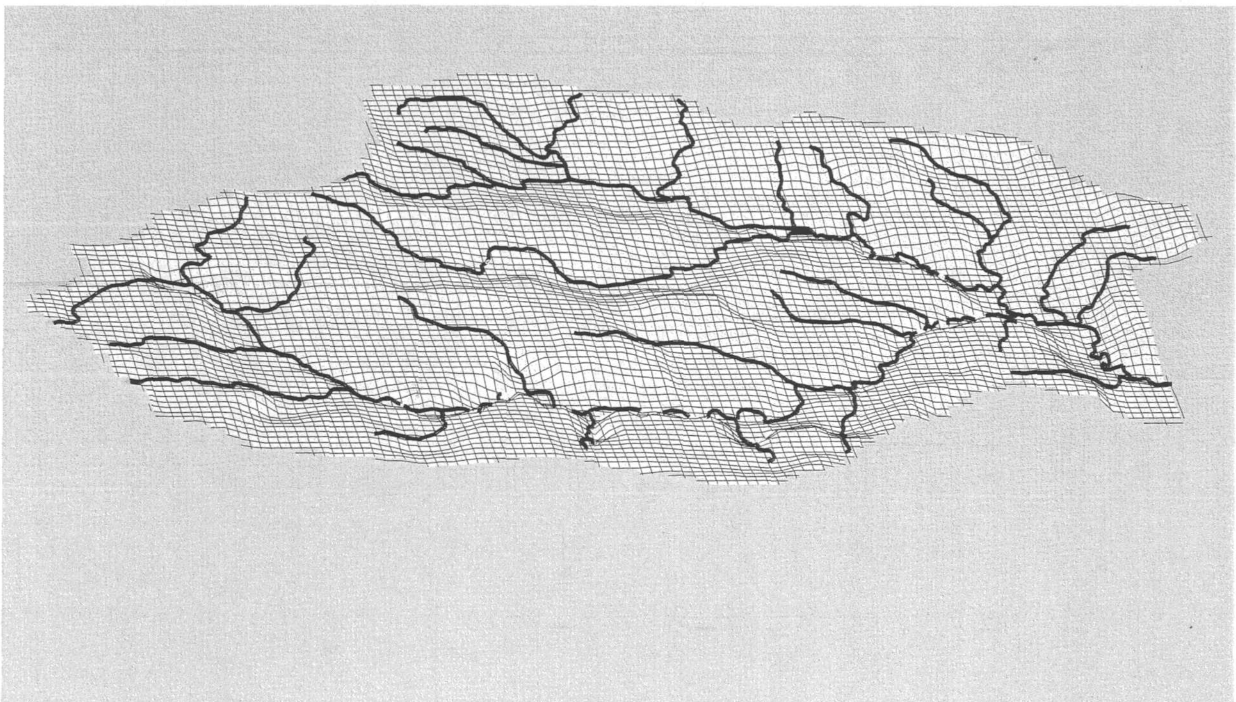
Description, Instructions, and Verification for Basinsoft, a Computer Program to Quantify Drainage-Basin Characteristics

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 95–4287



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By CRAIG A. HARVEY and DAVID A. EASH

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CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot per mile (ft/mi)	.1894	meter per kilometer
mile per square mile (mi/mi^2)	.621	kilometer per square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929—a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

DEFINITION OF TERMS

AML—ARC Macro Language is a post-processing language written for use with ARC/INFO.

ARC—Geographic Information System (GIS), licensed through Environmental System Research Institute, Inc.

ARC/EDIT—Geographic Information System (GIS) edit module licensed through Environmental System Research Institute, Inc.

ARC/GRID—Geographic Information System (GIS) raster modeling module, licensed through Environmental System Research Institute, Inc.

ARC/INFO—Geographic Information System (GIS) relational database software, licensed through Environmental System Research Institute, Inc.

ARC/PLOT—Geographic Information System (GIS) plotting module, licensed through Environmental System Research Institute, Inc.

ASCII—American Standard Character Code for Information Interchange refers to a non-binary computer file composed of text characters that can easily be edited, often called a flat file.

Attributes—are numeric or text characteristics that describe a specific spatial feature, attributes are commonly stored in a relational data base structure (Nebert, 1989).

Basinsoft—a computer program composed of a set of AMLs which process four source-data layers and quantify 27 selected morphometric drainage-basin characteristics and optional area-weighted characteristics for a selected drainage basin.

Clean—the connectivity of the topology is intact.

Clip—to reduce the areal extent of a coverage to match the areal extent of a different coverage.

Coverage (cover)—a digital data set depicting a defined spatial extent composed of one or more data layers.

CPL—Command Programming Language, a Primos operating-system script.

Data layer—a theme, such as hydrography or hypsography, within a coverage.

DEM—Digital Elevation Model is a file of digital-terrain elevations stored in raster or grid-cell format and organized by quadrangles.

DLG—Digital Line Graph data is a file of digital point coordinates representing linear features of data layers such as hydrography, hypsography, transportation, stored in vector format and organized by quadrangles.

FOS—First-Order Stream is a stream with no tributaries.

Fortran—a formula-translating computer programming language.

Global variable—a variable which remains active as long as the ARC session remains active.

Hydrography—surface-water drainage network.

Hypsography—elevation contours.

INFO-item—the name of an INFO-data-file item. INFO items can have values attributed to them.

Lattice—raster data stored in an ARC/INFO grid format.

Local variable—a variable which remains active as long as the AML from which it is defined remains active.

Module—an AML for which the output is a basin-characteristic measurement or computation.

Morphometric basin characteristic—measurement or description of the form and structure of a drainage basin and its drainage network, including measurements of area, length, relief, aspect, and stream order.

Platform—a type of computer system on which software runs.

Prime—computer running Primos operating system.

Script—computer program which is interpreted by the operating system line by line.

Source-data layer—one of four digital data layers required as input to Basinsoft.

Strahler stream-ordering method—widely used method, first proposed by Strahler (1952), for characterizing stream networks. A stream segment with no tributaries is defined as a first-order stream. Where two first-order streams join, they form a second-order stream, where two second-order streams join, they form a third-order stream, and so forth.

Topology—the explicit connectivity of spatial features. Topology is required in an arc-node data model (such as digital line graphs) for proper associations to be made among features (such as arcs, nodes, points, and polygons) and their attributes (Nebert, 1989).

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ABSTRACT

Basinsoft is a computer program developed to utilize digital cartographic data to quantify 27 selected morphometric characteristics and optional area-weighted characteristics for a drainage basin. The programs comprising Basinsoft were written in Arc Macro Language (AML), a post-processing language written to run in ARC/INFO, a proprietary geographic information system (GIS). Basinsoft requires the generation of four source-data layers, three coverages and one lattice, representing the drainage-divide, hydrography, hypsography, and a lattice elevation model of a drainage basin, and the attribution of the three source-data layer coverages. Preprocessing of these data layers is facilitated by specialized utility AML programs. Compared to manual methods of measurement, Basinsoft significantly decreases the amount of time and effort required to quantify selected characteristics for drainage basins, particularly when a large number of drainage basins need to be processed. The automaticity of Basinsoft and its utility programs facilitate implementation of Basinsoft without requiring extensive GIS experience. Basinsoft was developed entirely using AML to ensure portability between platforms running ARC/INFO version 7.0 or later.

Statistical comparison tests indicate Basinsoft quantifications are not significantly different from manual topographic-map measurements for 9 of 10 basin characteristics tested. The results also indicate that elevation contours generated by ARC/INFO from 1:250,000–scale digital elevation model (DEM) data are over-generalized when compared to elevation contours shown on 1:250,000–scale topographic maps, and that quantification of basin-slope thus is underestimated using DEM data. A qualitative comparison test indicated that the Basinsoft module used to quantify basin slope is valid and that differences in the quantification of basin slope are due to source-data differences.

INTRODUCTION

Surface-water runoff is a function of many interrelated factors including climate, soils, land-use, and the physiography of the drainage basin. A practical and effective method to quantify drainage-basin characteristics would allow analysis of the interrelations of these factors, leading to an improved understanding of the effects of drainage-basin characteristics on surface-water runoff. Historically, the quantification of drainage-basin characteristics has been a tedious and time-consuming process. Recent improvements in computer hardware and software technology have enabled the developers of a program called Basinsoft to automate this process. Basinsoft requires minimal preprocessing of data and provides an efficient, automated procedure for quantifying selected morphometric characteristics and the option to area-weight characteristics for a drainage basin.

Development of the Basinsoft program is continuing. Information regarding the status of this program may be obtained by accessing the U.S. Geological Survey, Iowa Home Page at http://dg00diaiwc.cr.usgs.gov or by sending email to basinsoft@maildiaiwc.cr.usgs.gov or by contacting the U.S.Geological Survey, P.O. Box 1230, Federal Building room 269, 400 South Clinton Street, Iowa City, Iowa 52244–1230 or by telephone at (319) 337–4191.

