DEVELOPING A GIS-BASED HYDROLOGIC MODEL TO ESTIMATE WATER AND SEDIMENT YIELDS

by

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INTRODUCTION

This paper develops a spatially distributed conceptual procedure to estimate water and sediment yields from the Little Colorado River (LCR) basin. A Geographic Information System (GIS) is used to incorporate the impacts of spatial changes in land utilization in the LCR basin on the amount of streamflow and sediment yield generated by the river basin over time. The alteration and conversion of natural systems through agricultural, silvicultural, settlement activities and other uses can have serious negative impacts on the amount and quality of the surface water within a watershed and associated receiving waters.

Geographic Information Systems enable planning and resource management agencies to assess current and future land use patterns and their potential water quality impacts in a realistic, accurate and cost effective manner. Further, a GIS provides an excellent basis for organizing and analyzing information that is collected through long-term monitoring from a large area and provides a mechanism for integrating the large amounts of spatially varying data types gathered. The greatest long-term benefit of a GIS methodology is its capability to facilitate sharing of historically and spatially linked information between scientists and among managers.

In this paper, the application of GIS to the LCR basin is described. The scope is done within the framwork of the specific objectives stated below. The scope of the materials covered in this paper are described briefly under the overview following the statement of objectives.

Objectives

The purpose of this paper is to develop a conceptual methodology for estimating the amount of water and sediment yields coming out of the LCR basin. Specifically, the paper will attempt to achieve the following objectives:

1. Provide an overview of the LCR system.
2. Describe the data available and suitable for use in GIS analysis.
3. Describe the procedure for GIS data base development, and
4. Discuss changes in the LCR system over time and space.

Overview

This report begins with an overview of the Little Colorado River System. It describes the physical biotic attributes of the LCR Basin, and reports changes in the system over time and space. The report covers the essential elements of a GIS and their application to hydrologic investigations. Data collection procedures are discussed and a variety of data sources reported. And finally, the integration of GIS with hydrologic models is addressed.

STUDY AREA

The Little Colorado River basin is a large area that contains numerous federal, state, and local jurisdictions, four sovereign Native American tribal lands, and privately held lands. All together the LCR Basin encompasses an area of 27,000 square miles in northeast

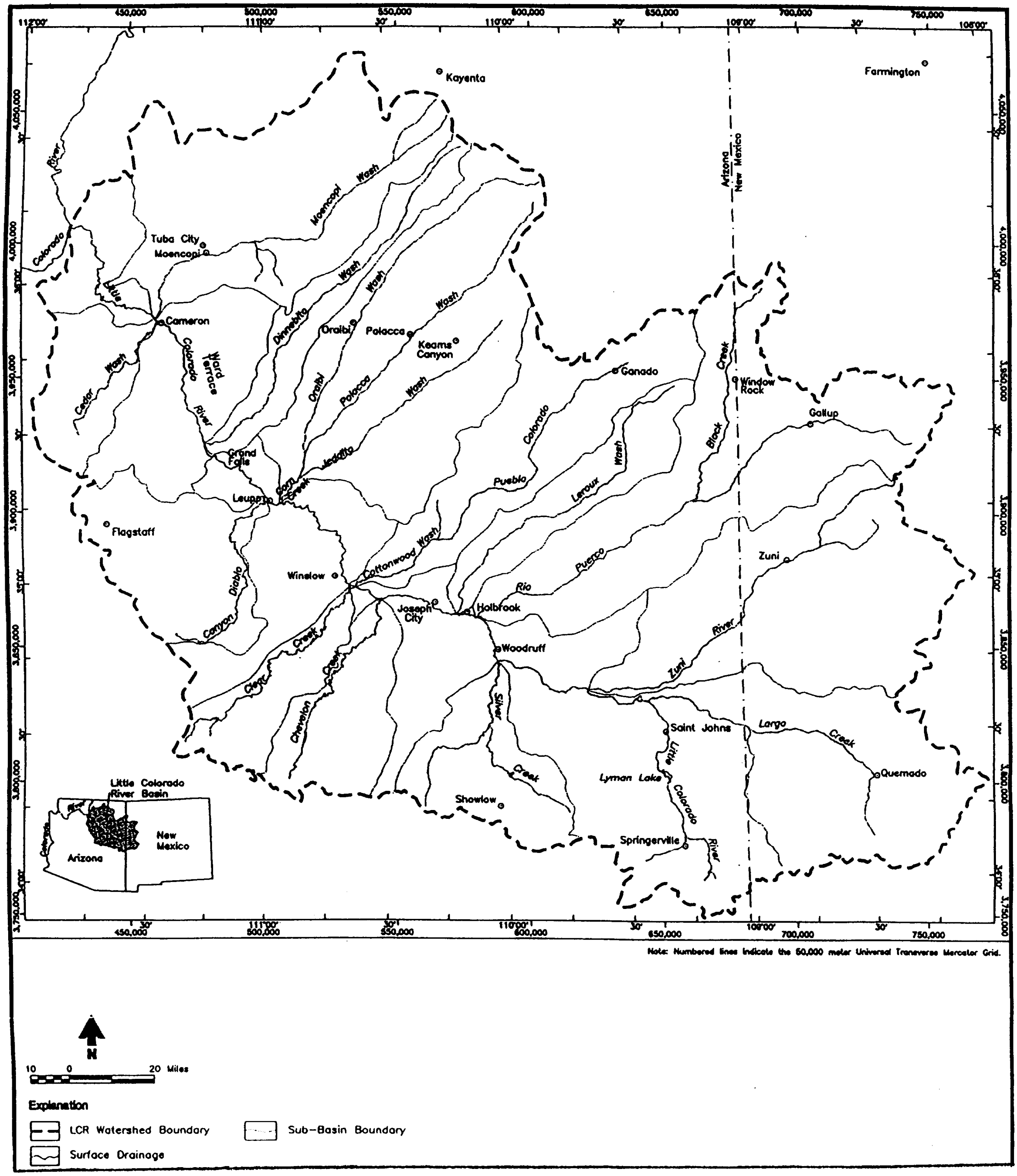
Arizona and northwest New Mexico. The bulk of the watershed which totals approximately 21,667 square miles lies within Arizona (SWCA 1996). There is no single entity with comprehensive land management authority or responsibility over the area. Its administration is shared by the different groups having claim over the land.

Figure 1 shows the LCR watershed boundary, sub-basin boundaries, and its major tributaries. The majority of the tributaries in the LCR Basin are ephemeral streams. Only a few reaches in the headwaters and along the twelve mile stretch from Blue Springs to the confluence with the Colorado River are perennial (ADWR 1989).

Elevation within the LCR Basin varies widely from, about 3,000 feet at the mouth of the watershed basin where the stream meets the main stem of the Colorado River to 12,600 feet in the San Francisco Peaks of north central Arizona. The topography of the area, likewise, varies dramatically within the Basin. It has highly contrasting features that vary from the forested highlands of the San Francisco Peaks and the White Mountains to the semi-arid desert environments of the Hopi Mesas, Painted Desert and the Defiance Plateau.

Precipitation in the LCR system is temporally distributed as the result of two distinct processes. Summer precipitation is characterized by highly localized, relatively intensive but short duration convective storms. The Gulf of California and Gulf of Mexico are the primary sources of moisture for summer precipitation. The runoff from these storms tends to be short lived and ephemeral in nature. The occurrence of the summer flow events has a greater year-to-year variability than the spring snowmelt (ADWR 1989). Thus, after the spring runoff has subsided, the northern washes and much of the mainstem and upper reaches of the LCR are dry or nearly dry between summer storm events. But, due to their

Figure 1. The Little Colorado River and its Major Tributaries.



intensity, the largest summer monsoon storms frequently result in a discharge peak which exceeds the spring peak, although the durations of these summer discharge peaks are much shorter (Morgan 1995).

Winter precipitation is the result of large cyclonic storms originating in the Pacific Ocean. The majority of the winter precipitation in the watershed falls as snow, particularly in the higher elevations. Winter precipitation produces most of the available surface water supply in the LCR basin (ADWR 1989). Figure 2 shows the combined average annual precipitation for the LCR basin in Arizona.

The duration and magnitude of runoff events are controlled by basin characteristics such as vegetative cover and watershed geomorphology. The upper reaches of the LCR respond nearly equally to winter and summer precipitation events, the upper-middle reaches are dominated by late summer storms, while the lower-middle to lower reaches are dominated by snowmelt runoff from the southern highlands and localized late summer thunderstorm runoffs (ADWR 1989).

