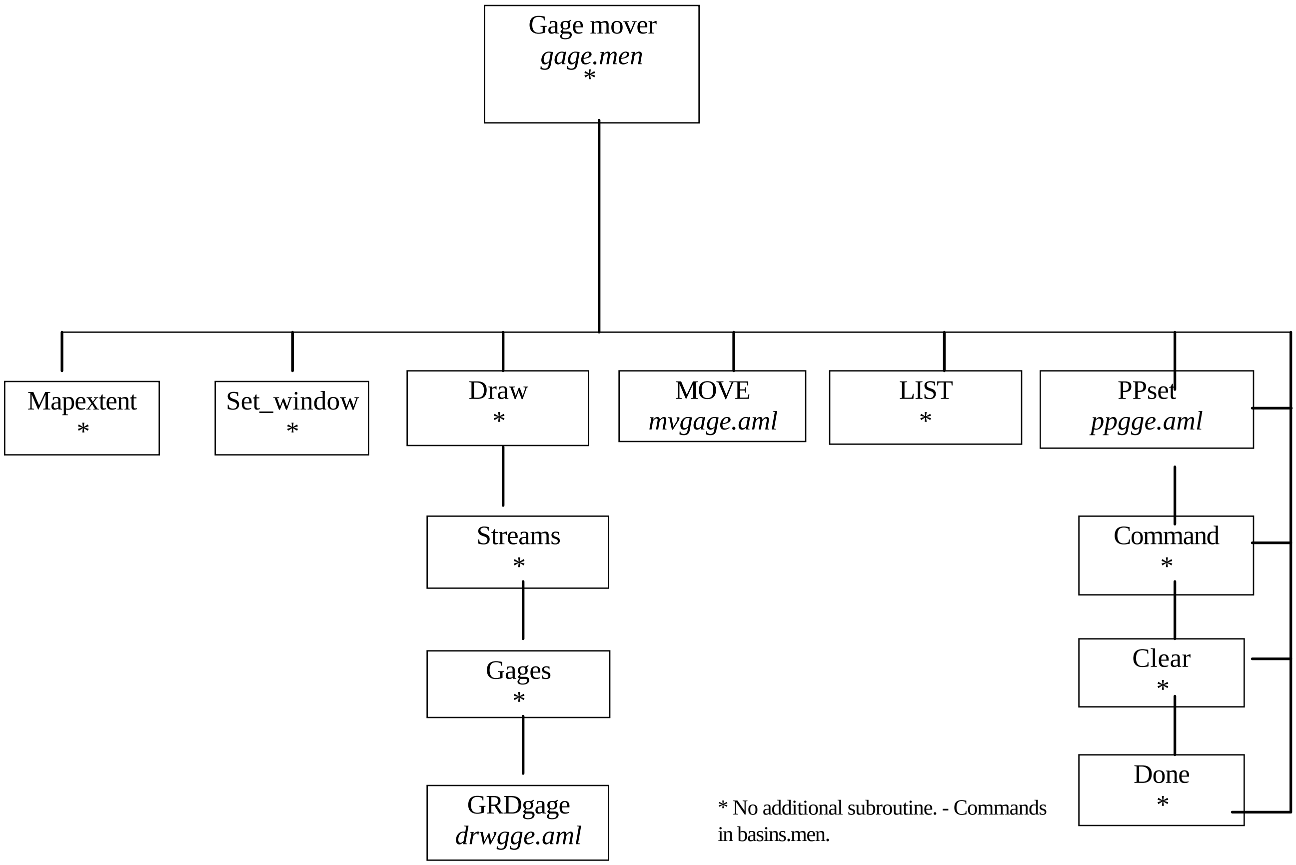


Figure 4-8: Menu layout for Gage Mover

added as attributes to either the delineated watershed or subarea coverage polygon attribute tables (PAT's). Calculated values that might be used in subsequent calculations within HDDS are stored as global variables.

Menus and Macros

HDDS comprises a main menu (basins.men) which is invoked from a variable initialization routine (hdds.aml). The initialization routine establishes default parameters and station settings such as the terminal and display environments. The main menu provides a user-interactive means of initiating functions or other macros which, in turn, may invoke sub-menus and macros.

File Naming Convention and Output Files

Rather than request user-defined file names, a simple convention is employed to minimize the need for user input: any grid or coverage that is created for other than temporary storage is named using three parts: (1) a prefix which represents the data set on which the process has operated, (2) an abbreviation representing the operation used to create the output, and (3) a user-defined suffix to make the name unique. The same suffix is applied to all created data during a particular series of analysis. For example, if the user uses the "tx" data set and specifies the suffix to be "BP", the grid of watershed area will be "txshedBP". If the user specifies a suffix for which files already exist for the current data set, the program will request a new suffix.

Data Preprocessor

The original data set "tx" was established manually as described in Section 4-1. A data preprocessor AML (preproc.aml) has been developed which emulates these steps. The preprocessor may be used on any Arc/Info format digital elevation grid to generate a new data set on which HDDS may operate. The routine also converts user-specified highway coverages in to grid coverages. Currently, this preprocessor is set up assuming the elevation data are in Texas so that the existing data such as design rainfall, land use, and soils data can be employed. However, it should not be difficult to modify the routines to accommodate data from other geographic regions.

Generally, the methods employed in the preprocessor are the same as those outlined in Section 4-1. However, automation of the map projection process required additional steps to overcome deficiencies in AML: the Arc/Info projection process allows a preset ASCII file containing input and output projection parameters. This is satisfactory only if projection files of the input coverage are always the same or if the user can create a specific ASCII projection file. In many instances, especially when the original data are in UTM, the input file projection parameters will vary. Arc/Info version 7.01 will not simultaneously determine the input projection parameters from the existing coverage and read an ASCII file of only output parameters.

A routine was developed to accommodate these shortcomings such that the user need not provide the appropriate parameters. Two ASCII files (utmalb.prj and geoalb.prj, Appendix A) were created in which the input projection parameters are defined as global variables and the output parameters are specified as those required for HDDS. The routine in preproc.aml (Appendix A, lines 173-179) uses the ARC command DESCRIBE to determine the input projection parameters and assigns the appropriate values to the same variable names as those established in the ASCII projection file. A conditional statement determines which projection file to use based on the selected scale of DEM data. When the projection process uses the projection parameter file, global variables are read for the input projection parameters and the fixed parameters are read for the output projection (Appendix A, preproc.aml, lines 180-194). This process could be modified further to avoid the need for two separate projection files.

Data Set Selection

The AML routine "infiles.aml" (Appendix A) allows a user to select a desired data set using standard AML procedures. As long as any new data sets are stored at the same directory level as the existing data sets ("tx" and "g"), they will be automatically available for selection. The name of the selected data set is stored as the prefix name (a global variable) for all subsequent data acquisition and file naming as discussed above.

Display Coverages

No analysis can be performed until data coverages have been displayed. The primary display coverages are major drainage basins (grid), major highways (lines), and streams (lines). Menu options in "basins.men" contain strings of standard ARCPLOT commands which draw these coverages on request. These coverages are the most basic display requirements for performing a hydrologic analysis at an existing highway crossing of a stream. If analysis at a location other than a highway is desired, other user-created vector coverages may be overlaid on the base data for visual aid.

Outfall Identification

A highway stream crossing constitutes the outfall to a watershed when the crossing is the subject of a hydrologic analysis. This would be the case for design of replacement bridges or culverts. No existing method is apparent in Arc/Info to easily and consistently select a specific location to be identified as an outfall. Several methods have been developed within HDDS for identification of an outfall location:

1. Highway/stream intersection
2. User-defined cell(s)
3. User-defined polygon(s)
4. User-adjusted stream gauge location(s).

The first method is designed for analyses at existing highway crossings of streams and relies on the presence of highway and stream coverages in both vector and grid format. The data were created such that the cell values of each gridded highway and stream link match the identifiers of the associated arc (vector coverage) of each highway and stream link respectively. The ARCPLOT RESELECT command is used to select interactively and store the identifiers of a desired highway and a stream. (Appendix A, idroad.aml, line 28 and idstrm.aml, line 27). In GRID, a conditional (CON) statement is employed to determine the cell at which the stream id and highway id are coincident (Appendix A, wshed.aml, line 53). The resulting cell is then stored as an outfall grid (or pour point) in which only one cell has a value of 1. **Figure 4-9** illustrates the process. It should be noted that, occasionally, a highway may cross the same segment of stream (arc) more than once, in which case more than one pour point could exist. The system will use the cell containing the lowest value, which may not be the desired location. One way to avoid this problem would be to modify the original highway or stream coverage by adding nodes between the highway/stream crossings to create intermediate arcs. This has not been performed for this project.

In some cases, an analysis may be desired at a stream location where no highway currently exists. Methods 2 and 3 were established for such instances. The cell method is the most simple in terms of programming: the GRID command SELECTPOINT is used to select interactively and store the value and location of the selected cell of a defined grid. HDDS incorporates a counted looping routine which allows the user to select as many points as desired (Appendix A, outfall.aml). A grid is created in which each selected point is represented by a cell containing a unique but sequential value set by the counter.

The polygon method is similar to the cell method except the GRID command SELECTPOLYGON is employed. This is nested within a zonal routine and conditional statement which determines the maximum flow accumulation cell contained within the defined polygon. Multiple polygons may be defined to create a grid of pour points (Appendix A, line.aml).

The fourth method creates a grid of pour points based on a grid coverage of stream gauges created using the gauge mover tool (see "Gauge Mover" later in this section).

The highway/stream intersection method of outfall identification is the most secure and consistent of the aforementioned methods: the repeated selection of a highway link and the stream link over which the highway crosses will always yield the same pour point. The polygon method will always select a pour point that falls within a stream as long as the user-defined polygon contains a stream cell. However, since the polygon method selects the cell containing the highest flow accumulation, the most downstream cell within the polygon will always be selected as the outfall. Repeatability then, is dependent on the user's ability to

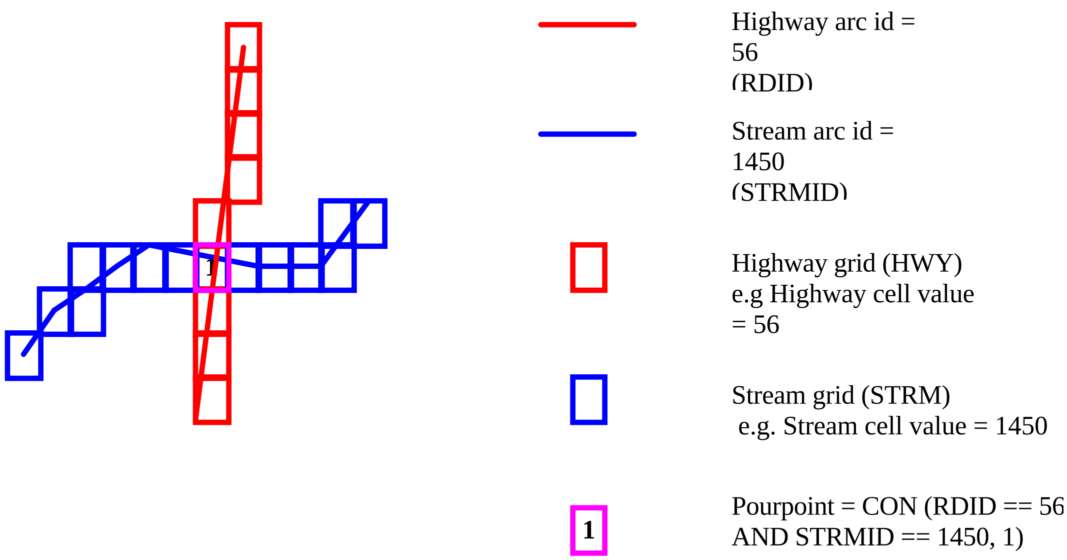


Figure 4-9: Locating the watershed outfall (pourpoint)

define a polygon in such a manner that the most downstream cell in the polygon is the desired location. Also, it is important that the defined polygon does not incorporate more than one stream. In many instances, the user may be satisfied with identifying the location of the outfall within an accuracy of one or two cells, in which case the polygon method will suffice.

The gauge location method is limited by the existence of stream gauges and the ability of the user to identify and select accurately the location of the gauge on a stream. Most stream gauges are sited on highway bridges, in which case it may be preferable to use the highway/stream intersection method.

The cell method is the least secure means of determining a pour point: the user must zoom in until the display resolution allows identification of individual cells. The cell selected may not always coincide with a stream (or highway) due accuracy limitations between the vector and grid coverages of streams and highways.

Watershed and Subarea Delineation

The outfall must be identified by one of the above methods. If only one outfall has been identified, a grid containing the outfall cell (pour point grid) is then used in conjunction with the flow direction grid to delineate the watershed boundary using the GRID command WATERSHED. This command uses the predetermined flow direction grid (described earlier) to identify all the cells that contribute flow to the defined pour point cell as indicated by **Figure 4-10**. The periphery of these cells defines the watershed boundary. The area is calculated by two methods:

1. The GRID command ZONALAREA is used to count all the cells containing the same cell value and then multiply the number of cells by the cell area to yield the total area of cells (Appendix A, wshed.aml, line 67).
2. The preprocessed data includes a flow accumulation grid for each data set (txacc and gacc). By accessing the cell in the accumulation grid that is coincident with the outfall cell (pour point), the area is calculated as the flow accumulation plus the outfall cell multiplied by the cell area (Appendix A, wshed.aml, line 65).

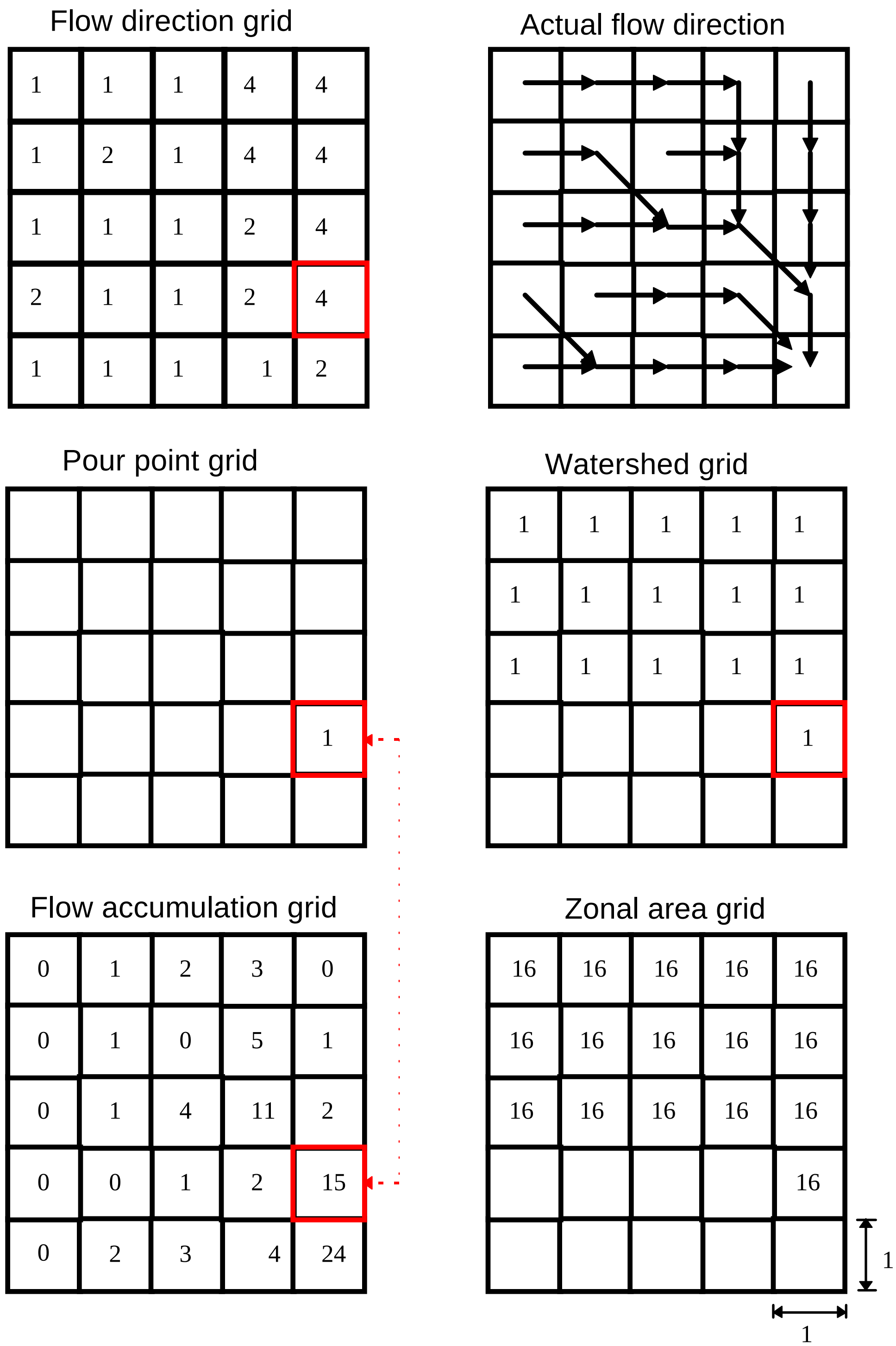


Figure 4-10: Determination of drainage area

The use of two methods allows for easier identification of errors. This is discussed in Section 5.

The resulting watershed grid is converted into a vector coverage and the calculated area (ZONALAREA) is added to the watershed polygon attribute table. Once the watershed has been delineated, the window area is reduced to just include the maximum extent of the watershed (Appendix A, winset.aml). This minimizes the amount of data needed for subsequent processing.

The subarea delineation process also uses the WATERSHED command. The difference is that subarea delineation uses multiple pour points as opposed to one. If a single pour point has been defined, the system combines the presence of stream tributaries and a user-defined area threshold to establish subarea pour points. Stream confluences with tributary sub-areas exceeding the threshold value will be defined as pour points. This step is bypassed if multiple pour points have been assigned using outfall identification methods (2), (3), or (4).

If multiple pour points were defined using the cell, polygon, or gauge mover methods, the subarea routine (subshed.aml) is used to determine drainage areas for the defined pour points rather than the watershed routine (wshed.aml). The pour points are assigned consecutive, unique values. These values are then assigned to the grid of delineated subareas such that each subarea can be uniquely identified. A vector coverage of the subareas is created using the subarea zone value as the polygon identifier. Calculated subarea sizes are added as attributes to the PAT of the subarea vector coverage and the values are written to an ASCII format file for possible use in external programs.

Longest Flow Path and Length

After the watershed has been delineated, the alignment and length of the longest flow path may be determined. GRID provides the command FLOWLENGTH which determines either the distance from the most remote cell to each cell in the grid (downstream option) or the distance from the outfall to every cell in the grid (upstream option). No provision is apparent in Arc/Info for providing directly the longest flow path.

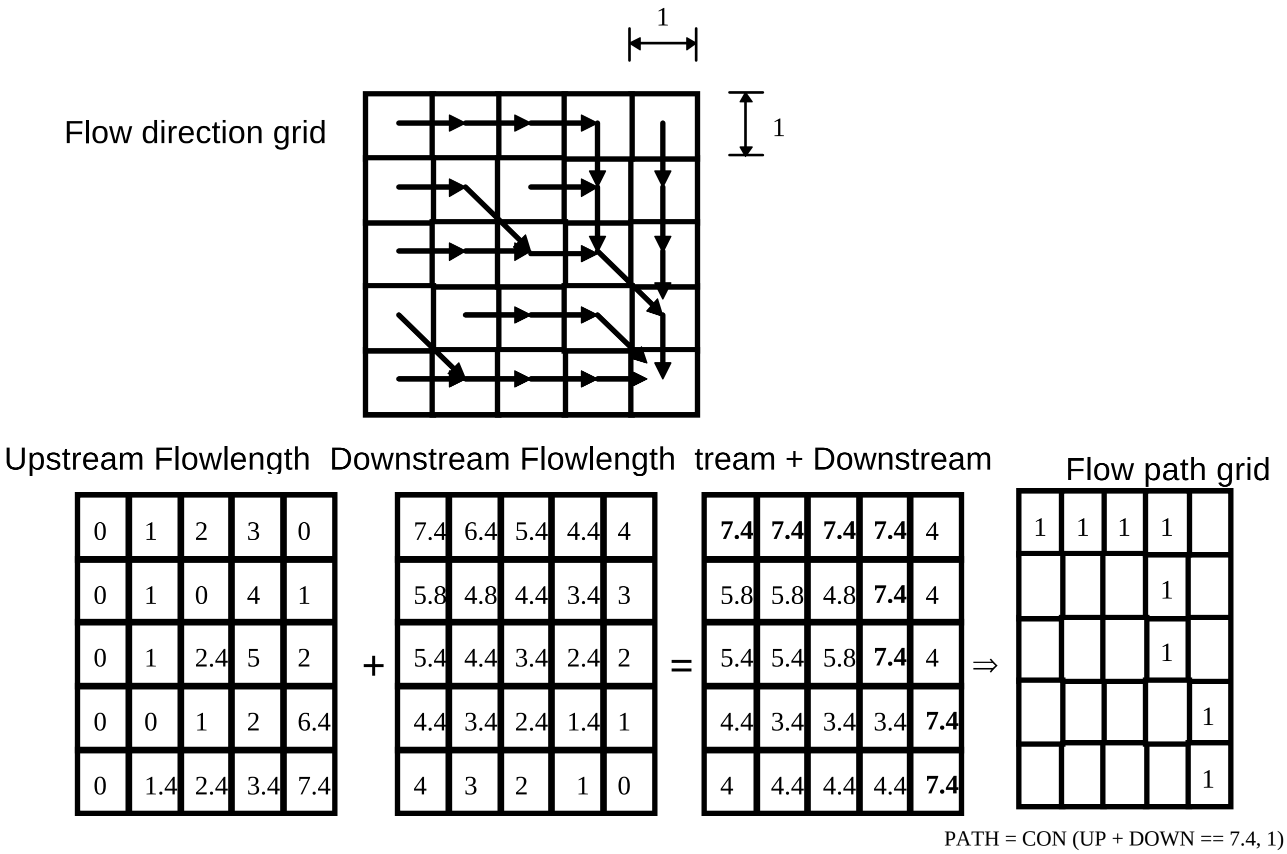


Figure 4-11: Method of flow path determination

The summation of an upstream flow length grid and downstream flow length grid yields a grid in which each cell in a unique string of cells has a value equal to the longest flow length. All other cells will have values that are lower than the maximum length. A conditional statement is then applied to isolate those cells whose value equals the maximum flow length. **Figure 4-11** demonstrates the process. Theoretically, the conditional statement could just check for each cell in the summation grid whose value is equal to the longest flow length. However, the occurrence of rounding errors precludes exact equality. Therefore, the conditional statement has been set to check for all cell values exceeding the sum of the value of flow length minus one (Appendix A, pthleng.aml, Line 48). This approach is reasonable as long as the cell resolution is greater than one meter! The resulting cells constitute the longest flow path.

The flow path grid is converted into a vector coverage so that it can be overlaid on the watershed display. The calculated path length is added to the watershed PAT.

Average Watershed Slope and Hydrologic Region

The average watershed slope was defined in Section 3.3.1 as the slope between the 10% and 85% points along the longest flow path. This system uses the delineated watershed and flow path, and calculated flow length to determine the cells at which the 10% and 85% points are located. Elevations are established at these points by accessing the elevation grid. The general procedure follows:

1. The cells in the upstream flow length grid that are coincident with the flow path are isolated using SELECTMASK with the gridded distance (not time) flow path as the mask grid operating on the upstream flow length grid (Appendix A, uslope.aml, line 38). This creates a grid containing a string of cells in which each cell value records the flow path distance of the cell from the watershed outfall.
2. Since no cell values in the string are likely to match the distances to the desired points, a conditional statement is employed to determine the cell in which the 85% point is located. A grid is created in which the desired point is represented by one

cell (Appendix A, uslope.aml, Lines 45 & 46). The same is done for the 10% point. The actual flow length values of the located cells are then stored for use in the slope calculation.

3. The grids containing the individual points are used as masks to determine the values of the coincident cells in the elevation grid using SELECTMASK (Appendix A, uslope.aml, Lines 53 & 56).
4. The slope is calculated as the quotient of the difference in the elevations determined in 3 and the difference of the flow length values determined in 2.

Generally, for highway design, the watershed average slope is computed for use in rural regression equations as described in Section 3.3.1. HDDS assumes that if the calculation of average slope is requested, the hydrologic region will also be required for use in the regression analysis. The hydrologic region number is determined by using the delineated watershed boundary coverage to clip the statewide hydrologic region coverage (gsrgns). The ARCPLOT commands RESELECT and SHOW SELECT are used to store the region number (Appendix A, uslope.aml, Lines 78 & 79).

The computed slope and identified hydrologic region number are added as attributes to the watershed PAT.

Estimation of Weighted Runoff Curve Number (RCN)

Section 3.3.3 discusses the use of the Soil Conservation Service runoff curve number method and indicates the derivation of curve numbers based on a description of land use/ land cover and hydrologic soil group. Typically, the manual process of determining weighted runoff curve numbers is tedious. HDDS mimics the manual process but on a much more refined scale than would normally be done manually. In order for the RCN routine to be performed, the watershed must have been delineated. The following steps outline the process:

1. The window extent of the watershed coverage is used to create a rectangular clip coverage (Appendix A, rcn.aml, Lines 47-78).

2. The land use (txlus) vector coverage is reduced to the watershed extent using the clip coverage created in 1 (Appendix A, rcn.aml, Line 82).
3. The reduced land use coverage is then converted in to a grid coverage using the same cell resolution as the elevation grid from which the watershed was delineated. The land use code number (lucode) is specified as the item on which the land use coverage is to be gridded (Appendix A, rcn.aml, Line 83).
4. The base soil data vector coverage (statsgo) is directly reduced and gridded to the window extent of the watershed coverage using the soil polygon identification number (statsgo-id) as the grid item. (Appendix A, rcn.aml, Line 88).

   The same one-step process could have been used for the land use data, however the processing speed would be much slower due to the inordinate number of polygons in the land use coverage.
5. The existing land use data for the current watershed may be modified interactively, the methods for which are described below.
6. The runoff curve number table (rcns.dat) is joined to the value attribute table (VAT) of the watershed land use grid by assigning an alternate name of "lucode" to the value item and using the item "lucode" as the relate item. Also, the attributes of the soil coverage (statsgo) are added to the watershed soil grid VAT in a similar manner using the "statsgo-id" as the relate item (Appendix A, rcn.aml, Lines 93-111).
7. Using either the watershed grid or the subarea grid as a mask grid, a runoff curve number is calculated for each cell in the watershed. This is accomplished using a DOCELL routine in which the fraction of each soil group (from the soil grid VAT) is multiplied by the runoff curve number associated with the land use code and soil group (from the land use grid VAT). The products are then summed to yield a weighted runoff curve number (Appendix A, rcn.aml, Lines 116-125).
8. Step 7 provides a grid in which every cell may have a unique value. The GRID command ZONALMEAN is used to determine the runoff curve numbers weighted by either watershed area or by subareas (Appendix A, rcn.aml, Line 128).

The resulting runoff curve numbers are appended to either the watershed PAT or the subareas PAT as appropriate.

This process is at least as accurate as current manual methods. In fact, it is likely that a user would describe varying land use conditions with more detail when using an automated, interactive system than when performing the task manually.

Modification of Land Use Codes

HDDS accommodates user-specified land-use codes which may be used to override existing land use data. This is achieved by allowing the user to specify a value of land use code to be established as the value for all cells within a user-defined polygon. A looping mechanism was developed to allow definition of as many polygons as desired to be drawn over the existing land use data. The current value of land use code is applied to each polygon. The land use code may then be changed and additional polygons defined (Appendix A, lupoly.aml , Lines 30-39).

Each defined polygon results in a separate grid. After each set of polygons has been defined, the polygon grids are merged with the existing land use grid, the override precedence being on the most recently defined polygon. That is, if any polygons overlap, the most recently defined values are used (Appendix A, lupoly.aml , Lines 40-48).

Since a merging process is used, wherever no polygons have been drawn within the watershed, the existing land use codes will remain. This allows the user to perform a before and after land development comparison and to accommodate changes that have occurred since the original data were developed.

Travel Time and Path

The time of travel of water over the land surface is estimated as a function of longitudinal slope and surface roughness as described in Section 3.3.3. The steeper the slope for a given surface roughness, the faster is the velocity of flow and the shorter the travel time. The path that determines the longest travel time (time of concentration) could be different from the longest distance path. The flowlength function is used in a similar manner to that described for flow path, however, a weighting factor is used to convert the length into time (Appendix A, tofc.aml). This is done by creating a grid of the reciprocal of the estimated velocity of flow in each cell which is used as the weight for the FLOWLENGTH function. Several means of establishing velocities are incorporated in HDDS (Appendix A, tcwt2.aml). These are:

1. The default method looks at the slope (S in m/m) of each cell, assigns a uniform velocity coefficient (b) to all cells, and calculates a velocity of flow (v in m/s) over each cell using **Eq. (4-1)** from Section 4.1 which is repeated here for clarity (Appendix A, tcwt2.aml, lines 67-74).

$$v = b \cdot S^{0.5} \tag{4-1}$$

   The default value of b is 4.58 (metric) and assumes short grass waterway (**Table 4-7**).

2. If selected by the user, the existing or user-modified land use coverage can be used to look up the velocity coefficient as assigned in **Table 4-6**. The velocity of flow in each cell is then calculated using **Eq. (4-1)** (Appendix A, tcwt2.aml, lines 47-53).

3. The user may draw polygons over the land use data to which are assigned user-defined velocities (Appendix A, luadj.aml). The user-defined velocities, the method for which is described below, will override those computed using method (2).

For methods (1) and (2), an implicit minimum velocity is applied by virtue of a threshold cell slope: if the cell slope is less than 0.3%, a cell slope of 0.3% is used to establish a lower velocity limit dependent on the assigned velocity coefficient. This is done instead of specifying a lower velocity threshold for two reasons: (1) If the slope is zero, no root exists and use of **Eq. (4-1)** would fail. (2) An explicit minimum velocity would not accommodate varying surface roughness characteristics. This approach seems reasonable considering that the calculated velocities can be overridden with user-defined velocities.

The longest time of travel is then computed using the inverse of the velocity as a weight factor in the flow length routine. (Time = length / velocity). The calculated watershed time of concentration is then added to the watershed PAT.

It should be recognized that methods (1) and (2) are only reasonable for overland sheet flow or shallow concentrated flow. Estimates of flow velocities in streams should be made using the average sectional properties of the stream and supplying the estimated velocities using method (3).