Purpose and Scope

The purposes of this report are to (1) provide instructions for preprocessing and processing the four source-data layers, representing selected aspects of a drainage basin, needed to quantify 27 selected morphometric basin characteristics, and (2) document and verify the methods and equations used by Basinsoft. The report is intended as a user's manual for the Basinsoft programs. The user of Basinsoft is assumed to have a limited amount of ARC/INFO experience. The report describes the Basinsoft program structure to the extent needed by the user to understand the provided directions for preprocessing and processing steps required to use Basinsoft and the procedure used for verification of Basinsoft.

Acknowledgments

The authors express their gratitude to the following individuals for their contributions to the development of Basinsoft: James J. Majure, formerly with the U.S.Geological Survey (USGS), and now with Iowa State University, Ames, Iowa, for the development of the original Basinsoft, after which the current version of Basinsoft was modeled; Philip J. Soenksen, USGS, for his help in the conceptualization of Basinsoft; Josef M. Pohl, USGS, who assisted with the trouble-shooting phase during the development of Basinsoft; Ronald B. Zelt, USGS, for his help in overcoming a programming obstacle dealing with the orientation of basins; and Keith W. McFadden, USGS, whose program segments were invaluable in automating the quantification of basin length.

History of the Development of Basinsoft

In 1988, USGS began developing a program called Basinsoft. The initial program quantified 16 selected drainage-basin characteristics from three source-data layers that were manually digitized from topographic maps using the versions of ARC/INFO, Fortran programs, and Prime system CPL programs available in 1988 (Majure and Soenksen, 1991). By 1991, Basinsoft was enhanced to quantify 27 selected drainage-basin characteristics from three source-data layers automatically generated from DEM data using a set of Fortran programs (Majure and Eash, 1991; Jenson and Dominique, 1988). Due to edge-matching problems encountered in 1991 with the preprocessing of the DEM data, the Basinsoft program was subsequently modified to quantify 24 selected drainage-basin characteristics from four source-data layers created from three types of data (topographic maps, DLG data, and DEM data) (Eash, 1993; Eash, 1994). The early versions of Basinsoft relied primarily on Fortran programs and Prime system CPL to manage data and calculate statistics, thus making them platform dependent.

In 1994, Basinsoft was redeveloped entirely using AML to increase portability among systems using ARC/INFO version 7.0.2 or later (Environmental Systems Research Institute, 1994). The current version of Basinsoft processes four source-data layers representing selected aspects of a drainage basin to quantify selected morphometric drainage-basin characteristics. The 27 selected basin characteristics quantified by Basinsoft are listed in appendix A as measurements or computations. Twelve of the drainage-basin characteristics constitute specific quantifications of area, length, relief, aspect, and stream order; the other 15 characteristics are computations that make use of the various quantifications to calculate other drainage-basin characteristics or statistics.

DESCRIPTION OF BASINSOFT PROGRAM STRUCTURE

The AML programs comprising Basinsoft are initialized so that each program performs specific tasks and when necessary, passes information required by the following program for subsequent processing. By programming in this modular manner, additional or future modules are easily appended to Basinsoft by the user.

The "core" AML programs comprising Basinsoft, listed with their associated functions in table 1, are referred to as modules in this report. Basinsoft.aml controls the modules found in the basinsoft directory (fig. 1) and can be modified to control some of the utility programs found in the tools directory (fig. 1). Modules are executed each time Basinsoft is initiated. Drainage basin characteristics are quantified within the modules. Examples of the directory structure required by Basinsoft are listed in table 2 and shown on figure 2.

Table 1. "Core" AMLs and associated functions

AML name	AMLfunction[a]
basinsoft.aml	Driver AML, initiates other core AMLs.
setup.aml	Defines system specific commands or syntax.
cleanup.aml	Removes residual files and coverages from previous Basinsoft runs.
basinit.aml	Initializes variables and creates an empty INFO table to hold drainage-basin characteristics as they are quantified by Basinsoft.
bam.aml	Quantifies TDA, NCDA, CDA.
clm.aml	Quantifies MCL and TSL.
azim.aml	Quantifies BP and BA.
orient.aml	Calculates and sets the global variable ".orient".
basinl.aml	Quantifies BL.
dfm.aml	Quantifies FOS, BSO, DF.
brm.aml	Quantifies BS and BR.
crm.aml	Quantifies MCS.
computations.aml	Quantifies BW, SF, ER, RB, CR, RR, MCSR, SD, CCM, MCSP, RN, SR, and RSD.

a. See appendix A for description of drainage-basin characteristic quantifications.

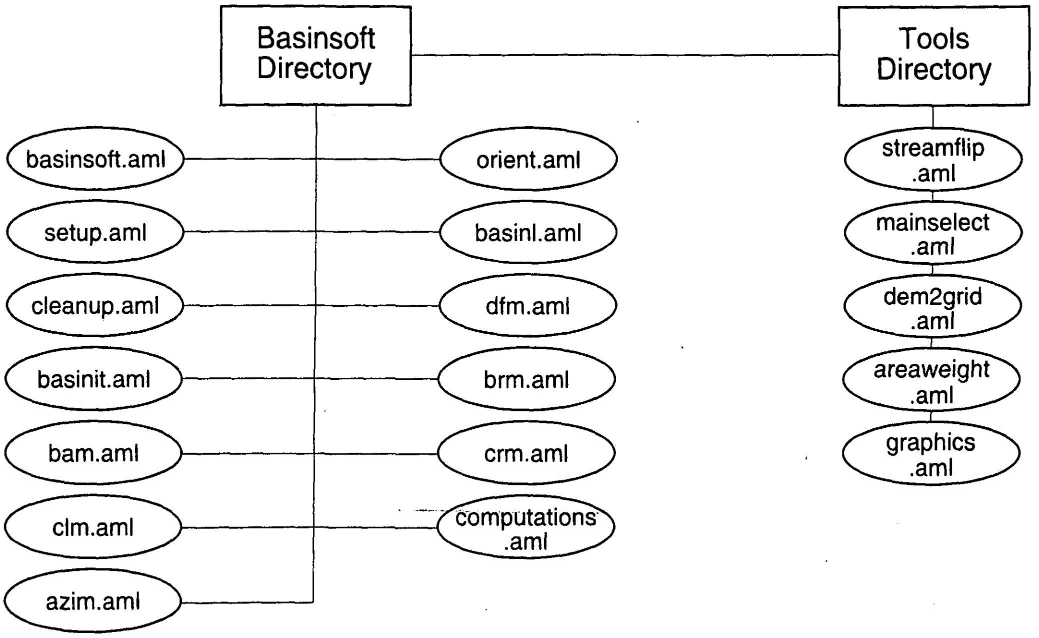

Figure 1. Example of Basinsoft program directory structure.

Table 2. Naming conventions and description of directory structure required by Basinsoft

Directory name	Description of directory
basin_name	This is the unique name defining a specific drainage basin (e.g. basin_a). The following data layers are source-data layers maintained under the basin_name directory.
cover_bas	Drainage-divide data layer.
cover_str	Hydrography data layer.
cover_con	Hypsography data layer.
cover_lat	Lattice data layer with areal extent clipped to drainage-basin boundary.
tbufcov_lat	Lattice data layer with areal extent to clipped buffered basin boundary.