The seasonal fluctuation of flow in the LCR is illustrated in Figure (3) using the mean monthly discharge measured by the USGS Gauging station near Cameron, Arizona (DBS&A 1995). The gauging station at Cameron is one of a number of primary gaging stations within the LCR Basin and is the nearest recording station to the point of confluence of the LCR and the Colorado River. Figure 4 shows the location of all the primary surface water gaging stations and climatological stations within the LCR Basin.

Ground water and surface water contribute approximately equal portions to the total streamflow that reaches the mouth of the LCR at the Grand Canyon. The mean annual

Figure 2. Average annual precipitation in inches for the Little Colorado River Basin.

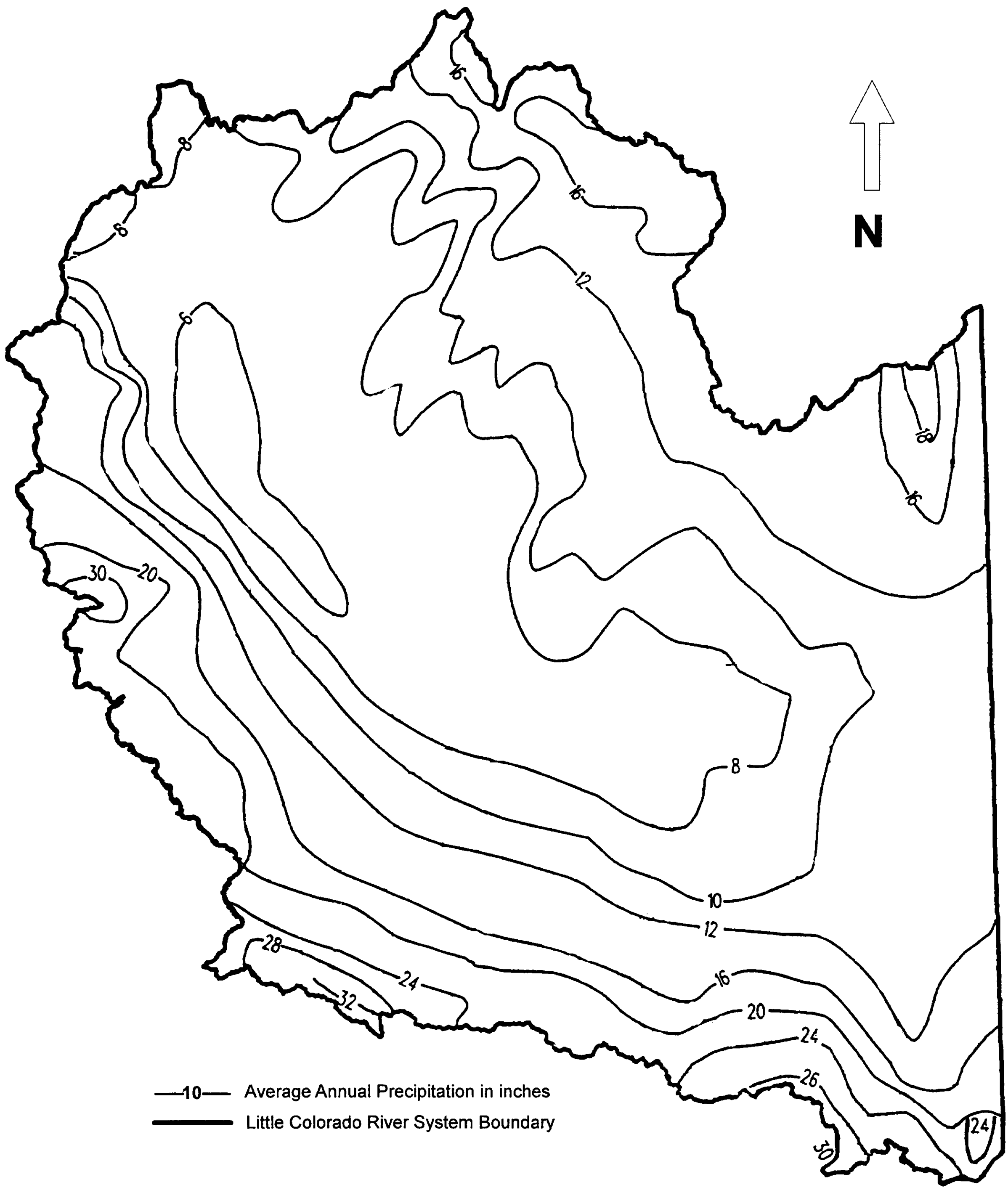


Figure 3. Mean Monthly Discharge of the LCR at Cameron, AZ.

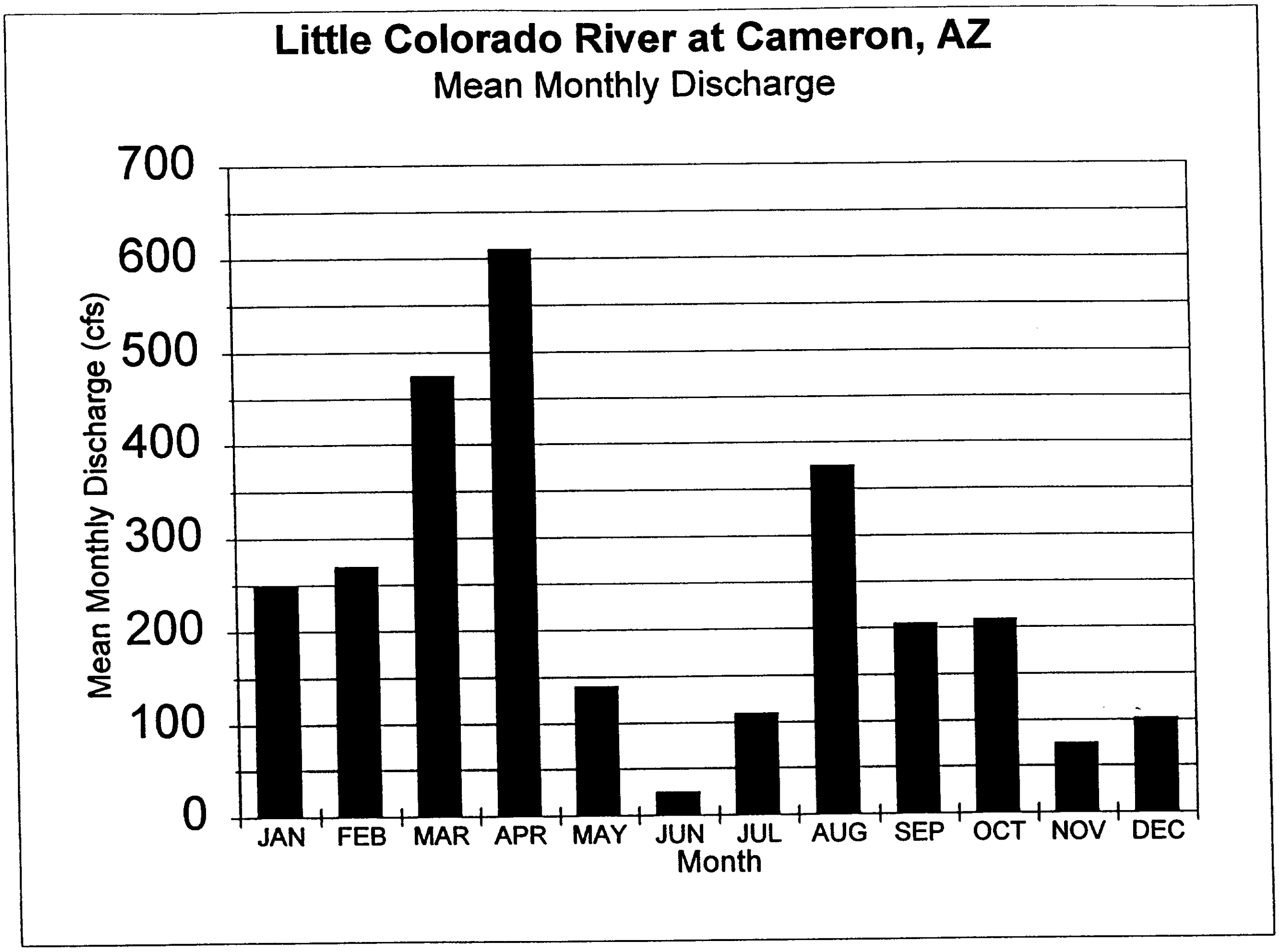
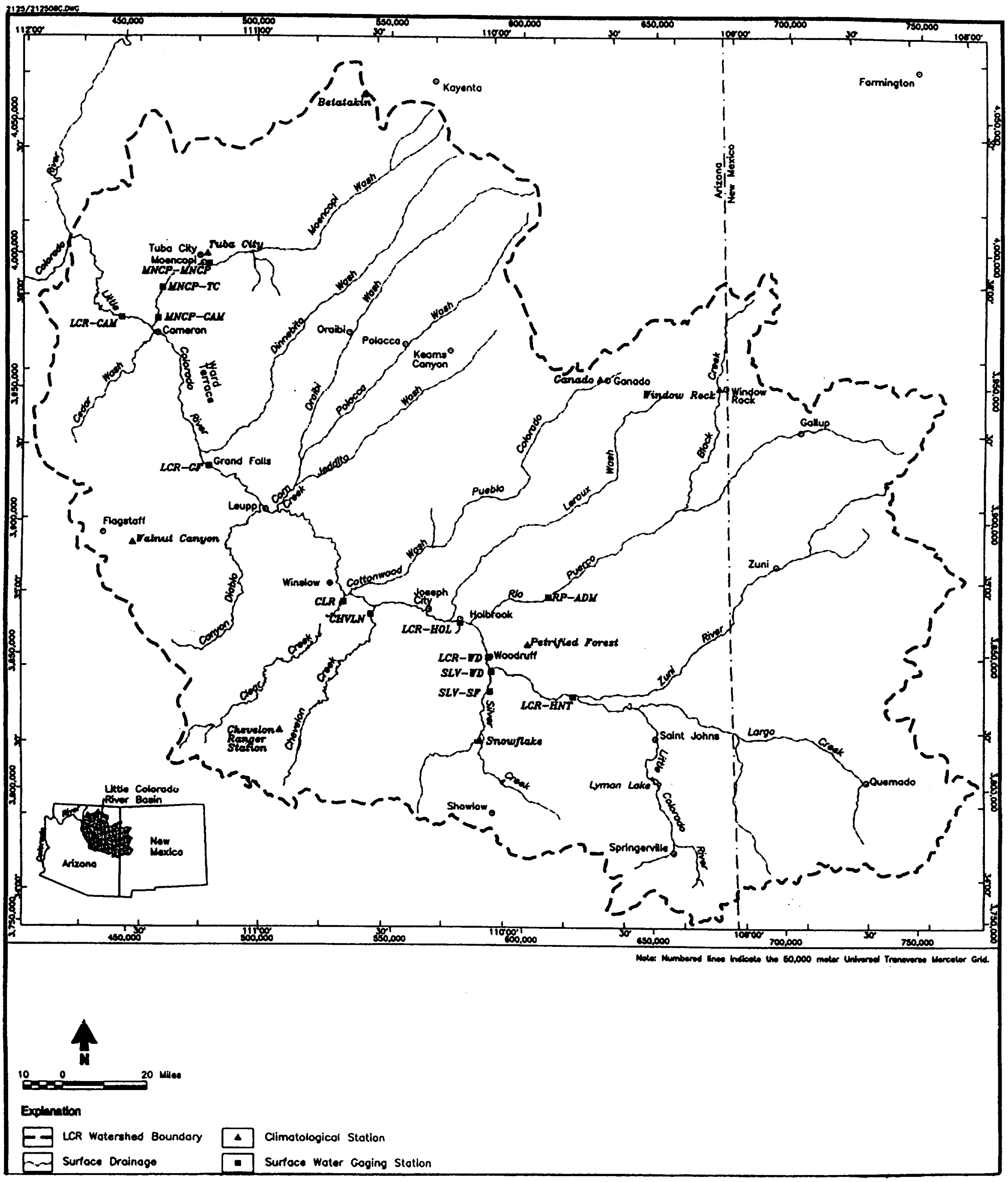