If the user has requested subarea delineation, HDDS will calculate subarea times of concentration. The process of computing the watershed time of concentration results in two time grids: one in which each cell value reflects the calculated travel time from its own location to the watershed outlet cell (upstream time), and the other in which each cell value reflects the travel time from the drainage divide to the cell (downstream time). The subarea time routine (Appendix A, tofc.aml, lines 86-126) uses these grids and the grid of subarea pour points to determine subarea path and times in the following manner:

1. The inverse of the watershed time path is created using the GRID command ISNULL. That is, a grid in which the flow path is reflected by NODATA and all other cells have a value of 1.
2. The upstream and downstream time of travel grids are summed such that every cell reflects the total time from the drainage divide to the outfall for the flow path that runs through the cell.
3. The cells constituting the main watershed path are removed from the total time grid using the GRID command SELECTMASK and using the grid created in (1) as the mask.
4. The remaining maximum times for each subarea are determined with the GRID command ZONALMAX using the subarea grid as the zone grid operating on the grid created in 3. That is, a grid is created in which all the cells within a subarea have the value of the maximum time of travel for the subarea to the watershed outfall (not the subarea pour point). If the main flow path cells had not been eliminated, the subareas through which the main flow path runs would result in cells containing the time of concentration of the whole watershed.
5. The flow paths for each subarea are determined in the same manner as the main path by recognizing that the sum of upstream and downstream time grids by

subarea should yield a string of cells in each subarea in which the sum equals the maximum time for the subarea.

6. Finally, the times of travel for each subarea are calculated as the difference between the time of travel between the most remote cell and the pour point in each subarea flow path. This is performed using the GRID function ZONALRANGE with the subarea path grid as the zone grid operating on the downstream time of travel grid.

Subarea times of concentration are added as attributes to the PAT of the delineated subarea vector coverage.

Specification of Flow Velocities

A grid of the reciprocal of cell flow velocities based on velocity coefficients is created in the time of concentration routine, as described above. Velocities may be defined to override use of the velocity coefficients in much the same manner as that described for land use codes. The existing reciprocal of velocity grid is merged with the polygons of the reciprocal of defined velocities (Appendix A, velpoly.aml).

This is especially useful for defining estimated flow velocities in streams: the stream segments may be subdivided as desired and a velocity assigned to each segment. Thus, the time of travel computation process can emulate the manual process with much less effort and much more detail, if desired.

Calculation of Ellipsoidal Scale Factors

Section 3.2 provided discussion on geodesy and map projections to familiarize the user with some important concepts relating to spatial accuracy and representation of data. All of the spatial data employed herein are projected on to a flat plane using the Albers Equal Area projection. This implies that relative area (size) is preserved but direction and distances are not. HDDS incorporates a scheme by which distances measured on the plane may be adjusted to account for the curvature of the Earth at the surface of the reference ellipsoid. It is recognized that the order of accuracy of measured lengths based on the 500m and 93m grids used here may result in greater uncertainty than the projection error. However, the process incorporated in HDDS demonstrates a potential capability that could allow analyses to be performed in one projection rather than defining a specific projection for each individual project.

A grid scheme was developed in which a longitudinal factor (h) and a latitudinal adjustment factor (k) are calculated for each attributed cell in the path length grid using the process described in Section 3.2.5 and the calculated centroidal coordinates of each cell. The scheme determines the direction of travel over each cell, the distance traveled over each cell, and creates a grid of adjusted travel length over each cell as follows:

- for East-West or West-East direction: adjusted length = cell size * k
- for North-South or South-North: adjusted length = cell size * h
- for NE-SW, SW-NE, NW-SE, or SE-NW: adjusted length = cell size * $(h^2 + k^2)^{0.5}$

The sum of the length values in each cell then yields the total adjusted length. This is performed using the GRID command ZONALSUM (Appendix A, sclfctr.aml). The adjusted length is appended to the watershed PAT.

Use of the Albers Equal Area projection negates the need for determining an area factor so HDDS does not attempt to do so. However, the scheme could be modified for use with other projections: the product of h and k can be determined for all cells in a zone (watershed or subarea) and summated using ZONALSUM. The resulting value can then be multiplied by the cell area to determine the adjusted area of the zone.

Watershed Shape Factor

The watershed and path length routines store the calculated area and maximum path length, respectively, as global variables. The watershed shape factor is a calculation of the watershed area divided by the square of the path length. Use of the global variables in this manner reduces the time-consuming need to access data stored in the attribute tables. The resulting shape factor is appended to the watershed PAT.

The current regression equations for determining flood frequency described in Section 3.3.1 do not call for a shape factor. However, on-going research indicates the need to consider such a variable (Slade, 1995, personal communication).

Design 24-Hour Rain

Section 3.3.3 described the use of design rainfall depths in the SCS runoff curve number method. HDDS uses the watershed grid or the subarea grid as a zone grid to weight the rainfall values of the coincident cells in the rainfall grid (raingrd). The rainfall grid contains the 2, 5, 10, 25, 50, and 100 year recurrence rainfall values (in inches) in the VAT. The GRID command ZONALMEAN is applied to each frequency item of the VAT to yield a grid of design rainfall amounts averaged over either the watershed or each subarea. The units are converted from inches into millimeters and the results are appended to the watershed PAT or subareas PAT, whichever is appropriate (Appendix A, dsgnrain.aml).

Digital Elevation Model Quadrangle Names

As indicated in Section 4.1, HDDS contains 1:2 M digital elevation data covering the whole of Texas and 1:250 K data covering a small portion of northeast Texas. It is anticipated that the 1:2 M data will suffice for basic hydrologic analysis of very large watersheds (of the order of thousands of square kilometers). Larger scale data will likely be needed for smaller watersheds, however, the 1:2 M data are still useful as a first level approximation: the drainage area can be delineated quickly using the 1:2 M data. The resulting watershed extent can be used to clip data from 1:250 K or 1:24 K scale quadrangle index coverages to determine the names of the higher resolution quadrangles required for more detailed analysis. The routine "fndquad.aml" (Appendix A) clips appropriate quadrangle index data and determines the number of polygons in the clipped coverage. The routine "slect.aml" (Appendix A) selects the name item of each polygon within the clipped index coverage and writes the name to an ASCII file. This file is subsequently displayed and can be used in the preprocessor (preproc.aml) to create a new data set, assuming the quadrangles of digital elevation data are available.

Gauge Mover

The presence and use of stream gauge data have been discussed in Sections 4.1 and 3.3.2 respectively. Often, the stream gauges are not coincident with the appropriate stream cell. This is a result of the combination of inaccuracies in the stream locations as determined from digital elevation data, and inaccuracies in the locations of the stream gauges as defined by coordinates of latitude and longitude. HDDS incorporates a routine that is designed to reduce the tedium of manually adjusting stream gauge locations. The relocated stream gauges may be used as pour points for subsequent drainage area delineation.

The following outlines the process, which assumes that the gauge coverage and gridded streams are displayed (a tool is provided to do so):

1. The stream gauge data are stored in a point coverage named txgages. The ARCPLOT command RESELECT is employed to select interactively a desired gauge (Appendix A, mvgage.aml, Line 34).
2. The identifier of the selected gauge is determined and stored using SHOW SELECT (Appendix A, mvgage.aml, Line 35).
3. The cell in the stream grid to which the gauge is to be relocated is identified using the GRID command SELECTPOINT (Appendix A, mvgage.aml, Line 40). This creates a grid with one cell containing the value of the gauge identifier.
4. Steps 1 to 3 are repeated for as many gauges as desired. A separate grid is created for each relocated gauge (Appendix A, mvgage.aml, Lines 32-45).
5. On completion of selecting gauges, the individual grids of relocated gauges are merged into one grid coverage (Appendix A, mvgage.aml, Lines 46-49).
6. The attributes of the original gauges are joined to the VAT of the relocated gauge grid (Appendix A, mvgage.aml, Lines 51-61).

This routine allows gauges to be placed only where a gridded stream exists.

The grid of relocated stream gauges may be used as a pour point grid. This is accomplished by renaming the grid as a pour point grid (e.g. txppa) and initializing a variable which indicates that a pour point grid has been determined for subsequent use. Also, the number of gauges in the grid is stored as a variable so that the program can prompt the user to use the watershed delineation tool when using a single pour point grid or the subarea tool for multiple pour points. The areas computed using HDDS may be compared with the documented drainage area which is stored as an attribute of the gauge grid VAT.

Hydrologic Computations

The system uses the Texas Hydraulics System computer program (THYSYS, 1977) to compute frequency versus discharge for frequencies of 2, 5, 10, 25, 50, and 100 years based on the regional regression equations discussed in Section 3.3.1.

The derivation of watershed area, average slope and hydrologic region were discussed above. The routine "usgs.aml" requests a job description and file name then writes this data and the global variables of area, slope and hydrologic region to an ASCII file in THYSYS input format. THYSYS can be invoked automatically from within HDDS using the newly created input file. THYSYS creates an ASCII output file from which HDDS abstracts the calculated peak discharge versus frequency data. These results are then appended to the watershed PAT (Appendix A, usgs.aml).

Currently, only the THYSYS regression analysis approach is run automatically from HDDS, however, the processes required for automatic analysis of the SCS runoff curve number method, or any other hydrologic method, are much the same.

Clip Coverages

Once the watershed is delineated and converted into vector format, it can be used to clip out any available data. This system contains the following data which are clipped by the watershed coverage:

- percentage of hydrologic soil group,
- county boundaries,
- highways,
- streams, and
- stream gauge sites.

Additionally, the watershed grid is used as a mask to create a grid of aspect of each cell in the watershed.

The resulting coverages and those already established by the methods previously described may then be imported into viewing and output generation software such as ARCVIEW.

Cleanup

Many coverages are created during the course of execution of this system. Those coverages that are not needed for documentation or possible subsequent analysis are removed automatically. The remaining coverages may be removed by the routine "cleanup.aml" (Appendix A) which checks that a coverage exists before eliminating it.

Summary of Data Created in HDDS

Table 4-8 provides a list of grids and vector coverages created by HDDS. This assumes a data set "tx" and a prefix "a" were used. Sample data are discussed in Section 6.

Documentation (Metadata)

Several tables describing geographic data set names and attributes are presented herein and constitute a data dictionary. These are useful for general reference. However, oftentimes specific detail of the data is required when data are used by someone other than the developer.s

Federal standards for documenting spatial data (metadata) were established by the Federal Geographic Data Committee (FGDC, 1994) with which all Federal government agencies should comply. These requirements are to ensure that the origin and intended use of spatial data are not lost during technology transfer or due to attrition within the agency developing the data.

The standards include the following items:

1. Identification information
2. Data quality information

3. Spatial data organization information
4. Spatial reference information
5. Entity and attribute information
6. Distribution information
7. Metadata reference information including citation, time period, and contact information.

The provision of metadata in accordance with the FGDC standards can be a daunting task. The standards currently apply to Federal agencies only, though it is likely that other agencies will adopt similar standards.

HDDS includes a menu-driven subsystem which is designed to conform with the intent of the FGDC standards (Appendix A, meta.men). Only two coverages, txrds (highways), and gsrgns (hydrologic regions) have metadata that can be accessed through HDDS. Additional coverage metadata can easily be added to the menu system once the information is written. Appendix B provides sample metadata for the highway coverage in the North Sulphur River (grds).

Table 4-8: Coverages created in HDDS

Data name	Feature type	Theme	Attributes
txsheda	GRID	watershed	No. of cells in the watershed
txtmpa	POLYGON	watershed	Area *
txsuba	POLYGON	subareas	Subarea id and size*
txptha	GRID	longest path	No. of cells in path
txptharca	LINE	longest path	path length
txtcwta	GRID	cell weight for t of c	reciprocal of velocity
txwtraina	GRID	rainfall grid	2 - 100 yr rainfall
txppa	GRID	watershed pour point	-
txsppa	GRID	subarea pour points	-
txaspcta	GRID	watershed aspect	direction of slope
txtptha	GRID	time of travel path	-
txtptharca	LINE	watershed time path	time of concentration
txstptha	GRID	subarea times of travel paths	-
txstptharca	LINE	subarea time paths	subarea t of c’s
txgagea	GRID	moved stream gauges	stream gauge data
txrcna	GRID	Runoff curve numbers	weighted RCN
txhydgrpa	POLYGON	hydrologic soil group	soil name, % hyd grp

* The path length, time of concentration, hydrologic region, average slope, weighted runoff curve number, shape factor, and calculated discharges are also appended if applicable.

5. Application

The Hydrologic Data Development System has been developed as a prototype package of spatial data and reference data which can be processed within an interactive menu system to determine surface hydrologic parameters for a user-defined site. The system also creates input data files for automatic submission to THYSYS, the Texas Department of Transportation hydrologic and hydraulic analysis computer program. Peak discharge versus frequency relations may be determined using rural regression equations for Texas.

This section provides general instructions for use of the program followed by a sample application.

5.1 User Instructions

HDDS has been set up on Compact Disc Read Only Memory (CDROM) and 4 millimeter Digital Audio Tape (4 mm DAT). The system may be run directly from the CDROM or the data may be installed onto a hard drive.

Two versions of the system are available: a large data set and a small data set. The large set comprises coverage of the State of Texas at the 1:2 M scale, the North Sulphur River watershed in Northeast Texas at the 1:250 K scale, and two tributaries of North Sulphur River at 1:24 K scale. The small data set includes the North Sulphur River watershed, Northeast Texas, at the 1:2 M scale, and the North Sulphur River watershed at the 1:250 K scale.

System Requirements (Hardware and Software)

1. UNIX-based workstation
2. Arc/Info version 7 (or higher)
3. CDROM Drive or 4 mm DAT drive
4. ArcView2 (optional and desirable)
5. Encapsulated Postscript compatible printer (optional, color desirable)
6. THYSYS (optional)

7. Hard drive: The large data set requires about 240 Megabytes of storage if installed on a hard drive. The small data set requires about 40 Megabytes of storage if installed on a hard drive.

Installation

For the CDROM Version, no installation procedures are necessary if HDDS is run from the CDROM drive. The system may be copied directly from the CDROM to any accessible directory level.

The 4 mm DAT version should be installed in the following manner:

1. Set the current directory to any desired location (including the home directory).
2. Load the desired tape. The long version is saved under a main directory "thesis" with several sub-directories (amls, tables, tx, s, and g). Type: “tar xv thesis”. The Short version is saved under a main directory "crp" with several sub-directories (amls, tables, tx, and g). Type: “tar xv crp”.
3. Edit the start up AML using a text editor:

For the long version, open [your directory]/thesis/amls/hdds.aml and change the line (Appendix A, hdds.aml, line 27) that reads

"&sv .PTH2 = /usr2/psmith/thesis/" to

"&sv .PTH2 = [your directory]/thesis/"

For the short version, open [your directory]/crp/amls/hdds.aml and change the line (Appendix A, hdds.aml, line 27) that reads

"&sv .PTH2 = /usr2/psmith/crp/" to

"&sv .PTH2 = [your directory]/crp/"

Running HDDS

The following instructions assume that the large data set version is being run from the hard drive. For the small data set, replace “thesis” with “crp”. To run from the CDROM, replace [your directory] with “/cdrom” and replace “hdds” with “hddscd”.

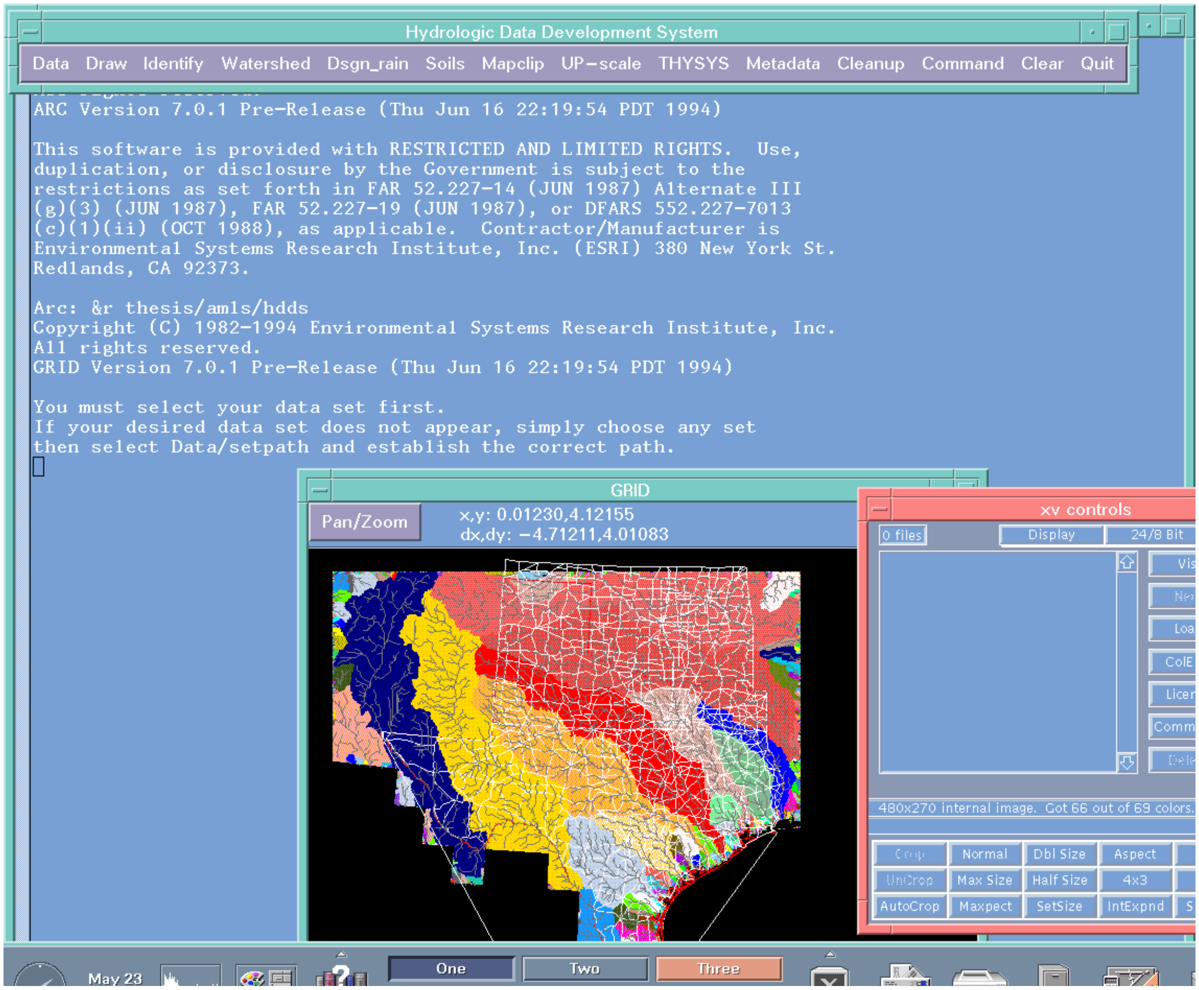


Figure 5-1: Sample menu and display screen

1. Invoke Arc/Info and create a workspace by typing: CREATEWORKSPACE <name>
2. Move to your workspace by typing: &WO <name>

   (There is also an option, "Data/Workspace", within HDDS that allows designation of a workspace).
3. Enter the following: &r [your directory]/thesis/amls/hdds

   After a few moments, the HDDS menu and start up message will appear.

   Quit out of the start up message by selecting Quit in the bottom right of the message box. *The HDDS menu will become active.*
4. Select "Data/Existing/tx"

   This represents 1:2 M scale coverage of the State of Texas.
5. Select the following in order: (1) "Draw/Basins" (2) "Draw/Roads" (3) "Draw/Streams."

   The display window should appear as shown in ***Figure 5-1****.*
6. Zoom to an area of interest at which a highway crosses a stream as follows: in the display window click on "Pan/Zoom" (top left). Select "Create." Identify the opposite corners of a rectangle to define a zoom area. Redo step 5 then bypass step 6 *

   * *This step is necessary because ARCPLOT does not automatically display active views in the zoom window.*
7. Select "Identify/Roads" and click on a road of interest (in the zoom window).
8. Select "Identify/Streams" and click on a the stream over which the selected road crosses.

   It is not necessary to hit the stream and road at their intersection point, however, no nodes must exist between the point selected and the intersection point.
9. Select "Watershed/Area." At the command line enter a desired suffix that will uniquely identify created files, e.g. a, abc, etc.. Select the opposite corners of a rectangle to include an area larger than the anticipated watershed extent. **

   ***This step helps minimize the amount of data required for processing. The backdrop of basins and streams can be used as a visual aid to approximate the extent of the watershed. The watershed will be delineated and two values of calculated area will appear: the watershed area and the zonal area. These values* *should be the same. However, if the zonal area is smaller than the watershed area, it is likely that the window was set too small such that some of the drainage basin was cropped. The zonal area is appended to the polygon attribute table (PAT) of the delineated watershed.*

10. Select “Watershed/Path_length”

    The path and maximum distance from the outfall (highway crossing) to the watershed boundary will be determined. The length will be added to the watershed coverage attribute table (PAT).

11. Select “Watershed/Av_Slope”

    The path length coverage will be used to determine the average watershed slope. The watershed coverage will be used to determine the hydrologic region (for which specific hydrologic regression equations are valid). The resulting values will be appended to the watershed PAT.

12. The data collected to this stage is sufficient for rural regression equations. Select “THYSYS/USGS” to create a THYSYS input file. At the prompt, enter a four letter file name under which the input data is to be saved, then enter any desired description. THYSYS may then be run by responding “y” at the prompt. If THYSYS is run, the THYSYS output file will be displayed and the frequency discharge data will be read and added to the watershed attribute table.

    Note: THYSYS must be compiled on the user’s computer if this option is desired.

13. Select “Watershed/Subareas”

    Quit the message box when it appears and enter a desired area threshold or leave blank to default to 1 sq.km.

14. Select “Watershed/Land”_use for estimation of weighted runoff curve numbers. A pop up window will request selection of “watershed” or “subareas” by which RCN’s will be weighted.

    After the desired response, the program will take several minutes while a clip coverage is created based on the current map extent and land use data will be abstracted from the statewide land use coverage using the clip coverage. Then the *vector coverage of land use will be converted into a grid. Also, the hydrologic soil group data will be abstracted from the statewide coverage.*

A command line prompt requests whether modification of land use data is desired. Answer “y” or “n”! If the response to the above is “y”, a new menu will appear and the display area will be cleared. The following steps will establish updated land use coverage and, if desired modified land use code/soil group/RCN relationships.

a) Select “View/Landuse”, “View/Watershed”, and “View/Streams” in order. The land use may look sparse!

b) Select “Check_value” and click on a location for which you wish to determine the assigned land use code. Click on as many locations as desired and enter “9” to stop.

You may review the land use descriptions and associated RCN’s that are represented by the land use codes by selecting ”List_codes”. At the command line prompt, keep hitting the enter key until you have seen all the records of interest. Type “n” to stop, or scroll to the end of the table. Pay attention to the codes and associated record numbers that you may wish to use to update the coverage and/or modify the land use table.

c) If you wish to modify the land use coverage, select “Setvalue” and, at the command line prompt, enter the numerical land use code to which subsequent user-defined areas will be assigned. Otherwise skip to part (f).

d) Select “Draw_polygon/Land_use” and identify the points to contain the area to which the active land use code value is to be assigned. To complete the polygon, type “9” on the keyboard. If you wish to draw more areas for the same land use category, respond “n” at the “Finished?” prompt and draw your new polygon(s). At the “Finished?” prompt, type “y” when done.

e) To add more areas using different land use codes, redo steps (c) and (d) for each desired land use code.

f) If you desire to add to the land use code table (rcns.dat) or modify the RCN’s to which the land use codes are assigned, select “Add_lucode”. A warning prompt will ask if you are sure changes are to be made because they will be made to the permanent data set. If so, answer "YES" not "y" or "Y" or "yes". A message box will appear with instructions. On closing this box, another menu will appear.

g) To adjust the RCN's assigned to land use codes, select "MODIFY_RCN". Enter the desired record number (from step (b)) at the command line prompt. The existing items and values will be displayed. At the "Edit?" prompt, type in the name of the item followed by a space and the value you wish to assign. You may reassign as many values in a record as you wish. To complete the record hit enter at the "Edit?" prompt. At the "record number" prompt, enter a new record number and repeat the process, or hit enter then type "quit" to finish modifying the table.

h) To add new land use codes and associated RCN's (velocity coefficients too), select "ADD_LUCODE" and type in the values of lucode, RCN's for each hydrologic soil group, and a velocity coefficient when prompted. You may continue to add records at will. To finish, simply hit enter then "quit" at the command prompt.

i) On completion of the above steps (g) and (h) select "Done" from the menu to revert to the previous menu.

j) You may check your updated land use coverage by selecting "View/Landuse". Steps (c) through (i) may be repeated as desired. On completion, select "Done".

Whether or not the land use data were modified, the land use grid and soil grid will be used to determine the weighted runoff curve number for the watershed or for each subarea in the watershed, whichever was requested.

15. Select "Watershed/Travel_time." At the command prompt for use of land use coverage enter "y". You can enter "n" if you wish, in which case the default surface coefficient for grassy waterway is applied to the whole watershed for estimation of velocity. The velocity is determined as a function of cell slope and surface velocity coefficient as described in Section 4.2. At the command prompt for defining velocities you may select "y" to assign velocities interactively by drawing polygons or default to the velocity surface coefficients assigned to the land use categories.

Designation of velocities is similar to land use modification: the same menu will appear and it is necessary to display the land use, watershed boundary and streams as shown in step (14a). Select "Setvalue" and enter a desired velocity (in meters per second). Select Draw_polygon/Velocity and identify the points to contain the area to which the active velocity value is to be assigned. To complete the polygon, type "9" on the keyboard. As many polygons and velocities may be established similar to steps (14c), (14d), and (14e). On completion, select Done. The times of travel will then be computed based on the user-defined velocities and the remaining existing velocity coefficients.

16. Now, if desired, and if higher resolution data have been preprocessed, select "Upscale/Call_data." At the prompt, type in the name of the higher resolution data set. For example, if the North Sulphur River had been selected from the 1:2 M data set "tx", the new data set "g" (1:250 K) could be requested. The screen will be updated to reflect the higher resolution data. Steps (7) through (15) may be performed on the new data for comparison.
17. Select "Watershed/Shape_fac" to determine the watershed shape factor.
18. Select "Watershed/Scale_factor" to compute the path length at the surface of the reference ellipsoid. The watershed boundary and flow length must have been established prior to invoking this option.
19. Select "Dsgn_rain/TP40" and choose "watershed" or "subareas" to define the means by which design rainfall data will be weighted. The weighted rainfall for 24 hour duration design frequencies of 2 years, 5 years, 10 years, 25 years, 50 years, and 100 years will be determined and added to the watershed or subarea PAT, as appropriate.
20. The option "Mapclip" will use the watershed boundary to clip any available data such as stream gauges and county boundaries.
21. "Upscale/Find_quads" will determine the name of quadrangles required for retrieval for 1:250 K or 1:24 K DEM's using the current watershed boundary. At the prompt, enter the name under which will be saved an ASCII file containing the names of standard USGS quadrangles in which the delineated watershed is represented. The appropriate DEM data can be acquired and the file can then be used in the preprocessor to establish a new data set for use in HDDS. The DEM data filenames

must match the names in the ASCII file. Thus the 1:2 M data is useful as a first level screening to identify what data is required for higher resolution analysis.

22. Metadata displays some provisional data for two coverages, the 1:250 K scale highway data and the 1:2 M scale hydrologic regions. A series of sub-menus allows the user to view available metadata in any desired order.

Alternate Outfall Designation

The outfall may also be located using "Identify/Cell," "Identify/Line," or by using the "Identify/Movegage" option. The use of the "Cell" option usually necessitates a zoom window such that each individual cell can be identified. At the prompt, enter a filename suffix (e.g. a). Then identify the desired outfall locations using the mouse. As many cells as desired may be selected after which the number 9 must be selected on the keyboard. If only one cell is identified, the "Watershed/Area" option must then be selected for subsequent watershed delineation. Otherwise, the "Watershed/Subareas" option should be invoked. The line option is much the same except that a polygon (minimum of three points) must be drawn using the mouse.

Movegage

The "Movegage" option allows the user to create a grid of gauges by selecting an appropriate gauge and then selecting the stream cell at which the gauge should be located. The following steps indicate its use.

1. Invoke HDDS, select a data set, and establish a work space as described earlier.
2. Select "Identify/Movegage." A new menu will appear.
3. The map extent will have been set to the extent of the selected data set, but may be modified using the "Mapextent" option.
4. Use the "Draw" option to display the streams and gauge locations.
5. Select "Setwindow" and use the mouse to identify an area that encloses the desired gauges. This reduces the amount of data processing required.
6. Select "MOVE." Use the mouse to hit two points to define a search tolerance, then select a desired gauge. At the prompt, use the mouse to click on the cell in the stream network to which the gauge is to be moved. Hit 9 on the keyboard to complete the move. At the "Finished?" prompt, enter "y" or "n". As many gauges may be moved as

desired. On completion, a grid of moved gauges is created in which the gauge attributes of the original point coverage are present.

7. Check the distribution of moved gauges using “DRAW/GRDgage” and list the attributes using “LIST.”
8. If the gauge locations are to be used as pour points for area determination, the “PPset” option will create a pour point grid for subsequent use. The window should be reset to the approximate extent of the basins of all selected gauges. If only one pour point has been established, the “Watershed/Area” option should be selected, otherwise choose “Watershed/Subareas.”

Data Preprocessor

The option “Data/Preprocess” invokes the preprocessor routine that prepares DEM data for use in HDDS. Also a user-selected existing highway Arc (vector) coverage is gridded.

The preprocessor requests the following responses at the command line:

1. Prefix name for data set. Enter a short, one or two letter name.
2. Directory path to DEM data files. Type in the full path.
3. Name of highway Arc coverage to be used. Type in the path and file name (e.g. /usr2/psmith/highways).
4. If the “Up-scale/Find_quads” option has been invoked in the current session, the routine requests if the file of quadrangle names is to be used. If not, the user may specify a file containing the names of the DEM data files or the name of a single DEM file should be entered on request.
5. If the “Upscale” option was not used, the routine will request the scale of DEM data used. This assumes the use of USGS DEM’s. The scale value establishes which projection files are to be used to transform the data to the HDDS projection.

On completion of the routine, the data will be available for use in HDDS as a selection option under “Data/Existing.” Currently, the system is limited to use in Texas since the preprocessor does not accommodate land use, soils, and rainfall data.