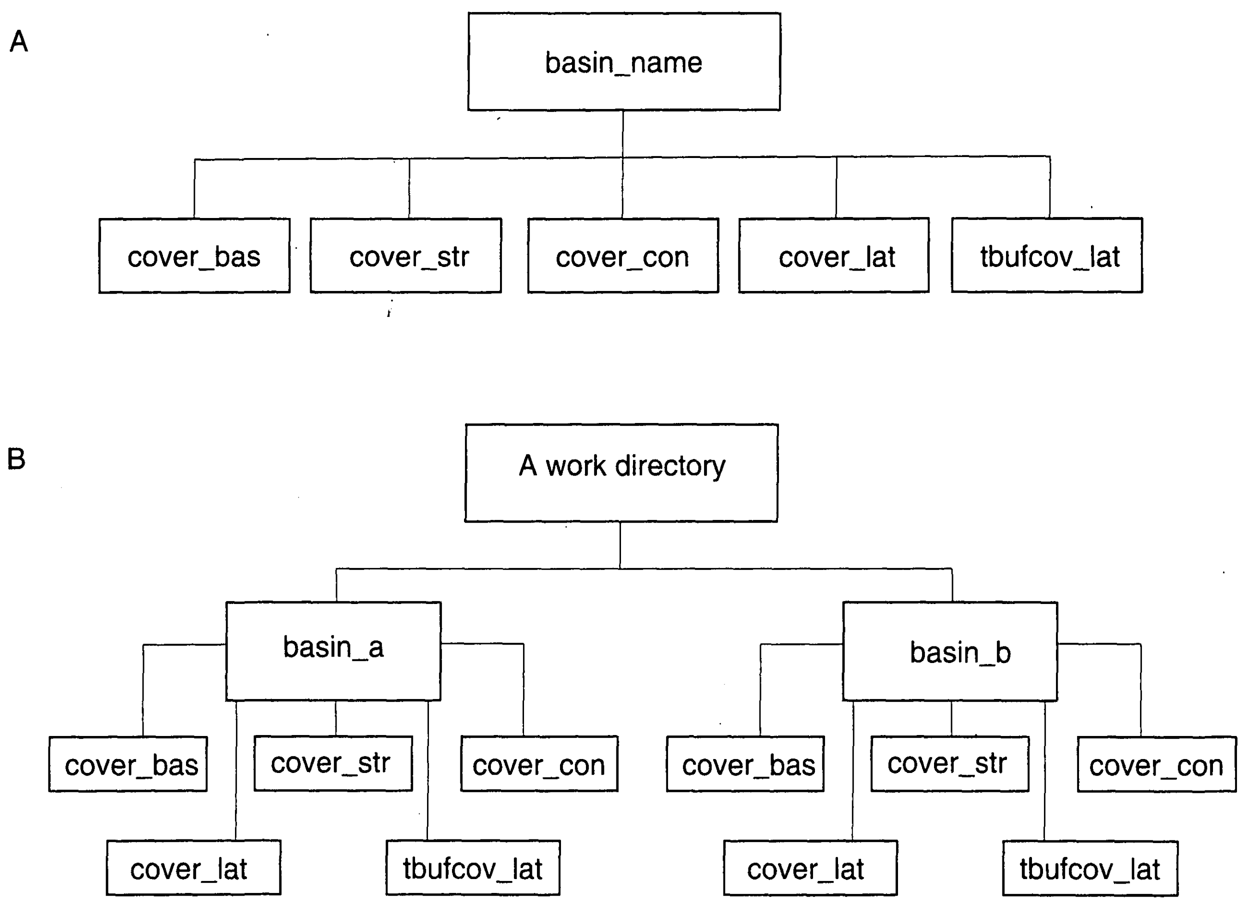

Figure 2. Naming conventions and directory structure required for processing multiple drainage basins.—(A) generic directory structure of single basin, (B) actual directory structure for multiple basins (e.g. basin_a and basin_b) maintained under a work directory.

COMPUTER RESOURCES REQUIRED TO EXECUTE BASINSOFT

Basinsoft was developed and tested on Data General Avion model 300, 530, and 550 workstations using ARC/INFO version 7.0.2. Basinsoft requires no compilation. System-specific commands such as "remove" or "delete" were defined as global variables and are included in the setup.aml (table 1). The setup.aml can be modified to configure Basinsoft to run on various computer platforms and to reflect system-specific usage or syntax requirements.

Processing time to execute Basinsoft varies between 5 and 20 minutes on a Data General Avion 530 for drainage basins with areas less than 3000 mi^2. Processing time on other systems may vary depending on their hardware capabilities. These processing times do not include time for preprocessing, which will vary according to the type of source data available for generating the four source-data layers required as input to Basinsoft. The time to execute the TOPOGRID command may range from 5 minutes to more than 1 hour, depending on the size of the drainage basin and hardware capabilities. The basin-length module also is computer-time, memory, and disk-space intensive.

SOURCE-DATA REQUIREMENTS OF BASINSOFT

Basinsoft requires the user to provide four source-data layers. Figure 3 shows examples of the four source-data layers, which are: (1) a drainage-divide (fig. 3A), (2) hydrography (fig. 3B), (3) hypsography (fig. 3C), and (4) a lattice elevation model (fig. 3D). These data layers are not required to be of any specific scale, however, the hydrography and hypsography data layers should be clipped to the areal extent of the drainage-divide data layer. The lattice elevation model is preprocessed into two lattice data layers — cover_lat, with the same areal extent as the drainage-divide data layer, and tbufcov_lat, with an areal extent set to a buffered region slightly larger than the drainage-divide data layer.

Several programs were developed to assist the user in preprocessing source-data layers in preparation for use with Basinsoft. These programs, which are found in the tools directory, perform various tasks such as creating a hydrologically accurate lattice elevation model, facilitating the creation of a hypsography data layer, and converting a 1:250,000–scale DEM to a lattice data layer. Several programs were developed to assist the user in assigning attributes to data layers according to a specialized attribute scheme required by Basinsoft. Examples of the specialized attribute tables required by Basinsoft for three source data-layer coverages are listed in appendix B.

PREPROCESSING OF SOURCE DATA FOR PROGRAM INPUT

Basinsoft was developed to run with minimal preprocessing; however, there are several steps required to prepare the source-data layers for subsequent processing by Basinsoft. The preprocessing and processing steps are listed in sequential order in appendix C. Preprocessing steps include the generation of four source-data layers as described above and the assignment of attributes. The arc segments of the hydrography data layer must be edited using the streamflip.aml to orient the arc segments in a downstream direction. The main channel of the drainage basin must be delineated, attributed, and extended to the drainage-divide. AMLs were developed to assist the user with nearly all aspects of the preprocessing required by Basinsoft. Throughout this report, ARC program commands and programs residing in the ARC/INFO home directory, normally "..../arcexe70/atool/arc", are referenced in capital letters. Syntax and help for these commands are located in the ARC/INFO command reference manuals or in the on-line help facility of ARC/INFO revision 7.0.2 or higher (Environmental Systems Research Institute, 1994).

Instructions for Preprocessing the Drainage-Divide Data Layer

The feature attributes required for the drainage-divide data layer (cover_bas) (fig. 3A) are listed in appendix B. The drainage-divide data layer must be attributed with an INFO-item named CONTRIB, defined as (1, 1, I) in the INFO data base. This item should have a value of '0' (the default) for contributing drainage areas (CDA) and a value of '1'