Figure 4. Location of Surface Water Gaging Stations and Climatological Stations within the LCR Basin.



streamflow recorded at the Cameron gauging station (Cameron USGS Station #4020) for the period 1927 to 1987, was approximately 196,162 acre feet per year (DBS&A 1995). The individual flows contributing to the annual flow are intermittent and vary greatly within a given year and between years (Figure 5). Snowmelt runoff from the San Francisco Mountains and the Mogollon Slope in the southern portion of the LCR watershed provides the bulk of the surface spring water flow measured at the Cameron gauging station. Thunderstorms in the watershed's northern portion are responsible for the majority of summer flows (AWRD 1989). During much of the year however, there is no surface flow in the lower mainstem of the LCR above Blue Springs, approximately 14 miles from the mouth of the LCR. The perennial flow in the lower 14 miles of the LCR is sustained by ground-water discharge from the springs located between LCR river miles 3.1 and 14.7 (SWCA 1996).

Vegetation within the watershed vary with elevation and precipitation patterns. The types of biotic communities in the LCR basin are illustrated in Figure 6. The vegetation communities range from conifer forests on the mountain uplands to woodlands, grasslands, and desert-scrub in the Basin's interior, to riparian areas along stream and river corridors(AWRD 1989). Vegetation and climatic patterns dictate the type of land use practiced in the area. Forested areas are utilized for their timber resources, recreational values, and as watersheds. Woodlands, grasslands and desert-scrub provide areas for grazing and agriculture.

The surficial geology of the LCR watershed includes volcanic and sedimentary rocks. The highest peaks are composed of volcanic rock lying atop of sedimentary layers,

Figure 5. Annual Streamflow for the Little Colorado River at Cameron, AZ.