Creating a New Workspace

The experienced Arc/Info user may create a workspace outside HDDS. Also, there is an option “Data/Workspace” which invokes a small menu: “Create” allows the user to specify the complete path and name of a new workspace. To change workspace, select “Change to” and select a workspace from the given options. The options include the home directory, the newly created workspace name, and “other”. “Other” allows the user to specify any existing workspace. The “Cancel” option restores the home directory as the active workspace. “Done” restores the main menu.

Accessing Other Data Sets

Often, the user will work within the preset system which includes data sets and program routines. However, it may be desirable to use the program routines from the hard drive to access data on the CDROM, or vice versa. The option “Data/Set_path” allows the user to override the path to the data sets. At the prompt, the full path to the desired data set must be provided, ending with a slash (/). For example, HDDS is being run from the hard drive but the large data set “tx” is desired from the CDROM. In this case, the path name to enter is “/cdrom/thesis/”. This option can be invoked at the beginning of a session or at any time while the main menu is active.

Other Utilities

In addition to displaying basins, roads and streams from the active data set, the main menu “Draw” option includes “other”. After selection of this option, the user is requested to select the type of coverage desired (GRID, point, line, or polygon coverage) after which appears a list of appropriate coverages that are available in the current workspace and the option “other”. Selection of “other” requires the user to specify the full path and name of the desired coverage.

The “Command” option relinquishes menu control to the user until the command “&return” is entered. This allows a user to perform any Arc/Info operation outside the control of HDDS. One specific use of this is to rename or copy coverages: the option “Cleanup” will delete all coverages created using the active prefix (data set name) and suffix. Prior to invoking “Cleanup”, the user may wish to rename specific coverages such as the watershed and subarea polygon coverages. On invoking “Cleanup”, the existing files are displayed and the current suffix is displayed. The user may opt to enter another suffix. At the delete prompt, the user should enter "YES" to delete (not "y" nor "yes"). To remove data from previous sessions, select "Data/existing" and choose the appropriate prefix, then select "Cleanup".

The "Clean" option clears the display window and Quit returns the user to the ARC system environment.

5.2 Sample Application

The need to determine frequency versus peak discharge at highway crossings of streams is a common requirement for computation of water surface profiles and flow velocities, hydraulic design of bridges and culverts and channel impact analysis, estimation of sediment transport potential, and estimation of potential scour at bridges.

For existing highway crossings, the potential for local bridge scour and general channel degradation is of concern for the integrity of bridge foundations. The Texas Department of Transportation is currently evaluating thousands of bridges throughout the state for potential scour failure of bridges due to flooding. Generally, the most time-consuming aspect of such evaluations often are the data acquisition and manipulation for hydrologic and subsequent hydraulic analyses.

Any number of sites could have been chosen for which an evaluation is required. However, the North Sulphur River, in Northeast Texas, is of particular concern: prior to the 1930's, the North Sulphur River comprised a shallow, poorly defined, highly sinuous main channel of less than 10 feet deep and an average bank-to-bank width of less than 100 feet. Channel banks were heavily vegetated with trees and dense brush and the flood plain was wide (of the order of 5000 ft.). Local drainage districts, under pressure from farmers, straightened out a 28 mile stretch of the river to create an earthen channel with minimal vegetation on its banks. The farmers subsequently removed much of the dense brush and trees for agricultural use of the land.

Over the last six decades, the river has degraded vertically to depths of about 30 feet below original levels and associated slope failures have widened the main channel to an average of about 300 feet. This is a result of significantly increased stream power from a steeper stream bed and increased runoff, and reduced erosion resistance from exposed soils.

Such unstable channel conditions are a constant threat to the integrity of existing bridge foundations in the stream bed. Also, it is desirable to try to predict the future rate of degradation of the system in order to determine appropriate design measures for bridge replacements and new crossings. The analysis process has been initiated here to the extent that some of the important hydrologic characteristics of this river have been established.

HDDS was applied at State Highway 24 which crosses the North Sulphur River approximately 14 miles south of Paris, Texas. The steps outlined in Section 5.1 were employed to determine the following:

- watershed area, watershed path length, scale-factored length, and average slope using 1:2 M scale data.
- watershed area, path length, and average slope using 1:250 K scale data,
- subareas using 1:250 K data,
- SCS runoff curve numbers, weighted by watershed area and subareas,
- times of travel for main watershed and subareas,
- design 24 hour rainfall weighted by watershed area and subareas, and
- frequency/discharge relationship using regression equations.

The 1:2 M data were used to compare with those taken from the finer resolution 1:250 K data.

In addition to the data determination at the North Sulphur River at SH 24, the 1:2 M scale data contained in the large data set (tx) were used to determine the watershed areas for several locations within the Trinity River watershed at which stream gauge stations are extant. Gage Mover steps (1) to (8) were employed to create a grid of stream gauge locations at the appropriate sites. The area attributes of the stream gauge grid VAT were then compared with the HDDS calculated areas.

6. Results

Figure 6-1 shows the major drainage basins for Texas (arcbasns). The basins are used mainly as a visual aid for identifying major rivers and to provide the user with an indication of the extent of a window that is required to reduce the amount of data.

Using the 1:2 M scale data set (tx) a watershed area of 832 km^2 and path length of 61.4 km were determined compared with an area of 826.7 km^2 and length of 60.91 km using the 1:250 K scale data set. The differences are less than one percent. The scale-factored length, compensating for the curvature of the Earth, was calculated to be 61.6 km. Calculated average watershed slopes were 1 m/km using the 1:2 M scale data and 1.3 m/km for the 1:250 K scale data.

Figure 6-2 shows delineated subareas for the North Sulphur River watershed at SH 24, south of Paris, Texas. These subareas are based on 1:250 K data. This would constitute a typical drainage area map for hydraulic analysis and documentation purposes. Using HDDS such results can be obtained in less than half an hour from start to finish!

Table 6-1 shows the polygon attribute tables of the watershed (gtmpa) and subareas (gsuba) that were created automatically during the analysis. Note that this includes frequency versus discharge data that were calculated using THYSYS. (usgs.aml sends the input data to THYSYS then reads the THYSYS output file and adds the results as attributes of the watershed PAT).

Figure 6-3 shows the names of soil types contained within the North Sulphur River watershed. **Figure 6-4** shows the percentages of each hydrologic soil group in the watershed. The presence of soil group A is negligible. These percentages were used to determine weighted runoff curve numbers along with the land use data. **Figure 6-5** shows a screen image of the existing land use data with the watershed boundary and streams superimposed.

Table 6-1: Polygon Attribute Tables for watershed (gtmpa) and subareas (gsuba)

gtmpa.pat

Area	826659328
Perimeter	203453.328
Gtmpa#	2
Gtmpa-id	1
Calc_area(sq.km)	826.659
Calc_pthl(km)	60.906
T_of_c(mins)	802
Shape_fac	0.2230000
Region#	2
Q2(cms)	214.38
Q5(cms)	467.10
Q10(cms)	694.76
Q25(cms)	1026.18
Q50(cms)	1308.01
Q100(cms)	1620.24

gsuba.pat

			Design Rainfall (mm)						Time	
GSUBA_ID	SUBA_SQ_KM	WSHEDA_SQ_KM	R2_24	R5_24	R10_24	R25_24	R50_24	R100_24	SUBTC_MIN_	WT_RCN
1	61.5	826.67	106	141	172	198	223	248	379	92
2	46.26	826.67	106	142	172	198	223	248	368	92
3	35.13	826.67	106	141	172	198	223	248	323	92
4	78.68	826.67	105	140	170	196	221	246	455	92
5	53.34	826.67	106	142	172	198	223	248	378	92
6	33.18	826.67	106	142	172	198	223	248	254	93
7	68.92	826.67	104	139	167	194	220	245	413	92
8	25.76	826.67	102	138	165	193	218	243	248	92
9	50.57	826.67	102	138	165	193	218	243	373	92
10	91.23	826.67	102	138	165	193	218	243	534	92
11	41.06	826.67	102	138	165	193	218	243	357	92
12	64.82	826.67	103	139	167	194	219	245	391	92
13	33.18	826.67	105	140	172	198	222	247	297	92
14	10.96	826.67	106	141	172	198	222	248	143	93
15	12.11	826.67	105	140	172	198	222	247	169	92
16	12.14	826.67	105	140	172	198	222	247	200	93
17	85.83	826.67	102	138	165	193	218	243	500	92
18	3.27	826.67	106	141	172	198	222	248	33	93
19	10.98	826.67	105	140	172	198	222	247	159	92
20	7.69	826.67	105	140	172	198	222	247	102	91

Figure 6-6 shows the gauge locations in the upper Trinity River Watershed that were moved to coincide with their appropriate streams. This includes a table of calculated subareas and recorded areas as determined by the USGS for existing stream gauge stations. The assumption may be that the stream gauge areas are correct, however, it is fair to note that these may be subject to error.

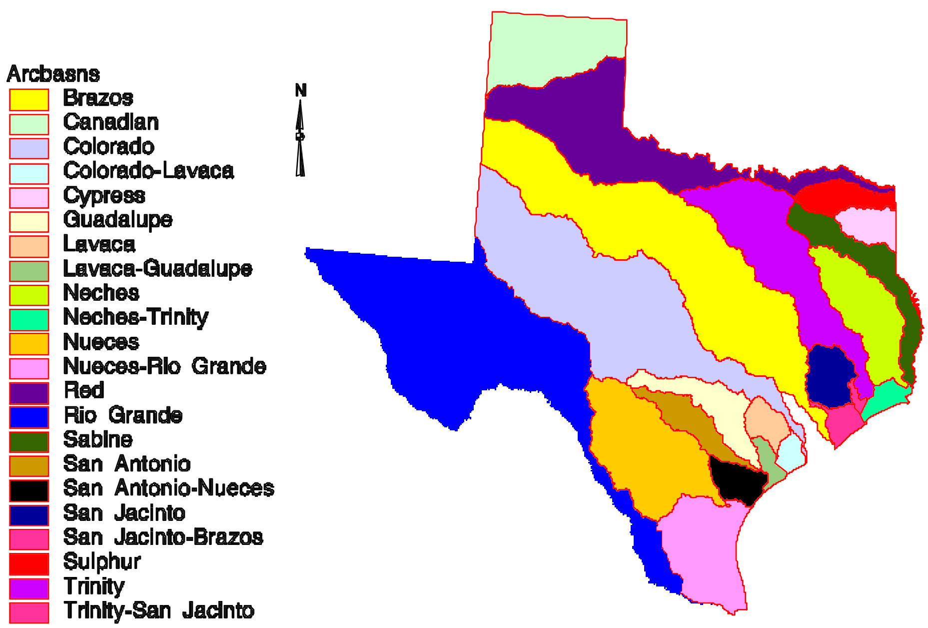


Figure 6-1: Major drainage basins of Texas

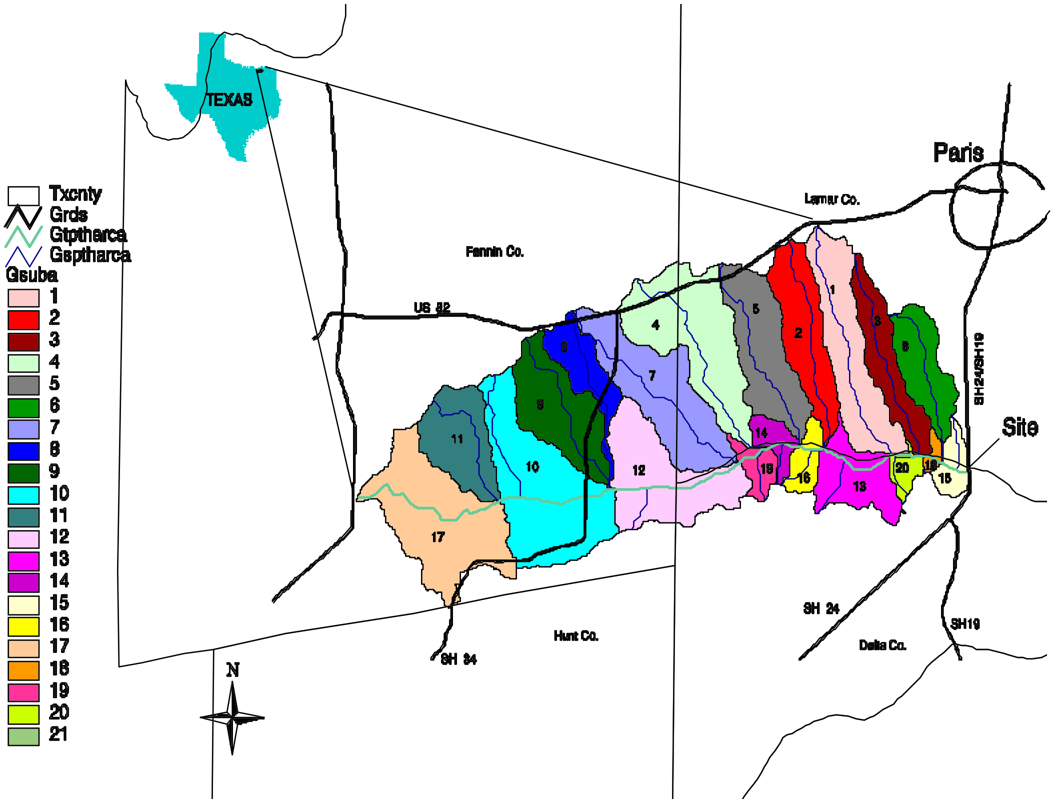


Figure 6-2: Subareas of the North Sulphur River above State Highway 24

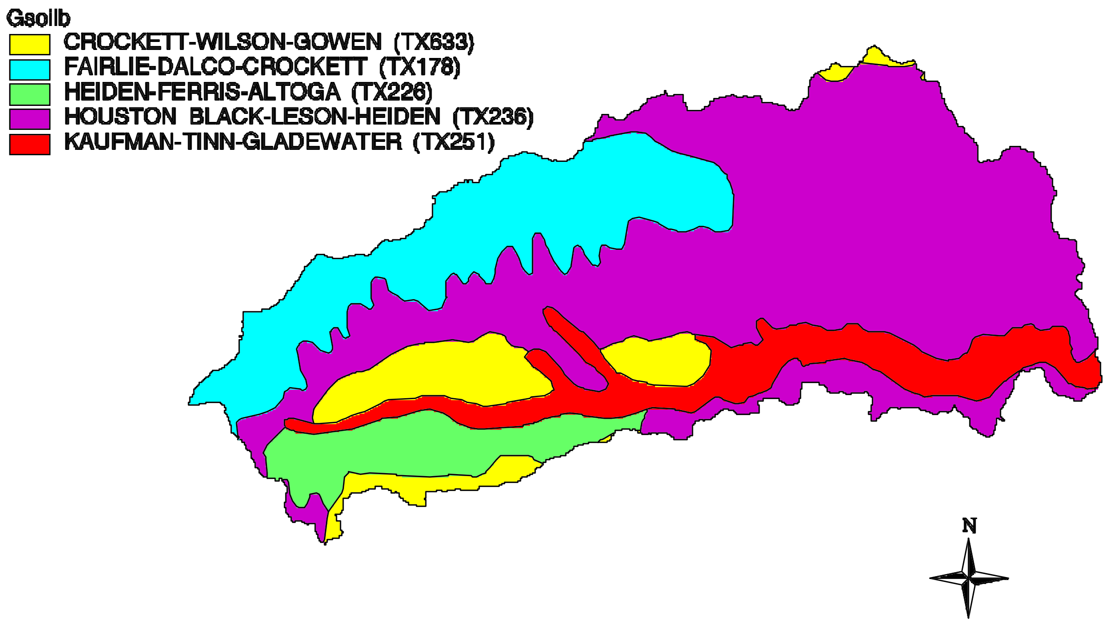


Figure 6-3: Soils in the North Sulphur River watershed

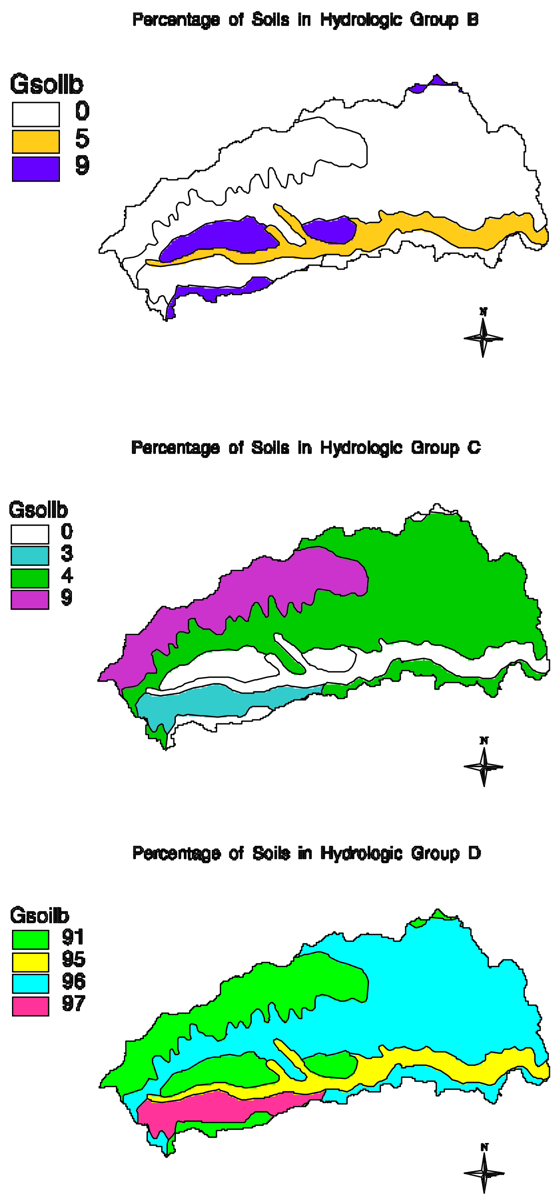


Figure 6-4: Hydrologic soil groups in the North Sulphur River watershed

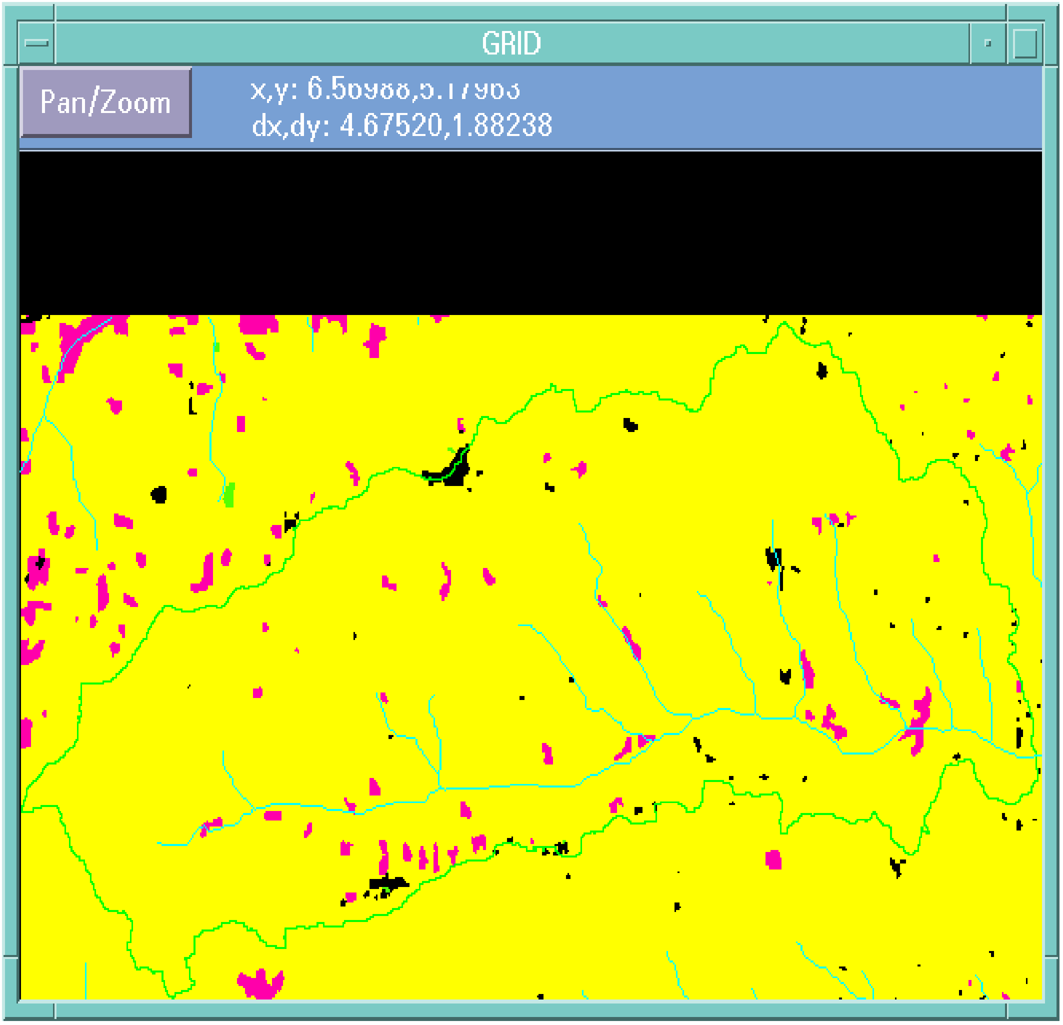
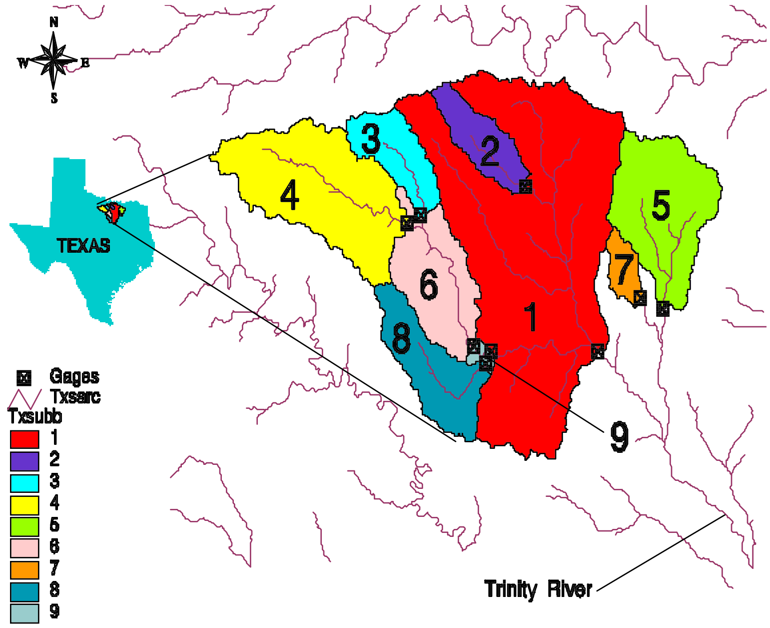


Figure 6-5: Image of land use grid for the North Sulphur River watershed



All areas in km^2

TXSUB B_ID	SUBA_S Q_KM	STATION	NAME	USGS_AR EA_	TOTAL_AR EA	% DIFF
1	8250.25	8057000	Trinity River at Dallas	15631.36	15830.00	1.27
2	778.75	8051500	Clear Creek near Sanger	755.20	778.75	3.12
3	885.00	8044000	Big Sandy Creek near Bridgeport	852.48	885.00	3.81
4	2954.25	8043500	West Fork Trinity River at Bridgeport	2936.32	2954.25	0.61
5	2185.00	8061500	East Fork Trinity River near Rockwall	2150.40	2185.00	1.61
6	1557.50	8045500	West Fork Trinity River at Lake Worth Dam above Fort Worth	5296.64	5396.25	1.88
7	313.00	8061540	Rowlett Creek near Sachse	307.20	313.00	1.88
8	1316.00	8047500	Clear Fork Trinity River at Fort Worth	1326.08	1316.00	-0.76
9	88.25	8048000	West Fork Trinity River at Fort Worth	6694.40	6801.00	1.59

Figure 6-6: Stream gages in the Upper Trinity River watershed

7. Assessment and Conclusion

7.1 Software

The intent of this work has not been to evaluate the Arc/Info and ArcView2, however, some comments are provided here:

Arc/Info

1. The use of the Arc/Info subsystem TABLES in the menu system is very slow. Several seconds elapse while just invoking TABLES. The system currently jumps in and out of TABLES as data is created. It would be less time consuming to minimize the number of times TABLES is invoked.
2. The recommended AML writing protocol is to indent each nested level of routine so that it is clear when a loop or conditional routine begins and ends. TABLES does not seem to like this! Indented routines using TABLES would return errors or lock up. This problem was averted by left justifying all TABLES routines.
3. TABS do not seem to be read as spaces on all platforms. On SUN stations, for example, a menu name must be separated from the desired action by at least one space, but a tab might be read as no space such that the menu name appears as the name and action information. All tabs in menus were replaced with spaces to eliminate this problem.
4. In TABLES, to add a new item, the ADDITEM must be invoked without having first selected the file to which the item is to be added. To update, add or alter, the file must first be selected.
5. INFO tables (as opposed to PAT's, AAT's etc.) can be referenced from any workspace, but I have had difficulty in modifying them from anywhere other than the directory in which the tables reside, yet I can modify PAT's or AAT's from anywhere!
6. Tables defined using TABLES or INFO are elusive! The defined table name does not appear in the directory list, therefore, it is hard to keep track of the nomenclature.
7. Using RESELECT in ARCPLOT, it is better to reference an integer id rather than character id: for some reason when I was trying to select Texas, no match was possible (nor Texas,

TEXAS, texas !). Note that the Info tables seem to use upper case, even if the user defined the items using lower case.

8. The integer function (INT) in GRID applied to a zone grid, e.g. ZONALAREA seems to result in fewer zones than the original GRID.

ArcView2

1. On maximizing the layout window, the layout frame remains unchanged. The zoom to page feature must be used to enlarge the frame. In one instance when I minimized the layout window, the frame reduced, but the contents disappeared!
2. Although the data sets are georeferenced, the automatic scale bar option in layouts indicates "unknown" scale.
3. On importing binary Color Graphics Metafile format files into Microsoft Word after having exported them from ArcView2, some data does not show: parts of some coverages do not appear.

7.2 Spatial Data

The means of acquiring and processing the data for HDDS are secure. The main limitations for HDDS were availability, large storage and processing memory requirements, and scale. For simplicity, some data were acquired at only one scale yet were re-sampled for use at other scales. For example, the original highway coverages were based on 1:2 M data yet were re-sampled to the 93 m cell size used for the 1:250 K data. The land use vector coverages were based on 1:250 K data but are re-sampled during execution of HDDS to the resolution of the selected DEM data. Generally, it is satisfactory to re-sample from a high resolution to a lower resolution, however, when re-sampling from a low resolution to high resolution, it should be recognized that the accuracy can be no better than that of the original data. Since HDDS is a prototype and is intended for demonstration of potential applications, the additional effort to create extensive high resolution coverages was not expended.

The sampling frequency and accuracy of the DEM data is the subject of some concern for the author: the delineation of streams from DEM data is sensitive to the resolution of the DEM data. At large cell sizes, chances are high that a stream could be missed entirely. For example, the true location of a 100 m wide stream might be missed by many cells on a 1 km grid resolution. In extreme cases, a flow path represented on a grid might run in a completely different direction to the real stream path. Therefore, it is important to ensure that the resolution of the DEM data is accurate enough for the intended purpose of the analysis. The streams generated from the 500 m DEM grid of Texas show favorable comparison with digitized streams and only a few major drainage basins show discrepancies between the DEM delineated ones and the digitized basins. In some instances, the discrepancies may be attributable to the DEM filling process. Also, in some areas, the topography may be too flat compared with the vertical accuracy of the data. In addition to these possibilities, differences between calculated areas and stream gauged areas could be attributable to the presence of non-contributing area.

Comparison of the analysis of the North Sulphur River at the 1:2 M and 1:250 K scales is favorable. Comparison of may more sites should be made before a more detailed statement can be made, However, the indication is that, for the type of topography existing in Northeast Texas, it may be reasonable to use 1:2 M DEM data for determination of drainage areas, path lengths and average watershed slopes for areas of the order of 800 sq. km and larger. For initial estimates of hydrologic conditions such as those needed for environmental assessment for proposed projects and preliminary sizing estimates, it would appear that verified 1:2 M data may be used for areas as small as a few hundred square kilometers. Also, the speed at which the 1:2 M data can be processed emphasizes the potential use as a first level screening for identification of data needed for higher resolution analysis.

At this stage, no definitive statements can be made as to the lower limits of applicability of the 1:250 K data, but a lower limit of about 1000 cells seems reasonable. This is equivalent to an area of about 10 sq. km at the 1:250 K scale. Also, it is fair to state that the accuracy should be comparable with what might be expected using the same scale paper maps.

7.3 HDDS Procedures

The success of application of HDDS for hydrologic parameter determination is primarily dependent on the accuracy of the base data sets on which the analyses are performed. The procedures incorporated in HDDS attempt to emulate those which have been employed using manual techniques. As such, the procedures should be at least as reliable as those determined by manual procedures. In fact, using a system such as HDDS, it is easier to provide a detailed rendering of features such as land use and reach flow velocities than by manual techniques. For example, for simplicity, a designer might divide a flow path into three reaches for which three average velocities are estimated and applied to calculate a time of concentration. In HDDS, it is not much more time-consuming to define ten or more reaches to accommodate changes in velocity. Also, the user has the ability to add and modify coefficients such as runoff curve numbers and velocity coefficients and simply draw areas to which the values should be assigned. With such capability, a designer is likely to define changes in conditions than that person would if only manual processes were to be employed.

7.4 Limitations and Future Needs

HDDS employs ARC Macro Language, which is powerful and reasonably straight forward. However, it is likely that many of the processes could be made more efficient by the creation of direct functions in the original programming language. Furthermore, the present system is reliant on proprietary software (Arc/Info), which is without doubt a powerful GIS package. However, only a fraction of the Arc/Info functionality is required for HDDS. A self-contained system providing only the desired functions would be much more compact, efficient and possibly more accessible to the engineering community.

As is often the case, time limitations precluded extending the system beyond its current capabilities and extent of data. An immediate data need is to add the highway names to the highway coverages: this would allow easy identification of appropriate sites. Currently, only several arcs have highway names. The process of adding attributes is simple but extremely tedious.