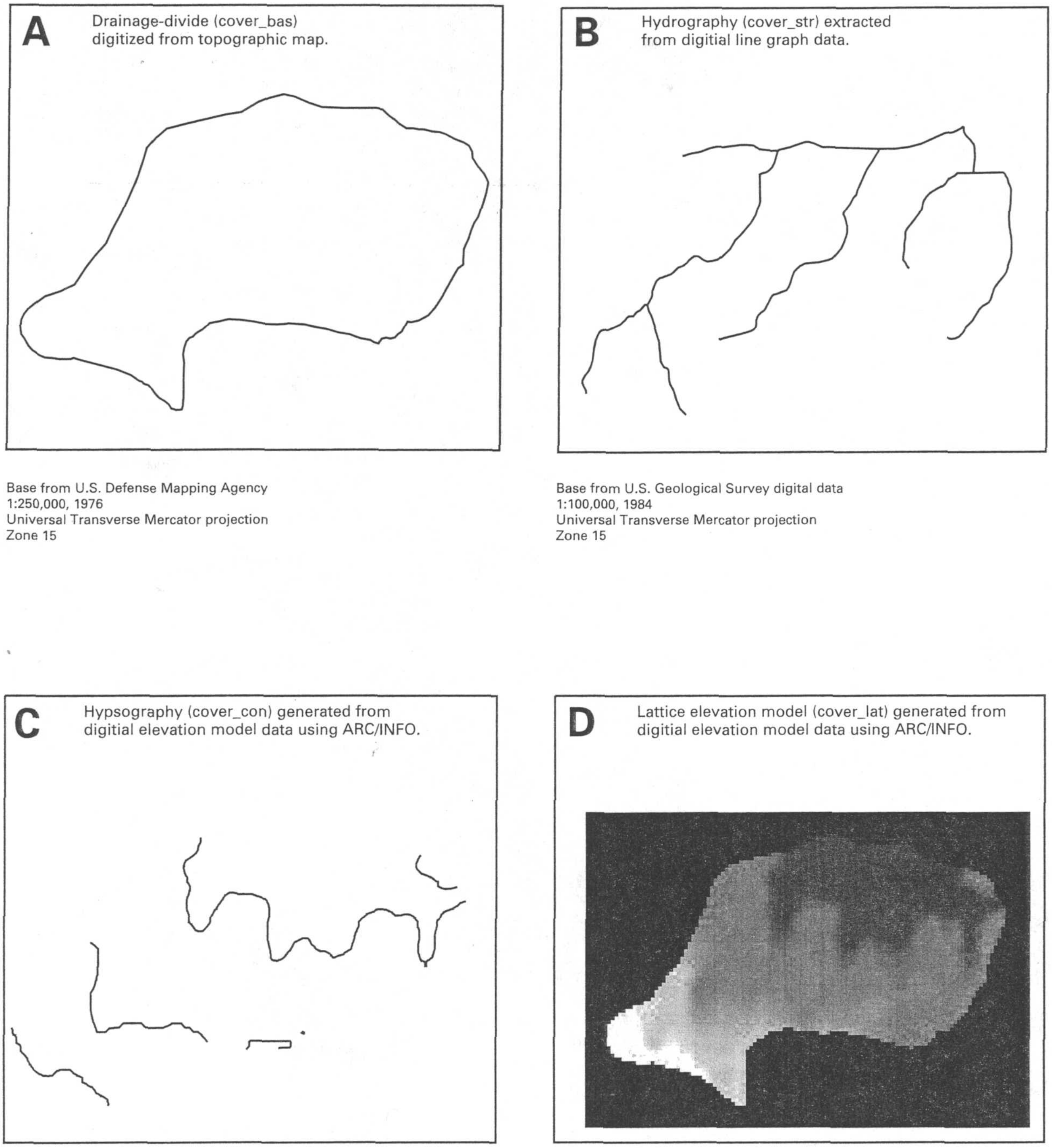

Figure 3. Examples of four source-data layers required by Basinsoft—(A) drainage-divide data layer, (B) hydrography data layer, (C) hypsography data layer, (D) lattice elevation model data layer.

for non-contributing drainage areas (NCDA); thus no attributing is necessary unless NCDA exist. A second INFO-item, BASINNAME, defined as (20,20,C) in the INFO data base, must be added to the drainage-divide data layer and attributed with an identifying name for the drainage basin.

A buffered area slightly larger than and surrounding the drainage area must be created using standard ARC/INFO commands such as: BUFFER <cover_bas> <cover_buff> # # 250 # {poly} (for data in meters) or BUFFER <cover_bas> <cover_buff> # # 750 # {poly} (for data in feet). This buffered drainage-divide data layer is subsequently used to create tbufcov_lat from which elevation contours are generated.

Instructions for Preprocessing the Hydrography Data Layer

The feature attributes required for the hydrography data layer (cover_str) (fig. 3B) are listed in appendix B. The topology of the hydrography data layer must be clean and the main channel must be delineated and attributed with an INFO-item named CODE. The arc segments in the hydrography data layer (cover_str) must be oriented in a downstream direction. AML programs named streamflip.aml and mainselect.aml were developed to assist in performing these tasks and specialized attributing.

Streamflip.aml

The number of first-order streams (FOS) within a drainage basin is used to quantify three drainage-basin characteristics. The number of first-order streams is determined within Basinsoft using ARC/INFO's STRAHLER program. The STRAHLER program requires that all FROM/TO nodes of arc segments representing the hydrography be oriented in a downstream direction. The streamflip.aml was developed to help the user accomplish this editing. The streamflip.aml is invoked from the ARC prompt and will open an ARC/EDIT session and prompt the user to select a point or points depicting the basin-outlet or outlets (in the case of braided streams or deltas) using standard ARC/EDIT on-screen digitizing techniques (Environmental Systems Research Institute, 1994). The AML will then orient the FROM/TO nodes of each arc segment in a downstream direction. Syntax for the utility program streamflip.aml is &RUN streamflip <cover_str>.

Mainselect.aml

The main channel length (MCL) is used to quantify four drainage-basin characteristics. By definition, MCL is measured along the main channel from the basin outlet to where the main channel, if extrapolated, were to meet the basin divide. The quantification of MCL requires the delineation or attribution of the main channel and, in most instances, the addition of an arc segment from the upstream node of the main channel to the drainage-basin divide. An automated procedure named mainselect.aml was developed to assist in extending and defining the main channel. The mainselect.aml requires arc segments to be oriented in a downstream direction.

The utility program mainselect.aml is invoked from the ARC prompt and will: 1) open an ARC/EDIT session, 2) initialize the edit environment, and 3) prompt the user to extend the main channel from the basin divide to the upstream node of the main channel. The direction that the arc is added is important; the arc segment added must begin at the basin divide and be extended until it meets the upper end of the main channel. Standard ARC/EDIT on-screen digitizing techniques are used (Environmental Systems Research Institute, 1994). The mainselect.aml will then prompt the user to select both ends of the main channel and then quit the edit session. The mainselect.aml then selects all of the arc segments representing the main channel between the two selected points, highlights the main channel, and pauses to allow the user to inspect the program-defined main channel and allow for changes. Once complete, the AML will assign a value of '1' to the INFO-item named CODE for arcs which represent part of the main channel, and a value of '0' (the default) to all other arcs in the hydrography data layer (cov_str). If the delineation of the main channel is incorrect, the mainselect.aml will need to be rerun.

Instructions for Preprocessing the Hypsography Data Layer

Elevation-contour data may be available in the form of DLG data or may need to be generated from DEM data. Other sources of data, such as triangular irregular network (TIN) data or digitized vector data, may be used to generate elevation-contour data. The feature attributes required for the hypsography data layer (cover_con) (fig. 3C) are listed in appendix B.

Several steps are necessary if hypsography data are to be generated from DEM data. A utility AML, dem2grid.aml, located in the tools directory, was developed to convert DEM (raster) data to hypsography (vector) data. This task also can be accomplished interactively using standard ARC/INFO commands. The DEM data can be converted to a lattice using the ARC/INFO command DEMLATTICE. The lattice can then be converted to contour data using the ARC/INFO command LATTICECONTOUR. A hypsography data layer generated from a lattice data layer, whose areal extent matches that of the drainage-divide data layer, will not use elevation data to the maximum extent of the basin divide to generate contours. To produce elevation contours that use data to the maximum extent of the basin divide, the elevation contours must be generated from an area slightly larger than the drainage basin, and then clipped to the areal extent of the drainage-divide data layer (cover_bas). Elevation contours are clipped using the ARC/INFO CLIP command.

Instructions for Preprocessing the Lattice Data Layer

If the hypsography data layer is developed using DEM data, and the utility AML dem2grid.aml is used to generate hypsography data, then the lattice elevation model (fig. 3D) is a by-product of executing dem2grid.aml.

Two lattice data layers need to be generated. One of the lattice data layers, cover_lat, will have its areal extent defined by the drainage-divide data layer (cover_bas). The other lattice data layer, tbufcov-lat, has its areal extent defined by a buffered region surrounding and slightly larger than the drainage-divide data layer. An optional module, dem2grid.aml was developed to create both of the lattice data layers and the hypsography data layer (cover_con) from DEM data. The ARC/INFO command DEMLATTICE may optionally be used to generate the required source-data layer. Further preprocessing can be accomplished using the ARC/INFO CLIP command.

The elevation source data (lattice elevation ~~model) (fig. 3D)~~ may be unavailable, or may be available at an inappropriate scale. Under these circumstances, it may be necessary to create or enhance the elevation data. One method is to use the ARC/INFO command TOPOGRID to create the lattice data layer. This command uses hypsography and a single-line hydrography network with options to use point elevation data and linear data as break lines in the topography to create a hydrologically accurate lattice data layer.

PROCESSING DATA LAYERS TO QUANTIFY DRAINAGE-BASIN CHARACTERISTICS

Basinsoft processing can be performed on either single or multiple basins. The process of quantifying basin characteristics for a number of drainage basins is highly repetitive; therefore, it is possible to automate much of this task once the preprocessing has been completed. Processing involves invoking the program Basinsoft.aml to quantify 27 selected morphometric drainage-basin characteristics. Appendix C sequentially lists the steps needed to quantify drainage-basin characteristics using Basinsoft.

Single-Basin Processing

A single drainage basin can be processed from the ARC prompt. Basinsoft is executed with the appropriate basin name as a command line argument (appendix C, step 7a). Upon execution of Basinsoft, the drainage basin is processed and selected output is written into the basin_name directory (fig. 2A).

Multiple-Basin Processing

Multiple drainage-basin processing can be performed using the program multi_p.aml, an AML provided in the tools directory. The user modifies the AML to include a list of names of drainage basins to be processed. Strict adherence to the naming convention defined in table 2 is necessary to automate this procedure. Upon execution, the program multi_p.aml loops through the list of basin names provided by the user (appendix C, step 7b), and output files are written into the basin_name directory (fig. 2B). The directory structure, as shown in figure 2B, is needed to execute the program multi_p.aml.