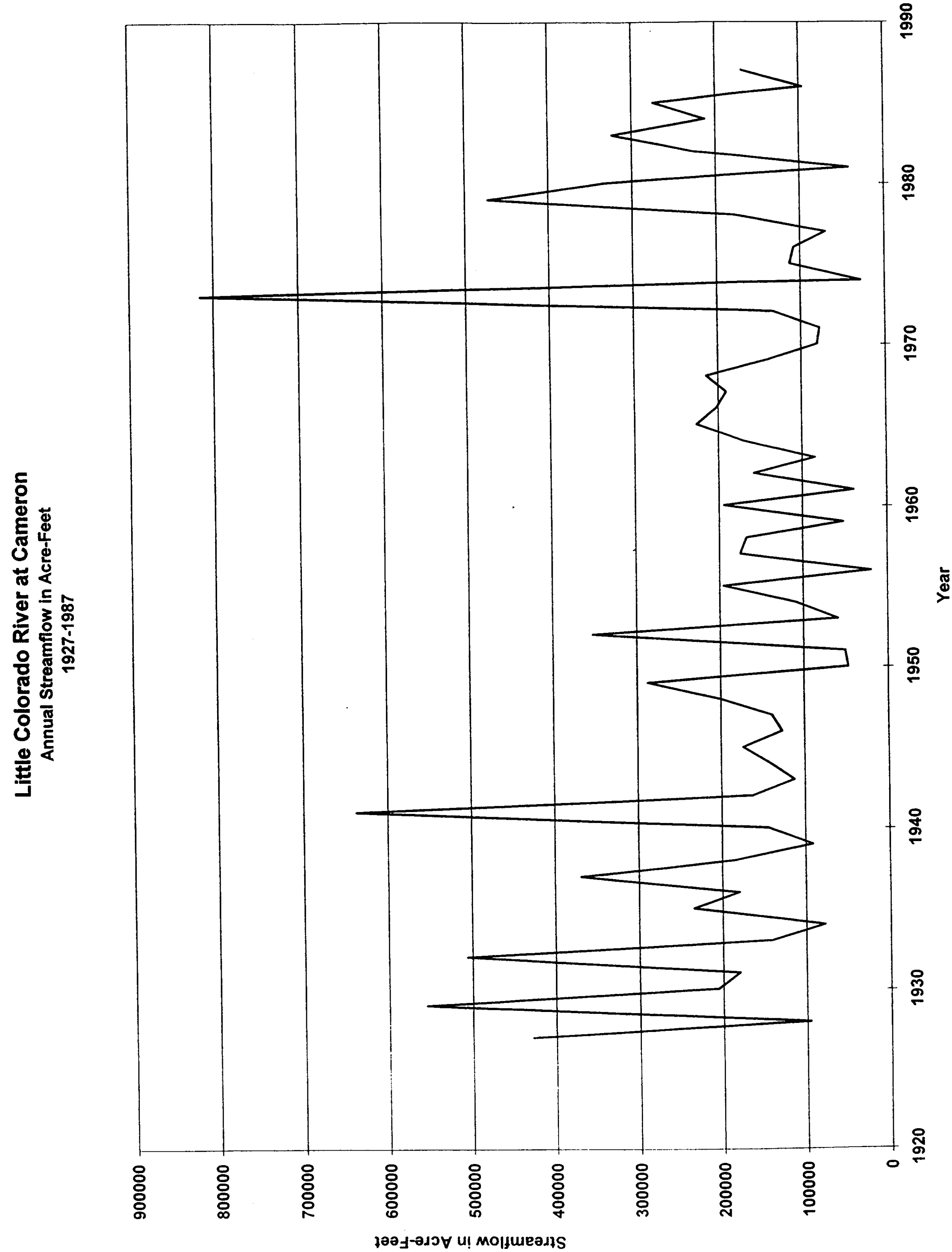
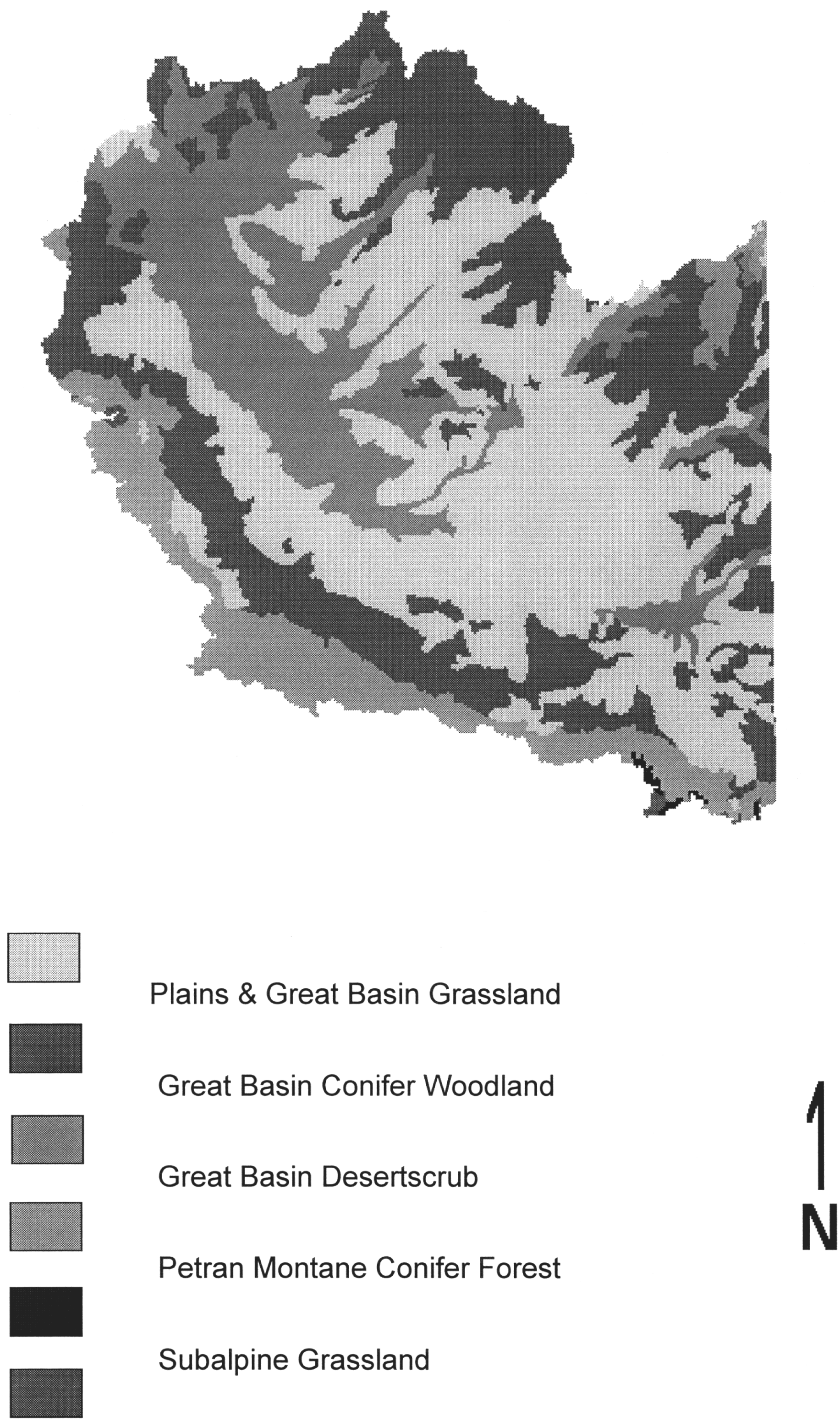


Figure 6. Vegetation types of the Little Colorado River Basin.

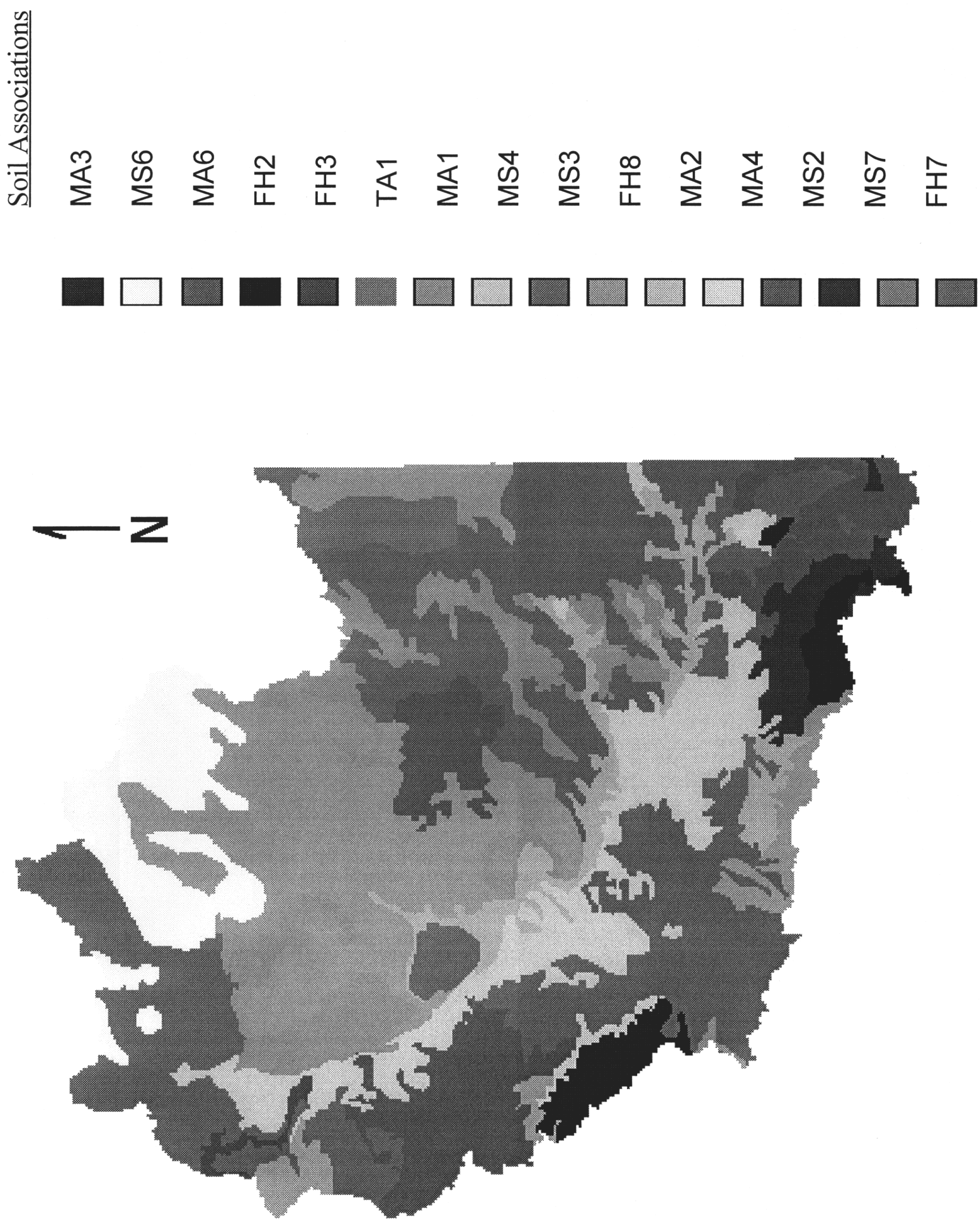


while the remainder of the Basin is underlain by horizontally stratified sedimentary rock deposits of varying ages and characteristics. In many places, these sedimentary layers have been eroded into canyons, plateaus, and buttes. The alluvial deposits in the floodplain of the LCR consist of loosely consolidated materials primarily of sedimentary origins. These materials were the source of most of the agricultural soils within the Basin (SWCA 1996). Figure 7 illustrates the different soil associations in the LCR Basin. A complete list of all the soil associations codes and corresponding definitions found in the LCR Basin, and Arizona are provided in Appendix A (AlRIS 1996).