The data developed for HDDS is limited to Texas at the 1:2 M scale and the North Sulphur River at the 1:250 K scale. It would be desirable, and feasible using CDROM, to create 1:250 K scale data for the whole of Texas. 1:24 K scale data is desirable too, however, coverage of Texas at this scale requires over four thousand quadrangles. The DEM data are becoming available at the 1:24 K scale but similar detail would be required of highway data, land use/land cover data, and soil data.

A means of creating a stream network is probably the most needed additional capability: HDDS provides the capability to determine areas, path lengths, times of travel, weighted runoff coefficients and weighted design rainfall. These are the most commonly needed variables for hydrologic analysis. However, at present, the user must visually inspect the resulting data to establish the subarea linkage and stream linkage. It is feasible to employ a grid system or a vector system to generate the stream network by which appropriate connectivity can be established within the system.

This project has focused on establishing a system within which hydrologic data can be established for current lumped hydrologic models: spatial data are drastically reduced to represent average conditions of a given area. The full power of GIS could be utilized with spatially distributed hydrologic models. Some of the methods employed in HDDS could be employed in such models.

7.5 Conclusion

The Hydrologic Data Development System is a prototype package of Arc/Info coverages, AMLS, menus and tables established to indicate the potential of GIS as an engineering analysis tool. Only limited data were available for this project, nevertheless, the system demonstrates the phenomenal speed and precision with hydrologic parameters can be determined.

HDDS allows determination of drainage boundaries, areas, flow path lengths, times of concentration, design rainfall amounts, weighted runoff coefficients, and other important parameters. The system can quickly establish data input sets for THYSYS, invoke THYSYS, and read the resulting design frequency versus discharge data. Data development and analysis times are reduced dramatically from current manual procedures.

Accuracy is probably the biggest concern with this process: no specific accuracy can be stated at this time, however, it is reasonable to say that the primary limit on accuracy of results is the accuracy of the original data coverages, especially the digital elevation models. The larger the scale, the more accurate the data. Comparison of many watersheds would be required for a more definitive statement, but for large areas (say 1000 km^2), use of 1:2 M DEM, 15 arc second data might suffice for all but very rigorous analyses. In any event, as long as the digital data are at least as accurate as paper maps, the results should be as accurate and possibly more accurate than those obtained by manual analysis. Furthermore, the potential for human error may be reduced. At present, the lack of DEM data at the 1:24,000 and larger scales probably precludes use of such a system on areas smaller than a few square kilometers. At the other extreme, it probably is not warranted to employ 1:24,000 scale data for a large area of thousands of square kilometers. The disk storage, random access memory and processing time required increase drastically with increasing area and resolution, yet preliminary indications are that the order of error of estimate of area is small for large areas.

GIS relies absolutely on correct georeferencing: it is paramount that all data are converted into a common projection using the same horizontal and vertical datum. All data employed in HDDS were transposed into a common projection, Albers equal area, to ensure consistency.

Finally, a large initial effort is required to establish suitable coverages for the database and periodic updates may be necessary. However, once the initial data is established, changes are relatively easy and analysis is no longer a chore.

Appendix A: Hydrologic Data Development System Coding

Arc Macro Language Files

```
/*
/* Name: addlu.aml
/*----------------------
/* Purpose: Accesses land use / RCN table for addition of land use codes and runoff curve numbers
/*----------------------
/* Calls: None
/*----------------------
/* Called by: lu_rcn.men
/*----------------------
/* Required variables:
/*----------------------
/* Global variables set: None
/*----------------------
/* Data created: adds records to  rcns.dat
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/31/95
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*----------------------
/*
&data arc tables
select rcns.dat
add
&end
&return
```

```
/* Name: chk.aml
/*----------------------
/* Purpose: This checks that the user has already selected a data set
/* prior to other operations
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn
/*----------------------
/* Global variables set: None
/*----------------------
/* Data created: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 05/08/95
/* Last update:
/*----------------------
/* Remarks:
/*----------------------
/*
&if [null %.basn%] &then &do
&type You must select your data set first.
&type If your desired data set does not appear, simply choose any set
```

```
&type then select Data/setpath and establish the correct path.
&run %.pth%infiles.aml
&end
&return

/* Name: cleanup.aml
/*----------------------
/* Purpose: This AML removes all working (no permanent) data that has been created during
/* HDDS sessions for the current basin prefix and suffix. The user may change the
/* current suffix here, but must change the prefix by selecting Data/Existing prior to
/* initiation of Cleanup
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: None
/*----------------------
/* Data created: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/30/95
/* Last update: 4/18/95
/*----------------------
/* Remarks:
/*----------------------
/*
setmask off
&popup %.PTH%clnup.txt
/* list coverages and grids
listgrids
listcoverages
/* Show current file set suffix
&type The current suffix is %.suff%
/* Allow user to modify suffix
&sv q = [response 'Do you wish to change this? (Yor N)']
&if %q% = Y or %q% = y &then &do
        &sv .suff = [response 'Enter the suffix for the files to delete']
        &end
&messages &on
&sv rid = [response 'Do you wish to erase these files? (YES, or n)']
&if %rid% = YES &THEN &do
&if [exists %.basn%pp%.suff% -grid] &THEN
kill %.basn%pp%.suff% all
&if [exists %.basn%da%.suff% -grid] &THEN
kill %.basn%da%.suff% all
&if [exists %.basn%shed%.suff% -grid] &THEN
kill %.basn%shed%.suff% all
&if [exists %.basn%tmp%.suff% -cover] &THEN
kill %.basn%tmp%.suff% all
&if [exists %.basn%up%.suff% -grid] &THEN
kill %.basn%up%.suff% all
&if [exists %.basn%dn%.suff% -grid] &THEN
kill %.basn%dn%.suff% all
&if [exists %.basn%tc%.suff% -grid] &THEN
kill %.basn%tc%.suff% all
&if [exists %.basn%tup%.suff% -grid] &then
```

```
kill %.basn%tup%.suff% all
&if [exists %.basn%tdn%.suff% -grid] &THEN
kill %.basn%tdn%.suff% all
&if [exists %.basn%l%.suff% -grid] &THEN
kill %.basn%l%.suff% all
&if [exists %.basn%ptharc%.suff% -cover] &THEN
kill %.basn%ptharc%.suff% all
&if [exists %.basn%pth%.suff% -grid] &THEN
kill %.basn%pth%.suff% all
&if [exists %.basn%tptharc%.suff% -cover] &THEN
kill %.basn%tptharc%.suff% all
&if [exists %.basn%tpth%.suff% -grid] &THEN
kill %.basn%tpth%.suff% all
&if [exists %.basn%rd%.suff% -cover] &then
kill %.basn%rd%.suff% all
&if [exists %.basn%strm%.suff% -cover] &then
kill %.basn%strm%.suff% all
&if [exists %.basn%cty%.suff% -cover] &then
kill %.basn%cty%.suff% all
&if [exists %.basn%cnty%.suff% -cover] &then
    kill %.basn%cnty%.suff% all
    &if [exists xcell%.suff% -grid] &then
    kill xcell%.suff% all
    &if [exists ycell%.suff% -grid] &then
    kill ycell%.suff% all
    &if [exists %.basn%seg%.suff% -grid] &then
    kill %.basn%seg%.suff% all
    &if [exists %.basn%acc%.suff% -grid] &then
    kill %.basn%acc%.suff% all
    &if [exists %.basn%sshed%.suff% -grid] &then
    kill %.basn%sshed%.suff% all
    &if [exists %.basn%spp%.suff% -grid] &then
    kill %.basn%spp%.suff% all
    if [exists cuma%.suff% -grid] &then
    kill cuma%.suff% all
    &if [exists suba%.suff% -grid] &then
    kill suba%.suff% all
    &if [exists %.basn%suba%.suff% -grid] &then
    kill %.basn%suba%.suff% all
    &if [exists subaply%.suff% -cover] &then
    kill subaply%.suff% all
    &if [exists subapnt%.suff% -cover] &then
    kill subapnt%.suff% all
    &if [exists cumapnt%.suff% -cover] &then
    kill cumapnt%.suff% all
    &if [exists %.basn%sub%.suff% -cover] &then
    kill %.basn%sub%.suff% all
    &if [exists %.basn%da%.suff% -cover] &then
    &if [exists %.basn%tcwt%.suff% -grid] &then
    kill %.basn%tcwt%.suff% all
    &if [exists %.basn%wtrain%.suff% -grid] &then
    kill %.basn%wtrain%.suff% all
    &if [exists %.basn%soil%.suff% -cover] &then
    kill %.basn%soil%.suff% all
    &if [exists %.basn%hydgrp%.suff% -cover] &then
    kill %.basn%hydgrp%.suff% all
    &if [exists %.basn%aspct%.suff% -grid] &then
    kill %.basn%aspct%.suff% all
    &if [exists %.basn%gage%.suff% -grid] &then
    kill %.basn%gage%.suff% all
```

```
&if [exists %.basn%qds%.suff% -cover] &then
kill %.basn%qds%.suff% all
&if [exists %.basn%subas%.suff% -grid] &then
kill %.basn%subas%.suff% all
&if [exists %.basn%stc%.suff% -grid] &then
kill %.basn%stc%.suff% all
&if [exists %.basn%spth%.suff% -grid] &then
kill %.basn%spth%.suff% all
&if [exists %.basn%stpth%.suff% -grid] &then
kill %.basn%stpth%.suff% all
&if [exists %.basn%stptharc%.suff% -cover] &then
kill %.basn%stptharc%.suff% all
&if [exists %.basn%sup%.suff% -grid] &then
kill %.basn%sup%.suff% all
&if [exists %.basn%sdn%.suff% -grid] &then
kill %.basn%sdn%.suff% all
&if [exists %.basn%stdn%.suff% -grid] &then
kill %.basn%stup%.suff% all
&if [exists %.basn%stdn%.suff% -grid] &then
kill %.basn%stdn%.suff% all
&if [exists %.basn%adj%.suff% -grid] &then
kill %.basn%adj%.suff% all
&if [exists %.basn%dir%.suff% -grid] &then
kill %.basn%dir%.suff% all
&if [exists %.basn%hydgrp%.suff% -cover] &then
kill %.basn%hydgrp%.suff% all
&if [exists %.basn%gage%.suff% -cover] &then
kill %.basn%gage%.suff% all
&if [exists %.basn%soil%.suff% -cover] &then
kill %.basn%soil%.suff% all
&if [exists %.basn%lugrd%.suff% -grid] &then
kill %.basn%lugrd%.suff% all
&if [exists %.basn%slgrd%.suff% -grid] &then
kill %.basn%slgrd%.suff% all
&if [exists %.basn%wtrcn%.suff% -grid] &then
kill %.basn%wtrcn%.suff% all
&if [exists %.basn%l85%.suff% -grid] &then
kill %.basn%l85%.suff% all
&if [exists e85%.suff% -grid] &then
kill e85%.suff% all
&if [exists %.basn%l10%.suff% -grid] &then
kill %.basn%l10%.suff% all
&if [exists e10%.suff% -grid] &then
kill e10%.suff% all
&if [exists %.basn%strng%.suff% -grid] &then
kill %.basn%strng%.suff% all
&if [exists %.basn%rgn%.suff% -cover] &then
kill %.basn%rgn%.suff% all
&if [exists %.basn%gages%.suff% -grid] &then
kill %.basn%gages%.suff% all
&if [exists %.basn%lunew%.suff% -grid] &then
kill %.basn%lunew%.suff% all
&if [exists h -grid] &then
kill h all
&if [exists k -grid] &then
kill k all
&if [exists l -grid] &then
kill l all
&if [exists *.s] &then
&sys rm *.s
```

```
	&if [exists *.x] &then
	&sys rm *.x
	&if [exists %.basn%tinv%.suff% -grid] &then kill %.basn%tinv%.suff% all
	&if [exists %.basn%tadd%.suff% -grid] &then kill %.basn%tadd%.suff% all
	&if [exists %.basn%tadd2%.suff% -grid] &then kill %.basn%tadd2%.suff% all
	&if [exists %.basn%smx%.suff% -grid] &then kill %.basn%smx%.suff% all
	&if [exists %.basn%spth%.suff% -grid] &then kill %.basn%spth%.suff% all
	&if [exists %.basn%stc%.suff% -cover] &then kill %.basn%stc%.suff% all
	&if [exists %.basn%tctmp%.suff% -grid] &then kill %.basn%tctmp%.suff% all
	&if [exists %.basn%vel%.suff% -grid] &then kill %.basn%vel%.suff% all
	&if [exists clippoly -cover] &then kill clippoly all
	&if [exists %.basn%rcn%.suff% -cover] &then kill %.basn%rcn%.suff% all
	&if [exists %.basn%r%.suff% -cover] &then kill %.basn%r%.suff% all
	&popup %.PTH%clnend.txt
&end
&return
```

```
/* Name: drawcov.aml
/*----------------------
/* Purpose: Draws coverage as select by user in askdraw.men
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: %.type% %.covt% %.comm% %.item%
/*----------------------
/* Global variables set: .cov
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/01/94
/* Last update: 5/1/95
/*----------------------
/* Remarks: The draw cover type is %.cov%, the draw command is %.comm% both of
/* which are set in askdraw.men
/*----------------------
&if [null %.type%] &then
	&return
&sv .cov = [GET%.type% * %.covt% -OTHER]
&sv q = [response 'Do you want the map extent set to the selected coverage? (Y/N)']
&if %q% = y or %q% = Y &then
	mape %.cov%
&if not [null %.covt%] &then &do
	&if %.covt% = -POLY &then &do
			&sv .item [getitem %.cov% -poly]
			%.comm% %.cov% %.item%
	&end
	&else
			%.comm% %.cov%
&end
&else
	%.comm% %.cov%
&return
```

```
/* Name: drwgge.aml
/*----------------------
/* Purpose: This aml draws the grid of newly moved gages
/*
/*----------------------
```

```
/* Calls: None
/*----------------------
/* Called by: gage.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: None
/*----------------------
/* Data created: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/01/94
/* Last update:
/*----------------------
/* Remarks:
/*
/*----------------------
&if [exists %.basn%gages%.suff% -grid] &then gridpaint %.basn%gages%.suff%
&else &type You need to select and move gages first
&return
```

```
/* Name: dsgnrain.aml
/*----------------------
/* Purpose: This aml uses the delineated watershed or subareas to determine
/* weighted rainfall amount(s) using TP40 design values for 24 hour storms.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 2/03/95
/* Last update: 5/08/95
/*----------------------
/* Remarks: Adds weighted rainfall to watershed PAT of subareas PAT
/*
/*----------------------
&if [exists %.basn%wtr2%.suff% -grid] &then kill %.basn%wtr2%.suff% all
&if [exists %.basn%wtr5%.suff% -grid] &then kill %.basn%wtr5%.suff% all
&if [exists %.basn%wtr10%.suff% -grid] &then kill %.basn%wtr10%.suff% all
&if [exists %.basn%wtr25%.suff% -grid] &then kill %.basn%wtr25%.suff% all
&if [exists %.basn%wtr50%.suff% -grid] &then kill %.basn%wtr50%.suff% all
&if [exists %.basn%wtr100%.suff% -grid] &then kill %.basn%wtr100%.suff% all
&if [exists %.basn%r%.suff% -cover] &then kill %.basn%r%.suff% all
&if [exists %.basn%shed%.suff% -grid] &then &do
&if [exists %.basn%sshed%.suff% -grid] &then &do
&sv q = [getchoice Watershed Subareas -prompt 'Select breakdown of RCN']
&if %q% = Watershed &then
&sv use = %.basn%shed%.suff%
/* Note it is best to use %.basn%pth%.suff% to minimize data size
&if %q% = Subareas &then
```

```
&sv use = %.basn%sshed%.suff%
&end
&else &do
&sv use = %.basn%shed%.suff%
&sv q = Watershed
&end
&if [exists %.basn%pth%.suff% -grid] &then &do
setwindow %.basn%pth%.suff%
&describe %.basn%pth%.suff%
&end
&else &do
&sv .mask %.basn%shed%.suff%
&run %.PTH%winset
&describe %.basn%shed%.suff%
&end
setmask off
&type Determining Weighted rainfall amount(s) based on TP 40
/* Note adding value of %use% here to ensure uniqueness for subareas. (superfluous for watershed only)
%.basn%wtR2%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f2_24) * 254000 + %use%)
&describe %.basn%wtR2%.suff%
/* Note: TP 40 values in inches, converted to mm
&sv .R2_24 = %GRD$ZMAX% / 10000
&sv .V2 = [calc %.R2_24% * %.AREA% * 1000] / 10000
%.basn%wtR5%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f5_24) * 254000 + %use%)
&describe %.basn%wtR5%.suff%
&sv .R5_24 = %GRD$ZMAX% / 10000
&sv .V5 = [calc %.R5_24% * %.AREA% * 1000] / 10000
%.basn%wtR10%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f10_24) * 254000 + %use%)
&describe %.basn%wtR10%.suff%
&sv .R10_24 = %GRD$ZMAX% / 10000
&sv .V10 = [calc %.R10_24% * %.AREA% * 1000] / 10000
%.basn%wtR25%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f25_24) * 254000 + %use%)
&describe %.basn%wtR25%.suff%
&sv .R25_24 = %GRD$ZMAX% / 10000
&sv .V25 = [calc %.R25_24% * %.AREA% * 1000] / 10000
%.basn%wtR50%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f50_24) * 254000 + %use%)
&describe %.basn%wtR50%.suff%
&sv .R50_24 = %GRD$ZMAX% / 10000
&sv .V50 = [calc %.R50_24% * %.AREA% * 1000] / 10000
%.basn%wtR100%.suff% = int (zonalmean (%use%, %.PTH2%tx/raingrd.f100_24) * 254000 + %use%)
&describe %.basn%wtR100%.suff%
&sv .R100_24 = %GRD$ZMAX% / 10000
&sv .V100 = [calc %.R100_24% * %.AREA% * 1000] / 10000
&label s1
&if %use% = %.basn%shed%.suff% &then &do
/* need to change this to write as file - possibly modify slect.aml
&type The following weighted TP 40 rainfall values have been established:
&type Freq.     Rain (mm)   Volume (cum)
&type 2         %.R2_24%              %.V2%
&type 5         %.R5_24%              %.V5%
&type 10        %.R10_24%             %.V10%
&type 25        %.R25_24%             %.V25%
&type 50        %.R50_24%             %.V50%
&type 100       %.R100_24%            %.V100%
&type
&data arc tables
additem %.basn%tmp%.suff%.pat R2_24 6 6 n 0
additem %.basn%tmp%.suff%.pat R5_24 6 6 n 0
additem %.basn%tmp%.suff%.pat R10_24 6 6 n 0
additem %.basn%tmp%.suff%.pat R25_24 6 6 n 0
```

```
additem %.basn%tmp%.suff%.pat R50_24 6 6 n 0
additem %.basn%tmp%.suff%.pat R100_24 6 6 n 0
select %.basn%tmp%.suff%.pat
calc R2_24 = [round %.R2_24%]
calc R5_24 = [round %.R5_24%]
calc R10_24 = [round %.R10_24%]
calc R25_24 = [round %.R25_24%]
calc R50_24 = [round %.R50_24%]
calc R100_24 = [round %.R100_24%]
quit
&end
&end
&else &do
%.basn%r%.suff% = gridpoly (%.basn%wtr2%.suff%)
&data arc tables
select %.basn%wtr2%.suff%.vat
alter value
R2_24
select %.basn%wtr5%.suff%.vat
alter value
R5_24
select %.basn%wtr10%.suff%.vat
alter value
R10_24
select %.basn%wtr25%.suff%.vat
alter value
R25_24
select %.basn%wtr50%.suff%.vat
alter value
R50_24
select %.basn%wtr100%.suff%.vat
alter value
R100_24
select %.basn%r%.suff%.pat
alter grid-code
r2_24
quit
&end
&sys arc joinitem %.basn%wtr2%.suff%.vat %.BASN%wtr100%.SUFF%.vat %.basn%wtr2%.suff%.vat $recno r2_24
```

```
&sys arc joinitem %.basn%wtr2%.suff%.vat %.BASN%wtr50%.SUFF%.vat %.basn%wtr2%.suff%.vat $recno r2_24
&sys arc joinitem %.basn%wtr2%.suff%.vat %.BASN%wtr25%.SUFF%.vat %.basn%wtr2%.suff%.vat $recno r2_24
&sys arc joinitem %.basn%wtr2%.suff%.vat %.BASN%wtr10%.SUFF%.vat %.basn%wtr2%.suff%.vat $recno r2_24
&sys arc joinitem %.basn%wtr2%.suff%.vat %.BASN%wtr5%.SUFF%.vat %.basn%wtr2%.suff%.vat $recno r2_24
&sys arc joinitem %.basn%r%.suff%.pat %.BASN%wtr2%.SUFF%.vat %.basn%r%.suff%.pat r2_24 r2_24
/* append to %.basn%sub%.suff%n
&sys arc joinitem %.basn%sub%.suff%.pat %.basn%r%.suff%.pat %.basn%sub%.suff%.pat $recno WSHEDA(SQ.KM)
calc %.basn%sub%.suff%.pat info r100_24 = r100_24 / 10000
calc %.basn%sub%.suff%.pat info r50_24 = r50_24 / 10000
calc %.basn%sub%.suff%.pat info r25_24 = r25_24 / 10000
calc %.basn%sub%.suff%.pat info r10_24 = r10_24 / 10000
calc %.basn%sub%.suff%.pat info r5_24 = r5_24 / 10000
calc %.basn%sub%.suff%.pat info r2_24 = r2_24 / 10000
&end
&if [exists %.basn%wtr2%.suff% -grid] &then kill %.basn%wtr2%.suff% all
&if [exists %.basn%wtr5%.suff% -grid] &then kill %.basn%wtr5%.suff% all
&if [exists %.basn%wtr10%.suff% -grid] &then kill %.basn%wtr10%.suff% all
&if [exists %.basn%wtr25%.suff% -grid] &then kill %.basn%wtr25%.suff% all
&if [exists %.basn%wtr50%.suff% -grid] &then kill %.basn%wtr50%.suff% all
&if [exists %.basn%wtr100%.suff% -grid] &then kill %.basn%wtr100%.suff% all
&if %q% = Watershed &then list %.basn%tmp%.suff%.pat
&if %q% = Subareas &then list %.basn%sub%.suff%.pat
&end
&else &do
&popup %.pth%noshed.txt
&end
&type Done
&return
```

```
/* Name: fndquad.aml
/*----------------------
/* Purpose: This AML identifies which dem quadrangles are needed
/* for delineation of areas at 1:250k or 1:24k scales for Texas.
/*
/*----------------------
/* Calls: slect.aml
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: .scale .count .cover .item .subject .nos .upsc
/*----------------------
/* Data created:  %.basn%qds%.suff% %.cover%.qd
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 2/03/95
/* Last update: 4/18/95
/*----------------------
/* Remarks: An ASCII output of quadrangle names is created. This may
/* contain duplicate names which must be deleted if used for subsequent
/* data set up in prerpoc.aml. DEM files must have the exact name as
/* contained in this file.
/*
/*----------------------
setmask off
&if [exists %.basn%tmp%.suff% -cover] &then &do
        &if [exists %.basn%qds%.suff% -cover] &then
        kill %.basn%qds%.suff% all
```

```
	&sv .scale = [getchoice 1:250K 1:24K -prompt 'At which scale do you wish to work?']
	&if %.scale% = 1:250K &then &do
			&sys arc clip %.PTH2%tx/tx250ndx %.basn%tmp%.suff% %.basn%qds%.suff%
			&end
	&if %.scale% = 1:24K &then &do
			&sys arc clip %.PTH2%tx/tx24ndx %.basn%tmp%.suff% %.basn%qds%.suff%
			&end
	&describe %.basn%qds%.suff%
	&sv .count = [calc %DSC$POLYGONS% - 1]
	&sv .cover = %.basn%qds%.suff%
	&sv .item = quad_name
	&sv .subject = quad_names
	&sv .nos = 0
	&run %.PTH%slect.aml
	&sv .upsc = Y
	&sys mv %.cover%.dat %.cover%.qd
	&popup %.PTH%preproc.txt
	&popup %.cover%.qd
	&end
&else
	&type %.basn%shed%.suff% does not exist. You need to run watershed first.
&return
```

```
/* Name: hdds.aml
/*----------------------
/* Purpose: This invokes the project menu for the Hydologic Data Development System
/* Global variables are initialized which include paths for permanent data.
/* System environment is also established.
/*----------------------
/* Calls: basins.men
/*----------------------
/* Called by: &run [path]/basmenu from ARC prompt
/*----------------------
/* Required variables: None
/*----------------------
/* Global variables set: .PTH .PTH2 .scale .suff .upsc .basn .nopps .outfall .rdid .strmid
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/01/94
/* Last update: 3/30/95
/*----------------------
/* Remarks:
/* 1. On installation, the variable .PTH2 should be preset to reflect
/* the directories in which the amls and data reside.
/* 2. The routine may be run from any workspace at the ARC prompt.
/*----------------------
&station 9999
/* The user needs only to change the following line on installation
&sv .PTH2 = /usr2/psmith/thesis/
/* establish path to amls
&amlpath %.pth2%amls
/* Initialize global variables
/* path to amls, menus, and messages
&sv .PTH = %.pth2%amls/
&sv .scale =
&sv .suff =
&sv .upsc =
&sv .basn
&sv .outfall = n
```

```
&sv .nopps = 1
&sv .work =
&sv .rdid
&sv .strmid
&sv .lucode
GRID
&popup %.PTH%strt.txt
&menu %.PTH%basins.men &position &UC &stripe ~
'Hydrologic Data Development System'
&return
```

```
/* Name: hddscd.aml
/*----------------------
/* Purpose: This invokes the cdrom version project menu for the Hydologic Data
/* Development System.
/* Global variables are initialized which include paths for permanent data.
/* System environment is also established.
/*----------------------
/* Calls: basins.men
/*----------------------
/* Called by: &run [path]/hdds from ARC prompt
/*----------------------
/* Required variables: None
/*----------------------
/* Global variables set: .PTH .PTH2 .scale .suff .upsc .basn .rdis .strmid .work
/* .outfall .nopps
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/01/94
/* Last update: 4/18/95
/*----------------------
/* Remarks:
/* 1. On installation, the variables .PTH and .PTH2 and amlpath should be
/* preset to reflect the directories in which the amls and data reside.
/* 2. The routine may be run from any workspace at the ARC prompt.
/*----------------------
&station 9999
/* establish path to amls
&amlpath /cdrom/thesis/amls
/* Initialize global variables
&sv .PTH = /cdrom/thesis/amls/
&sv .PTH2 = /cdrom/thesis/
&sv .scale =
&sv .suff =
&sv .upsc =
&sv .basn
&sv .outfall = n
&sv .nopps = 1
&sv .work
&sv .rdid
&sv .strmid
&sv .lucode
GRID
&popup %.PTH%strt.txt
&menu %.PTH%basins.men &position &UC &stripe ~
'Hydrologic Data Development System'
&return
```

```
/* Name: idroad.aml
```

```
/*----------------------
/* Purpose: Request user to select a stretch of road that will be used in conjunction
/* with an identified stream to locate a watershed outfall.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn
/*
/*----------------------
/* Global variables set: .rdid
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/02/94
/* Last update: 3/30/95
/*----------------------
/* Remarks:
/*
/*----------------------
LINECOLOR 2
&type 'Please select a road.'
&severity &error &routine redo
/* User identify road with mouse
RESELECT %.PTH2%%.basn%/%.basn%rds ARCS ONE *
&messages &off
/* save id of selected arc (road stretch)
&sv .rdid = [SHOW SELECT %.PTH2%%.basn%/%.basn%rds LINE 1 ITEM %.basn%rds-id]
&severity &error &fail
&type setting road id to %.rdid%...
/* Reselect all attributes
aselect %.PTH2%%.basn%/%.basn%rds arcs MAPE
&messages &on
&type Selection complete.
&return
&routine redo
/* No arc identified select all arcs again
&severity &error &fail
aselect %.PTH2%%.basn%/%.basn%rds arcs MAPE
&popup %.PTH%missed.txt
aselect %.PTH2%%.basn%/%.basn%rds arcs MAPE
&messages &on
&return &error
```

```
/* Name: idstrm.aml
/*----------------------
/* Purpose: Requests user to identify stretch of stream to be used in conjunction
/* with selected road to locate watershed outfall.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn
/*----------------------
/* Global variables set: .strmid
/*----------------------
```

```
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/02/94
/* Last update: 3/30/95
/*----------------------
/* Remarks:
/*
/*----------------------
LINECOLOR 2
&type 'Please select a stream.'
&severity &error &routine redo
/* User select arc with mouse
RESELECT %.PTH2%%.basn%/%.basn%sarc ARCS ONE *
&messages &off
&sv .strmid := [SHOW SELECT %.PTH2%%.basn%/%.basn%sarc LINE 1 ITEM %.basn%sarc-id]
&type setting stream id to %.strmid%...
&type Reselecting all attributes
aselect %.PTH2%%.basn%/%.basn%sarc arcs MAPE
&messages &on
&type Selection complete.
&return
&routine redo
/* No stream selected, reselect all arcs
&severity &error &fail
aselect %.PTH2%%.basn%/%.basn%sarc arcs MAPE
&popup %.PTH%missed.txt
&messages &on
&return &error
```

```
/* Name: infiles.aml
/*----------------------
/* Purpose: This aml requests desired coverage database and sets variables for the
/* selected coverage database. Also established initial map extent for display and
/* search tolerance for subsequent identification of arcs.
/*----------------------
/* Calls:
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .scale .suff .upsc .basn
/*----------------------
/* Global variables set: .wspace .data .basn .outfall
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/01/94
/* Last update: 4/12/95
/*----------------------
/* Remarks:
/*
/*----------------------
setmask off
setwindow maxof
/* Save the current workspace name
&sv .wspace = [show wo]
&wo [trim %.PTH2% -right /]
/* Determine which data set to use
&sv .data = [getfile * -workspaces 'Select your data source']
&sv .basn = [entryname %.data%]
/* On start up no outfall will have been specified
```

```
&sv .outfall = n
&wo %.wspace%
MAPE %.PTH2%%.basn%/%.basn%bas
&describe %.PTH2%%.basn%/%.basn%bas
/* set the tolerance as 4 times cell size
searchtolerance [calc %GRD$DX% * 4]
&return
```

```
/* Name: line.aml
/*----------------------
/* Purpose: This aml allows identification of pour points using a user-defined
/* polygon.
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: .suff
/*----------------------
/* Data created: %.basn%pp%.suff% or %.basn%spp%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/14/95
/* Last update: 4/18/95
/*----------------------
/* Remarks: At least three nodes are required. The cell with the maximum flow
/* accumulation inside the polygon will be selected as the pour point.
/* For a single pour point, the Watershed/ Area option should subsequently be
/* selected. Watershed/Subareas for multiple pour points.
/*
/*----------------------
/*
&sv .suff [response 'Enter the suffix name for files to be created (e.g. a)']
&do &while [exists %.basn%pp%.suff% -grid]
    &type %.basn%pp%.suff% already exists.
    &sv .suff = [response 'Please enter a new suffix e.g. b or c ..']
&end
&popup %.PTH%selw.txt
/* A bug in Arc/info does prevents interactive selection of box without
/* first drawing something else!
arcs %.pth2%tx/txpoly
/* Request user to define window extent (snapped to flow accumulation grid)
setwindow * %.PTH2%%.basn%/%.basn%acc
&popup %.pth%pps.txt
&sv count = 1
&sv stop =
&s .merge =
/* Allow user to establish as many polygons as desired.
/* A grid is created for each pour point then when the user is
/* finished all pour points are merged into one grid
&do &until %stop% = y or %stop% = Y
    /* select a point and create grid
    pp%count% = con (zonalmax (int (selectpolygon (%.PTH2%%.basn%/%.basn%acc, *) / %.PTH2%%.basn%/%.basn%acc),
%.PTH2%%.basn%/%.basn%acc) == ~
    %.PTH2%%.basn%/%.basn%acc, %count%)
    /* same problem here with interactive drawing
    arcs %.PTH2%tx/txpoly
```

```
	&sv stop = [response 'Finished? (y)']
	/* Store all names of individual pour point grids
	&sv .merge = %.merge%pp%count%,
	&sv count = %count% + 1
&end
&sv count = %count% - 1
/* store number of pour points created
&sv .nopps = %count%
&sv merge = [trim %.merge% -right ,]
/* For one pour point only, save file for use in Watershed/area, otherwise for
/* use in Watershed/Subareas
&if %.nopps% = 1 &then %.basn%pp%.suff% = int (merge (%merge%))
&else %.basn%spp%.suff% = int (merge (%merge%))
/* Ensure sequential numbering of pour point values starting from one
&dv .merge
&do &until %count% = 0
&if [exists pp%count% -grid] &then kill pp%count% all
&sv count = %count% - 1
&end
&popup %.pth%ppend.txt
&sv .outfall = y
&return
```

```
/* Name: luadd.aml
/*----------------------
/* Purpose: Checks to see if changes can be made to land use table (rcns.dat)
/* and  sets environment for modifying table, then initiates menu for updating
/* table.
/*----------------------
/* Calls: lu_rcn.men
/*----------------------
/* Called by: lu.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 04/01/95
/* Last update: 04/05/95
/*----------------------
/* Remarks:
/* Have problems modifying table from any directory other than location of table, so
/* routine saves workspace location to return after table modification is done.
/*----------------------
/*
/* add new lucode and rcns to permanent table or adjust rcns
&if %.pth% NE cdrom/thesis/amls/ &then &do
	&sv q [response 'Sure you want to make changes to the permanent table? (YES/N)']
	&if %q% = YES &then &do
			&popup %.pth%adjtab.txt
			&sv .home = [show workspace]
			&wo %.pth2%tables
			&menu %.pth%lu_rcn.men &stripe 'LU/RCN/SoilGRP Table'
			&wo %.home%
	&end
&end
&else &type Since you are running off the CDROM, no changes can be made.
&type Done
```

```
&return

/* Name: luadj.aml
/*----------------------
/* Purpose: Allows user-defined polygons to modify grid of land use codes and,
/* if necessary add new land use codes/RCN's to permanent database.
/*
/*----------------------
/* Calls: lu.men
/*----------------------
/* Called by: rcn.aml
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 04/01/95
/* Last update: 04/05/95
/*----------------------
/* Remarks: The user-defined polygons only modify the land use codes for the working
/* grid of land use, not the permanent vector coverage.
/*
/*----------------------
/*
clear
&if [exists %.basn%pth%.suff% -grid] &then mape %.basn%pth%.suff%
&else &do
        &sv .MASK = %.basn%shed%.suff%
        &run %.pth%winset.aml
        mape [show setwindow]
&end
&menu %.pth%lu.men &pulldown &stripe 'Land Use/ RCN Adjustment'
&return

/* Name: lupoly.aml
/*----------------------
/* Purpose: Draw polygons to update landuse values
/*
/*----------------------
/* Calls: none
/*----------------------
/* Called by: lu.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/04/95
/* Last update:
/*----------------------
/* Remarks: The value assigned to the land use polygon must represent a
/* land use code and should be set using setval in lu.menu prior to this
/* Currently assumes lucode already exists with associated RCN's - modify later
/*----------------------
/*
/*
```

```
&if NOT [null %.lucode%] &then &do
    setmask off
    &popup %.pth%poly.txt
    &sv count = 1
    &sv .merge =
    &do &until %more% = y or %more% = Y
        lu%count% = selectpolygon (%.basn%shed%.suff%, *) * %.lucode%
/* the following is merely to overcome a problem in grid which
/* otherwise does not allow sequential drawing of polys. Drawing any
/* other grid or arc will avoid the problem!
        arcs  %.basn%tmp%.suff%
        &sv more = [response 'Finished? (y)']
        &sv .merge = %.merge%lu%count%,
        &sv count = %count% + 1
    &end
    &sv count = %count% - 1
    &sv merge = [trim %.merge% -right ,]
    %.basn%lunew%.suff% = merge (%merge%)
    &dv .merge
    &do &until %count% = 0
        &if [exists lu%count% -grid] &then kill lu%count% all
        &sv count = %count% - 1
    &end
    lutmp = merge (%.basn%lunew%.suff%, %.basn%lugrd%.suff%)
    &if [exists %.basn%lugrd%.suff% -grid] &then kill %.basn%lugrd%.suff% all
    &if [exists %.basn%lunew%.suff% -grid] &then kill %.basn%lunew%.suff% all
    %.basn%lugrd%.suff% = lutmp
    &if [exists lutmp -grid] &then kill lutmp all
    arcs  %.basn%tmp%.suff%
&end
&else &popup %.pth%nocode.txt
&type Done
&return
```

```
/* Name: modrcn.aml
/*----------------------
/* Purpose: Accesses land use / RCN table for modification
/*----------------------
/* Calls: None
/*----------------------
/* Called by: lu_rcn.men
/*----------------------
/* Required variables:
/*----------------------
/* Global variables set: None
/*----------------------
/* Data created: modifies rcns.dat
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/31/95
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*----------------------
/*
&data arc tables
select rcns.dat
update
&end
```

```
&return
```