BASINSOFT OUTPUT

Basinsoft output is generated in two formats. An INFO table named COVER_CHAR and a flat file named CHARS.TXT are generated in the basin_name directory (table 2). The flat file is generated from the INFO table. Both files are output with the following format: characteristic_name = value. Table 3 shows an example output in the flat-file format. An optional graphic-output module named graphics.aml is available in the tools directory.

BASINSOFT VERIFICATION

To verify the accuracy of the drainage-basin characteristics quantified using Basinsoft, manual measurements of 12 selected drainage-basin characteristics were made from USGS topographic maps for drainage areas upstream of 11 streamflow-gaging stations in Iowa. Manual measurements were made at identical scales as the quantifications done by Basinsoft. The results of the comparisons are shown in table 4.

The Wilcoxon signed-ranks test was applied to determine the statistical significance between median manual measurements and median Basinsoft quantifications of 10 of the 12 drainage-basin characteristics listed in table 4 using STATIT procedure SIGNRANK (Statware, Inc., 1990). No test was performed for non-contributing drainage area (NCDA) and basin stream order (BSO) because these characteristics either were equal to zero or there was no difference between manual measurements and Basinsoft quantifications for all 11 drainage basins. Results of the statistical

Table 3. Example of flat file (ASCII) output from Basinsoft

Basin Name	=	beavtr
TDA	=	11.890
NCDA	=	0.000
CDA	=	11.890
BL	=	5.271
BP	=	15.528
BS	=	53.549
BR	=	151.246
BA	=	55.063
BW	=	2.256
SF	=	2.336
ER	=	0.739
RB	=	1.834
CR	=	1.270
RR	=	9.740
MCL	=	5.689
TSL	=	15.086
MCS	=	23.381
MCSR	=	1.079
SD	=	1.269
CCM	=	0.788
MCSP	=	1.176
RN	=	191.896
SR	=	0.437
FOS	=	6.000
BSO	=	3.0
DF	=	0.505
RSD	=	0.313

Table 4. Comparisons of manual measurements and Basinsoft quantifications of selected drainage-basin characteristics for 11 streamflow-gaging stations in Iowa

[TDA, total drainage area, in square miles; NCDA, noncontributing drainage area, in square miles; BL, basin length, in miles; BP, basin perimeter, in miles; BS, average basin slope, in feet per mile; BR, basin relief, in feet; BA, basin azimuth, in degrees; MCL, main-channel length, in miles; TSL, total stream length, in miles; MCS, main-channel slope, in feet per mile; FOS, number of first-order streams; BSO, basin stream order; MAN, manual measurement; BSOFT, Basinsoft quantification; % DIFF, percentage difference between MAN and BSOFT; ND, not determined; WSRT, Wilcoxon signed-ranks test; NT, no test performed because all values for % DIFF = 0]

Station number	Measurement technique	Drainage-basin characteristic											
		TDA[a]	NCDA	BL	BP	BS	BR	BA	MCL	TSL	MCS	FOS	BSO
05411600	MAN	177	0	27.0	73.3	166	297	144	36.4	242	5.61	84	4
	BSOFT	178	0	25.6	73.9	73.6	280	143	36.3	236	6.14	84	4
	% DIFF	+0.6	0	-5.2	+0.8	-55.7	-5.7	-0.7	-0.3	-2.5	+9.4	0	0
05414450	MAN	21.6	0	8.81	21.9	426	444	104	11.4	31.9	19.1	10	3
	BSOFT	22.3	0	8.47	21.3	264	439	104	11.1	31.5	23.1	10	3
	% DIFF	+3.2	0	-3.9	-2.7	- 38.0	-1.1	0	-2.6	-1.3	+20.9	0	0
05414600	MAN	1.54	0	2.31	5.32	246	280	68	2.63	2.63	101	1	1
	BSOFT	1.53	0	2.10	5.97	208	299	75	2.58	2.58	108	1	1
	% DIFF	-0.6	0	-9.1	+12.2	-15.4	+6.8	+10.3	-1.9	-1.9	+6.9	0	0
05462750	MAN	11.6	0	4.84	15.0	157	160	52	5.74	15.2	28.3	6	3
	BSOFT	11.9	0	5.27	15.5	53.5	151	55	5.69	15.1	23.4	6	3
	% DIFF	+2.6	0	+8.9	+3.3	-65.9	-5.6	+5.8	-0.9	-0.7	-17.3	0	0
05463090	MAN	56.9	0	11.6	33.5	ND	181	91	17.4	73.5	7.27	28	3
	BSOFT	57.0	0	11.4	33.1	52.3	187	89	16.8	73.9	8.67	28	3
	% DIFF	+0.2	0	-1.7	-1.2	ND	+3.3	-2.2	-3.4	+0.5	+19.3	0	0
05470500	MAN	204	0	24.4	69.8	99.6	318	150	37.8	210	7.52	60	4
	BSOFT	208	0	25.3	67.7	49.0	309	151	35.7	192	7.81	51	4
	% DIFF	+2.0	0	+3.7	-3.0	-50.8	-2.8	+0.7	-5.6	-8.6	+3.9	-15.0	0
05481000	MAN	844	0	51.5	139	ND	303	175	88.1	685	2.04	152	5
	BSOFT	852	0	52.3	139	33.4	269	176	88.9	685	1.50	155	5
	% DIFF	+0.9	0	+1.6	0	ND	-11.2	+0.6	+0.9	0	-26.5	+2.0	0

Table 4. Comparisons of manual measurements and Basinsoft quantifications of selected drainage-basin characteristics for 11 streamflow-gaging stations in Iowa—Continued

Station number	Measurement technique	Drainage-basin characteristic											
		TDA[a]	NCDA	BL	BP	BS	BR	BA	MCL	TSL	MCS	FOS	BSO
05489490	MAN	22.9	0	10.5	24.8	289	280	70	13.3	28.4	14.8	10	2
	BSOFT	22.2	0	10.6	26.2	165	286	68	13.0	27.6	20.2	10	2
	% DIFF	-3.1	0	+1.0	+5.6	-42.9	+2.1	-2.9	-2.3	-2.8	+36.5	0	0
06609500	MAN	871	0	80.9	206	352	537	201	101	1,230	3.18	477	5
	BSOFT	869	0	81.7	210	197	491	203	99.9	1,270	3.34	487	5
	% DIFF	-0.2	0	+1.0	+1.9	-44.0	-8.6	+1.0	-1.1	+3.3	+5.0	+2.1	0
06807780	MAN	42.7	0	21.1	47.4	346	268	204	22.2	52.7	9.37	18	3
	BSOFT	42.8	0	21.5	48.8	195	283	205	22.2	55.3	10.1	19	3
	% DIFF	+0.2	0	+1.9	+3.0	-43.6	+5.6	+0.5	0	+4.9	+7.8	+5.6	0
06903400	MAN	182	0	21.9	79.0	152	224	57	39.5	228	3.24	80	4
	BSOFT	184	0	21.3	79.6	82.2	200	57	39.6	231	3.37	80	4
	% DIFF	+1.1	0	-2.7	+0.8	-45.9	-10.7	0	+0.3	+1.3	+4.0	0	0
WSRT p-value[b]		0.1192	NT	0.6248	0.2125	0.0092	0.2296	0.3447	0.0908	0.9291	0.1000	0.3742	NT

a. Manual TDA measurements are streamflow-gaging station drainage areas published by the U.S. Geological Survey in annual streamflow reports.

b. In general, p-values greater than 0.05 indicate that there is not a statistically significant difference between the median of the manual measurements and the median of the Basinsoft quantifications, using a 95% level of significance for a two-tailed Wilcoxon signed-ranks test.

comparison tests indicate that Basinsoft quantifications are not significantly different (p-value >.05) from manual measurements for 9 of the 10 drainage-basin characteristics tested (table 4). Basin slope (BS) was the only characteristic tested for which Basinsoft quantifications were significantly different (p-value <.05) from manual measurements.

The results of a comparison test for average basin slope (BS) using three methods of measuring elevation-contour lengths are listed in table 5. The results indicate that Basinsoft quantifies basin slope with acceptable results; however, ARC/INFO is unable to generate appropriate elevation contours from 1:250,000–scale DEM data for comparison with manual measurements of elevation contours from 1:250,000–scale topographic maps. Comparisons for basin slope (tables 4 and 5) appear to indicate that the 1:250,000–scale DEM data are too coarse for ARC/INFO to accurately reproduce elevation contour data with the sinuosity found on the 1:250,000–scale topographic maps. Figure 4 shows elevation contours generated from DEM data using ARC/INFO (fig. 4A) are much more generalized than elevation contours digitized from topographic maps of the same scale (fig. 4B). Thus, the total length of contours generated from DEM data are under-represented when compared to contours shown on topographic maps (table 5). This contour over-generalization illustrates how the total length of the elevation contours are underestimated by Basinsoft using the "contour-band" method to quantify basin slope (appendix A).