There are a number of land uses practiced within the LCR Basin, that can significantly affect the quantity and quality of the surface and ground water resources in the area. The most important ones include agriculture, mining, industrial and municipal land uses. Of these groups, agriculture which includes grazing, and dry and irrigated farming is the primary land use. Irrigation in the LCR Basin is a notable water use activity. Several major irrigation companies and many private individual operators utilize both surface and ground water for agricultural purposes. Only on non-Indian lands within the LCR Basin, over 46,500 acre-feet of water is used annually for irrigation (AWRD 1989).

Another land use that relies upon surface and ground water resources is mining. Over 16,500 acre-feet of surface water is diverted annually for mining and industrial purposes. Due to the ephemeral nature of surface water flow in the LCR system, industrial and municipal projects rely mostly on ground-water resources. With over 47,110 acre-feet of ground water pumped annually for industrial, commercial, and power generation (AWRD 1989), potential threats to the water quality of the LCR system include discharges of

Figure 7. Soil Associations of the Little Colorado River System. (See Appendix A for description of the soil codes used in this map).



hazardous materials at industrial or municipal facilities and radio nuclides at active or abandoned uranium mines and/or uranium ore processing facilities (SWCA 1996).

Changes In The System

Like many riparian ecosystems in the Southwest, the riparian zones within the LCR Basin have undergone drastic changes in terms of both areal extent and biotic composition (AWRD 1989). By 1977, it was estimated that statewide only about 15 percent of the natural riparian ecosystems in pre-settlement Arizona were present (Brown et al. 1977). Presently the types of plants dominating the riparian ecosystem in the LCR are phreatophytes, plants with extensive taproot systems that can draw a great deal of water from saturated zones at great depths. Most cottonwood stands have been replaced by thickets of the non-native tamarisk (Tamarix chinensis), a common phreatophyte. The rapid growth rates and effective taproot systems have allowed tamarisk to displace most of the native cottonwoods and willows that previously characterized riparian areas in the LCR basin (ADWR 1989). Although tamarisk dominates the overstory in the riparian areas, the species is not as dominant in the LCR system as in other similar habitats in the Southwest probably due to frequent scouring of stream banks by floods (AWRD 1989). In any case, this change in the vegetation regime has been considered to have a direct influence on the general reduction of instream flows in the LCR basins.

Vegetation changes elsewhere in the LCR basin have been extensive and the present cover little resembles those found by early explorers and settlers (DBS&A 1994). The extent and quality of the grasslands in the area have been reduced by a century of overgrazing. The U.S. Natural Resources Conservation Service estimates that 50 percent of the rangelands in the LCR basin are in poor condition being replaced by pinyon-Juniper Woodlands that have expanded to occupy much of the former grassland (AWRD 1989). Also, like many forested areas of the Southwest, the forests on the higher elevations of the LCR watershed such as the ponderosa pine forests of the Apache-Sitreaves National Forest, have gone through extensive structural and compositional changes since European settlement of the area in the late 1800s (Garrett and Soulen 1996). Changes in forest composition, stand density, and increased litter accumulation over the past century have been attributed to fire suppression and increased livestock grazing (Harrington and Sackett 1990, Dieterich 1980).

The surface waters of the LCR system have satisfied the needs of wildlife, vegetation, and native peoples for thousands of years. The availability of such water was a key factor in drawing the European settlers into the area in the 1870's (ADWR 1989). However, the development of water resources to satisfy such needs in the LCR Basin has brought a decrease in the extent of perennial river and tributary reaches. For example, the stretch of the LCR from Woodruff to Winslow was historically perennial, but it is now intermixed with intermittent and ephemeral stretches due to anthropogenic development (DBS&A 1994).

A study by the Arizona Department of Water Resources (1989) estimates that depletion due to anthropogenic activities may be responsible for the reduction in the total LCR discharge reaching the Navajo Nation border below Winslow by 25%, or 60,000 acre-feet annually. In addition, ground-water pumping has probably reduced surface water flow in several areas. Pumping from the Coconino aquifer can reduce ground water discharge which is directly responsible for maintaining baseflow, or it can reduce ground water discharge to the alluvium zone which, in turn, maintains baseflow (ADWR 1989).

Sediment yields from the LCR basin are among the highest in the world, partly due to cyclic climatic change and localized influences from over grazing (ADWR 1989). Erosion has carved deeply incised channels within the LCR basin and has removed large quantities of sediment in the process. The initial widespread incision observed during the late 19th century, attributable to higher precipitation, resulted in increased sediment yield from the LCR Basin. Beginning in the early 1940s, reduced peak streamflows have resulted in stabilization of the main LCR channel system with vegetation. As a result, since the 1940s, sediment transport has been relatively constant throughout the basin (DBS&A 1994).

The sediment carried down through the LCR Basin is derived principally from erosion of weathered bedrock at the head of the various tributaries. Spatial variability of sediment storage sites results from the non-linear downstream distribution of stream power and its sediment-transport capacity within the channel system. Along the main-stem, the sediment-transport capacity diminishes somewhat due to decreased slopes and wider channels. This reduced carrying capacity results in increased storage of sediment within the floodplains (DBS&A 1994).

Suspended sediment samples collected by (Graf et al. 1995) in the LCR main-stem contained more than 90% silt and clay sized materials, while bed material consisted of medium-grained sands with minor amounts of silt and clay. The suspend sediment data shows approximately 55 percent of the sediment transported along the main-stem to be finer than medium clay (0.002mm).

Methods and Procedures

Elements of a GIS

Even though, a significant amount of information relevant to the study is available, more data and additional time are needed to perform a comprehensive GIS analysis of the study. Therefore, the efforts in this study will focus on identifying critical layers which would help achieve project objectives.

A GIS analytical procedure is usually designed to perform various tasks that can satisfy the needs of many users. It is constructed to be robust and able to being continuously updated as new data becomes available. Generally, it is built around a framework of four basic interrelated modular structures: data input, data management, manipulative operations, and data output products.

Data input converts data from their existing form into one that can be used by the GIS. Georeferenced data are commonly provided as paper maps, tables of attributes, electronic files of maps and associated attribute data, air photos, and satellite imagery (Star and Estes 1990). Input data is usually of two types, spatial data and associated nonspatial attribute data. The spatial data represent the geographic location of features. Points, lines, and areas are used to represent geographic features like a river, a lake, or a forest stand. The non-spatial attribute data provide descriptive information like the name of a street, the salinity of a lake, or the composition of a forest stand. During data input, the attribute and spatial data must be entered and correctly linked (Pain 1989).

Data management in GIS includes those functions needed to store and retrieve data from the data base. The methods used to implement these functions affect how efficiently the system performs all operations with the data. Because of the large volume and variety of data, plus the wide range of potential applications, data management is extremely important for the successful and efficient operation of a GIS (Avery and Berlin 1992). Data management systems typically consist of a series of computer programs constructed to facilitate data entry, storage, retrieval, and maintenance tasks.

The data manipulation and analysis functions of a GIS determine the information that can be generated. A GIS is capable of performing both surface analysis and overlay analysis. Surface analysis applies to intra variable relationships that exist within one data plane, while overlay analysis applies to intervariable relationships created by overlaying or stacking two or more data planes (Aronoff 1995).

Spatial information stored in a GIS is typically represented with a cartographic model in one of two formats: vector or raster. Although there are numerous variations of data structures based on each of these spatial data formats, it is possible to describe a general differentiation between the two formats. That is, vector formats use a node, line and area model to flexibly distinguish between non-overlapping areas (or polygons), whereas a raster model samples the occurrence of events over a regular, predetermined grid (Aronoff 1995).