/* Name: **mvgage.aml**

```
/*----------------------
/* Purpose: Creates grid of interactively relocated streamgages from original vector
/* coverage without modifying existing coverage. This allows the user to ensure that a
/* gage record is placed on the apprpriate stretch of stream.
/*----------------------
/* Calls: None
/*----------------------
/* Called by: gage.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created:  %.basn%gages%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/31/95
/* Last update: 4/18/95
/*----------------------
/* Remarks: This routine does not actually move the vector points which represent a gage.
/* The gage id of a selected streamgage is assigned to the selected cell in a separate grid
/* and the attributes of the gage are added to the vat.
/*----------------------
/*
/* The gage coverage and stream grid should first be in view.
&sv count = 1
&sv more = n
&s .merge =
&type Please set the search tolerance
searchtolerance *
&do &until %more% = y or %more% = Y
    /* select the gage
    RESELECT %.PTH2%tx/txgages points ONE *
    &sv .ggeid = [SHOW SELECT %.PTH2%tx/txgages point 1 ITEM txgages-id]
    &type Select the move to cell
    aselect %.PTH2%tx/txgages points txgages-id > 0
    /* Assumes value of 1 in gstrms. If using other grid with values other than one
    /* simply divide grid by itself in selectpoint statement
    gage%count% = selectpoint (%.pth2%%.basn%/%.basn%strms, *) * %.ggeid%
    &sv more = [response 'Finished? (y)']
    /* Could also try merging one by one in previous loop
    &sv .merge = %.merge%gage%count%,
    &sv count = %count% + 1
&end
&sv count = %count% - 1
&sv merge = [trim %.merge% -right ,]
%.basn%gge%.suff% = merge (%merge%)
&dv .merge
&label skip
&data arc tables
select %.basn%gge%.suff%.vat
alter value



txgages-id
```

```

quit
&end
&sys arc joinitem %.basn%gge%.suff%.vat %.PTH2%tx/txgages.pat %.basn%gge%.suff%.vat txgages-id count
&do &until %count% = 0
&if [exists gage%count% -grid] &then kill gage%count% all
&sv count = %count% - 1
&end
&type You now have a grid coverage of selected stream gages named %.basn%gge%.suff%
&return
```

```
/* Name: outfall.aml
/*----------------------
/* Purpose: This aml allows user selction of outfall locations
/* by identifying individual cells.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .outfall
/*----------------------
/* Global variables set: .suff .outfall .nopps
/*----------------------
/* Data created: %.basn%pp%.suff% or %.basn%spp%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 03/29/94
/* Last update: 4/18/95
/*----------------------
/* Remarks: If one cell is selected then the Watershed/Area should be used after
/* this routine. For two or more pour points, the Watershed/Subareas routine
/* should be selected. This is a less secure way of identify outfall since the
/* arcs and grid accuracy is limited. The road/stream intersection or line methods
/* are better.
/*
/*----------------------
&sv .suff [response 'Enter the suffix name for files to be created (e.g. a)']
&do &while [exists %.basn%pp%.suff% -grid]
        &type %.basn%pp%.suff% already exists.
        &sv .suff = [response 'Please enter a new suffix e.g. b or c ..']
&end
&popup %.PTH%selw.txt
/* the next line could be any draw item to avoid a bug incurred
/* by previous use of the select command
arcs %.pth2%tx/txpoly
/* use accumulation grid as snap-to for window to ensure coincidence of
/* subsequent grids.
setwindow * %.PTH2%%.basn%/%.basn%acc
&popup %.pth%pps.txt
&sv count = 1
&sv stop =
&s .merge =
/* Allow user to specify multiple pour points if desired.
/* Each pour point is saved as a grid, then all pour points are merged
/* into one grid.
&do &until %stop% = y or %stop% = Y
        /* select a point and create grid
```

```
        pp%count% = int (selectpoint (%.PTH2%%.basn%/%.basn%acc, *) ~
        / %.PTH2%%.basn%/%.basn%acc * %count%)
        arcs %.PTH2%tx/txpoly
        &sv stop = [response 'Finished? (y)']
        /* save the names of pour point files as one character string
        &sv .merge = %.merge%pp%count%,
        &sv count = %count% + 1
&end
&sv count = %count% - 1
&sv .nopps = %count%
/* merge individual pour point grids into one
&sv merge = [trim %.merge% -right ,]
/* If only one pp, save for use in Watershed/Area, otherwise for
/* Watareshed/Subareas
&if %.nopps% = 1 &then %.basn%pp%.suff% = merge (%merge%)
&else %.basn%spp%.suff% = merge (%merge%)
/* Ensure sequential numbering of pour point values starting from one
&dv .merge
&do &until %count% = 0
&if [exists pp%count% -grid] &then kill pp%count% all
&sv count = %count% - 1
&end
&popup %.pth%ppend.txt
&sv .outfall = y
&return

/* Name: ppgge.aml
/*----------------------
/* Purpose: Sets previously created grid gage as pour point file for subsequent
/* delineation of areas
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: gage.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .
/*----------------------
/* Global variables set: .suff .outfall .nopps
/*----------------------
/* Data created: %.basn%pp%.suff% or %.basn%spp%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/10/94
/* Last update: 4/12/95
/*----------------------
/* Remarks:
/*
/*----------------------
&if [exists %.basn%gge%.suff% -grid] &then &do
        &sv .gpp = [response 'Do you wish to use the gage locations for determining areas? (Y or N)']
&if %.gpp% = Y or %.gpp% = y or %.gpp% = YES or %.gpp% = yes &then &do
        &sv .suff = [response 'Enter the suffix for your proposed data sets']
        &if [exists ycell%.suff% -grid] &then kill ycell%.suff% all
        &if [exists xcell%.suff% -grid] &then kill xcell%.suff% all
        &do &while [exists %.basn%shed%.suff% -grid]
                                &type %.basn%shed%.suff% already exists
                                &sv .suff = [response 'Please enter a new suffix e.g. b or c or bb etc...']
                &end
```

```
			&describe %.basn%gge%.suff%
			&sv .nopps = %grd$nclass%
			&if %.nopps% = 1 &then &do
				&if [exists %.basn%pp%.suff% -grid] &then kill %.basn%pp%.suff%
				copy %.basn%gge%.suff% %.basn%pp%.suff%
			&end
			&else &do
				&if [exists %.basn%spp%.suff% -grid] &then kill %.basn%spp%.suff%
				copy %.basn%gge%.suff% %.basn%spp%.suff%
			&end
			&sv .outfall = y
			&popup %.PTH%selw.txt
			setwindow * %.pth2%%.basn%/%.basn%acc
	&end
&end
&else &type %.basn%gge%.suff% Does not exist. Please move gages first.
&type Done
&return

/* Name: preproc.aml
/*----------------------
/* Purpose: This is a preprocessing aml that is intended to set up coverages required
/* for the Hydrologic Data Development System.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .prefix .dir .FILE .dem .GO .mergfil .wspace .HWY .proj
/* .units .zunits .datum .sph .zone .scale .upsc
/*----------------------
/* Global variables set: .prefix .dir .FILE .dem .GO .mergfil .wspace .HWY .proj
/* .units .zunits .datum .sph .zone
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/28/95
/* Last update: 3/30/95
/*----------------------
/* Remarks: Only sets up dem-based and highway-based data.
/* i.e. filled dem, flowdirection, flowaccumulation, gridded streams,
/* stream links, arc streams, cell slope, drainage basins, and highway grid
/*----------------------
/*
&sv .prefix = [response 'What do you want to call this system of data?']
&sv .dir = [response 'Please enter the full path to the directory in which the ~
dem data reside']
&sv .HWY = [response 'Enter the arc coverage name of the highways']
/* can use an existing ascii file of dem names. First line must have record name
/* or other, second through penultimate must contain dem grid name (one per line)
/* last line must be "end". The option Up-scale/fndquad can be used to find the
/* names associated with the current delineated watershed.
&if [exists %.basn%qds%.suff% -cover] &then &do
	&type The current quad file is %.basn%qds%.suff%.dat
	&sv q = [response 'Do you wish to use the quads in this file?']
	&if %q% = Y or %q% = y &then &do
			&sv .FILE = %.basn%qds%.suff%.qd
	&end
	&else &do
```

```
                &sv .FILE = [getfile *qds*.qd -NONE -OTHER 'Choose which quad index file you need']
        &end
&end
&else &do
        &sv .FILE = [getfile *.qd -NONE -OTHER 'Choose which quad index file you need']
&end
/* if no name file selected, request name of only one dem for processing.
&if [NULL %.FILE%] &then &do
        &popup %.PTH%qdfile.txt
        &sv .dem = [response 'Enter the name of the DEM file']
        &if [NULL %.dem%] = .FALSE. &then &do
                /* check that dem exists
                &if [exists %.dir%/%.dem% -grid] &then &do
                        &sv .GO = Y
                &end
                &else &do
                        &type %.dir%/%.dem% does not exist.
                        &sv .GO = N
                &end
        &end
        &else &do
                /* No Go ! Just checking balance of if's and elses
                &sv .GO = N
        &end
&end /* If only one dem so miss merge routines
&else &do
/* check if quads exist
/* open and read quad file
        &type 1
        &sv unit = [open %.FILE% openstat -read]
        &if %openstat% = 0 &then &do
                &sv quad = start
                &sv count = 1
                &sv .GO = Y
                &sv .mergfil
                &sv .quad%count% = [read %unit% readstat]
                &do &until %quad% = end /*end of file
                        &sv quad = [read %unit% readstat]
                        &if %quad% NE end &then
                                &if [exists %.dir%/%quad% -grid] = .FALSE. &then &do
                                        &type The dem quad %.dir%/%quad% does not exist
                                        &sv .GO = N
                                &end
                                &else &do
                                        &sv .quad%count% = %quad%
                                        &type [value .quad%count%]
                                        &sv .mergfil = %.mergfil%[value .quad%count%],
                                &end
                        &sv count = %count% + 1
                        &end
                &end
                &sv .no = %count% - 1
                &sv closestat = [close %unit%]
                &sv .mergfil = [trim %.mergfil% -right ,]
                &if %closestat% = 0 &then
                        &type File closed
/*&else &do
                /*&type Couldn't open file. Please start over from Data/Preprocess
                /*&sv .GO = N
        /*&end
```

```
&end
&if %.GO% = Y &then &do
        setwindow MAXOF
        &sys arc createworkspace %.PTH2%%.prefix%
        &sv .wspace = [show workspace]
        &wo %.dir%
        &if [NULL %.FILE%] = .FALSE. &then &do
                /* Note: Not valid if original data in multiple UTM zones. need to put in warning.
                %.PTH2%%.prefix%/%.prefix%dem1 = merge (%.mergfil%)
        &end
        &else &do
        %.PTH2%%.prefix%/%.prefix%dem1 = %.dem%
        &end
        &wo %.PTH2%%.prefix%
        &if [NULL %.scale%] &then
        &sv .scale = [getchoice 1:250K 1:24K -prompt 'At what scale is the data?']
        /* Determine existing projection parameters
        /* Currently transforms to Albers equal area
        &type 2
        &describe %.prefix%dem1
        &sv .proj = %PRJ$NAME%
        &sv .units = %PRJ$UNITS%
        &sv .zunits = %PRJ$ZUNITS%
        &sv .datum = %PRJ$DATUM%
        &sv .sph = %PRJ$SPHEROID%
        &sv .zone = %PRJ$ZONE%
        &type Projecting the file to Albers equal area ...
/* This is specific to USGS DEM data. The 1:250k are in geographic
/* and the 1:24 for Texas are in UTM. The routine stores the existing
/* projection parameters to be used as variables in the appropriate
/* projection file. This seems necessary because the project command will not
/* default to the existing input projection parameters if a projection
/* file is specified. If the user desires to transform using alternate
/* projection parameters, simply alter the ASCII files geoalb.prj and
/* utmalb.prj to reflect the desired parameters.
        &if %.SCALE% = 1:250k or %.SCALE% = 1:250K &then &do
                %.prefix%dem = project (%.prefix%dem1, %.PTH%geoalb.prj)
        &end
        &if %.SCALE% = 1:24k or %.SCALE% = 1:24K &then &do
                %.prefix%dem = project (%.prefix%dem1, %.PTH%utmalb.prj)
        &end
        &if NOT [null %.upsc%] &then &do
                &if [exists %.wspace%/%.basn%pth%.suff%] &then
                        setwindow %.wspace%/%.basn%pth%.suff%
                &else
                        setwindow %.wspace%/%.basn%shed%.suff%
        &end
        /* fill dem
        fill %.prefix%dem %.prefix%fil1
        /* Sometimes need to fill twice, other times superfluous
        fill %.prefix%fil1 %.prefix%fil
        kill %.prefix%fil1 all
        /* Create flowdirection, flowaccumulation, streams, streamlinks, basin
        %.prefix%dir = flowdirection (%.prefix%fil)
        %.prefix%acc = flowaccumulation (%.prefix%dir)
        &describe %.prefix%acc
        &sv thresh = [round [calc 250000 / %GRD$DX%]]
        %.prefix%strms = con (%.prefix%acc > %thresh%, 1)
        %.prefix%bas = basin (%.prefix%dir)
        %.prefix%slnk = STREAMLINK (%.prefix%strm, %.prefix%dir)
```

```
        %.prefix%sarc = streamline (%.prefix%slnk, %.prefix%dir)
        %.prefix%slope = slope (%.prefix%fil, PERCENTRISE)
        setwindow %.prefix%fil
        %.prefix%rdgrd = linegrid (%.HWY%, [entryname %.HWY%-id], #, #, %GRD$DX%)
        /* need to clip HWY down to window area instead of converting grid back to lines
        %.prefix%rds = gridline (%.prefix%rdgrd, #, #, #, #, %.prefix%rds-id)
        &wo %.wspace%
        &popup %.PTH%newdat.txt
        &label skip3
&end
&return
```

```
/* Name: pthleng.aml
/*----------------------
/* Purpose: Determines the longest travel distance and path from watershed boundary to outfall
/*
/*----------------------
/* Calls: winset.aml
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .upsc .outfall .rdid .strmid
/*----------------------
/* Global variables set: .MASK .LENGTH
/*----------------------
/* Data created:  %.basn%up%.suff% %.basn%dn%.suff% %.basn%l%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/16/94
/* Last update: 5/08/95
/*----------------------
/* Remarks: Not to be confused with path for time of concentration which may differ
/* Adds resulting length to watershed attribute table
/*----------------------
/*
/* Ensure that Watershed/Area has already been run
&if [exists %.basn%shed%.suff% -grid] &then &do
        &sv .MASK = %.basn%shed%.suff%
        /* Reduce analysis window to just include watershed area
        &run %.PTH%winset.aml
        /* Determine upstream flowlength in watershed
        %.basn%up%.suff% = flowlength ( selectmask (%.PTH2%%.basn%/%.basn%dir, ~
        %.basn%shed%.suff%), #, UPSTREAM)
        /* longest travel distance is maximum value in grid and occurs at the pour point
        &describe %.basn%up%.suff%
        &sv .LENGTH = [round  %GRD$ZMAX%] / 1000
        /* Determine downstream flowlength in watershed
        %.basn%dn%.suff% = flowlength ( selectmask (%.PTH2%%.basn%/%.basn%dir, ~
        %.basn%shed%.suff%), #, DOWNSTREAM)
        %.basn%l%.suff% = ZONALMAX (%.basn%shed%.suff%, ~
        %.basn%up%.suff%)
/*
/* The sum of the upstream flowlength grid and downstream flowlength grid
/* should yield a grid in which a unique string of cells contain the maximum length value.
/* All other cells with have values less than this. Then isolate cells to determine flowpath
/* Value of 1 in %.basn%shed%.suff% is subtracted to account for possible rounding
/* errors in summation.
/*
        %.basn%pth%.suff% = con (%.basn%up%.suff% + %.basn%dn%.suff% ~
```

```
	> %.basn%l%.suff% ~
	- 1, 1)
	/* Convert grid to vector coverage for display
	%.basn%ptharc%.suff% = gridline (%.basn%pth%.suff%)
	linecolor 2
	arcs %.basn%ptharc%.suff%
	&type 'The longest path length is' %.LENGTH% km
	/* Add pathlength as attribute in %.basn%shed%.suff%
	/*&label skip
/* no indentation is use here because it seems to affect the tables environment
&data arc tables
additem %.basn%tmp%.suff%.pat Calc_pthl(km) 10 10 N 3
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc Calc_pthl(km) = %.LENGTH%
quit
&end
	&popup %.PTH%pthend.txt
&end
&else &do
	&popup %.PTH%doshed.txt
&end
&type Done
&return
```

```
/* Name: rcn.aml
/*----------------------
/* Purpose: Uses watershed or subarea grid to clip landuse and soils coverage,
/* convert to grid, allow user-modified land use, and compute weighted RCN's in grid
/*
/*----------------------
/* Calls: luadj.aml
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created: %.basn%lugrd%.suff% %.basn%slgrd%.suff% %.BASN%WTRCN%.SUFF%
/* %.BASN%RCN%.SUFF%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 03/20/95
/* Last update: 05/08/95
/*----------------------
/* Remarks: Adds weighted RCN's to watershed PAT or subarea PAT requested
/* The coverage joins data from rcns.dat a table of landuse v hydrologic soil
/* group.
/*
/*----------------------
/*
&if not [exists %.basn%shed%.suff% -grid] &then &do
	&popup %.pth%noshed.txt; &return
&end
&if [exists %.basn%lugrd%.suff% -grid] &then kill %.basn%lugrd%.suff%
&if [exists %.basn%slgrd%.suff% -grid] &then kill %.basn%slgrd%.suff%
&if [exists %.basn%wtrcn%.suff% -grid] &then kill %.basn%wtrcn%.suff%
&if [exists %.basn%rcn%.suff% -cover] &then kill %.basn%rcn%.suff%
```

```
&sv q = [getchoice Watershed Subareas -prompt 'Select breakdown of RCN']
&if %q% = Watershed &then
    &sv use = %.basn%shed%.suff%
/* Note it is best to use %.basn%pth%.suff% to minimize data size
&if %q% = Subareas &then
    &if [exists %.basn%sshed%.suff% -grid] &then

    &else &do
            &popup %.pth%nosub.txt
            &return
    &end
&if [exists %.basn%pth%.suff%] &then &do
    setwindow %.basn%pth%.suff% %.PTH2%%.basn%/%.basn%acc
    &describe %.basn%pth%.suff%
    &end
&else &do
    &sv .mask %.basn%shed%.suff%
    &run %.PTH%winset
    &describe %.basn%shed%.suff%
    &end
setmask off
/*
/* get extent of watershed grid and create clip cover from extent
/*
&sv .xmin %grd$xmin%
&sv .ymin %grd$ymin%
&sv .xmax %grd$xmax%
&sv .ymax %grd$ymax%
/* reduce lu to window area of watershed.
&if [exists clippoly -cover] &then kill clippoly
&data arc generate clippoly
copytics %.basn%tmp%.suff%
polygons
%.xmax%,%.ymax%
%.xmax%,%.ymax%
%.xmax%,%.ymin%
%.xmin%,%.ymin%
%.xmin%,%.ymax%
END
END
quit
&end
&sys arc build clippoly
/*
/* convert lu to grid using only extent of watershed
/*
&sys arc clip %.pth2%tx/txlus clippoly %.basn%luclp%.suff% poly
%.basn%lugrd%.suff% = polygrid (%.basn%luclp%.suff%, lucode, #, #, %grd$dx%)
kill %.basn%luclp%.suff% all
/*
/* convert soils to grid using window area of watershed.
/* possibly use clippoly as with txlu if faster
%.basn%slgrd%.suff% = polygrid (%.pth2%tx/statsgo, statsgo-id, #, #, %grd$dx%)
setmask off
&sv q2 = [response 'Do you wish to check and possibly modify landuse codes for this watershed?']
&if %q2% = Y or %q2% = y &then &run %.pth%luadj.aml
/* add (or maybe just relate later!) soil attributes
&data arc tables
select %.basn%lugrd%.suff%.vat
alter value /* next 3 lines deliberately blank
```

```
lucode
select %.basn%slgrd%.suff%.vat
alter value /* next 3 lines deliberately blank



statsgo-id
quit
&end
&sys arc joinitem %.basn%lugrd%.suff%.vat %.pth2%tables/rcns.dat %.basn%lugrd%.suff%.vat ~
lucode count
&sys arc joinitem %.basn%slgrd%.suff%.vat %.pth2%tx/statsgo.pat %.basn%slgrd%.suff%.vat ~
statsgo-id count
Setmask %use%
setwindow %use% %.pth2%%.basn%/%.basn%acc
/* now for each cell in area calc wt rcn by determining rcn for each % of hyd group,
/* and wt per cell then mean value per wshed or subarea.
docell
/* wt rcn per cell, soil hydrologic group is in pct
/* Note : divide by total percentage incase do not add up exactly to 100%
totpct := %.basn%slgrd%.suff%.a-pct + %.basn%slgrd%.suff%.b-pct + %.basn%slgrd%.suff%.c-pct + %.basn%slgrd%.suff%.d-pct
wtcella := %.basn%slgrd%.suff%.a-pct * %.basn%lugrd%.suff%.hyd-a / totpct
wtcellb := %.basn%slgrd%.suff%.b-pct * %.basn%lugrd%.suff%.hyd-b / totpct
wtcellc := %.basn%slgrd%.suff%.c-pct * %.basn%lugrd%.suff%.HYD-C / totpct
wtcelld := %.basn%slgrd%.suff%.d-pct * %.basn%lugrd%.suff%.HYD-D / totpct
totwt = wtcella + wtcellb + wtcellc + wtcelld
end
/* note: for future distributed models could calc runoff for each cell.
/* return grid containing weighted rcn for each zone
%.BASN%WTRCN%.SUFF% = int (zonalmean (%use%, totwt) * 1000)
/* convert to polygon coverage
%.BASN%RCN%.SUFF% = gridpoly (%.BASN%WTRCN%.SUFF%)
kill totwt all
/* kill %.BASN%WTRCN%.SUFF% all
/* Add weighted RCN as attribute of polygon coverage
&if %use% = %.basn%shed%.suff% &then &do
        &describe %.BASN%WTRCN%.SUFF%
&data arc tables
additem %.basn%tmp%.suff%.pat Wt_RCN 7 7 n 3
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc Wt_RCN = %grd$zmax% / 1000
quit
&end
&end
&else &do
/* need to add each zone value to relevant subarea
/* need to find way of ensuring as many rcn's as suba's. - Currently, if same
/* rcn in several suba's then only one zone for those suba's (multiplied
/* vals by 1000 before rounding, then divide back by 1000)
&data arc tables
select %.BASN%RCN%.SUFF%.pat
alter grid-code
WT_RCN /* next 3 lines intentionally blank
```

```
calc WT_RCN = WT_RCN / 1000
alter %.BASN%RCN%.SUFF%-id /* next 3 lines intentionally blank
%.basn%sub%.suff%-id
quit
&end
&sys arc joinitem %.basn%sub%.suff%.pat %.BASN%RCN%.SUFF%.pat %.basn%sub%.suff%.pat %.basn%sub%.suff%-id Wsheda(sq.km)
list %.basn%sub%.suff%.pat
&end
&popup %.pth%endrcn.txt
&type Done
&return
```

```
/* Name: sclfctr.aml
/*----------------------
/* Purpose: This AML calculates linear adjustment factors to accommodate
/*the curvature of the Earth. Valid only for Albers meters/parameters as in txbas at the moment.
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: .L2
/*----------------------
/* Data created: H (meridian factor) K (parallel factor) L adjusted length, Adj length
/* added to watershed PAT
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 03/01/94
/* Last update: 4/12/95
/*----------------------
/* Remarks: When using a cell resolution of 500m, this procedure is academic
/* since the uncertainty in measurement of length generally will be far
/* greater than the effect of the adjstment factor.
/*----------------------
/*
&if [exists h -grid] &then kill h all
&if [exists k -grid] &then kill k all
&if [exists l -grid] &then kill l all
&if [exists %.basn%pth%.suff% -grid] &then &do
/* Check projection
&describe %.basn%shed%.suff%
&select %PRJ$NAME%
        &when ALBERS; &do
/* %PRJ$UNITS% = METERS &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
/* &if %PRJ$SPHEROID% = GRS1980 &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
/*&if %PRJ$SP1% = '29 30 00*****' &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
```

```
/*&if %PRJ$SP2% = '45 30 00*****' &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
/*&if %PRJ$CM% = '-96 00 00*****' &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
/*&if %PRJ$LATORIG% = '23 00 00*****' &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
/*&if %PRJ$FE% = 0 AND %PRJ$FN% = 0 &then &do
/*      &sv .check = [calc %.check% + 1]
/*      &end
                &if %PRJ$UNITS% = METERS &then &do
                                &sv .am = 6378137
                                &sv .e = 0.081819221
                                &sv .m1 = 0.871062964
                                &sv .m2 = 0.702105833
                                &sv .q1 = 0.979314365
                                &sv .q2 = 1.4201783
                                &sv .q0 = 0.776760266
                                &sv .n = 0.602902769
                                &sv .C = 1.34918203
                                &sv .rho0 = 9928937.007
                                &sv .lam0 = [extract 1 %PRJ$CM%] + [extract 2 %PRJ$CM%] / 60 ~
                                + [truncate [extract 3 %PRJ$CM%]] / 3600
                                &sv mil = 1
                                &sv f1 =  %mil% * [calc %.e% ** 2 / 3 + 31 * %.e% ** 4 / 180 + 517 * %.e% ** 6 / 5040] /* constant A in Sneider 3-18 / 3-34 P.16 and 19
                                &sv f2 =  %mil% * [calc 23 * %.e% ** 4 / 360 + 251 * %.e% ** 6 / 3780] /* constant B in Sneider 3-18 / 3-34 P.16 and 19
                                &sv f3 =  %mil% * [calc 761 * %.e% ** 6 / 45360] /* constant C in Sneider 3-18 / 3-34 P.16 and 19
                                &sv l1 = %GRD$DX% /* cell width
                                &sv go = y
                        &end
                &else &do
                        &type Sorry, only programmed for Albers/meters
                        &sv go = n
                &end
        &end
&end
&if %go% = y &then &do
/* for each cell, calculate length factor based on direction of flow
/* and centroidal coordinates
setmask %.basn%pth%.suff%
setwindow %.basn%pth%.suff%
setcell %GRD$DX%
/* xcell%.suff & %ycell%.suff% are grids containing
/* the centroidal coordinates of each cell
docell
/* rho = [calc %x% ** 2 + [calc %.rho0% - %y%] ** 2] ** 0.5
        &type 1
        rho := pow (pow (xcell%.suff%, 2) + pow (%.rho0% - ycell%.suff%, 2), 0.5)
        &type 2
        theta := ATAN (xcell%.suff% / (%.rho0% - ycell%.suff%))
/* theta = [ATAN [calc %x% / [calc %.rho0%  - %y%]]]
        &type 3
        q = (%.C% - pow (rho, 2) * pow (%.n%, 2) / pow (%.am%, 2)) / %.n%
        &type 4
/* component of 14-21 follows
```

```
        v := LN ((1 - %.e%) / ( 1 + %.e%))
/* Sneider equation 14-21 P102 follows
        &type 5
        beta := ASIN (q / (1 - (1 - pow (%.e%, 2)) / 2 / %.e% * v))
/* Sneider Equation 3-18 components represented by b2, b4 & b6 follow
        &type 6
        b2 := %f1% * SIN (2 * beta) /* radians
        &type 7
        b4 := %f2% * SIN (4 * beta) /* radians
        &type 8
        b6 := %f3% * SIN (4 * beta) /* radians
/* Sneider Eq 3-18 follows: Note phi in radians
        &type 9
        phi := %mil% * beta + b2 + b4 + b6
        &type 10
/* Sneider EQ 14-7 p 100 follows.
/* adjustment factor along meridian scaled up by 1 million
        h = 1000 * (cos (phi / %mil%) / pow (%.C% - 2 * %.n% * sin (phi / %mil%), 0.5))
/* note: K = 1/h  = factor along parallel ( Sneider 14-180 ) so no areal adjustment necessary.
        k = 1000000 / h
/* Now use h and k to adjust length of travel across each cell and summate to
/* determine adjusted length. Note: This is academic at the 1:2m scale due to the resolution
/* of cells (500 m)
        if (%.PTH2%%.basn%/%.basn%dir == 1 or %.PTH2%%.basn%/%.basn%dir == 16) l = %l1% * k
        else if (%.PTH2%%.basn%/%.basn%dir == 4 or %.PTH2%%.basn%/%.basn%dir == 64) l = %l1% * h
        else l = %l1% * pow (pow (h,2) + pow (k, 2), 0.5)
        endif
end
&if [exists q -grid] &then kill q all
%.basn%adj%.suff% = zonalsum (%.basn%pth%.suff%, l) / 1000
&describe %.basn%adj%.suff%
&sv .l2 = %grd$zmax%
&end
setmask off
/* Add adjusted length as attribute of polygon coverage
&data arc tables
additem %.basn%tmp%.suff%.pat ADJ_lngth(km) 10 10 N 2
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc ADJ_lngth(km) = %.l2% / 1000
quit
&type The adjusted length is %.l2% metres
&describe %.basn%up%.suff%
&type versus a plane length of %grd$zmax% metres
&end
&end
&else &type You need to run pathlength first!
&type Done
&return
```

```
/* Name: shedmask.aml
/*----------------------
/* Purpose: This aml clips the following coverages to fit within the delineated watershed:
/* Roads, Streams, Cities, County boundaries, aspect, streamgages.
/* These may be used for plotting and or subsequent analysis such as:
/* Subwatershed delineation
/* Plotting drainage area map
/*
/*----------------------
/* Calls: None
```

```
/*----------------------
/* Called by: basmenu.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: none
/*----------------------
/* Data created: %.basn%rd%.suff %.basn%strm%.suff% %.basn%cnty%.suff%
/* %.basn%cty%.suff% %.basn%gage%.suff% %.basn%aspct%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 03/03/95
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
/*
/* Use gridded are to mask grid coverages
/* Use poly of wshed to clip arc coverages
&if [exists %.basn%tmp%.suff% -cover] &then &do
        &messages &off
        &sv extent = %.basn%tmp%.suff%
        &if [exists %.basn%pth%.suff%] &then
        &sv extent = %.basn%pth%.suff%
        setwindow %extent%
        &sys arc clip %.PTH2%%.basn%/%.basn%rds %.basn%tmp%.suff% %.basn%rd%.suff% LINE
        &sys arc clip %.PTH2%%.basn%/%.basn%sarc %.basn%tmp%.suff% %.basn%strm%.suff% LINE
        &sys arc clip %.PTH2%tx/txcnty %.basn%tmp%.suff% %.basn%cnty%.suff%
        &sys arc clip %.PTH2%tx/txcty %.basn%tmp%.suff% %.basn%cty%.suff% POINT
        &sys arc clip %.PTH2%tx/txgages %.basn%tmp%.suff% %.basn%gage%.suff% POINT
        %.basn%aspct%.suff% = aspect (selectmask (%.PTH2%%.basn%/%.basn%fil, %.basn%shed%.suff%))
        &type The following arc coverages are available for plotting:
        &type %.basn%rd%.suff%, %.basn%strm%.suff%, %.basn%cnty%.suff%, %.basn%cty%.suff%,~
        %.basn%gage%.suff%, %.basn%aspct%.suff%
        &type
        clear
        mape %.basn%shed%.suff%
        gridpaint %.basn%aspct%.suff% value linear nowrap gray
        linecolor 1
        arcs %.basn%cnty%.suff%
        linecolor 5
        arcs %.basn%strm%.suff%
        linecolor 3
        arcs %.basn%rd%.suff%
        linecolor 0
        arcs %.basn%shed%.suff%
        &type Finished processing
        &messages &on
        setmask off
&end
&else &do
        &popup %.pth%noshed.txt
&end
&type Done
&return
```

```
/* Name: slect.aml
/*----------------------
```

```
/* Purpose: /* this aml creates an ascii file of values or names
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: fndquad.aml
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .count .cover .item .subject .nos
/*----------------------
/* Global variables set: .suff .AREA .A2
/*----------------------
/* Data created: %.cover%.dat
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 02/03/95
/* Last update: 4/18/95
/*----------------------
/* Remarks:
/*
/*----------------------
reselect %.cover% poly %.cover%-id > 0
&do &while [exists %.cover%.dat]
        &type %.cover%.dat already exists.
        &sv q = [response 'Overwrite? (Y/N)']
        &if %q% = y or %q% = Y &then &do
                &sys rm %.cover%.dat
        &end
        &else &do
                &sv new [response 'Enter new name for existing file (no extension)']
                &sys mv %.cover%.dat %new%.dat
        &end
&end
&sv unit = [open %.cover%.dat openstat -write]
&sv writestat = [WRITE %unit% [quote %.subject% for %.cover%]]
&do &while %.count% > 0
        &sv a = [show select %.cover% POLY %.count% ITEM %.item%]
        &if %.nos% = 1 &then &do
                &sv writestat = [WRITE %unit% [quote %.count%, %a%]]
                &end
&else &do
                &sv writestat = [WRITE %unit% [quote %a%]]
                &end
        &sv .count = %.count% - 1
        &end
&if %.nos% = 0 &then &do
        &sv writestat = [WRITE %unit% end]
&end
&sv &closestat = [close %unit%]
&type The file %.cover%.dat has been created.
&return
```

```
/* Name: slect2.aml
/*----------------------
/* Purpose: this aml creates an ascii file of rainfall values
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: dsgnrain.aml
```

```
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .count .cover .item .subject .nos
/*----------------------
/* Global variables set: .suff .AREA .A2
/*----------------------
/* Data created: %.cover%.dat
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 02/03/95
/* Last update: 4/18/95
/*----------------------
/* Remarks:
/*
/*----------------------
reselect %.cover% poly %.cover%-id > 0
&do &while [exists %.cover%.dat]
	&type %.cover%.dat already exists.
	&sv q = [response 'Overwrite? (Y/N)']
	&if %q% = y or %q% = Y &then &do
		&sys rm %.cover%.dat
	&end
	&else &do
		&sv new [response 'Enter new name for existing file (no extension)']
		&sys mv %.cover%.dat %new%.dat
	end
&end
&sv unit = [open %.cover%.dat openstat -write]
&sv writestat = [WRITE %unit% [quote %.subject% for %.cover%]]
&do &while %.count% > 0
	&sv a = [show select %.cover% POLY %.count% ITEM %.item%]
	&if %.nos% = 1 &then &do
		&sv writestat = [WRITE %unit% [quote %.count%, %a%]]
	&end
	&else &do
		&sv writestat = [WRITE %unit% %a%]
	&end
	&sv .count = %.count% - 1
&end
&sv &closestat = [close %unit%]
&type The file %.cover%.dat has been created.
&return
```

```
/* Name: soilgrp.aml
/*----------------------
/* Purpose: Uses watershed to clip soils coverage and
/* determine percentage of hyd soil group.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created: %.basn%soil%.suff% %.basn%hydgrp%.suff%
/*----------------------
/* Creation Information
```

```
/* Author: Peter N. Smith, P.E.
/* Original coding date: 02/02/95
/* Last update: 05/08/95
/*----------------------
/* Remarks:
/*
/*----------------------
/*
&if [exists %.basn%tmp%.suff% -cover] &then &do
        &sv use = %.basn%tmp%.suff%
        &sys arc clip %.PTH2%tx/statsgo %use% %.basn%soil%.suff%
        &sys arc intersect %.basn%soil%.suff% %use% %.basn%hydgrp%.suff%
        clear
        mape %.basn%hydgrp%.suff%
        polygonshades %.basn%hydgrp%.suff% A-PCT
        polygonshades %.basn%hydgrp%.suff% B-PCT
        polygonshades %.basn%hydgrp%.suff% C-PCT
        polygonshades %.basn%hydgrp%.suff% D-PCT
&end
&else &do
        &popup %.pth%noshed.txt
&end
&type Done
&return
```

```
/* Name: setpth.aml
/*----------------------
/* Purpose: This allows the user to override the path to the desired data set
/*----------------------
/* Calls: none
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: None
/*----------------------
/* Global variables set: .PTH2
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 5/09/94
/* Last update:
/*----------------------
/* Remarks:
/* If the user is running amls from say the cdrom and wishes to use a data set
/* on disk (or vice versa), the path to the data may be reset.
/*----------------------
&sv .oldpth = %.PTH2%
&type You may provide a path to your data or hit enter to leave existing path.
&type The path should be to the directory above the subdirectory(ies) containing the data.
&type For example there are data sets tx and g in /cdrom/thesis.
&type The path would be typed as /cdrom/thesis/ not /cdrom/thesis/tx/ nor /cdrom/thesis/g/
&type *****Note that you must provide a slash (/) at the end of the path*****
&sv .PTH2 = [response 'Enter the full path to your data set. e.g /usr2/psmith/']
&if [null %.pth2%] &then &do
        &sv .pth2 = %.oldpth%
        &type The data path is still %.pth2%.
        &type If you wish to change this, please reselect Data/Setpath.
&end
&else &do
        &type The data path is now set to %.pth2%.
```

```
    &type If this is incorrect, please reselect Data/Setpath.
    &type You must now select Data/existing to choose your new data set
    &type ***Note: If your data set does not show up as an opion under Data/existing
    &type you may have typed in the wrong path.
&end
&return
```

```
/* Name: subshed.aml
/*----------------------
/* Purpose: This AML delineates subareas of a delineated watershed
/* based on a user-defined threshold area and the existence of tributaries.
/* The sub watersheds are delineated as those tributaries
/* having areas in excess of the threshold. The routine
/* calculates each subarea,
/* then accesses path length routines to compute the
/* flowlength of each subarea.
/*----------------------
/* Calls:
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created: %.basn%tinv%.suff%
/* %.basn%tadd%.suff% %.basn%tadd2%.suff% %.basn%smx%.suff% %.basn%spth%.suff%
/* %.basn%stc%.suff% %.basn%sshed%.suff% %.basn%acc%.suff% %.basn%seg%.suff%
/* %.basn%subas%.suff% %.basn%sub%.suff% %.basn%stc%.suff% outsub
/*
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/12/94
/* Last update: 5/08/95
/*----------------------
/* Remarks:
/*----------------------
/*
setmask off
&if [exists %.basn%tinv%.suff% -grid] &then kill %.basn%tinv%.suff% all
&if [exists %.basn%tadd%.suff% -grid] &then kill %.basn%tadd%.suff% all
&if [exists %.basn%tadd2%.suff% -grid] &then kill %.basn%tadd2%.suff% all
&if [exists %.basn%smx%.suff% -grid] &then kill %.basn%smx%.suff% all
&if [exists %.basn%spth%.suff% -grid] &then kill %.basn%spth%.suff% all
&if [exists %.basn%stc%.suff% -cover] &then kill %.basn%stc%.suff% all
&if [exists %.basn%sshed%.suff% -grid] &then kill %.basn%sshed%.suff% all
&if [exists %.basn%acc%.suff% -grid] &then kill %.basn%acc%.suff% all
&if [exists %.basn%seg%.suff% -grid] &then kill %.basn%seg%.suff% all
&if [exists %.basn%subas%.suff% -grid] &then kill %.basn%subas%.suff% all
&if [exists %.basn%sub%.suff% -cover] &then kill %.basn%sub%.suff% all
&if [exists %.basn%stc%.suff% -grid] &then kill %.basn%stc%.suff% all
&if [exists outsub -grid] &then kill outsub all
&if [exists %.basn%spp%.suff% -grid] and %.nopps% = 1 &then kill %.basn%spp%.suff% all
/*
&if [exists %.basn%shed%.suff% -grid] or %.outfall% = y &then &do
    &if [exists %.basn%pth%.suff% -grid] &then &do
        setwindow %.basn%pth%.suff% %.PTH2%%.basn%/%.basn%acc
    &end
    &else &do
```

```
                &sv .MASK = %.basn%shed%.suff%
                &run %.PTH%winset
        &end
        /* mask only delineated watershed
/* If only one pour point previously identified, then determine subarea pour
/* points as location of tributary confluences whose area exceeds user-specified
/* threshold
        &if %.nopps% = 1 &then &do
                %.basn%acc%.suff% = selectmask (%.PTH2%%.basn%/%.basn%acc, %.basn%shed%.suff%)
                /* Find maximum flowaccumulation for each stream link
                %.basn%seg%.suff% = zonalmax (%.PTH2%%.basn%/%.basn%slnk, %.PTH2%%.basn%/%.basn%acc)
                /* It is possible, but not likely, that two (or more) streamlinks
                /* will have the same max flow accumulation. May add ceck.
                /*
                /* Request threshold area for identification of subarea pour points.
                &popup %.PTH%sublimit.txt
                &sv sublim = [response 'Enter the threshold area (sq.km)']
                /* default to 1 sq.km
                &if [null %sublim%] &then &sv sublim = 1
                /* convert area to no. of cells
                &describe %.basn%seg%.suff%
                &sv thresh = [round [calc 1000000 * %sublim% / %GRD$DX% ** 2]]
                /* locate subarea pour points
                %.basn%ptmp%.suff% = con (%.basn%seg%.suff% == %.basn%acc%.suff% AND ~
                %.basn%acc%.suff% > %thresh%, %.PTH2%%.basn%/%.basn%slnk)
                /* For some reason, this may not include watershed outlet, so ensure this
                /* is included:
                /* Note: Use streamlink here only to force pp's to be numbered consecutively
                /* from 1 upwards. Need to find better way.
                %.basn%spp%.suff% = streamlink (merge (%.basn%ptmp%.suff%, %.basn%pp%.suff%),
%.PTH2%%.basn%/%.basn%dir)
                &if [exists %.basn%ptmp%.suff% -grid] &then kill %.basn%ptmp%.suff%
        &end
        /* Delineate subareas
        %.basn%sshed%.suff% = watershed ( %.PTH2%%.basn%/%.basn%dir, %.basn%spp%.suff%)
        mape %.basn%sshed%.suff%
        %.basn%subas%.suff% = int (zonalarea (%.basn%sshed%.suff%))
        /* create polygon cov of subsheds
        %.basn%sub%.suff% = gridpoly (%.basn%subas%.suff%)
        &describe %.basn%sub%.suff%
        /* set variables for use in slect.aml (save as ascii file)
        &sv .count = [calc %DSC$POLYGONS% - 1]
        &sv .nopoly = %.count%
        &sv .cover = %.basn%sub%.suff%
        &sv .item = grid-code
        &sv .subject = Subareas
        &sv .nos = 1
        &run %.PTH%slect
        /* Add suba's as attributes to %.basn%sub%.suff%
        &sv .count = %.nopoly%
        &if %.nopps% > 1 &then &sv .a2 = 0
&data arc tables
additem %.basn%sub%.suff%.pat Suba(sq.km) 14 14 N 2
additem %.basn%sub%.suff%.pat Wsheda(sq.km) 14 14 N 2
select %.basn%sub%.suff%.pat
calc Suba(sq.km) = grid-code
calc Wsheda(sq.km) = %.A2%
quit
&end
        clear
```

```
        mape %.basn%sshed%.suff%
        gridpaint %.basn%sshed%.suff%
        linecolor 0
        arcs %.PTH2%%.basn%/%.basn%sarc
        &popup %.basn%sub%.suff%.dat
        &popup %.PTH%endsub.txt
&end
&else
        &popup %.PTH%noshed.txt
&type Done
&return
```

```
/* Name: tcwt2.aml
/*----------------------
/* Purpose: This aml computes a weighting factor (velocity) for each cell for
/* subsequent computation of time of travel.
/*
/*----------------------
/* Calls: luadj.aml
/*----------------------
/* Called by: tofc.aml
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .tc .MASK .TIME
/*----------------------
/* Global variables set:
/*----------------------
/* Data created:  %.basn%tcwt%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/10/95
/* Last update: 4/16/95
/*----------------------
/* Remarks:
/* This routine uses existing or user-modified land use data and cell
/* slope to estimate velocities or overrides with user-defined
/* velocities, or uses a uniformly distributed default surface cover coefficient..
/* Equations derived from TxDOT hydraulic Manual Fig 5 P 2-24, 1985. The general
/* equation is log v = 0.5 logS + b (v=velocity, S = slope L/L, b = coefficient
/* dependent on surface cover. (or v = 10^b * sqrt (S))
/* Cover          b          10^b
/*____________________________________________
/* Forest        -0.1252     0.7495
/* Fallow         0.151      1.4158
/* short grass    0.3185     2.0821
/* bare           0.4646     2.9147
/* grass waterway 0.6609     4.5804
/* paved          0.7335     5.4138
/* weight = 1/velocity = 1/10 ^ (0.5 logS + b) (TxDOT / SCS) then t = length * wt
/*----------------------
&sv .q1 [response 'Do you want to use land use/ velocity coefficient data? (y or n)']
&if %.q1% = Y or %.q1% = y &then &sv .q = y
&else &sv .q = n
&sv q2 [response 'Do you want to specify velocities? (y or n)']
&if %q2% = Y or %q2% = y &then &run %.pth%luadj.aml
&sv b = 4.5804 /* metric
/*
&if [exists %.basn%vel%.suff% -grid] and [exists %.basn%lugrd%.suff% -grid] and %.q% = y &then &do
/* assign user defined velocity as inverse weight if provided, otherwise use existing land use and
/* associated velocity coefficient
```

```
    DOCELL
    if (%.PTH2%%.basn%/%.basn%slope > 0.3) %.basn%tctmp%.suff% = 1 DIV (SQRT (%.PTH2%%.basn%/%.basn%slope DIV 100) * %.basn%lugrd%.suff%.vcoeff)
    else %.basn%tctmp%.suff% = 1 DIV (SQRT (.003) * %.basn%lugrd%.suff%.vcoeff)
    END
    %.basn%tcwt%.suff% = merge (1 / %.basn%vel%.suff%, %.basn%tctmp%.suff%)
    &if [exists %.basn%tcwt%.suff% -grid] &then kill %.basn%tctmp%.suff% all
/*
&end
&else &do
    /* use existing grid of velocity coeffs (10^b) - not currently user-definable
    /* but could modify luadj.aml to incorporate.
    &if [exists %.basn%b10%.suff% -grid] &then &do
        DOCELL
        if (%.PTH2%%.basn%/%.basn%slope > 0.3) %.basn%tcwt%.suff% = 1 DIV (SQRT (%.PTH2%%.basn%/%.basn%slope DIV 100) * %.basn%b10%.suff%)
        else %.basn%tcwt%.suff% = 1 DIV (SQRT (.003) * %.basn%b10%.suff%)
        END
    &end
    &else &do
        /* use default cover (grassed waterway) and user-defined velocities
        &if [exists %.basn%vel%.suff% -grid] &then &do
            DOCELL
            if (%.PTH2%%.basn%/%.basn%slope > 0.3) %.basn%tctmp%.suff% = 1 DIV (SQRT (%.PTH2%%.basn%/%.basn%slope DIV 100) * %b%)
            else %.basn%tctmp%.suff% = 1 DIV (SQRT (.003) * %b%)
            END
            %.basn%tcwt%.suff% = merge (1 / %.basn%vel%.suff%, %.basn%tctmp%.suff%)
            &if [exists %.basn%tcwt%.suff% -grid] &then kill %.basn%tctmp%.suff% all
        &end
    &end
&end
&if %.q1% = n and %q2% = n &then &do
    /* Just use default cover velocity coefficient
    DOCELL
    if (%.PTH2%%.basn%/%.basn%slope > 0.3) %.basn%tcwt%.suff% = 1 DIV (SQRT (%.PTH2%%.basn%/%.basn%slope DIV 100) * %b%)
    else %.basn%tcwt%.suff% = 1 DIV (SQRT (.003) * %b%)
    END
&end
&return
```

```
/* Name: tofc.aml
/*----------------------
/* Purpose: Determines the time of concentration and time path from
/* watershed boundary to outfall and individual subarea pour points
/* if subareas has been run.
/*
/*----------------------
/* Calls: winset.aml tcwt2.aml
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .tc .MASK .TIME
/*----------------------
/* Global variables set: .tc .MASK .TIME
/*----------------------
/* Data created:  %.basn%tup%.suff% %.basn%tdn%.suff% %.basn%tc%.suff%
/* %.basn%tptharc%.suff% %.basn%tpth%.suff%
/*----------------------
```

```
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/10/95
/* Last update: 4/16/95
/*----------------------
/* Remarks:
/* Adds resulting time to watershed attribute table or subarea attribute table
/* Dummy variable currently used to describe surface roughness in rcns.dat
/*----------------------
/*
/* The time of concentration is calculated using the flowlength function
/* using a weight value calculated in tcwt.aml. It is necessary to run
/* flowlength upstream and downstream, not to get the total time but to
/* establish the path(s) similar to pthleng.aml.
/* Ensure that watershed coverage exists
&if [exists %.basn%tup%.suff% -grid] &then kill %.basn%tup%.suff%
&if [exists %.basn%tdn%.suff% -grid] &then kill %.basn%tdn%.suff%
&if [exists %.basn%tcwt%.suff% -grid] &then kill %.basn%tcwt%.suff%
&if [exists %.basn%tc%.suff% -grid] &then kill %.basn%tc%.suff%
&if [exists %.basn%tpth%.suff% -grid] &then kill %.basn%tpth%.suff%
&if [exists %.basn%tptharc%.suff% -cover] &then kill %.basn%tptharc%.suff%
&if [exists %.basn%shed%.suff% -grid] &then &do
    &type 'Be patient, this might take a while!'
/* If already run pathlength set analysis window to pathlength coverage otherwise run winset to reduce analysis
/* window.
    &if not [exists %.basn%pth%.suff% -grid] &then &do
            &sv .MASK = %.basn%shed%.suff%
            &run %.PTH%winset.aml
    &end
    &else setwindow %.basn%pth%.suff%
    setmask %.basn%shed%.suff%
    /* calculate weights (1/velocity for each cell)
    &run %.PTH%tcwt2.aml
    &sv .tc = [exists %.basn%tcwt%.suff% -grid]
    setmask off
    /* Since the weight is 1/velocity, can calculate time of travel per cell
    /* as length /velocity i.e. length * weight
    /* Only an upstream run is required to determine total time but
    /* need downstream to help determine path as in pthleng.aml
    %.basn%tup%.suff% = flowlength ( selectmask (%.PTH2%%.basn%/%.basn%dir, %.basn%shed%.suff%), %.basn%tcwt%.suff%, UPSTREAM)
    %.basn%tdn%.suff% = flowlength ( selectmask (%.PTH2%%.basn%/%.basn%dir, %.basn%shed%.suff%), %.basn%tcwt%.suff%, DOWNSTREAM)
    &type 'Computing time of concentraction...'
    /* Total travel time is maximum value in %.basn%tup%.suff%
    %.basn%tc%.suff% = ZONALMAX (%.basn%shed%.suff%, ~
    %.basn%tup%.suff%)
    &describe %.basn%tc%.suff%
    /* calculate time in mins
    &sv .TIME = [round [calc %GRD$ZMAX% / 60]]
    /* Similar to pthleng.aml, find path as being those cells whose up and down
    /* lengths summate to the maximum time.
    /*
    %.basn%tpth%.suff% = con (%.basn%tup%.suff% + %.basn%tdn%.suff% ~
    > %.basn%tc%.suff% ~
    - %.basn%shed%.suff%, 1)
    /* convert to vector coverage for display
    %.basn%tptharc%.suff% = gridline (%.basn%tpth%.suff%)
    &type The time of concentration is %.TIME% minutes
    /* Add calculated time of concentration as attribute of polygon coverage
```

```
&data arc tables
additem %.basn%tmp%.suff%.pat T_of_C(mins) 10 10 N
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc T_of_C(mins) = %.TIME%
quit
&end
    linecolor 0
    arcs %.basn%tptharc%.suff%
    &if [exists %.basn%subas%.suff% -grid] &then &do
            /* Note: Actual times already computed if tofc for whole watershed computed
            /* just need to abstract times and calculate differences
            /* from tofc grid at pour points.
            &type 'Determining times of concentraction for subareas...'
            setwindow %.basn%spp%.suff%
            /* create inverse of main time path
            %.basn%tinv%.suff% = isnull (%.basn%tpth%.suff%)
            /* add up and down times (should have done in Time of travel routine!)
            %.basn%tadd%.suff% = %.basn%tup%.suff% + %.basn%tdn%.suff%
            /* eliminate times associated with main path
            %.basn%tadd2%.suff% = selectmask (%.basn%tadd%.suff%, %.basn%tinv%.suff%)
            /* Find remaining maximum times in each subarea. These are t's from each subarea
            /* to the outfall!
            %.basn%smx%.suff% = zonalmax (%.basn%sshed%.suff%, %.basn%tdn%.suff%)
            /* Find subarea paths using value of subwatershed as id
            %.basn%spth%.suff% = con (%.basn%tadd2%.suff% > %.basn%smx%.suff% - 1, %.basn%sshed%.suff%)
            /* now need to determine subarea tc's as difference between max times per subarea
            /* and time from outfall to subarea pourpoint.
            %.basn%stc%.suff% = int (zonalrange (%.basn%spth%.suff%, %.basn%tdn%.suff%))
            /* convert subarea paths to vector
            %.basn%sptharc%.suff% = gridline (%.basn%spth%.suff%, #, #, #, #, value)
            /* join values of time w/ subareas
            &if [exists %.basn%stc%.suff% -grid] &then &do
&data arc tables
select %.basn%stc%.suff%.vat
alter value
SubTC(min)
select %.basn%subas%.suff%.vat
alter value
Suba(sq.km)
quit
&end
                &sys arc joinitem %.basn%subas%.suff%.vat %.basn%stc%.suff%.vat %.basn%subas%.suff%.vat $recno value
                &sys arc joinitem %.basn%sub%.suff%.pat %.basn%subas%.suff%.vat %.basn%sub%.suff%.pat Suba(sq.km) Wsheda(sq.km)
&data arc tables
select %.basn%sub%.suff%.pat
calc Suba(sq.km) = grid-code / 1000000
calc SubTC(min) = SubTC(min) / 60
quit
&end
            &end
    &end
```

```
        &popup %.PTH%tcend.txt
&end
&else &popup %.PTH%noshed.txt
&type Done
&return
```