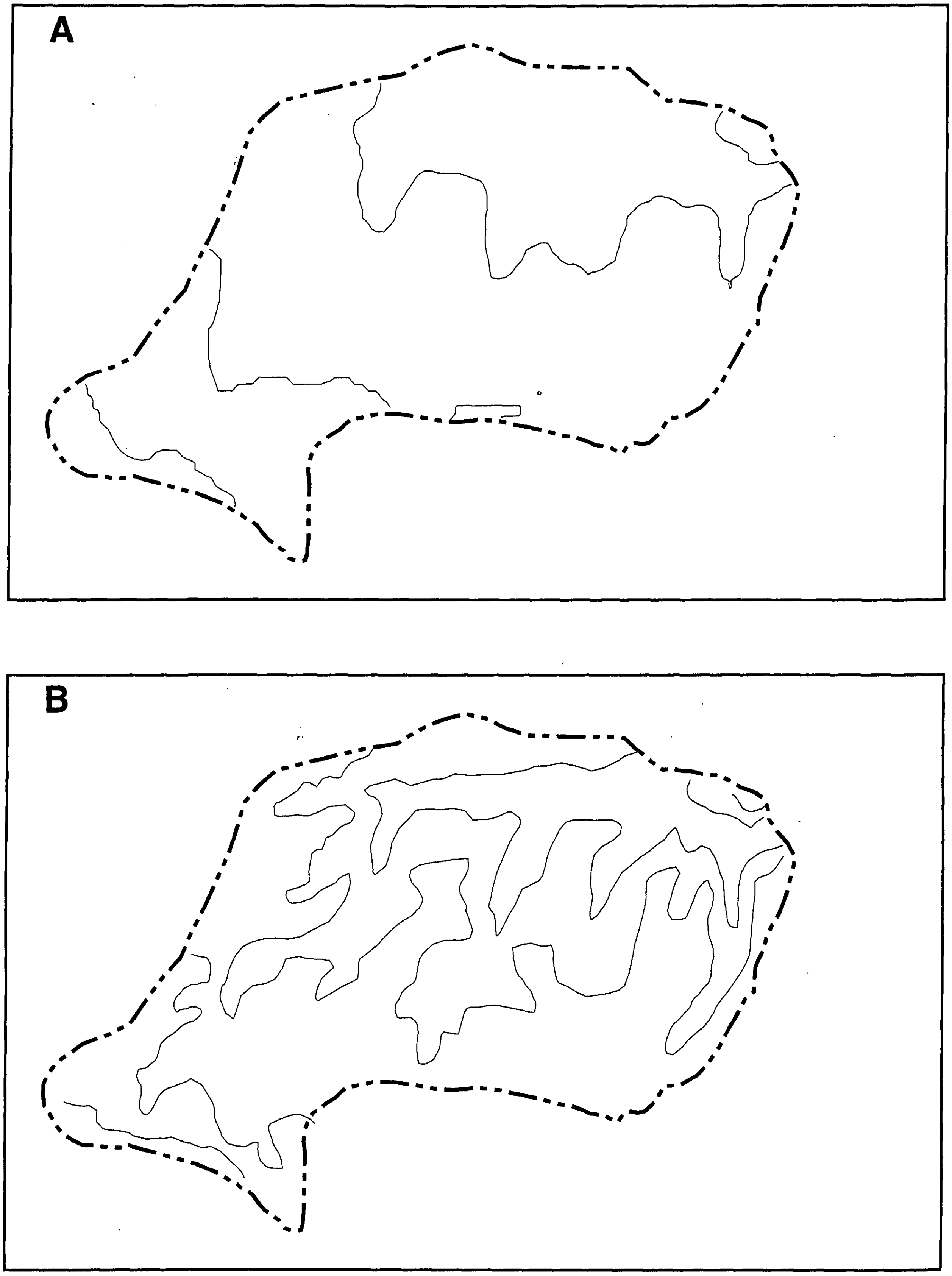

Figure 4. Elevation contours generated (A), with a 50-foot interval from 1:250,000-scale DEM data using ARC/INFO and (B), with a 50-foot interval digitized from a 1:250,000-scale topographical map.

Table 5. Comparison of elevation-contour length measurements used to quantify basin slope

Source data (all data were 1:250,000-scale)	Method of measurement	Elevation-contour length (CL) measurement, in miles	Contributing drainage area (CDA), in square miles	Contour interval (CI), in feet	Average basin slope quantified using CL * CI/ CDA, in feet per mile
Topographic map	Manual measurement of elevation contours from topographic map	37.23	11.89	50	156.6
Topographic map (fig. 4B)	Basinsoft quantification of elevation contours digitized from topographic map	35.05	11.89	50	147.4
DEM data (fig. 4A)	Basinsoft quantification of elevation contours generated using ARC/INFO	12.73	11.89	50	53.5

Understanding the reason for differences between the manual measurements and quantifications made by Basinsoft is important in determining the type of comparisons which may be relevant in analysis of this type of data. The data in table 5 indicate that it is not preferable to compare Basinsoft quantifications of contour data generated by ARC/INFO with either digitized contours or contours generated from DLG data; however, it is assumed that measurements based on elevation contours digitized from contour maps and those based on elevation contours generated from DLG data would be similar.

Basinsoft quantifications of main-channel slope (MCS) have the greatest range in percent difference between manual measurements and Basinsoft quantifications of the 10 selected drainage-basin characteristics listed in table 4. There are two main components of the MCS equation, length and elevation (appendix A). Quantification differences for MCS ranged from -26.5 to +36.5 percent (table 4). However, quantification differences for main channel length (MCL) ranged from -5.6 to +0.9 percent (table 4). These quantification differences indicate that the variation between manual measurements and Basinsoft quantifications of MCS are due mainly to differences in the determination of the streambed elevation at points 10 percent and 85 percent of the distance along the main channel from the basin outlet.

The approximate time required for an experienced ARC/INFO user to process three of the drainage basins listed in table 4 using Basinsoft was 8 hours. The three basins represent large, intermediate, and small drainage areas. Manual measurements made from the same scales of topographic maps as used by Basinsoft for these three drainage basins required approximately 50 hours.

Preliminary comparisons between basin-characteristic measurements made from various scales of cartographic data for these three drainage basins, appear to indicate that several of the basin characteristics (BS, MCL, TSL, MCS, FOS, BSO) are map-scale dependent. (Eash, 1993; Eash, 1994). Map-scale dependency refers to the effect on a measurement when that measurement is made from a cartographic data source of some specific scale as compared to that same measurement made from a different scale. Thus, interbasin comparisons of Basinsoft quantifications may be unreliable if different scales of cartographic data, or different sources of digital data (that is, raster versus vector), are used in generating the four source-data layers for each drainage basin.

Source-data layers obtained from larger-scale cartographic data and processed using Basinsoft may provide the best drainage-basin quantifications for a study area. However, the scales and sources of cartographic data available for a study area may be a limiting factor in generating the four source-data layers required by Basinsoft. In general, Basinsoft can process most scales and sources of cartographic data available for a study area once the preprocessing is complete for the four source-data layers (Majure and Soenksen, 1991; Majure and Eash, 1991; Eash, 1993).

OPTIONAL PROGRAMS

Optional programs included in the tools directory for use with Basinsoft are described below with instructions specific to each program. The tools directory contains several variations of some programs, such as dem2grid.aml, which was developed to process one DEM at a time. The dem3grid.aml and dem4grid.aml process 3 and 4 DEM files at a time, respectively.

Area Weighting

A program to weight data by area, named areaweight.aml, is located in the tools directory. This program can be used as a module or as a stand-alone program to quantify characteristics from a variety of data, such as climatic data (annual precipitation and the 2-year 24-hour precipitation intensity), which are stored in multi-polygonal data layers (Eash, 1993). Minimal preprocessing is needed to execute this module. The areaweight.aml requires statewide or large area multi-polygonal data layers representing the distribution of a characteristic, such as precipitation values, land-use values, pedologic values, geologic values, etc. The multi-polygonal data layer must be larger than and encompass the drainage-divide data layer. Output is written to an auxiliary file specified by the user on the command line. The syntax for this module from the ARC prompt is: &RUN areaweight <area of interest> <multi-polygonal data layer with items to be weighted> <item to weight> <output_file_name>. The program will output the area-weighted value for the specified <item to weight>.

Dem2grid

The optional dem2grid.aml preprocessing program, located in the tools directory, is designed to convert a DEM file to a lattice data layer and project it into a user-specified projection. This module buffers the drainage-divide data layer (cover_bas), and then creates both of the required lattice data layers. The syntax for this module from the ARC prompt is: &RUN dem2grid <in_dem_file>.