Data output is the procedure by which information from the GIS is presented in a form suitable to the user. Data are output in one of three formats: as hardcopy, softcopy, or electronic files. Hardcopy outputs are a permanent means of display such as charts, tables, and maps. Softcopy output includes tabular or graphic output displayed on a computer monitor. Output in electronic formats consists of computer-compatible files. They are used to transfer data from one computer system to another for additional analysis or to produce a hardcopy output from a remote location (Avery and Berlin 1992).

Data Collection

Modern data entry systems have expanded the variety of data available for input into GIS. Some of the most commonly used data entry systems include: keyboard entry, coordinate geometry, manual digitizing, scanning, and the input of existing digital files.

Keyboard entry involves manually entering data at a computer terminal. Attribute data are commonly input by keyboard, while spatial data are rarely entered this way. In coordinate geometry procedures, the survey data are entered by keyboard and the data coordinates of the spatial features are calculated and a GIS compatible file created (Star and Estes 1990).

Manual digitizing is the most widely used method for entering spatial data from maps. Maps are mounted on a digitizing table and a hand held device is used to trace each map feature and accurately generate the coordinate data in digital form (Pain 1989). Scanning is a more automated method for entering map data. A raster digital image of the map is produced after which additional computer processing is done to improve the quality of the image and to convert the raster data to vector format. Operator-assisted editing and checking is then done to generate the final GIS-compatible data file (Avery and Berlin 1992).

In the past, when a GIS was implemented virtually all of the data to be input had to be converted into a digital form and structured in the format specific to a particular system

(Aronoff 1995). Recently, standard digital geographic data sets have become more widely available. Automated methods of data conversion, such as scanning, allow for the direct generation of digital files. For example, GIS-compatible data sets can now be generated directly from digital satellite imagery (Engman and Gurney 1995).

Modern remote sensing technology provides a number of efficient and consistent ways to gather spatial data. Remote sensing technologies are important sources of data for geographic information system analysis (Arnoff 1995). Today most natural resource mapping is done through the use of remote sensing technologies. Aerial photography has been used to produce virtually all topographic maps and most forestry, geology, land use, and soils maps. More recently, airborne radar and scanner data as well as satellite imagery are being used to acquire data for these types of mapping applications (Engman and Gurney 1995).

Remote sensing often requires other kinds of ancillary data to achieve both its value and the highest levels of accuracy as a data and information acquisition technology. Geographic information systems can provide this capability. They allow the integration of datasets acquired from library, laboratory, and fieldwork with remotely sensed data. Conversely, applications of GIS are heavily dependent on both the timeliness or currency of the data they contain, as well as the geographic coverage of the database (Arnoff 1995). Remotely sensed data are available from a variety of sources. Numerous satellite and airborne instruments provide the spectral coverage and resolution necessary for land use classifications. Selection of a specific instrument depends upon study objectives.

Survey referenced data are point, line, and/or polygon data that are referenced by a survey crew on site. Using GIS software, the data can be transferred from coordinate data to digital GIS data. Depending on the amount of control used to define the spatial data, survey referencing can be very accurate. However, it is also very time and cost intensive (Star and Estes 1990).

Map referenced data also consists of point, line, and/or polygon data that are referenced to a mapsheet, generally topographic. The resulting line data must be converted into digital format by digitizing or scan-digitizing and then attributed. Accuracy in this methodology is dependent on the scale and accuracy of the topographic map used, as well as the ability of the interpreter to correctly assess lines of elevation between the constructed map and the real world it represents (Aronoff 1995).

Sources of Data

Existing digital data are becoming more readily available and digital data sets are produced to satisfy a wide range of users (Aronoff 1995). When spatial data are found in a digital form, there may be a significant cost saving to the user since the digitizing process is not required. At the federal level, these data sets are produced by the national mapping agencies and agencies responsible for census and other nationwide statistical data. At the state level, data conversion programs may vary from state to state given differing data standards. Natural resource information is being converted to digital form at both the state and federal levels.

In the United States there has been considerable effort made to coordinate and standardize the production and distribution of digital geographic data. At the federal level, the Federal Interagency Coordinating Committee on Digital Cartography was formed for this purpose in 1983 (Star and Estes 1990).

In the United States, much spatial data collected by government agencies, including maps, photographs, and many kinds of digital data, are considered public domain. Thus, there are effectively no restrictions on access to this data. Some of the Government agencies which make digital data available include: The U.S. Geological Survey National Mapping Division, the U.S. Fish and Wildlife Service, the U.S. Department of Agriculture natural resource service, the U.S. Census Bureau, the Defense Mapping Agency, the Department of Energy, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration (Aronoff 1995). The types of data available from these Government agencies include: topographic, land use and land cover, hydrography, socioeconomic and demographic data, soils, wetlands, and a variety of remotely sensed data (Star and Estes 1990).

In Arizona, one source of digital spatial data is the Arizona Land Resource Information System (ALRIS) established by the Arizona State Legislature in 1982 to provide a geographic information system for public agencies in the state. The ALRIS program supplies digital spatial data to public agencies (state, federal, local, tribal) in Arizona at little or no cost. Digital data is organized in coverages or layers which group logically related geographic features and their attributes.

The data used in this study were obtained in digital form from ALRIS. The program has a large number of digital data layers (coverages) for Arizona including the LCR basin. After reviewing the list of coverages available from ALRIS, the following coverages were selected from the ALRIS spatial data library for use in this paper:

1. Arizona (Arizona State Boundary)
2. HUCS (Hydrologic Unit Code Areas)
3. HYDRO (Arizona Hydrography)
4. AZSOILS (General Soil Map of Arizona by USGS SCS)
5. NATVEG (Arizona's Natural Vegetative Biotic Communities)
6. STEAMS (Arizona's Streams and Rivers)
7. AZGEOLOGY (Geologic Formations of Arizona)
8. LAND (Land Ownership and County Boundaries)
9. Amerind (American Indian Reservation Boundaries)

Data transfer was made via FTP from ALRIS system to a work station in my office. The data were in the ARC/INFO export format when received. The data were then imported into ARC/VIEW for processing and output production. The fact that the ALRIS data are organized and stored in a computer directory tree structure under a master directory to facilitate information access and analysis made it easy to import the data. An example of the metadata (data about data) which accompanies each individual ALRIS coverage is located in Appendix B.

However, the ALRIS coverages, while illustrating some of the digital data available, do not cover the full extent of the LCR basin. They do not include information on the Basin outside of Arizona, and did not provide complete coverage of the Tribal lands located within the basin. It must be noted that to provide a complete detailed coverage of the LCR basin for the purpose of estimating water and sediment yields additional data layers would be required that are beyond the scope of the study. Ultimately, the GIS database built to provide a detailed hydrologic study, would contain a combination of preexisting digital data layers, digitized aerial photographs, digital satellite images, and digitized map layers.

Procedures

The Little Colorado River system is a complex drainage system consisting of a network of many tributary streams and associated watersheds (ADWR 1989). The land area that contributes surface runoff to any point of interest is called a watershed. The sizes of watersheds may vary from a few acres to thousands of square miles. A large watershed usually contains many smaller subwatersheds. Watershed areas supply water to rivers or streams in the form of surface and subsurface discharges (Viessman 1989). Data requirements for a drainage basin hydrologic model include areal topography, climate records, soil characteristics, ground cover, and land use activities (Avery and Berlin 1992).

Drainage basin topographic information is an important component of hydrologic modeling. The topography of an area refers to surface characteristics, such as the relief of an area. The topography of a land surface can be represented in a GIS by digital elevation data. This data set consists of the elevations of a large number of representative sample points distributed throughout the area of interest. These points are commonly organized as a grid, essentially in a raster form of organization (Aronoff 1995). An alternative form of representation is the Triangulated Irregular Network or TIN used in vector-based systems. In the TIN, a network of triangular facets is generated by GIS from a set of elevation sample points that can be irregularly distributed. These facets can then be manipulated as polygons and the elevation, slope, aspect, and other parameters can be assigned to the facets as polygon attributes (Star and Estes 1990). Numerous sources of digital elevation data exist. The United States Defense Mapping Agency (DMA) produces digital elevation data from

1:250,000 scale topographic maps. Digital elevation models corresponding in coverage to 7.5-min topographic quadrangles are produced for selected areas of the country by the USGS (Star and Estes 1990).