upscale.aml

```
/* This AML is intended to use the 500m delineated area to
/* change to 90m or 30 m resolution for which processed coverages
/* already exist.
setmask off
&if [exists %.basn%shed%.suff% -grid] &then &do
&sv .old = %.basn%
&sv .basn = [response 'enter the prefix for the higher resolution data']
/* Use existing extent of pathlength or find extent of existing shed to
/* limit analysis area. (May need to increase tolerance in winset.aml)
&if [exists %.PTH2%%.basn%/%.basn%dir -grid] &then &do
&if [exists %.old%pth%.suff%] &then &do
setwindow %.old%pth%.suff% %.pth2%%.basn%/%.basn%acc
mape %.old%pth%.suff%
&end
&else &do
setwindow %.old%shed%.suff% %.pth2%%.basn%/%.basn%acc
mape %.old%shed%.suff%
&end
/*establish pour point at higher resolution
/* Once highway and stream names are added to coverages, should be able to
/* use to automatically determine outfall location at higher resolution
&describe %.PTH2%%.basn%/%.basn%bas
setcell %GRD$DX%
searchtolerance [calc %GRD$DX% * 4]
&sv .upsc = Y
&popup %.PTH%upscale.txt
clear
gridshades %.PTH2%%.basn%/%.basn%bas
linecolor 3
arcs %.PTH2%%.basn%/%.basn%rds
linecolor 5
arcs %.PTH2%%.basn%/%.basn%sarc
&end
&else &do
&type The data sets for %.PTH2%%.basn%/%.basn% do no exist.
&type Please reselect the Scale option and enter a valid data set name
&type or run preprocess
&sv .basn = %.old%
&end
&end
&else &do
&popup %.PTH%noscale.txt
&end
&return
```

```
/* Name: usgs.aml
/*----------------------
/* Purpose:
/* This aml sets up input records for the HYDRO routine in THYSYS
/* for regression equations. The area, slope, region and rainfall
/* are taken from the current watershed analysis. The calculated discharges
/* are then added to the watershed PAT
/* All units are metric
```

```
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created: thys.dat thys.lis
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 02/20/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
&if [exists %.basn%tmp%.suff% -cover] &then &do
    &sv job = [response 'Please give upto a four character id for this job.']
    &if [exists %job%.dat] &then &do
        &type The file %job%.dat already exists.
        &sv quest = [response 'Do you want to overwrite? (YES or N)']
        &if %quest% = YES &then &do
            &type Overwriting %job%.dat...
        &end
        &else &do &while [exists %job%.dat]
            &sv job = [response 'Please give a new name four character id for this job.']
        &end
    &end
    &sv title = [response 'Please enter a job title']
    &sv unit = [open thys.dat openstat -write]
    &sv writestat = [WRITE %unit% [quote JOB %job% "%title%" I=M O=M]]
    &sv writestat = [WRITE %unit% [quote FREQ %job% 2, 5, 10, 25, 50, 100]]
    &sv writestat = [WRITE %unit% [quote REG %job% %.rgn%, %.AREA%, %.SLOPE%]]
    &sv &closestat = [close %unit%]
    &type The file thys.dat has been created.
    &sv GO = [response 'Do you want to run THYSYS now? (Yor N)']
    &if %GO% = Y OR %GO% = y &then &do
        /* Run Thysys then come back
        &sys mv thys.dat /usr2/psmith/thysys
        &sys /usr2/psmith/thysys/thys thys.dat
        &popup thys.lis
    &end
/*&return
    /* add results to watershed PAT
    /* open and read thysys output file
        &type 1
        &sv unit = [open thys.lis openstat -read]
        &if %openstat% = 0 &then &do
            &sv count = 1
            &sv blank = [read %unit% readstat]
            &do &until %count% = 21
                &sv qs = [read %unit% readstat]
                &sv count = %count% + 1
            &end
            &sv .no = %count% - 1
            &sv closestat = [close %unit%]
            &if %closestat% = 0 &then
```

```
                        &type File closed
            &end
&type %qs%
&data arc tables
additem %.basn%tmp%.suff%.pat Q2 10 10 N 2
additem %.basn%tmp%.suff%.pat Q5 10 10 N 2
additem %.basn%tmp%.suff%.pat Q10 10 10 N 2
additem %.basn%tmp%.suff%.pat Q25 10 10 N 2
additem %.basn%tmp%.suff%.pat Q50 10 10 N 2
additem %.basn%tmp%.suff%.pat Q100 10 10 N 2
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc Q2 = [extract 3 [unquote %qs%]]
calc Q5 = [extract 4 [unquote %qs%]]
calc Q10 = [extract 5 [unquote %qs%]]
calc Q25 = [extract 6 [unquote %qs%]]
calc Q50 = [extract 7 [unquote %qs%]]
calc Q100 = [extract 8 [unquote %qs%]]
quit
&end
&end
&else &do
    &popup %.pth%noshed.txt
&end
&type Done
&return
```

```
/* Name: uslope.aml
/*----------------------
/* Purpose:
/* This aml computes the average watershed slope (USGS) using txfil,
/* %.basn%up%.suff%, %.basn%pth%.suff%,
/* note: if %.basn%pth%.suff% changed in tofc.aml to represent time path
/* rather than longest distance, then need to compute longest distance path
/* and use instead. Also uses wshed to determine usgs region number from gsrgns.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Data created:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/03/94
/* Last update: 4/4/95
/*----------------------
/* Remarks:
/*
/*----------------------
&if [exists %.basn%strng%.suff%] &then kill %.basn%strng%.suff% /* temporary
&if [exists %.basn%l84%.suff%] &then kill %.basn%l84%.suff% /* temporary
&if [exists %.basn%l10%.suff%] &then kill %.basn%l10%.suff% /* temporary
&if [exists E85%.suff%] &then kill E85%.suff% /* temporary
&if [exists E10%.suff%] &then kill E10%.suff% /* temporary
```

```
&if [exists %.basn%rgn%.suff%] &then kill %.basn%rgn%.suff% /* temporary
&if [exists %.basn%pth%.suff% -grid] &then &do
&messages &off
&type Determining average slope, please wait.
%.basn%strng%.suff% = selectmask (%.basn%up%.suff%, %.basn%pth%.suff%)
&describe %.basn%strng%.suff%
&sv wl85 = [calc %GRD$ZMAX% * 0.15]
&sv wl10 = [calc %GRD$ZMAX% * 0.90]
/* might want to check to see if there is a "nearest" function otherwise locate
/* cells in path which include 85% & 10% points as follows
&sv cs = [sqrt [calc  %GRD$DX% ** 2 * 2]] / 2
%.basn%l85%.suff% = con (%.basn%strng%.suff% > %wl85% - %cs% & ~
%.basn%strng%.suff% < %wl85% + %cs%, %.basn%strng%.suff%)
&describe %.basn%l85%.suff%
&sv LUP = %GRD$ZMAX%
%.basn%l10%.suff% = con (%.basn%strng%.suff% > %wl10% - %cs% & ~
%.basn%strng%.suff% < %wl10% + %cs%, %.basn%strng%.suff%)
&describe %.basn%l10%.suff%
&sv LDOWN = %GRD$ZMAX%
E85%.suff% = selectmask (%.PTH2%%.basn%/%.basn%fil, %.basn%l85%.suff%)
&describe E85%.suff%
&sv EUP = %GRD$ZMAX%
E10%.suff% = selectmask (%.PTH2%%.basn%/%.basn%fil, %.basn%l10%.suff%)
&describe E10%.suff%
&sv EDOWN = %GRD$ZMAX%
&sv .SLOPE = [calc [calc %EUP% - %EDOWN%] / [calc %LDOWN% - %LUP%]] * 1000
&format 1
&type [format 'The average watershed slope is %1% m/km' %.SLOPE%]
/* Find region for USGS regression equations (Texas rural only)
&type Determining current USGS region in which watershed is located
&sys arc clip %.pth2%tx/gsrgns %.basn%tmp%.suff% %.basn%rgn%.suff%
&data arc tables
additem %.basn%rgn%.suff%.pat tota 10 10 n 2
additem %.basn%rgn%.suff%.pat pct_a 7 7 n 2
select %.basn%rgn%.suff%.pat
reselect %.basn%rgn%.suff%# > 1
/* pct-a may not add to exactly 100 because of conversion from grid
/* could use bounding polygon area instead.
calc tota = %.a2%
calc pct_a = area / 1000000 / tota * 100
quit
&end
/* Note: could have area in more than one region
/* For the moment, take one region
reselect %.basn%rgn%.suff%.pat info %.basn%rgn%.suff%# = 2
&sv .rgn = [show select %.basn%rgn%.suff%.pat info 1 ITEM region#]
&type The USGS region is %.rgn%
/* add the region id to watershed atttribute table
&data arc tables
additem %.basn%tmp%.suff%.pat Region# 3 3 i
select %.basn%tmp%.suff%.pat
calc Region# = %.rgn%
quit
&end
&goto skip
/* find how many polys
&describe %.basn%rgn%.suff%
&sv count = %dsc$polygons%
/* Select each record in turn and save percent area in region
&do &while %count% > 1
```

```
        reselect %.basn%rgn%.suff%.pat info item region# = 1
        &sv count2 = [show number select]
        &sv rgn1_pct
        &do &while %count2% > 0
                &sv rgn1_pct = rgn1_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
        reselect %.basn%rgn%.suff%.pat info item region# = 2
        &sv count2 = [show number select]
        &sv rgn2_pct
        &do &while %count2% > 0
                &sv rgn2_pct = rgn2_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
        reselect %.basn%rgn%.suff%.pat info item region# = 3
        &sv count2 = [show number select]
        &sv rgn3_pct
        &do &while %count2% > 0
                &sv rgn3_pct = rgn3_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
        reselect %.basn%rgn%.suff%.pat info item region# = 4
        &sv count2 = [show number select]
        &sv rgn4_pct
        &do &while %count2% > 0
                &sv rgn4_pct = rgn4_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
        reselect %.basn%rgn%.suff%.pat info item region# = 5
        &sv count2 = [show number select]
        &sv rgn5_pct
        &do &while %count2% > 0
                &sv rgn5_pct = rgn5_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
        reselect %.basn%rgn%.suff%.pat info item region# = 6
        &sv count2 = [show number select]
        &sv rgn6_pct
        &do &while %count2% > 0
                &sv rgn6_pct = rgn6_pct + [show select %.basn%rgn%.suff%.pat info %count2% pct_a]
                &sv count2 = %count2% - 1
        &end
&end
/* Add info to watershed table %.basn%tmp%.suff%.pat
additem %.basn%tmp%.suff%.pat rgn1_pct 5 5 n 2
additem %.basn%tmp%.suff%.pat rgn2_pct 5 5 n 2
additem %.basn%tmp%.suff%.pat rgn3_pct 5 5 n 2
additem %.basn%tmp%.suff%.pat rgn4_pct 5 5 n 2
additem %.basn%tmp%.suff%.pat rgn5_pct 5 5 n 2
additem %.basn%tmp%.suff%.pat rgn6_pct 5 5 n 2
select %.basn%tmp%.suff%.pat
&label skip
&if [exists %.basn%strng%.suff% -grid] &then kill %.basn%strng%.suff%
&if [exists %.basn%l85%.suff% -grid] &then kill %.basn%l85%.suff%
&if [exists %.basn%l10%.suff% -grid] &then kill %.basn%l10%.suff%
&if [exists E85%.suff% -grid] &then kill E85%.suff%
&if [exists E10%.suff% -grid] &then kill E10%.suff%
&popup %.PTH%slpend.txt
&end
&else &type You need to run pathlength first!
```

```
&type Done
&return
```

```
/* Name: velpoly.aml
/*----------------------
/* Purpose: Draw polygons to create a grid of velocity values for
/* subsequent estimation of time of concentration.
/*
/*----------------------
/* Calls: none
/*----------------------
/* Called by: lu.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 04/12/95
/* Last update:
/*----------------------
/* Remarks: The value assigned should be in m/s and will override surface
/* cover coefficients. This is usually aplicable to stream reaches or areas of
/* concentrated flow.
/*----------------------
/*
/*
&if NOT [null %.vel%] &then &do
    setmask off
    &popup %.pth%poly.txt
    &sv count = 1
    &sv .merge =
    &do &until %more% = y or %more% = Y
        v%count% = selectpolygon (%.basn%shed%.suff%, *) * %.vel%
/* the following is merely to overcome a problem in grid which
/* otherwise does not allow sequential drawing of polys. Drawing any
/* other grid or arc will avoid the problem!
        arcs  %.basn%tmp%.suff%
        &sv more = [response 'Finished? (y)']
        &sv .merge = %.merge%v%count%,
        &sv count = %count% + 1
    &end
    &sv count = %count% - 1
    &sv merge = [trim %.merge% -right ,]
    %.basn%v%.suff% = merge (%merge%)
    /*&dv .merge
    &do &until %count% = 0
        &if [exists v%count% -grid] &then kill v%count% all
        &sv count = %count% - 1
    &end
    &if [exists %.basn%vel%.suff% -grid] &then &do
        vtmp = merge (%.basn%v%.suff%, %.basn%vel%.suff%)
        &if [exists %.basn%vel%.suff% -grid] &then kill %.basn%vel%.suff% all
        &if [exists %.basn%v%.suff% -grid] &then kill %.basn%v%.suff% all
        %.basn%vel%.suff% = vtmp
        &if [exists vtmp -grid] &then kill vtmp all
    &end
    &else &do
        %.basn%vel%.suff% = %.basn%v%.suff%
```

```
                &if [exists %.basn%v%.suff% -grid] &then kill %.basn%v%.suff% all
        &end
        arcs  %.basn%tmp%.suff%
&end
&else &popup %.pth%nov.txt
&type Done
&return
```

```
/* Name: winset.aml
/*----------------------
/* Purpose: This AML sets a window automatically to accommodate the largest extent
/* of an input coverage. This helps reduce processing time and replaces
/* a user-defined window.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: tofc.aml and pthleng.aml, subshed.aml
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: .mask
/*----------------------
/* Data created: %.basn%pp%.suff% %.basn%shed%.suff% %.basn%tmp%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/26/94
/* Last update: 5/8/95
/*----------------------
/* Remarks: The grid accuracy may be a problem here
/*
/*----------------------
/*
/* Use the cell size of the grid with which a window is being set
setcell %.MASK%
setwindow %.MASK%
&sv tst [exists xcell%.suff% -grid]
&sv tst1 [exists ycell%.suff% -grid]
&if %tst%%tst1% = .FALSE..FALSE. &then &do
        xcell%.suff% = selectmask ($$wx0 + $$cellsize * (0.5 + $$colmap), %.MASK%)
        ycell%.suff% = selectmask ($$wy1 - $$cellsize * (0.5 + $$rowmap), %.MASK%)
        &end
&describe xcell%.suff%
&sv .xmin = [calc %GRD$ZMIN% - %GRD$DX% * 2]
&sv .xmax = [calc %GRD$ZMAX% + %GRD$DX% * 2]
&describe ycell%.suff%
&sv .ymin = [calc %GRD$ZMIN% - %GRD$DY% * 2]
&sv .ymax = [calc %GRD$ZMAX% + %GRD$DY% * 2]
/* set the window to two cells larger than the extent of the watershed
/* and snap to cells of flow accumulation grid to keep resulting grids
/* coincident
setwindow %.xmin% %.ymin% %.xmax% %.ymax% %.pth2%%.basn%/%.basn%acc
&return
```

```
/* Name: wshape.aml
/*----------------------
/* Purpose: This aml calculates a watershed shape factor as being
/* the area divided by path length squared.
/*
```

```
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.menu
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set: .sfac
/*----------------------
/* Data created: Shape factor added to Watershed PAT
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/20/95
/* Last update:
/*----------------------
/* Remarks:
/*
/*----------------------
&if [exists %.basn%pth%.suff% -grid] &then &do
        &type %.AREA% %.a2% %.length%
        &sv fac =  1000 * %.A2% / [calc %.LENGTH% ** 2 ]
        &sv .sfac = [round %fac%] / 1000
        &type The shape factor is calculated to be %.sfac%
        /* Add shape factor as attribute of polygon coverage
&data arc tables
additem %.basn%tmp%.suff%.pat Shape_fac 10 10 N 7
select %.basn%tmp%.suff%.pat
reselect $recno = 2
calc Shape_fac = %.sfac%
quit
&end
&end
&else &type You need to run Watershed/Pathlength first!
&type Done
&return
```

```
/* Name: wshed.aml
/*----------------------
/* Purpose: This aml uses the identified highway and stream, selected cell, user-specified pour
/* point coverage, or drawn line to locate the watershed outfall (pour point).
/* Then determines the watershed boundary and drainage area to the outfall.
/*
/* Note: need to modify area calcs to accommodate different scales.
/*
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff .upsc .outfall .rdid .strmid
/*----------------------
/* Global variables set: .suff .AREA .A2
/*----------------------
/* Data created: %.basn%pp%.suff% %.basn%shed%.suff% %.basn%tmp%.suff%
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/03/94
/* Last update: 4/12/95
```

```
/*----------------------
/* Remarks:
/*
/*----------------------
setmask off
&messages &off
&if %.outfall% = n &then &do
/*  Using roads and stream to find outfall
        /* ensure that outfall can be located
        &if [null %.strmid%] and [null %.rdid%] &then &type Please identify your highway and stream first
        &if [null %.strmid%] and [null %.rdid%] &then &goto jump
        &sv .suff = [response 'Enter the suffix for your proposed data sets']
        &if [exists ycell%.suff% -grid] &then kill ycell%.suff% all
        &if [exists xcell%.suff% -grid] &then kill xcell%.suff% all
        &do &while [exists %.basn%pp%.suff% -grid]
                &type %.basn%pp%.suff% 'and/or' %.basn%shed%.suff% already exist
                &sv .suff = [response 'Please enter a new suffix e.g. b or c or bb etc...']
        &end
        /* If no window set, request user to set analysis window
        /* This step could be precluded by use of HUC coverages to automatically
        /* reduce analysis window, but requires much more programming for little benefit!
        &if [null %.upsc%] &then &do
                &popup %.PTH%selw.txt
                setwindow * %.PTH2%%.basn%/%.basn%acc
        &end
        /* Find outlet as being intersection of selected road and stream.
        /* Note: Preprocessor creates vector and grid coverage of streams and
        /* highways with vector id's matching cell values.
        &type 'Determining pour point...'
        %.basn%pp%.suff% = con (%.PTH2%%.basn%/%.basn%rdgrd == %.rdid% & %.PTH2%%.basn%/%.basn%slnk ==
%.strmid%, 1)
&end
&if %.nopps% < 2 &then &do
        &sv .outfall = n
/* Delineate watershed using predetermined direction grid and pour point grid.
        &type 'Delineating watershed...'
        %.basn%shed%.suff% = WATERSHED (%.PTH2%%.basn%/%.basn%dir, %.basn%pp%.suff%)
        &type 'Calculating drainage area...'
        /* Temporarily using two methods to determine area
        /* 1. Find flow accumulation at pour point and add one cell area to include pour point.
        %.basn%d%.suff% = con (%.basn%pp%.suff% == 1, %.PTH2%%.basn%/%.basn%acc)
        &describe %.basn%d%.suff%
        &sv .AREA = [calc %GRD$DX% * %GRD$DY% * ( %GRD$ZMAX% + 1 ) / 1000000]
        /* 2. Summate cells in zone
        %.basn%da%.suff% = zonalarea (%.basn%shed%.suff%) / 1000000
        &describe %.basn%da%.suff%
        &sv .A2 = %GRD$ZMAX%
        &type 'The drainage area of' %.basn%shed%.suff% 'is' %.AREA% sq. km.'
        &type 'The zonal area of' %.basn%shed%.suff% 'is' %.A2% sq. km.'
        &type Creating polygon coverage of watershed
        /* convert grid of watershed into polygon coverage for display and assignment of attributes.
        %.basn%tmp%.suff% = gridpoly (%.basn%shed%.suff%)
        /* draw resulting watershed on top of existing coverages
        &if [null %.upsc%] &then
                mape %.PTH2%%.basn%/%.basn%bas
        linecolor 1
        arcs %.PTH2%%.basn%/%.basn%sarc
        linecolor 3
        arcs %.PTH2%%.basn%/%.basn%rds
        linecolor 0
```

```
        arcs %.basn%tmp%.suff%
        /* Add calculated drainage area as attribute of polygon coverage
        /* Note for multiple areas, there is the potential that the gridpoly process
        /* will result in more polygons than there are zones. To accommodate this
        /* possibility, the subareas are added using the grid code rather than the polygon
        /* id. Therefore the same area size may appear twice in the PAT.
        &sv count = 1
&type Adding watershed area to polygon PAT
&data arc tables
additem %.basn%tmp%.suff%.pat Calc_area(sq.km) 12 12 N 3
select %.basn%tmp%.suff%.pat
calc Calc_area(sq.km) = %.A2%
quit
&end
        /* Remove temporary coverages
        &if [exists %.basn%d%.suff% -grid] &then kill %.basn%d%.suff%
        &popup %.PTH%endw.txt
        &messages &on
&label jump
&end
&else &type Please select watershed/subareas since you have multiple pour points.
&type Done
&return
```