There are several variations of this program in the tools directory. The various forms of dem2grid simultaneously preprocess up to 4 DEM files at a time. The syntax for these programs is essentially the same with only slight variations from the syntax for dem2grid.aml. The syntax can be found in the header of each of these programs located in the tools directory.

Graphical Output

The graphical output module, graphics.aml, is located in the tools directory and can be used as a module or as a post-processing program. Graphical output can be used in the interpretation of output generated by Basinsoft and can be useful in quality-control checking for obvious errors. The graphical output is in the form of an ARC/INFO graphics file which can be readily converted to a postscript file. Figure 5 shows an example of graphical output. Data contained in the graphical output include: 1) tables of the basin characteristics quantified, 2) variables used by Basinsoft, and 3) a plot of the drainage-divide data layer, elevation contours, main channel, basin-length measurement line, points depicting the 10 and 85 percent distances along the main-channel from the basin outlet, and a point at the basin outlet (outfall). Syntax for this module from the ARC prompt is &RUN graphics.aml <basin-name>.

SUMMARY

A computer program named Basinsoft has been developed by the U.S. Geological Survey to quantify 27 morphometric drainage-basin characteristics using a geographic information system. Basinsoft was developed entirely using AML to increase portability among systems. Basinsoft uses ARC/INFO AMLs written for ARC/INFO version 7.0.2 or later. Basinsoft requires four source-data layers representing the drainage-divide, hydrography, hypsography, and a lattice elevation model of a selected drainage basin. Minimal preprocessing is required to prepare the source data used by Basinsoft. Optional programs and modules were developed to enhance the usability and functionality of Basinsoft.

Statistical comparison tests indicate that Basinsoft quantifications are not significantly different (p-value >.05) from manual topographic-

```
BASINNAME    =   'blkhg '
TDA      =   56.955
NCDA     =    0.000
CDA      =   56.955
BL       =   11.441
BP       =   33.066
BS       =   52.319
BR       =  186.644
BA       =   89.425
BW       =    4.978
SF       =    2.298
ER       =    0.745
RB       =    1.804
CR       =    1.236
RR       =    5.645
MCL      =   16.819
TSL      =   73.896
MCS      =    8.674
MCSR     =    1.470
SD       =    1.297
CCM      =    0.771
MCSP     =    5.711
RN       =  242.162
SR       =    0.166
FOS      =   28
BSO      =    3
DF       =    0.492
RSD      =    0.292
```

```
Local:
 No local variables defined
Global:
 .X1            1,1647170.25,15388594
 .AREALR          .00000003587
 .X2            2,1702812,15389152
 .Y1            15388594
 .Y2            15389152
 .ENDS            1647170.25,15388594,1702812,15389152
 .BX            1647170.25
 .BY            15388594
 .EX            1702812
 .EY            15389152
 .INTERVAL         50
 .ORIENT          Ur
 .BNAME            'blkhg '
 .X1E           1148.826
 .X2E           1020.106
 .BASIN          COVER
 .LINEARR         .0001894
 .EAZIM          0.5745680763237
 .NAZIM          89.4254319236
 .UNITS          feet
```

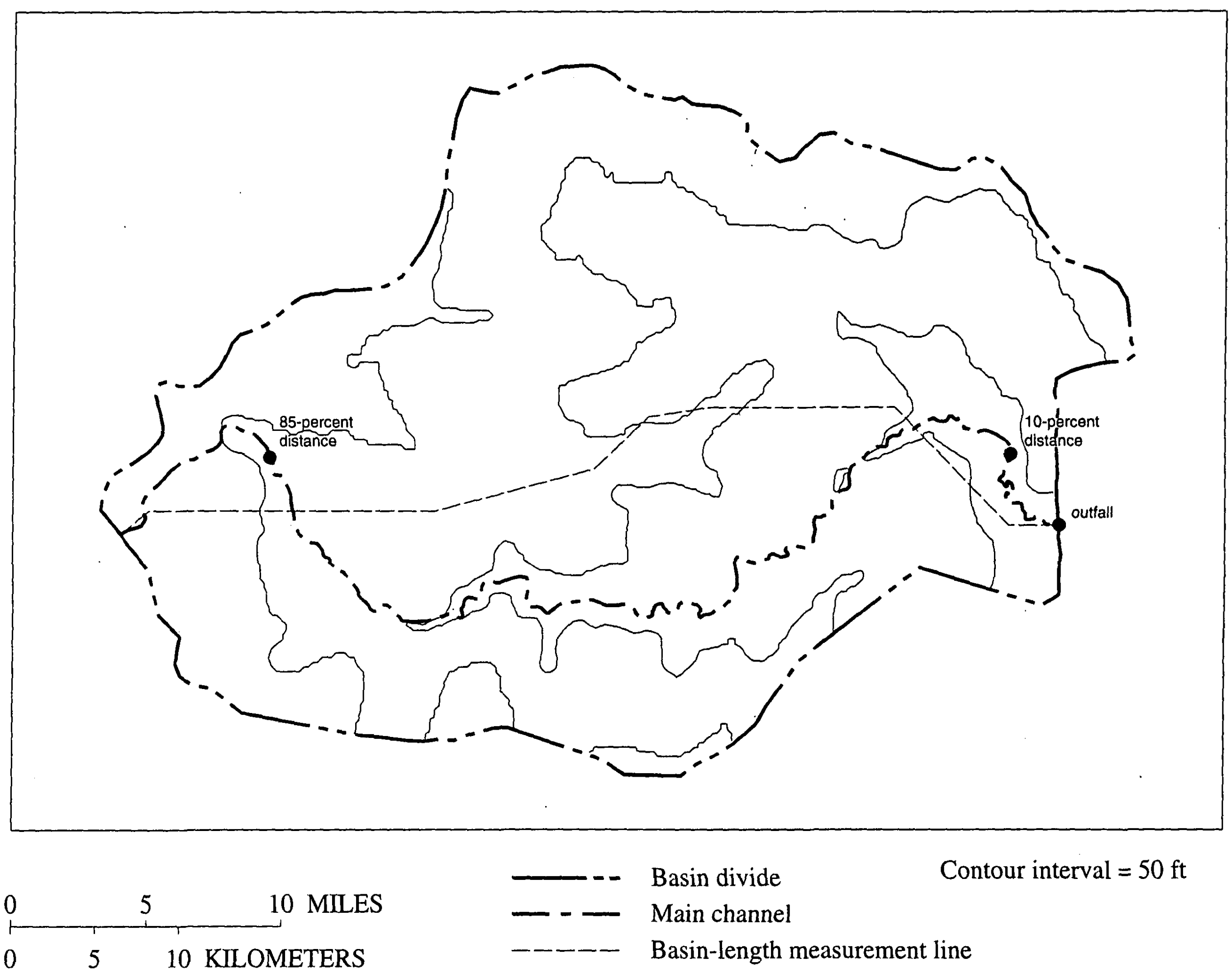

Figure 5. Example of graphical output from Basinsoft.

map measurements for 9 of 10 basin characteristics tested. Results also indicate that elevation contours generated by ARC/INFO from 1:250,000–scale DEM data are substantially over-generalized when compared to elevation contours shown on 1:250,000–scale topographic maps and that quantification of basin-slope thus is underestimated using the DEM data. A qualitative comparison test indicated that the Basinsoft module used to quantify basin slope is valid and that differences in quantified basin slope are due to source-data differences.

Basinsoft provides an automated computer procedure for the quantification of drainage-basin characteristics and reduces the amount of time required to quantify drainage-basin characteristics when compared to manual methods of measurement.

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APPENDIXES

APPENDIX A

Selected Drainage-Basin Characteristics Quantified Using Basinsoft

[superscripts a–g, footnotes at end of the appendix reference the literary sources for drainage-basin characteristics]

Basin-Area Quantifications

TDA—Total drainage area[a,b], in square miles, an internal measurement maintained by ARC/INFO. TDA is acquired from the drainage-divide data layer (cover_bas) attribute table as the area measurement and it includes noncontributing areas.

NCDA—Noncontributing drainage area[a], square miles, is the total area that does not contribute to surface-water runoff at the basin outlet. NCDA is obtained by computing summary statistics on the drainage-divide data layer (cover_bas) attribute table based on the item CONTRIB.

Basin-Length Quantifications

BL—Basin length[a], in miles, measured along a line areally centered through the drainage-divide data layer (cover_bas) from basin outlet to where the main channel extended meets the basin divide. This process uses ARC/GRID to calculate the center-line.

BP—Basin perimeter[a], in miles, measured along entire drainage-basin divide. BP is an internal measurement maintained by ARC/INFO and is acquired from the drainage-divide data layer (cover_bas).