Climatic data are the other important component of hydrologic modeling. Data from rain gauges are commonly analyzed by an approach which involoves the use of thiessen or voronoi polygons to define individual areas of influence around each of a set of points. Data from rain gauges are commonly analyzed in this way. It is an approach of extending point information which assumes that the "best" information for locations with no observations is the value at the closest point with a known value (Aronoff 1995, Viessman et al. 1989). The rain gauge locations are represented in the GIS as points. Thiessen polygons are then generated around each point and the rainfall value for the rain gauge is assigned to its surrounding polygon. The rainfall at all locations within each Thiessen polygon is considered to be that of the contained rain gauge station. The amount of rain falling on each polygon can then be calculated as the amount recorded by the rain gauge multiplied by the area of the polygon. While this method is often used in GIS precipitation analysis, it does have limitations. Thiessen polygons do not assume that points close together are more similar than points far apart (Burrough 1986).

The subdivision of drainage basins into watersheds, and subwatersheds, is often required in hydrologic investigations. This requires partitioning both basins and watersheds into sub-areas that are assumed to be homogeneous in their hydrologic response based on characteristics such as topography, soils, land use, cover type, and climate records (Aronoff 1995). As a general example of how land surface attributes are combined into watershed structure, one watershed from the LCR basin (Chevelon Canyon) was selected to illustrate graphically the overlapping of data layers.

The Chevelon Creek Watershed is an elongated north-south running drainage that encompasses nearly 800 square miles of the south central Little Colorado River basin. The watershed is made up of two subwatersheds components from which nearly all streamflow is derived. These two subwatersheds are the upper Chevelon Canyon on the West, and Black Canyon on the East. Figure 8 shows the location of the Chevelon Creek Watershed within the LCR basin, and illustrates basin subdivision and the data layering procedure used for the assignment of attributes to individual watersheds.

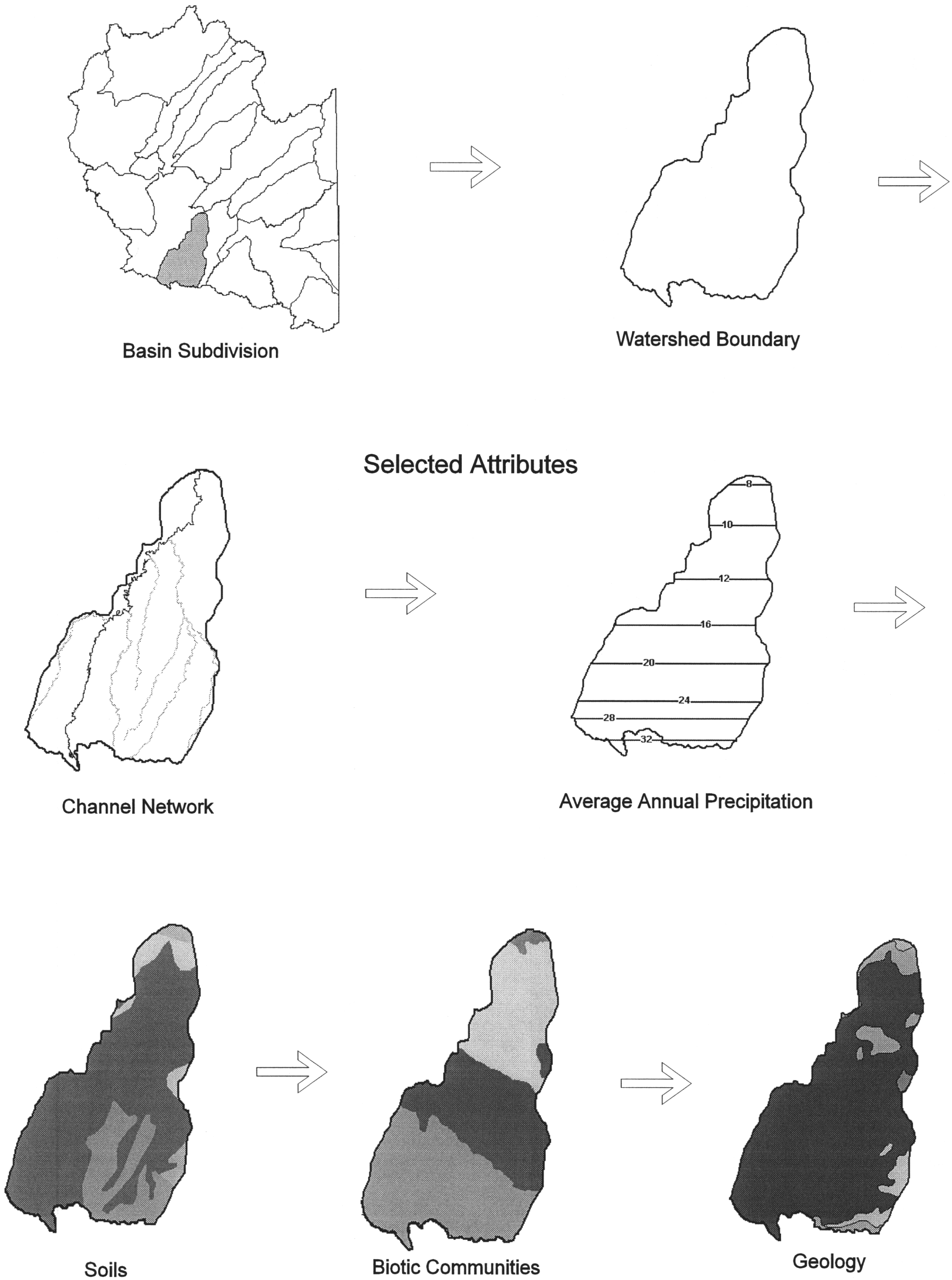
Watershed Models

Hydrologic modeling is often used to study such processes as streamflow and sediment yield by constructing hydrologic models, mathematical simulations that use estimated streamflow and sediment yields that might be caused by precipitation events of a given magnitude. Such models provide a means of assessing the effects of proposed changes in land use because they can estimate the effects of such changes before they actually occur (Mercado 1993).

Combining hydrologic modeling with GIS results in an objective and efficient model-building process that can produce acceptable simulations of hydrologic responses to land use or climate change (Luker et al. 1993). The integration of GIS with hydrologic models can:

1) eliminate laborious data entry by accessing spatial data bases and delineating model parameters, 2) provide quick testing of different land use scenarios, 3) represent model

Figure 8. Location of the Chevelon Creek Watershed and associated data layers.



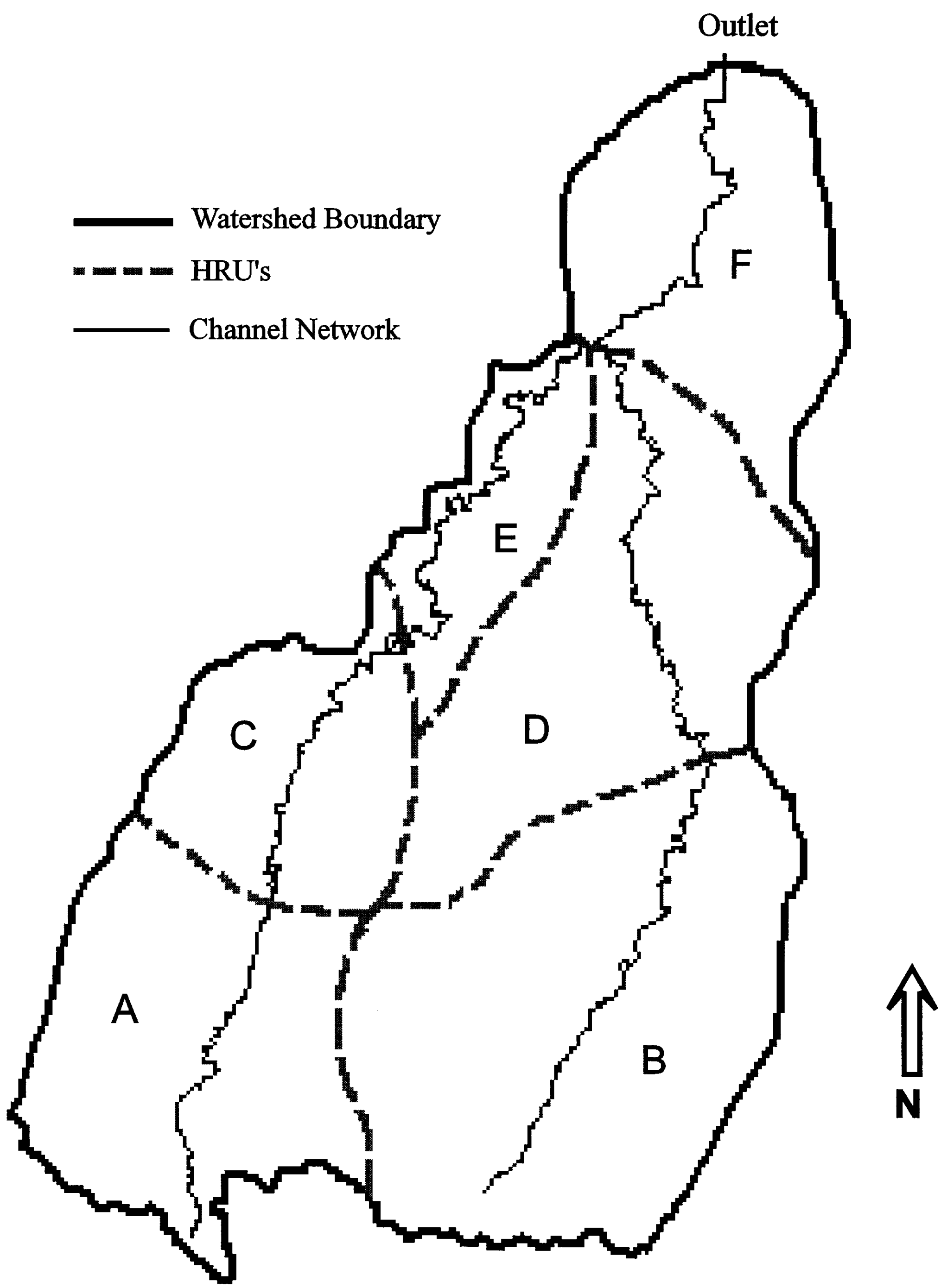
output in an easy to interpret map format, and 4) incorporate model output into additional GIS-based spatial analysis (Jeton and Smith 1993). Numerous models exist for estimating runoff and sediment yield from a given drainage basin. Most hydrologic models simulate outputs for a given basin by partitioning watersheds into areas that each have a homogeneous hydrologic response to precipitation or snowmelt. These land units, are often called hydrologic-response units (HRU's), subwatersheds, catchments, or subcatchments and are characterized according to physical properties such as slope, aspect, vegetation, soils, geology, and climate patterns (Jeton and Smith 1993). Figure 9 shows the Chevelon Creek Watershed, and illustrates an example of how a watershed might be subdivided into units of homogenous hydrologic response.