Menu Files

```
/* Name: askdraw.men
/*----------------------
/* Purpose: Request user to select feature class for display coverage
/* and stores appropriate drawing
/* commands
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: .type .covt .comm
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/01/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
2  /*askdraw.men
/* Draw user- specified coverage
GRID        &sv .type GRID; &sv .covt =; &sv .comm GRIDPAINT; &return
Points    &sv .type COVER; &sv .covt -POINT; &sv .comm POINTS; &return
Lines     &sv .type COVER; &sv .covt -LINE; &sv .comm ARCS; linecolor [response 'Enter a number for the color']; &return
Polygons  &sv .type COVER; &sv .covt -POLY; &sv .comm POLYGONSHADES; ~
     &return
NONE        &sv .type; &return

/* Name: basins.men
/*----------------------
```

```
/* Purpose: This is the main menu for HDDS.
/*----------------------
/* Calls: (On request) infiles.aml preproc.aml idroad.aml idstrm.aml
/* outfall.aml wshed.aml pthleng.aml tofc.aml uslope.aml wshape.aml
/* subshed.aml sclfctr.aml dsgnrain.aml soilgrp.aml rcn.aml shedmask.aml
/* upscale.aml fndquad.aml usgs.aml cleanup.aml setpath.aml
/*----------------------
/* Called by: hdds.aml
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: .home
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 12/01/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 HDDS  /* Pulldown menu
Data
 Existing  &run %.PTH%infiles.aml
 Preprocess  &run %.PTH%preproc.aml
 Workspace  &sv .home [show workspace]; &menu %.pth%wo.men &stripe 'Workspace'
 Set_path   &run %.PTH%stpth.aml
Draw
 Basins   &run %.PTH%chk.aml; GRIDSHADES %.PTH2%%.basn%/%.basn%bas; linecolor 2; arcs %.PTH2%tx/txpoly
 Roads    &run %.PTH%chk.aml; LINECOLOR 1; ARCS %.PTH2%%.basn%/%.basn%rds
 Streams  &run %.PTH%chk.aml; LINECOLOR 15; ARCS %.PTH2%%.basn%/%.basn%sarc
 dlgstrms &run %.PTH%chk.aml; ARCS %.PTH2%%.basn%/%.basn%sdlg
 Other          &menu %.PTH%askdraw.men &sidebar &stripe 'Feature type'; ~
                &run %.PTH%drawcov.aml
Identify
 Road    &run %.PTH%chk.aml; &TYPE Select road with cursor; &run %.PTH%idroad
 Stream &run %.PTH%chk.aml; &TYPE Select stream with cursor; &run %.PTH%idstrm
 Cell   &run %.PTH%chk.aml; &run %.PTH%outfall.aml
 Line   &run %.PTH%chk.aml; &run %.pth%line.aml
 Movegage  &run %.PTH%chk.aml; &menu %.PTH%gage.men &stripe 'Relocate Gage'
Watershed
 Area &run %.PTH%wshed.aml
 Path_length &run %.PTH%pthleng.aml
 Subareas      &run %.PTH%subshed.aml
 Land_use &run %.PTH%rcn
 Travel_time &run %.PTH%tofc.aml
 Av_Slope      &run %.PTH%uslope.aml
 Shape_fac     &run %.PTH%wshape.aml
 Scale_factor  &run %.PTH%sclfctr.aml
Dsgn_rain
 TP40    &run %.PTH%dsgnrain.aml
 ebd     &type Sorry, not active yet!
 Av.Ann  &type Sorry, not active yet!
Soils  &run %.PTH%soilgrp.aml
Mapclip    &run %.PTH%shedmask
UP-scale
 Call_data &run %.PTH%upscale.aml
 Find_quads &run %.PTH%fndquad.aml
THYSYS
 USGS &run %.PTH%usgs.aml
```

```
  SCS  &type Sorry, not active yet!
  Rational &type Sorry, not active yet!
  Gage  &type Sorry, not active yet!
Metadata  &menu %.pth%meta.men &stripe 'Metadata for HDDS'
Cleanup    &run %.PTH%cleanup.aml
Command    &popup %.PTH%tty.txt; &sv .exit = &return; &sv .e = &return; &tty
Clear
Quit
```

```
/* Name: cref.men
/*----------------------
/* Purpose: Displays menu for coordinate reference metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* cref.menu
'Horizontal Coord'   &popup %.pth%%.name%cref1.dat
'Vertical Coord'  &popup %.pth%%.name%cref2.dat
Backup  &return
```

```
/* Name: dg.men
/*----------------------
/* Purpose: Displays menu for data quality metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* dq.menu
'Attribute Accuracy'   &popup %.pth%%.name%dq1.dat
Consistency   &popup %.pth%%.name%dq2.dat
Completeness   &popup %.pth%%.name%dq3.dat
'Positional Accuracy'   &popup %.pth%%.name%dq4.dat
Lineage   &popup %.pth%%.name%dq5.dat
```

```
'Process Step'  &popup %.pth%%.name%dq6.dat
Backup &return

/* Name: dist.men
/*----------------------
/* Purpose: Displays menu of distribution information metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* dist.menu
Contact   &popup %.pth%%.name%d1.dat
Medium   &popup %.pth%%.name%d2.dat
Liability  &popup %.pth%%.name%d3.dat
Backup  &return

/* Name: ea.men
/*----------------------
/* Purpose: Displays menu for entity and attribute metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* E&A.menu
Overview   &popup %.pth%%.name%ea1.dat
Backup &return

/* Name: gage.men
/*----------------------
/* Purpose: Displays menu for streamgage mover
/*----------------------
/* Calls: On requuest - drwgge.aml mvgage.aml ppgge.aml
/*----------------------
/* Called by: basins.men
```

```
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/01/94
/* Last update: 5/8/95
/*----------------------
/* Remarks: Allows user to create grid of relocated streamgage points to ensure coincidence with
/* gridded streams. Streamgage attributes are appended to the grid VAT. The resulting grid of relocated
/* gages can be set as a pourpoint file for subsequent watershed/subarea delineation using PPset.
/*----------------------
1 /* gage.men
Mapextent   mape [getcover * -other]; setwindow [show mape]; &popup %.pth%gwin.txt
Set_window  setwindow * %.PTH2%%.basn%/%.basn%acc
DRAW
  Streams  gridpaint %.pth2%%.basn%/%.basn%strms
  Gages    pointmarkers %.PTH2%tx/txgages 2; points %.PTH2%tx/txgages
  GRDgage  &run %.pth%drwgge.aml
MOVE       &run %.pth%mvgage.aml
LIST       List %.basn%gages%.suff%.vat
PPset      &run %.pth%ppgge.aml
Command    &tty
Clear      Clear
DONE       &return
```

/* Name: **id.men**

```
/*----------------------
/* Purpose: Displays menu for identification metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* id.menu
Citation   &popup %.pth%%.name%id1.dat
Description   &popup %.pth%%.name%id2.dat
'Time period'   &popup %.pth%%.name%id3.dat
Status   &popup %.pth%%.name%id4.dat
'Spatial Domain'   &popup %.pth%%.name%id5.dat
Keywords   &popup %.pth%%.name%id6.dat
Access   &popup %.pth%%.name%id7.dat
Use   &popup %.pth%%.name%id8.dat
Backup  &return

/*----------------------
```

```
/* Name: lu.men
/*----------------------
/* Purpose: establishes menu for viewing and  polygon drawing to establish
/*  new land use values and cell velocities  for current watershed.
/*
/*----------------------
/* Calls: On request - lupoly.aml velpoly.aml luadd.aml
/*----------------------
/* Called by: luadj.aml
/*----------------------
/* Required variables: .PTH .PTH2 .basn .suff
/*----------------------
/* Global variables set:
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 01/04/95
/* Last update:
/*----------------------
/* Remarks: The user-defined polygons only modify the land use codes for the working
/* grid of land use, not the permanent vector coverage.
/*
/*----------------------
1 /* pulldown
View
  landuse  gridpaint %.basn%lugrd%.suff% value linear
  Soil gridpaint %.basn%slgrd%.suff%
  Watershed  Linecolor 3; arcs %.basn%tmp%.suff%
  Roads  Linecolor 4; arcs %.pth2%%.basn%/%.basn%rds
  Streams  Linecolor 5; arcs %.pth2%%.basn%/%.basn%sarc
  Cities  points %.pth2%tx/txcty
  County  linecolor 6; arcs %.pth2%tx/txcnty
Check_value
  Landuse  cellvalue %.basn%lugrd%.suff% *
  PCT_soilgrp cellvalue %.basn%slgrd%.suff% *
  Velocity cellvalue %.basn%vel%.suff% *
List_codes
  Landuse list %.pth2%tables/rcns.dat
Setvalue
  Land_use &sv .lucode = [response 'Enter the land use code']
  Velocity &sv .vel = [response 'Enter the velocity (m/s)']
  pct-soilgrp /* &sv .pctsl = [response 'Enter the ??? code']
Draw_polygon
  Land_use &run %.pth%lupoly
  Velocity &run %.pth%velpoly
  PCT_soilgrp &run %.pth%slpoly
Add_lucode &run luadd.aml
Command &popup %.pth%tty.txt; &tty
Clear
Done &return

/* Name: lu_rcn.men
/*----------------------
/* Purpose: Dsiplays menu options for adjusting or appending landuse code/ runoff
/* curve number table (rcns.dat)
/*----------------------
/* Calls: On request - addlu.aml modrcn.aml
/*----------------------
/* Called by: luadd.aml
/*----------------------
```

/* Required variables: .PTH .PTH2
/*---------------------
/* Global variables set:
/*---------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/01/94
/* Last update: 5/8/95
/*---------------------
/* Remarks:
/*
/*---------------------
1 /* lu_rcn.men
ADD_LUCODE &r %.pth%addlu.aml
MODIFY_RCN &r %.pth%modrcn.aml
COMMAND &TTY
DONE &return

/* Name: **m.men**
/*---------------------
/* Purpose: Displays menu for metadata reference information
/*---------------------
/* Calls: None
/*---------------------
/* Called by: meta.men
/*---------------------
/* Required variables: .PTH .PTH2
/*---------------------
/* Global variables set:
/*---------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*---------------------
/* Remarks:
/*
/*---------------------
1 /* m.menu
General &popup %.pth%%.name%m1.dat
Backup &return

/* Name: **meta.men**
/*---------------------
/* Purpose: Displays main metadata menu
/*---------------------
/* Calls: On request - id.men dg.men org.men cref.men ea.men dist.men m.men
/*---------------------
/* Called by: basins.men
/*---------------------
/* Required variables: .PTH .PTH2
/*---------------------
/* Global variables set: .name
/*---------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 3/01/94
/* Last update: 5/8/95
/*---------------------
/* Remarks: The user must first select the coverage name for which metadata are available using

```
/* the Coverage option. The metadata are provisional and intended to comply with the Federal
/* Content Standards for Digital Geospatial Metadata, June 8, 1994
/*----------------------
1 /* Metadata menu system
Coverage  &sv .q [getchoice Highway Hydrologic_Region ~
-prompt 'Select the coverage for which you want metadata']; ~
&if %.q% = Highway &then &sv .name Hi; ~
&if %.q% = Hydrologic_Region &then &sv .name Hy
Identification       &menu %.pth%id.men &stripe 'Identification Information'
'Data Quality'       &menu %.pth%dg.men &stripe 'Data Quality Information'
Organization         &menu %.pth%org.men &stripe 'Spatial Data Organization'
'Coverage Reference'  &menu %.pth%cref.men &stripe 'Spatial Data Reference'
'Entity & Attribute'  &menu %.pth%ea.men &stripe 'Entity & Atrribute Information'
Distribution         &menu %.pth%dist.men &stripe 'Distribution Information'
'Metadata Reference'  &menu %.pth%m.men &stripe 'Metadata Reference'
Done &return

/* Name: org.men
/*----------------------
/* Purpose: Displays menu for organization information metadata
/*----------------------
/* Calls: None
/*----------------------
/* Called by: meta.men
/*----------------------
/* Required variables: .PTH .PTH2
/*----------------------
/* Global variables set: None
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 4/21/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
/*----------------------
1 /* org.menu
'Indirect Spatial Reference'   &popup %.pth%%.name%org1.dat
Backup  &return

/* Name: wo.men
/*----------------------
/* Purpose: Allows user to create and move to workspace
/*----------------------
/* Calls: None
/*----------------------
/* Called by: basins.men
/*----------------------
/* Required variables: .PTH .PTH2 .home .work
/*----------------------
/* Global variables set: .work
/*----------------------
/* Creation Information
/* Author: Peter N. Smith, P.E.
/* Original coding date: 5/8/94
/* Last update: 5/8/95
/*----------------------
/* Remarks:
/*
```

```
/*----------------------
1 /* wo.men
Create &sv .work [response 'Enter the full path and name']; ~
&sys arc createworkspace %.work%; &type Done
'Change to' &wo [getchoice %.work% %.home% -other -prompt ~
'Which workspace?']; &type Done
Cancel &wo %.home%; &return
Done  &return
```

Message Files

adjtab.txt
You are about to make some permanent changes to the
landuse/RCN/velocity table RCNS.dat.

To modify:
Select the record number at the prompt. At the "Edit?:"
prompt,
enter the item and new value.
e.g. hyd-a = 96
If you are finished, hit return until the "Enter Command:"
prompt appears then type QUIT.

To add:
Simply enter the appropriate data at each prompt, hit enter
until the
"Enter Command:" prompt appears then type QUIT.

clnend.txt
Finished cleaning up.
You may identify a new outfall or quit.

clnup.txt
This process will eliminate the coverages that have just been
created.
If you wish to delete all the files with the active prefix and
suffix
enter "YES" at the command line prompt. (Don't worry no
permanent data
will be lost and it will be easy to regenerate no data!)

doshed.txt
It is neccessary to run the watershed option prior to this.
Please idetntify your outfall and run watershed or quit.

endrcn.txt
The weighted Runoff Curve number estimation is complete.
Please choose another option.

endw.txt
The subareas ahave been delineated and measured.

endw.txt
Finished processing - wasn't that fun!
You may now select pathlength, Travel_time, Subareas,
reselect
identify for another location, or quit.

gpp.txt
For determination of areas (only) for preset pour points such
as gages
or well points, please now select Watershed / Subareas.
Or if you still wish to calculate a single area, identify the
road/stream
or cell location, then run Watershed / Area. The subarea
option will still
determine areas for the multiple points which you have just
established.

gwin.txt
The window area will be set to the map extent unless
you over-ride using the setwindow option.
Processing speed will be minimized by setting the
window area to contain only the desired gages.

missed.txt
You missed the feature. Please select identify again.
You may wish to create a closer view using Pan/Zoom,
but you'll have to redraw coverages.

newdat.txt
Your new data environment has been established. Now you
may select
Data/Existing and choose your data set. The settings will be
adjusted
accordingly and then you may draw and analyze your data.

nocode.txt
You have not yet specified a land use code value.
Please select Set value/ land use and enter a suitable
code before drawing polygons.

nopth.txt
path file PTH.txt does not exist.
Please create a one line file file the full path to where
the watershed amls reside e.g. usr2/smith/texas/
Don't forget the trailing "/"

noscale.txt
The watershed area must be determined first in order to
establish the
required quadrangles for higher resolution analysis. Please
identify your
outfall and then run Watershed/Area.

noshed.txt
No watershed exists for this run.

Please identify an outfall and run watershed
before running subareas.

nosub.txt
You selected a subarea break down but
no subareas exist. Please rerun and
select a Watershed break down or run
Watershed/subareas then try a subarea
break down.

notime.txt
The time of travel routine has not been run.
Prior to running the subarea routine, the
watershed area and time of travel must have been
determined.

nov.txt
You have not yet specified a velocity value.
Please select Set value/ velocity and enter a suitable
value in m/s before drawing polygons.

poly.txt
You may draw as many polygons as you wish. On
completion of each polygon,
hit 9 while in the display window. When you are finsihed
adding polygons
type "y" at the command line prompt.

ppend.txt
A grid of pour points has been created.
You may now select Watershed/Area.

pps.txt
You many select your outfall cell location(s).
After each point is selected, hit 9.
When you have defined all your outfall points
respond "Y" at the prompt. Otherwise, simply
hit enter at the prompt to continue selecting
cells.

preproc.txt
The file of required quadrangles will appear next. If you have
the dems for
these quadrangles, you may select Data/Preprocess to
prepare the data for
use in this system.

pthend.txt
The path length and flow path routine is complete.
Please select another option.

qdfile.txt
Since you have not selected a record of quad names, you
must specify
the name of a single dem for processing. If you wish to use
multiple
quads, you may either merge theses outside of this system or
create
an ascii file with the names of desired quads. e.g.

Title: DEM names
Tyler
Texarkana
Sherman
end

note that the name is case sensitive.

If you do not enter a name in the following response, you will
return to
the main menu.

selw.txt
Select an area to include basin(s) & outfall(s).
The defined box must at least contain the
anticipated drainage area. It's ok if you
overshoot, but the larger the area the
longer the processing time!

slpend.txt
Finished processing.
Now you may run THYSYS, clean up, identify another
outfall, or quit.

strt.txt
This subsystem determines watersheds and flowpaths and
other hydrologic
parameters using grids of DEM data, flow direction, flow
accumulation, slope,
stream links and highways and arc coverages of streams and
highways.

General information will appear in windows like this one, but
keep an eye on
your command line window from which you invoked
Arc/Info. That is where you
will be prompted and receive status information. To continue,
close this
window by selecting quit in the bottom right corner of this
window. All popup
comment windows must be exited in the same fashion.

sublimit.txt
Your hydrologic analysis can be as complex as you desire.
However, you may wish to limit the number of subareas to
be
delineated by specifying an area threshold below which no
subarea will be defined.

tcend.txt
The time of concentration routine is complete.
Please select another option.

tofc.txt
To minimize processing time, select a box size that just
incorporates

the displayed watershed area.

tol.txt
In order to minimize the possibility of selecting the wrong arc, select two consecutive points on the display to define the width of the search box. Follow the instructions in the command
window.

tty.txt
This option temporarily passes control to the command line. After performing desired independent commands, please type
&return to get back to the main menu.

upscale.txt
Now you may perform analyses on the higher resolution data.
Currently, the attribute data is not sufficient to allow automatic
locating of the outfall at the higher resolution. Therefore, please
use "Identify" to reselect the stream. The highway id is still valid
so you do not need to re-establish that.

Projection Files

geoalb.prj
input
projection geographic
units %.UNITS%
spheroid %.SPH%
datum %.DATUM%
zunits %.UNITS%
parameters
output
projection albers
units meters
spheroid GRS1980
datum NAD83
parameters
29 30 00
45 30 00
-96 0 00
23 0 00
0.0
0.0
end

utmalb.prj
input
projection %.proj%
units %.units%
zunits %.ZUNITS%
datum %.DATUM%
spheroid %.SPH%
zone %.ZONE%
parameters
output
projection albers
units meters
spheroid GRS1980
datum NAD83
parameters
29 30 00
45 30 00
-96 0 00
23 0 00
0.0
0.0
end

Appendix B

Metadata for Arc/Info format Highway Vector Coverage

HDDS provides a METADATA option which allows the user to select one of two coverages, highways and hydrologic regions, then browse through sections of metadata in any order. Only the highway metadata are printed here.

1. Identification_Information: Coverage name txrds
 Citation:
  Citation_Information:
   Originator: Peter N. Smith, Graduate Student, University of Texas at Austin
   Publication_Date: 1995
   Title: Sulphur River Basin State Highways
   Publication_Information: CRP report "Hydrologic Data Development System"
    Publication_Place: Center for Research in Water Resources, UT
    Publisher: Dr. David Maidment
 Description:
  Abstract:
   The highways within a rectangular map extent of the Sulphur River Basin in northeast Texas are contained in an ArcInfo format vector coverage of lines. The highways were abstracted from the USGS 1:2,000,000 digital line graphs after having been line delimited, imported into ArcInfo and projected into Albers Equal Area. Highway names were subsequently added as attributes.
  Purpose:
   The highways are used for locational purposes and to identify highway crossings of streams for a prototype hydrologic analysis tool entitled Hydrologic Data Development System.
 Time_Period_of_Content:
  Time_Period_Information:
   Range_of_Dates/Times:
    Beginning_Date: Jan 1995
    Ending_Date: May 1995
  Currentness_Reference: publication date
 Status:
  Progress: Complete
  Maintenance_and_Update_Frequency: None scheduled
 Spatial_Domain:
  Bounding_Coordinates:
   West_Bounding_Coordinate: -35154.781
   East_Bounding_Coordinate: 50935.356
   North_Bounding_Coordinate: 1185953.813
   South_Bounding_Coordinate: 1141838.434
 Keywords:
  Theme:
   Theme_Keyword_Thesaurus: None.
   Theme_Keyword: Highways
   Theme_Keyword: DLG
   Theme_Keyword: Digital Line Graph
  Place:
   Place_Keyword_Thesaurus: None
   Place_Keyword: University of Texas at Austin

Place_Keyword_Thesaurus: None

Access_Constraints: None
Use_Constraints:
None.

2. Data_Quality_Information

Attribute_Accuracy:
Attribute_Accuracy_Report:
The accuracy of hyghway names was tested by performing spatial queries within ArcInfo and comparing selected arcs with a Texas Department of Transportation Highway paper map.

Logical_Consistency_Report:
There are no extraneous intersections; that is, a line does not join or cross another line, or itself, except at a node. No line extends through a node.

Completeness_Report:
Data completeness generally reflects the content of the original source digital line graphs.
Positional_Accuracy:
Horizontal_Positional_Accuracy:
Horizontal_Positional_Accuracy_Report:
There is noticable displacement between this coverage and larger scale (1:100, 000) data.
Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: U.S. Geological Survey
Publication_Date: 1980
Title: 1:2000,000 scale Digital Line Graphs
Geospatial_Data_Presentation_Form: Digital
Publication_Information:
Publication_Place: Reston, Virginia
Publisher: U.S. Geological Survey
Source_Scale_Denominator: 2000000
Type_of_Source_Media: Internet
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 1980
Source_Currentness_Reference: publication date
Source_Citation_Abbreviation: DLG
Source_Contribution: spatial and attribute information

Process_Step:
Process_Description:
The source data was retrieved from the USGS World Wide Web Site:•

The data was line delimited in UNIX and then imported into ArcInfo. The highways in the vicinnity of the Sulphur River basin were then clipped and projected into an Albers Equal Area

Projection. Highway names were then added as attributes in the Arc Attribute table for the highway coverage.
Source_Used_Citation_Abbreviation:
DLG
Process_Date: Jan 1995

3. Spatial_Data_Organization_Information

Indirect_Spatial_Reference:
For original linear features:
U.S. Department of the Interior, U.S. Geological Survey.:
Direct_Spatial_Reference_Method: Arc/Info Vector

4. Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:
Planar:
Map_Projection:
Map_Projection_Name: Albers Conical Equal Area
Albers_Conical_Equal_Area:
Standard_Parallel:
1st standard parallel 29.5N
Standard_Parallel:
2nd standard parallel 45.5N
Longitude_of_Central_Meridian: 96.0W
Latitude_of_Projection_Origin: 23.0N
False_Easting: 0.0
False_Northing: 0.0
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 50.80
Ordinate_Resolution: 50.80
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum 1927
Ellipsoid_Name: Clark 1866
Semi-major_Axis: 6378206.4
Denominator_of_Flattening_Ratio: 294.98

5. Entity_and_Attribute_Information:

Overview_Description:
Entity_and_Attribute_Overview:
No attributes from the original DLG data were employed. The DLG attributes did not include highway name. Since highway name is intended to be the main means by which highways are identified, it was necessary to manually edit the arc attribute tables to include the Texas DOT designation.
Entity_and_Attribute_Detail_Citation:
Hydrologic Data Development System, Masters Thesis, Peter N. Smith, P.E., Aug 1995 1995.

6. Distribution_Information:

Distributor:
Contact_Information:
Contact_Organization_Primary: Dr. David Maidment
Contact_Organization: University of Texas
Contact_Address:
Address_Type: Mailing
Address: University of Texas at Austin
City: Austin
State_or_Province: Texas
Postal_Code:
Contact_Voice_Telephone: 512-471-0129
Hours_of_Service: **Pot luck!**
Contact_Instructions:

Resource_Description: Sulphur River Basin State Highways

Distribution_Liability:
This data is prototypical only. No warranty expressed or implied is made by the author regarding the utility of the data, nor shall the act of distribution constitute any such warranty.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ArcInfo
Format_Version_Date: 7.02
Format_Specification: Vector
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name: txrds

Offline_Option:
Offline_Media:
Recording_Format:
Offline_Option:
Offline_Media:
Recording_Capacity:
Recording_Density:
Recording_Density:
Recording_Density_Units:
Recording_Format:
ASCII
Fees:

7. Metadata_Reference_Information:

Metadata_Date: April 1995
Metadata_Contact:
Contact_Information: Peter N. Smith c/o Dr. David Maidment
Contact_Organization_Primary: CRWR @University of Texas

Contact_Organization: University of Texas
Contact_Address:
Address_Type: mailing address
Address: University of Texas at Austin
City: Austin
State_or_Province: Texas
Postal_Code:
Contact_Voice_Telephone: 512-471-0065 (tee hee)
Metadata_Standard_Name: Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: 19940608

Appendix C

Questionnaire Summary of Responses
Geographic Information Systems

1. Is your agency using or planning use of GIS for:

a. general mapping (e.g. highway routes, political boundaries, etc.)
b. data management (e.g. location-based inventories)
c. engineering design/analysis
d. other, please specify
e. none of the above
f. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a		x		x	x	x		x	x	x	x	x	x	x	x	x		x	x	x	x	x		x		x	x	x	x	x		x	25
b		x	x	x	x	x		x		x	x		x	x	x	x		x	x	x	x	x	x	x		x	x	x	x	x			24
c				x					x			x	x		x				x	x				x			x		x		x	x	12
d		x			x									x			x					x								x			6
e	x						x																										2
f																																	0

- AR state and federal highway (roadway inventory, bridge inventory/rating, ADT, pavement management, accidents, needs, railroads, airports, projects (completed, under construction, and planned))
- CA use and implementation of GIS is just beginning - the Dept. sees a lot of potential, but we've only scratched the surface on how we will ultimately use it
- CO other - NPDES
- GA only in the investigation stage at this time
- IL in the beginning stages of using GIS for design and analysis
- MD the GIS-HYDRO system has become the basis for all hydrology studies performed by the Structure Hydrology and Hydraulics (formerly Bridge Hydraulics) Unit
- MI spatial analysis (Polygon)
- MN engineering design/analysis - future
- MT MT DOT is using GIS developed in-house for road log, construction, ADT, and sufficiency rating information
- NC system under development - may identify other uses
- NE planning to use for engineering design/analysis
- ND ND DOT is just completing the pilot phase of the GIS. We will begin full implementation shortly by converting our county base maps.
- NY wide range of uses was planned, including Capital Program Planning, Maintenance Activity tracking, special hauling permit processing, environmental analysis, transit management, etc.
- OH flight records/mapping projects
- TX planning use of GIS and have test sites
- VA VA DOT is currently in the most conceptual of planning stages for adoption of a GIS

- VT planning use of GIS
- WA environmental impact analysis, maintenance planning and programming tool, future engineering design/analysis

2. Which GIS software is your agency using?

a. Arc/Info
b. ArcView
c. Intergraph MGE
d. GRASS
e. other, please specify
f. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a			x	x	x	x					x		x		x	x			x		x	x							x	x	x		14
b				x	x	x							x		x	x		x	x		x	x							x	x			12
c		x						x		x		x	x	x	x					x			x	x		x				x			12
d																																	0
e									x				x				x										x						4
f																												x					1

- IL GEOPAK
- MD MapInfo, VistaMap, GIS-HYDRO (by R. Ragan of the Univ. of Maryland)
- MN ArcInfo, ArcView - low resolution, 1:24,000
  Intergraph MGE - starting to look into for higher resolution
- MT software developed in-house
- TX Evaluating ARCINFO and MGE for statewide use
- VT planning use of ArcInfo and ArcView
- WY GEOPAK

3. Is your agency using or developing GIS for:

a. assisting in meeting NPDES MS4 and/or construction activities permit requirements
b. hydrologic and hydraulic analyses
c. storm water quality issues in addition to NPDES requirements
d. bridge inventory and bridge hydraulic data management
e. none of the above
f. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a				x	x								x		x			x						x			x			x			8
b									x			x	x						x	x							x	x				x	8
c																			x											x			2
d		x		x	x					x			x		x	x			x	x		x						x				x	12
e			x			x		x			x						x				x		x	x		x							9
f														x															x		x		3

- AR an ongoing research project on soil erosion prediction for construction sites using the GRASS (GIS) system
- CA GIS software has not been distributed to all district offices yet, but will be very soon. As staff becomes more familiar, uses are expected to increase.
- CO GPS was used to obtain location of CO DOT outfalls. The information obtained was included in CO DOT's GIS. The information, as well as the

maps, was submitted to the regulatory agency as part of CO DOT’s NPDES municipal permit application.

- GA bridge inventory will eventually be hooked up to the GIS system
- IL hydraulic analysis (not hydrologic)
- MD the system is capable of using both TR-20 and USGS regression equations
- MN developing ArcView application to facilitate access to NWI maps and use for coordinating bridge scour evaluations and flood monitoring efforts
- NE planning to use for hydrologic and hydraulic planning
- OK (1) currently obtaining digital USGS information, and plan to develop hydrologic and hydraulic analysis capacity in the future
  (2) joint effort between OK DOT and metropolitan planning organization
- TX in development
- VA We have asked for this capability but don’t know if we will get it.
- VT extent of use still to be determined

4. Which of the following <u>digital</u> data sources do you use?

a. STATSGO - SCS soils
b. USGS highway and streams digital line graphs (1:24,000; 1:100,000; 1:2,000,000)
c. USGS DEM 1:250,000
d. USGS DEM 1:24,000
e. GIRAS land use
f. other

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a												x				x											x						3
b				x		x		x				x			x	x		x				x		x		x	x	x					12
c																											x	x					2
d		x																	x								x	x					4
e																											x						1
f					x				x				x	x					x											x			6

- CA GDT street address mapping
- CO digitized county map basis (1:50,000)
- MD (1) Internal 1:24,000 and 1:6M maps
  (2) GIS-HYDRO has its own digital mapping
  (3) the current version is based on the 1990 aerial mapping developed by the State Office of Planning
- MI Michigan DNR, MI Resource Inventory System (MIRIS) files
- MN plan to use USGS 1:100,000 DLG for streams - another state agency has added labels; getting access to NWI, watersheds, and protected waters created by other agencies; MN DOT has digitized highways (1:24,000) and is in the process of labeling.
- MO 1:100,000
- NC 1:100,000
- ND We are presently converting our county base maps to digital format. We will use 1:24,000 USGS Quads also.
- NY have our own 1:24,000 roads file, use USGS 100k hydrography files

- OK digitized own set of line work for state hwy., city streets, and county roads
- SC digitize data “in-house”
- TX test cases only
- WA digitized USGS 1:24,000
- WY aerial photos → DTM → GEOPAK, would use USGS if available

5. Is your agency using a GIS for assistance in estimating drainage areas and storm water runoff rates?

a. yes
b. no
c. don’t know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a												x	x						x									x				x	5
b			x	x	x			x	x									x				x				x	x			x			10
c																																	0

- CA We would like to do this if the appropriate mapping were available (soils, land use, etc.).
- MD The system is based on the existing land use while the design in Maryland has to be based on the ultimate development discharges. Thus, the ultimate development map is prepared by hand and then digitized to obtain both existing and ultimate development RCN values that plugged into direct runoff equations (see TR-55). The ratio of ultimate and existing direct runoff volumes is then used to multiply the existing development discharges to account for the ultimate development changes.
- ND a future application
- TX not currently, but plan to
- VA We would like this but don’t know if our system will include such capabilities
- WA There is future potential to use GIS for recording drainage courses and delineating basins.
- WY drainage area only

6. In what way do you determine drainage area size?

a. manual delineation and planimeter
b. digitize boundary over paper topographical map
c. digitize boundary over digitized topographical map
d. use digital elevation data and terrain model to define
e. other, please specify

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a			x		x				x			x	x					x	x			x				x	x	x		x		x	13
b													x														x					x	3
c												x																					1
d																																x	1
e																																	0

7. When determining drainage areas, do you:

a. use original topographic or DEM map projection
b. transform to other projection
c. don’t know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a			x						x			x	x					x	x								x	x		x		x	10
b																																	0
c					x																												1

- MD Unfortunately, the system does not use real elevations; it uses only average slopes based on the knowledge of the range of slopes associated with different type soils. For this reason, watershed boundaries have to be delineated by hand.

8. Which of the following GIS coverages do you use to help determine appropriate hydrologic modeling parameters? Please specify type and source.

a. soils
b. land use/cover/vegetation
c. rainfall data
d. evaporation data
e. topography
f. other
g. none of the above

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a												x	x						x														3
b												x	x																				2
c												x	x																				2
d																																	0
e												x							x													x	3
f													x																				1
g			x		x				x									x				x					x	x		x			8

- MD Soils : SCS county soil maps, USGS soil maps
  Land use : (1) 1990 State Planning maps for existing land use
  (2) zoning maps for future use
  Rainfall : TR-20 rainfall tables (for TR-20 applications only)
  Other : soil slopes (SCS maps)
- ND Soils : uncertain at this time
  Topography : USGS Quad’s
- VA We would probably use all the listed parameters if the system includes such provisions.
- WA We have need and use all the above parameters [those listed in Ques. 8], however, we presently are not obtaining this information by GIS
- WY Topography : aerial photos or data collectors

9. How is this data being used for hydrologic modeling?

- LA integrate HEC 1 and 2
- MD (1) to develop land cover distribution, SCS runoff curve numbers, and urban characteristics for use in hydrologic modeling, regression analysis, etc.
  (2) the preferred methodology is USGS regression equations. The system is

capable of calculating values of appropriate variables (e.g. drainage area, storage, forest cover, etc.) and discharges. For TR-20 applications, the system can either develop the necessary variables or accepts the parameter entered based on hand calculations for variables like T_c or reach routing data.

- WY use to get drainage areas, slopes, and channel x-sections

10. Please describe problems or deficiencies you perceive with applying GIS to determine hydrologic modeling parameters.

- LA under development
- MD (1) lack of up-to-date data - it costs too much to update frequently (regarding land use/cover)
  (2) lack of real elevations
  (3) The resolution of data is a very important factor - it may cause errors in calculations and determines when it is applicable.
  (4) jazzy computer graphics don't make up for expertise in hydrologic modeling
  (5) Extraordinary detail is easy to produce. In hydrology, the saying goes: "Detail in - garbage out." The real work in hydrology is more than mechanical detail. There is a danger that this aspect gets forgotten.
- ND this will be a future application
- WY (1) Need to automate drainage area and slopes to compute hydrologic estimates for both culvert sites and storm drains
  (2) Need to interface topo DTM with our CDS culvert design software to allow flood routing through culverts

11. Is your agency using a GIS for assistance in performing floodplain analysis?

a. yes
b. no
c. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a									x			x							x													x	4
b			x	x	x			x					x					x				x					x	x		x			10
c																																	0

- VA would probably use it if we had it

12. Please briefly describe how your agency is using a GIS for assistance in performing floodplain analysis.

- IL currently using mapping on a small number of jobs to get cross sections
- LA under development
- ND Our plan is to share data with USGS in a joint effort, including the purchase of scanned USGS Quads.
- WY extract x-sections for WSPRO or CDS analysis

13. **Please describe problems or deficiencies you perceive with applying GIS to assist in performing floodplain analysis.**

- IL survey data has to be tied in for stream cross sections in areas covered by water
- WY under water topography is difficult to obtain to supplement DTM from aerial photography

14. **Is your agency using GIS to map calculated floodplain limits?**

a. yes
b. no
c. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a												x							x														2
b			x	x	x			x	x				x					x				x		x			x	x		x		x	13
c																																	0

15. **Does your GIS software incorporate coordinate geometry (COGO) functions?**

a. yes
b. no
c. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a				x					x					x		x			x													x	6
b		x				x							x											x		x		x		x			7
c			x		x			x		x		x						x				x					x						8

16. **Are these COGO functions being used by your agency?**

a. yes
b. no
c. don't know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a						x			x					x					x														4
b																x										x		x					3
c													x																			x	2

- CA Our right-of-way divisions will make use of the COGO functions. We do not have a site license for COGO.
- MN We use GEOPAK and Intergraph as our design software. We are just starting to try out MGE.
- ND Once we have concluded our data conversion, we will have this capability.

17. Has your agency customized a GIS system to meet your specific needs?

a. yes
b. no
c. don’t know

	AL	AR	AZ	CA	CO	GA	HI	IA	IL	KS	KY	LA	MD	MI	MN	MO	MT	NC	ND	NE	NM	NY	OH	OK	OR	SC	TX	VA	VT	WA	WV	WY	Total
a					x					x		x	x			x			x														6
b		x	x			x		x						x	x			x				x		x		x	x	x		x			13
c									x																								1

- CO The NPDES GIS application was created by CO DOT’s GIS group to meet NPDES needs.
- MD (1) developed dynamic segmentation software before available commercially
  (2) The original GIS was developed for bridge hydraulic engineers for watersheds of 400 acres or more. It has now changed to include much smaller watersheds to enable highway hydraulic engineers to use it in their studies.
- ND We are presently concluding our pilot phase of the GIS, which includes a customized cartography application.
- NY Future application customizing planned for several different applications. Most customizing to be done in the ArcView environment (using AVENUE).
- WY We are planning to customize an interface with CDS.

18. Please indicate any hydraulic or stormwater quality-related use of GIS not already addressed.

- LA bridge and culvert design
- MD (1) MD SHA cannot use its GIS-HYDRO system in hydraulic applications due to the lack of real elevations and its resolution. We intend, however, to use it in the future to create the hydrology/hydraulic inventory for all SHA crossings.
  (2) GIS of structures, with pictures and previous evaluation for scour mnitoring and analysis
  (3) water quality BMPs
  (4) Any hydraulics related activities (permits) by location can be valuable GIS application. This can also be used as an indexing system for stored computations.
- MN (1) Our division has made a proposal to use GIS to interface with proposed hydraulic structure/info database (storm sewer, culverts, ...) - project in proposal status.
  (2) MN DOT is contracting with USGS to do series of watershed reports. USGS is using ArcInfo to prepare. Eventually, MN DOT Hydraulics plans to access the information with GIS.
- WA to delineate wetlands and delineate water quality treatment facilities and to be able to distinguish between the two

19. What general issues do you consider to be hindering more wide scale application of GIS in hydraulic design?

- AZ (1) accuracy of mapping
  (2) cost versus value - infrequent need for data - must be "cheap!!" to acquire and use
- CA The availability of DEMS and DTMS, as well as land use mapping
- CO (1) training is needed
  (2) management is not convinced of GIS benefits
  (3) not enough data available in CO DOT's GIS to perform hydraulic design
  (4) cost
- GA GIS is not fully developed at this time
- IL The expense and time consumed getting topographic information is the biggest problem. Training could become the issue if the information problem is resolved.
- KS securing resources to implement GIS
- LA technical support
- MD (1) see comments under Ques. 10
  (2) The scale of mapping required to do hydraulic studies in Maryland is 1"=100' or better; the resolution offered by our GIS is not acceptable for hydraulic studies.
  (3) Data availability - data may or may not be available. When available, it may not be to the resolution that is acceptable for hydraulic studies.
- MI lack of readily available data
- MN (1) availability of watershed data at appropriate resolution
  (2) skills/training of hydraulic personnel
- NC (1) access
  (2) other priority usage
- ND the cost and availability of digital USGS Quad maps
- SC lack of contour data
- WA lack of technical support for the development and implementation of GIS technology
- WY lack of USGS digitized mapping or cross-sections used in FEMA flood plain studies

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Peter Neil Hynd Smith was born in Durham, England on August 27, 1961, the son of Elizabeth Joan Smith and Alexander Hynd Smith. He received the degree of Bachelor of Engineering from the University of Bradford, England in July, 1983. He was employed as a civil and structural engineer in Leeds, England for one year after which he took employment with the Texas Department of Transportation (TxDOT) in June, 1984. In January, 1994, while still employed with the TXDOT, he entered the Graduate School at the University of Texas.

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