Basin-Relief Quantifications

BS—Average basin slope[a,b], in feet per mile, measured by the "contour-band" method, within the contributing drainage area (CDA). Summary statistics are performed on the hypsography data layer (cover_con). The output from the statistics command is used in conjunction with the user-designated elevation-contour interval as input into the formula to calculate BS. BS = (total length of all selected elevation contours) (contour interval) / CDA.

BR—Basin relief[c], in feet, measured as the difference between the elevation of the highest grid cell and the elevation of the grid cell at the basin outlet. BR uses the lattice (grid) data layer (cover_lat) to determine the minimum elevation as the land-surface elevation at the basin outlet. The maximum elevation is determined from the lattice data layer (cover_lat) statistics INFO file item ZMAX.

Basin-Aspect Quantification

BA—Basin azimuth[a,b], in degrees, compass direction of a line projected from where the main channel, if extended, meets the basin divide downslope to the basin outlet. Measured clockwise from north at 0°.

Basin Computations

CDA—Contributing drainage area[a,b], in square miles, defined as the total area that contributes to surface-water runoff at the basin outlet, CDA = TDA - NCDA.

BW—Effective basin width[a], in miles, BW = CDA / BL.

SF—Shape factor[a], dimensionless, ratio of basin length to effective basin width, SF = BL / BW.

ER—Elongation ratio[a], dimensionless, ratio of (1) the diameter of a circle of area equal to that of the basin to (2) the length of the basin, $ER = [4\ CDA / \pi\ (BL)^2]^{0.5} = 1.13\ (1 / SF)^{0.5}$.

RB—Rotundity of basin[a], dimensionless, $RB = [\pi\ (BL)^2] / [4\ CDA] = 0.785\ SF$.

CR—Compactness ratio[a], dimensionless, the ratio of the perimeter of the basin to the circumference of a circle of equal area, $CR = BP / 2\ (\pi\ CDA)^{0.5}$.

RR—Relative relief[d], in feet per mile, RR = BR / BP.

Channel- or Stream-Length Quantifications

MCL—Main channel length[a,b], in miles, measured along the main channel from the basin outlet to where the main channel, if extended, meets the basin divide. Summary statistics are computed on the hydrography data layer (cover_str) based on the item CODE.

TSL—Total stream length[c], in miles, computed by summing the length of all stream segments within the CDA using summary statistics on the hydrography data layer (cover_str) based on the item LENGTH.

Channel-Relief Quantification

MCS—Main-channel slope[a,b], in feet per mile, an index of the slope of the main channel computed from the difference in streambed elevation at points 10 percent and 85 percent of the distances along the main channel from the basin outlet to the basin divide. A route system is developed based on the INFO-item CODE equal to 1 in the hydrography (cover_str) data layer. The 10 and 85 percent distances from the basin outlet are calculated and nodes are placed at those positions along the route. The nodes are converted to points and elevations are determined for each point from the lattice data layer (cover_lat) and attributed to a temporary data layer for use in the MCS formula. $MCS = (E_{85} - E_{10}) / (0.75\ MCL)$.

Channel or Stream Computations

MCSR—Main-channel sinuosity ratio[a], dimensionless, MCSR = MCL / BL.

SD—Stream density[a], in miles per square mile, within the CDA, SD = TSL / CDA.

CCM—Constant of channel maintenance[a], in square miles per mile, within the CDA, CCM = CDA / TSL = 1 / SD.

MCSP—Main channel slope proportion[c], dimensionless, $MCSP = MCL / (MCS)^{0.5}$.

RN—Ruggedness number[e], in feet per mile, RN = (TSL) (BR) / CDA = (SD) (BR).

SR—Slope ratio of main-channel slope to basin slope[c], dimensionless, within the CDA, SR = MCS / BS.

Stream-Order Quantifications

FOS—Number of first-order streams within the CDA[f], dimensionless. FOS is computed using Strahler's method of stream ordering and summary statistics on the hydrography data layer (cover_str).

BSO—Basin Stream Order[f], dimensionless, stream order of the main channel at the basin outlet. BSO is computed by intersecting the main channel with the drainage-divide data layer and determining the Strahler-stream order of the stream at the basin outlet.

Stream-Order Computations

DF—Drainage frequency[c], in number of first-order streams per square mile, within the CDA, DF = FOS / CDA.

RSD—Relative stream density[g], dimensionless, within the CDA, $RSD = (FOS)(CDA)/(TSL)^2 = DF/(SD)^2$.

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[a]Modified from Office of Water Data Coordination (1978, p. 7-9—7-16).

[b]Modified from National Water Data Storage and Retrieval System (Dempster, 1983, p. A-24—A-26).

[c]Modified from Strahler (1958, p. 282–283 and 289).

[d]Modified from Melton (1957).

[e]Modified from Robbins (1986, p. 12).

[f]Modified from Strahler (1952, p.1120).

[g]Modified from Melton (1958).

APPENDIX B

Example of Source-Data Attribute Tables

The following specialized attribute-tables scheme is required for source-data layer coverages prior to executing Basinsoft. Basinsoft will add various attribute items throughout the execution of the program and will populate these items in the attribute tables as needed. The only items manually added to the attribute tables are CONTRIB and BASINNAME, which are added to the drainage-divide data layer (cover_bas) by the user.

Table B-1. Feature attribute table from ARC/INFO of the drainage-divide data layer (cover_bas)

Column	Item Name	Width	Output	Type	N.DEC
1	AREA	4	12	F	3
5	PERIMETER	4	12	F	3
9	COVER_BAS#	4	5	B	-
13	COVER_BAS-ID	4	5	B	-
17	CONTRIB	1	1	C	-
20	BASINNAME	20	20	C	-

Table B-2. Feature attribute table from ARC/INFO of the hydrography data layer (cover_str)

Column	Item Name	Width	Output	Type	N.DEC
1	FNODE#	4	5	B	-
5	TNODE#	4	5	B	-
9	LPOLY#	4	5	B	-
13	RPOLY#	4	5	B	-
17	LENGTH	4	12	F	3
21	COVER_STR	4	5	B	-
25	COVER_STR-ID	4	5	B	-
29	CODE	1	1	I	-
30	ORDER	4	5	B	--

Table B-3. Feature attribute table from ARC/INFO of the hypsography data layer (cover_str)

Column	Item Name	Width	Output	Type	N.DEC
1	FNODE#	4	5	B	-
5	TNODE#	4	5	B	-
9	LPOLY#	4	5	B	-
13	RPOLY#	4	5	B	-
17	LENGTH	4	12	F	3
25	COVER_CON	4	5	B	-
29	COVER_CON-ID	4	5	B	-
33	ELEV	4	5	F	3

APPENDIX C

Sequential Listing of Preprocessing and Processing Steps

The following steps are performed when using a digitized drainage-divide data layer, a hydrology data layer extracted from DLG data, and a hypsography data layer generated from DEM data, to quantify drainage-basin characteristics using Basinsoft.

1. Delineate and attribute the drainage divide and any noncontributing drainage area within.

2. Clip the hydrography (source_str) to match the areal extent of the drainage-divide data layer using the ARC/INFO command CLIP. Output of the CLIP command is (cover_str).

3. Set the aml path to the directory containing the Basinsoft AMLs: ARC> &AMLPATH {path to the Basinsoft directory}.

4. The hypsography data layer is generated from DEM data. The AML dem2grid or dem3grid is used. The lattice data layers and the hypsography data layers (cover_con) will be generated by this AML. ARC> &RUN dem2grid.aml <in_dem>.

5. Orient the arc segments of the hydrography data layer (cover_str) in a downstream direction using the program STREAMFLIP or the streamflip.aml in the tools directory. ARC:STREAMFLIP cover_str or ARC: &RUN streamflip.aml cover_str. The user will be prompted by the streamflip.aml to select the outfall point or points of the basin using mouse button 1. The control key plus mouse button 3 will conclude the edit session.

6. Delineate and attribute the main channel using the mainselect.aml: ARC:&RUN mainselect cover_str.aml. Place the cross-hair cursor on the basin-divide at the point to where the main channel should be extended and use mouse button 2 to begin the addition of an arc segment. Mouse button 1 is used to digitize intermediate vertices. To end the addition of the arc segment the user will place the cross-hair cursor on the upper node of the main channel and digitize a node using mouse button 2. To conclude this edit session, use the control key plus mouse button 3. At this point the AML will process the information and display the main channel as delineated using the provided information. If the main channel is erroneously delineated, the mainselect AML will have to be repeated.

7. All preprocessing is complete at this point and the data can be processed using Basinsoft.
a) ARC> &RUN basinsoft.aml {cover| name} {meters|feet}
b) ARC> &RUN multi_p.aml
The flat file (ASCII) format is generated in the directory where the source-data is located.