Summary and Conclusions

Much of the information used in hydrologic investigations has a geographic orientation (Zelt 1991). Combining hydrologic modeling with GIS results in an objective and efficient model-building process that can produce acceptable simulations of hydrologic responses to land use or climate change (Luker et al. 1993). Remotely sensed spatial databases combined with GIS can provide useful modeling strategies for hydrologic simulation. Numerous satellite and airborne instruments provide the spectral coverage and resolution necessary for land use classification (Engman and Gurney 1995).

Improvement in Hydrologic forecasting and simulation can be achieved by modifying existing models to use remote sensing image processing and spatial data analysis through a GIS (Aronoff 1995). Such models would resemble contemporary simulation

Figure 9. Subdivision of the Chevelon Creek Watershed.



models structurally but would be able to account for the spatial variability found in natural basins in a more realistic way. Also, the subprocess algorithms (i.e. evapotranspiration, precipitation, etc.) would be written to use remote sensing data as a primary input as well as more typical inputs.

In conclution, there are many new and exciting observations of the hydrologic cycle that are going to be available from new remote sensing systems, and, further, new models to allow the data to be used quantitatively in physical interpretations.

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Appendix A. Codes and definitions of the different soil Associations found in Arizona.

HA1 TORRIFLUVENTS
HA2 CASA GRANDE-MOHALL-LA PALMA
HA3 MOHALL-VECONT-PINAMI
HA4 GUNSIGHT-RILLITO-PINAL
HA5 LAVEEN-RILLITO
HA6 LITHIC CAMBORTHIDS-ROCK OUTCROP-LITHIC HAPLARGIDS
HA7 LAVEEN-CARRIZO-ANTHO
HA8 TREMANT-COOLIDGE-MOHALL
HA9 HARQUA-PERRYVILLE-GUNSIGHT
HA10SUPERSTITION-ROSITAS
TA1 TORRIORTHENTS-CAMBORTHIDS-ROCK OUTCROP
TA2 ANTHONY-VINTON-AGUA
TA3 LITHIC TORRIORTHENTS-ROCK OUTCROP-LITHIC HAPLARGID
TA4 LATENE-ANTHONY-TRES HERMANOS
TA5 PALEORTHIDS-CALCIORTHIDS-TORRIORTHENTS
TS1 TORRIFLUVENTS-TORRIPSAMMENTS
TS2 TORRIFLUVENTS
TS3 TUBAC-SONOITA-GRABE
TS4 WHITE HOUSE-BERNARDINO-HATHAWAY
TS5 CARALAMPI-HATHAWAY
TS6 LITHIC TORRIOTHENTS-LITHIC HAPLUSTOLLS-ROCK OUTCRO
TS7 WHITE HOUSE-CARALAMPI
TS8 CARALAMPI-WHITE HOUSE
TS9 LATENE-NICKEL-PINALENO
TS10CHIRICAHUA-CELLAR
TS11GOTHARD-CROT-STEWART
TS12CONTINENTAL-LATENE-PINALENO
TS13KARRO-GOTHARD
TS14NICKEL-LATENE-CAVE
TS15BONITA-GRAHAM-RIMROCK
TS16PENTHOUSE-LATENE-CORNVILLE
TS17SIGNAL-GRABE
TS18GRAHAM-LAMPSHIRE-HOUSE MOUNTAIN
TS19ANTHONY-SONOITA
MA1 BADLAND-TORRIORTHENTS-TORRIFLUVENTS
MA2 MOENKOPIE-SHALET-TOURS
MA3 SHEPPARD-FRUITLAND-ROCK OUTCROP

MA4 TOURS-NAVAJO
MA5 TORRIORTHENTS-TORRIFLUVENTS
MA6 FRUITLAND-CAMBORTHIDS-TORRIFLUVENTS
MS1 TORTUGAS-PURNER-JACKS
MS2 WINONA-BOYSAG-ROCK OUTCROP
MS3 PALMA-CLOVIS-TRAIL
MS4 RUDD-BANDERA-CABEZON
MS5 ROUNDTOP-BOYSAG
MS6 LITHIC TORRIORTHENTS-LITHIC HAPLARGIDS-ROCK OUTCR
MS7 CABEZON-THUNDERBIRD-SPRINGERVILLE
MS8 PASTURA-POLEY-PARTRI
MS9 LONTI-BALON-LYNX
MS10PASTURA-ABRA-LYNX
MH1 CASTO-MARTINEZ-CANELO
MH2 LITHIC HAPLUSTOLLS-LITHIC ARGIUSTOLLS-ROCK OUTCROP
MH3 SHOWLOW-DISTRHEFF-CIBEQUE
MH4 ROUNDTOP-TORTUGAS-JACKS
MH5 OVERGAARD-ELLEDGE-TELEPHONE
MH6 PACHIC ARGIUSTOLLS-LYNX
FH1 MIRABAL-DANDREA-BROLLIAR
FH2 SPONSELLER-ESS-GORDO
FH3 SOLDIER-HOGG-MCVICKERS
FH4 SOLDIER-LITHIC CRYOBOROLLS
FH5 MIRABAL-BALDY-ROCK OUTCROP
FH6 EUTROBORALES-MIRABAL
FH7 CRYORTHENTS-EUTROBORALFS
FH8 GORDO-TATIYEE

Appendix B. Example of Metadata.

NAME OF DATA SET: HUCS

DATA TYPE: Vector; Polygon

DESCRIPTION OF CONTENT:
Hydrologic unit code areas.

FORMAT:
Arc/Info

DATA SIZE: Data Set 7.5" quad
Approximate Megabytes : .23 -

METHOD OF ACCESS:
This cover can be accessed by using the following pathname: /gis/covers/million/hucs.

HISTORY:
Digitized from 1:500,000 scale, 'Hydrologic Unit Map - 1974 State of Arizona', by U.S. Dept. of the Interior and U.S. Department of the Army.

****NOTE**** This map has been through rubber sheeting processes and should be used for statewide planning purposes only.

MAINTENANCE:
NONE

PROJECTION:
UTM (Zone 12 with -3.2 million meter Y shift(northing))

ITEMS:
Item name: AREA
Description: The value of each polygon in square meters
Format: 4,12,F,3
Code table:

Item name: PERIMETER
Description: Perimeter of the polygon arcs in meters
Format: 4,12,F,3
Code table: