GIS-Based Drainage Study for San Joaquin County

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Abstract

A Geographical Information System (GIS) was developed for hydrologic analyses for a drainage study conducted for the County of San Joaquin, California. Data layers incorporated in the GIS data base are base maps, rainfall isohyetal maps, land use and soil type, unit hydrograph data, watershed boundaries, stream channels and channel nodal points, node elevations, and the linkage information for the nodes. The GIS was used for hydrological analyses to determine storm runoff quantities, to plan flood management facilities, for floodplain analysis, and for drainage system evaluation.

Introduction

A Geographical Information System (GIS) was developed for the County of San Joaquin, California to produce a computerized county-wide hydrologic model for flood runoff determination. The GIS application uses software to access a data base containing the information needed to perform the study. The basic computations are similar to those used in standard hydrologic studies. Runoff is computed from rainfall with abstractions made for losses based on soil type and land use. In this application, unit hydrograph calculations are used to compute the runoff hydrograph. Individual hydrographs are computed at each node point in the model.

GIS applications involve a number of components that span several technical fields, including data base management, geographical information systems, hydrologic and hydraulic modeling, graphical presentation of data, flood control engineering, engineering planning, and other subjects. This permits complete analysis of the entire system using a single pass of the computer model. In the analysis of alternative future plans, appropriate components of the data base can be modified and a new simulation can be quickly made. This procedure makes the review of alternatives very economical and fast.

The San Joaquin County data base incorporates a number of different types of data organized into "data layers." Some of the layers making up the data base were already available in digital form from various local governmental units.

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These layers were directly incorporated into the GIS with minimum effort and cost. Other layers were digitized from maps on which watershed boundaries, stream channel alignments, soil types, and land uses were marked. Additional information was put into digital form by direct drafting using a graphics software package. Rapid communication of hydrologic data and runoff estimates in graphical form is easily attainable because the entire hydrologic model is represented by graphics layers in digital graphics format.

The GIS study for San Joaquin County is based on procedures incorporated in a recently developed hydrology manual for the county (San Joaquin County 1995). The manual provides computational techniques and criteria for the estimation of storm runoff volume and time distribution of runoff (or for calculation of the peak discharge) to be used for the analysis and design of stormwater management facilities for areas within the county. Runoff is computed from rainfall for specific frequencies and duration. The rational method is used for small subbasins (less than one square mile in area), and unit hydrograph calculations are made for larger subbasins. Appropriate loss rates are computed from current and future land uses and soil types. Streamflow routing is used for the analysis of channel modifications and situations where channel storage has a large effect on the routed flows. Reservoir routing techniques can be used for the analysis of "flow-through" and "flow-by" detention basins.

Geographical Data Base

For the GIS analysis the hydrologic model is linked to a set of digital graphic layers, each of which can represent a hydrologic parameter or an attribute. Other layers provide background information for graphical displays and hard copy maps. The layers used in the San Joaquin County GIS data base are:

1. *Base Map*—Includes topographic contours, roads, political boundaries, etc.
2. *Subarea Boundaries*—More than 300 individual subbasins were used to define areas contributing in the county
3. *Flow Paths*—A flow path was defined for each subarea (the major stream course was used to define this)
4. *Hydrologic Nodal Points*—The inlet node and the outlet node were specified for each subarea
5. Hydrologic Soil Group Map—The SCS soil maps for the county were used to define hydrologic soil groups
6. *Land Use Map*—Land use was based on future use as defined on county planning maps
7. *Rainfall Isohyetal Map*—The mean annual rainfall isohyetals are used to compute rainfall time distribution and intensity-duration-frequency curves
8. *Hydrologic Modeling Element Type*—Defines the type of hydrologic computation being performed (rainfall-runoff calculation, routing, etc.)

Primary hydrologic computation parameters used in the hydrologic computer model are land use, hydrologic soil group, rainfall, and hydrologic subarea data such as area, length of flow path, and the elevation of the node points. In addition, maps can be generated for graphical representation of the data in the data base.

Model Data Base

As an example, some of the layers used in the San Joaquin County Hydrologic Model data base are depicted in Figure 1. This figure shows the portion of the county included in the model, the subareas, and some of the water courses. The southwestern part in the Coast Range and the eastern edge of the county in the foothills of the Sierra Nevada have significant relief, and the subarea boundaries in these areas follow ridge lines and well-defined divides. In the central portion of the county the topography is very flat and the subareas are bounded by roads, railroads, irrigation canal embankments, and levees; that is why many of these subarea boundaries are straight lines. The central-western and northwestern part of the county is part of the Sacramento-San Joaquin Delta region. Much of this area is near or below sea level, and the land areas are surrounded by levees. The Delta region was not included in the hydrologic model because most of the drainage of this area is not free-flowing and requires pumping.

The rectangular grid superimposed on the map in Figure 1 represents the boundaries of the USGS quad sheet maps for this region. The name of each quadrangle is in a data base layer and was included, along with the county boundary line (in another layer) to provide information to allow the viewer of the map to orient various features relative to each other. Some of the subbasins extend beyond the county boundaries, and these areas were included in the model, except for major river basins. Major rivers and streams enter the county on the south (Stanislaus River and San Joaquin River) and on the east (Dry Creek, Mokelumne River, Calaveras River, and other streams). These rivers have contributing areas that are much larger than the area of the design storm used in the model. The maximum area represented by the design storm is 300 square miles. Also, boundary inflows to the model which are releases from a reservoir are represented as "rim inflows."

Hydrologic Computations

The GIS-based computations are based on procedures given in the San Joaquin County Hydrology Manual. The manual provides computational techniques and criteria for the estimation of storm runoff volume and time distribution of runoff (or for calculation of the peak discharge) to be used for the analysis and design of stormwater management facilities for the areas within the county administered by the County Department of Public Works.

Unit hydrograph calculations are used to determine runoff from subbasins over one square mile in area, and the unit hydrograph S-graph type is defined in one of the GIS layers. Loss rates are computed from land use and soil type data given in other GIS layers. Rainfall is computed in the form of a design storm using basin mean annual rainfall. The mean annual rainfall is determined from a rainfall map for the county that is stored in yet another GIS layer. The design storm procedure is described by DeVries (1994).

A key element of the GIS analysis procedure is the ability to intersect all these graphical layers. The data are resolved into "cells" in which the parameters are homogeneous. For a given subarea the boundaries of the soil types, the land uses, and other parameters do not coincide, but boundaries of areas on the various maps overlap each other. In order to develop appropriate data for each subarea runoff computation the representative parameters for each subarea must be developed from the data provided. For example, one subarea may have in it two or more areas of the four possible soil types. Also, several types of land development may overlap the soil types. The subarea being analyzed may, in addition, be represented by more than one unit hydrograph type as well.

In the hydrologic analysis an average value for each parameter is needed in order to define loss rates, the unit hydrograph, and the rainfall amount in each computational time period. This data development is performed in GIS by using a polygon processor.

Polygon Processor

The boundary of each individual region defining the value of a parameter can be described geometrically by a polygon. The location of each vertex of the polygon is defined by its x and y coordinates. The polygons are listed in sequence in the data base by their vertices. The vertices are taken in order around the boundary of the polygon in a counter-clockwise direction. An individual polygon can be intersected with a group of polygons, each of which represents a particular property (say soil type), and then further intersected with another group of polygons (for example, a polygon for a specific development type). The area of the resulting intersection now gives the fraction of the original area for a specific soil type and land use. Multiple intersections of polygons form new polygons; each new polygon has its own set of vertices. Every polygon has an area that can be readily computed, providing information for the calculation of weighted average values of parameters for each subarea. The polygon processing technique used in this model is described by Hromadka *et al.* (1993).

Unit Hydrograph Modeling Approach

A calibration analysis for the unit hydrograph and loss rate parameters was made using data from Bear Creek in the north-eastern part of the county. Only a very limited amount of data was available for calibration (five individual storm events), but the analysis confirmed the appropriateness of using the standard Corps of Engineers S-graphs. The Corps of Engineers developed their S-graphs from a large data base in Southern California (Hromadka *et al.* 1993).

The unit hydrographs used in the San Joaquin County hydrologic model are determined from generalized unit hydrographs in the form of dimensionless S-graphs. The hydrographs are "dimensionalized" by computing the ultimate S-graph discharges from the watershed area and unit hydrograph time increment and computing the times associated with the discharges from the watershed ***lag.***

The hydrologic modeling approach used in this study differs somewhat from that typically used for link-node models as for example with HEC-1 (Hydrologic Engineering Center 1987). In this study unit hydrographs are computed for the entire area above a collection point. This is in contrast to modeling approaches in which the unit hydrograph is computed separately for each individual small subarea of the watershed. The computed flows are then routed from node to node. The hydrographs at node points are calculated by adding the ordinates of the hydrographs representing local inflows from within the subarea to the hydrograph ordinates for the flow that is separately routed through the subarea from the upstream node.

The approach used in this model was considered to be a more appropriate for several reasons: First, the physical processes involved in routing of both upstream flows and local flows are not independent processes; second, the parameters for the empirical routing procedures used in most hydrologic models (such as the Muskingum method) are not known for the individual stream reaches; third, the typical link-node model uses individual subareas smaller than 1 square mile in area, while the watersheds from which the S-graphs were developed are in the range of approximately 10 to 100 square miles. Calculating the runoff from individual subbasins of one square mile or less in area and then routing and combining these individual computed hydrographs does not match the original calibration conditions for the synthetic unit hydrographs.

The unit hydrograph used, the basin rainfall (average rainfall distributed in time over the watershed), and the effective rainfall (which depends on the manner in which hydrologic losses are calculated) all must go together. The appropriate way to calculate runoff from a watershed using a unit hydrograph procedure is to use rainfall and loss rate data which are consistent with the data used in the calibration of the unit hydrographs.

Conclusions

A Geographical Information System (GIS) is an effective tool for hydrological analysis with the computerized county-wide drainage model described in this paper. Data layers in the GIS data base included base maps, rainfall isohyetal maps, land use, soil type, unit hydrograph data, watershed boundaries, stream channels and channel nodal points, node elevations, and the linkage information for the nodes. Using GIS with these data permits complete analysis of the entire system using a single pass of the computer model. Alternative future plans can be quickly and easily analyzed by simply changing only the appropriate components of the data base.

References

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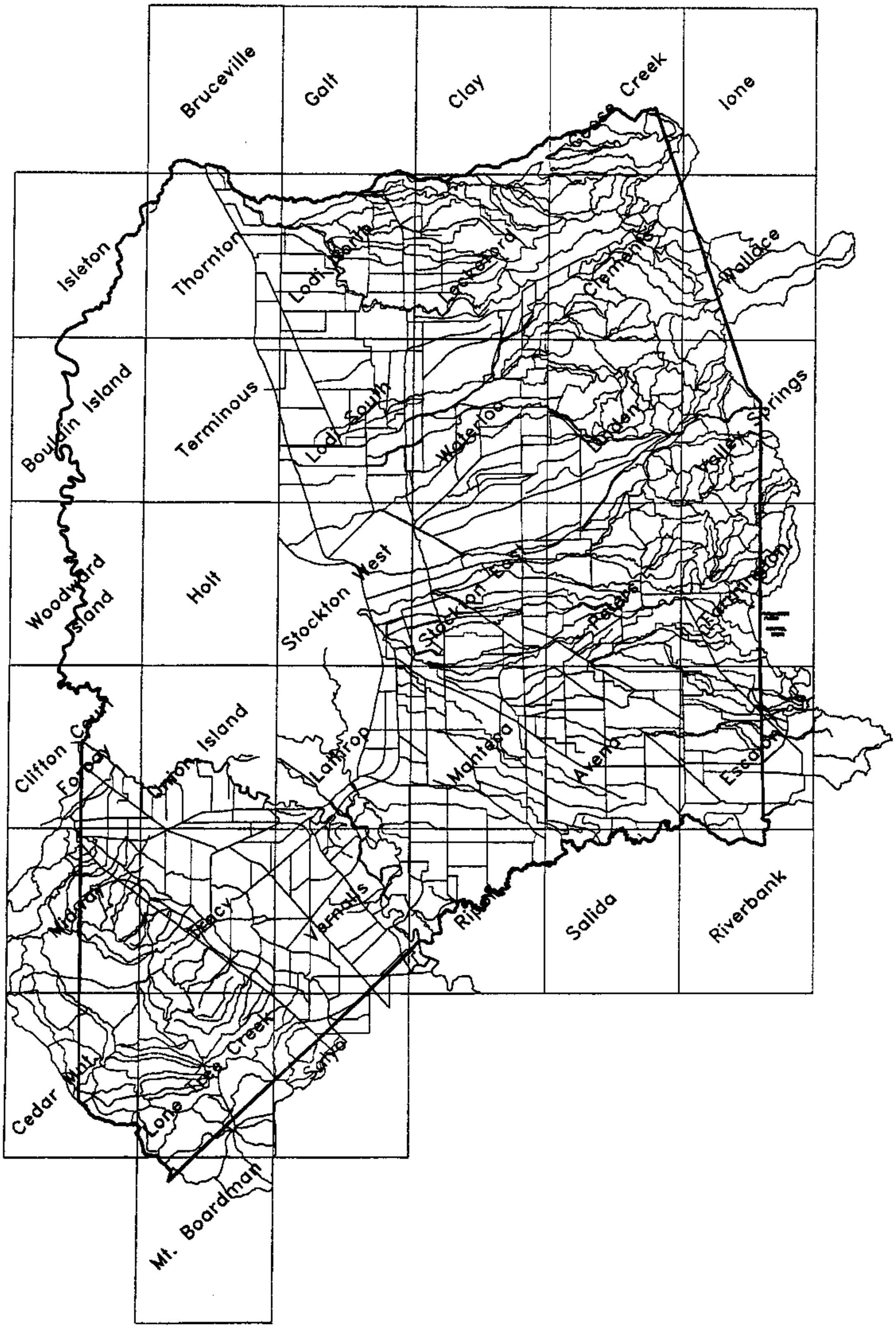


Figure 1. Map of San Joaquin County Showing GIS Information

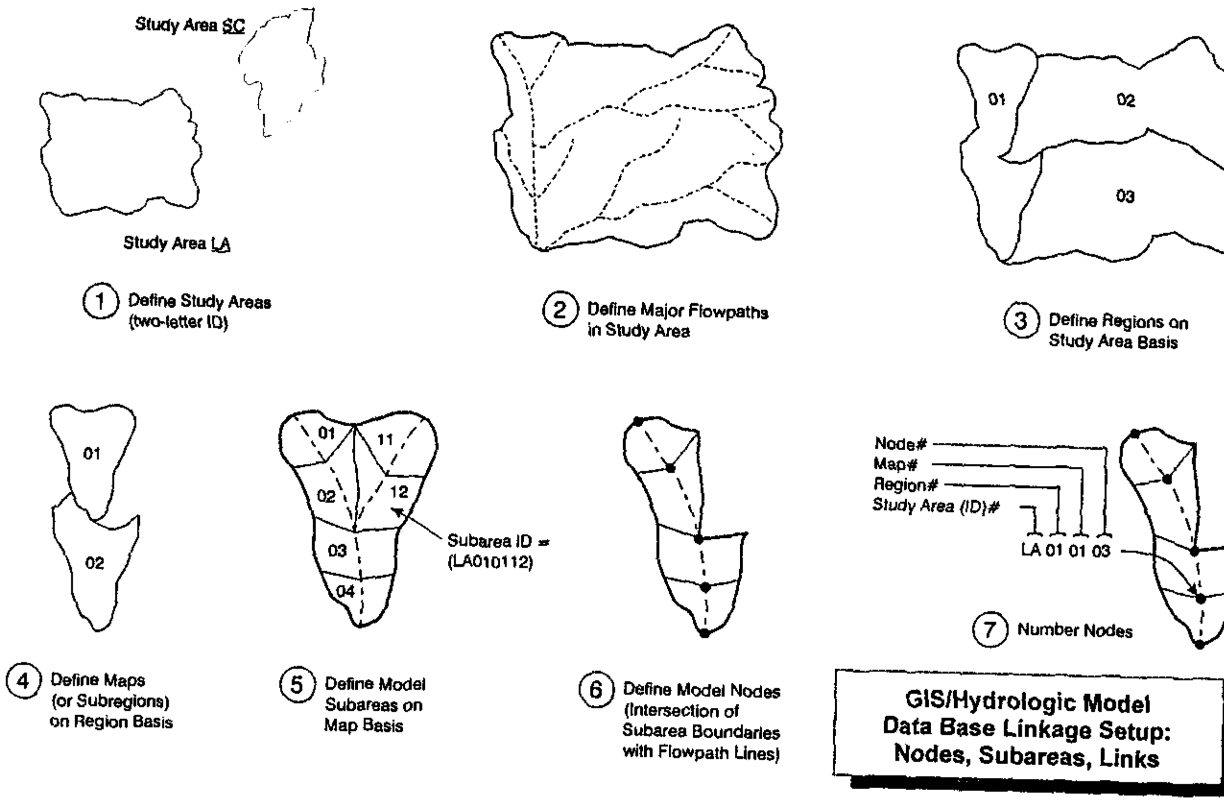
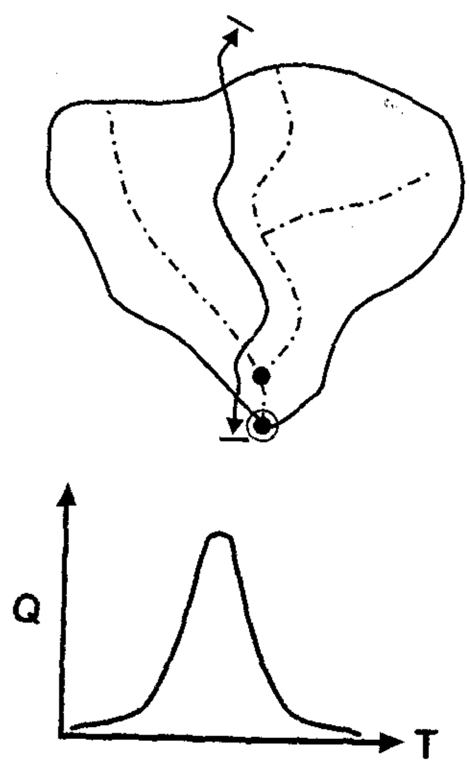


Figure 2. GIS/Hydrologic Model Data Base Linkage Setup



- ***Finds Longest Watercourse, L***
- **Computes Tc of Longest Watercourse**
- **Lag = 0.8 Tc**
- **S-Graph, Precipitation, Loss Rates, Depth-Area Analysis**
- **Develops UH, *Runoff Hydrograph***
- **Gets Qp for Entire Tributary Area, for Each Node**

Figure 3. Unit Hydrograph Modeling Approach Used in San Joaquin County GIS-Based Hydrologic Model

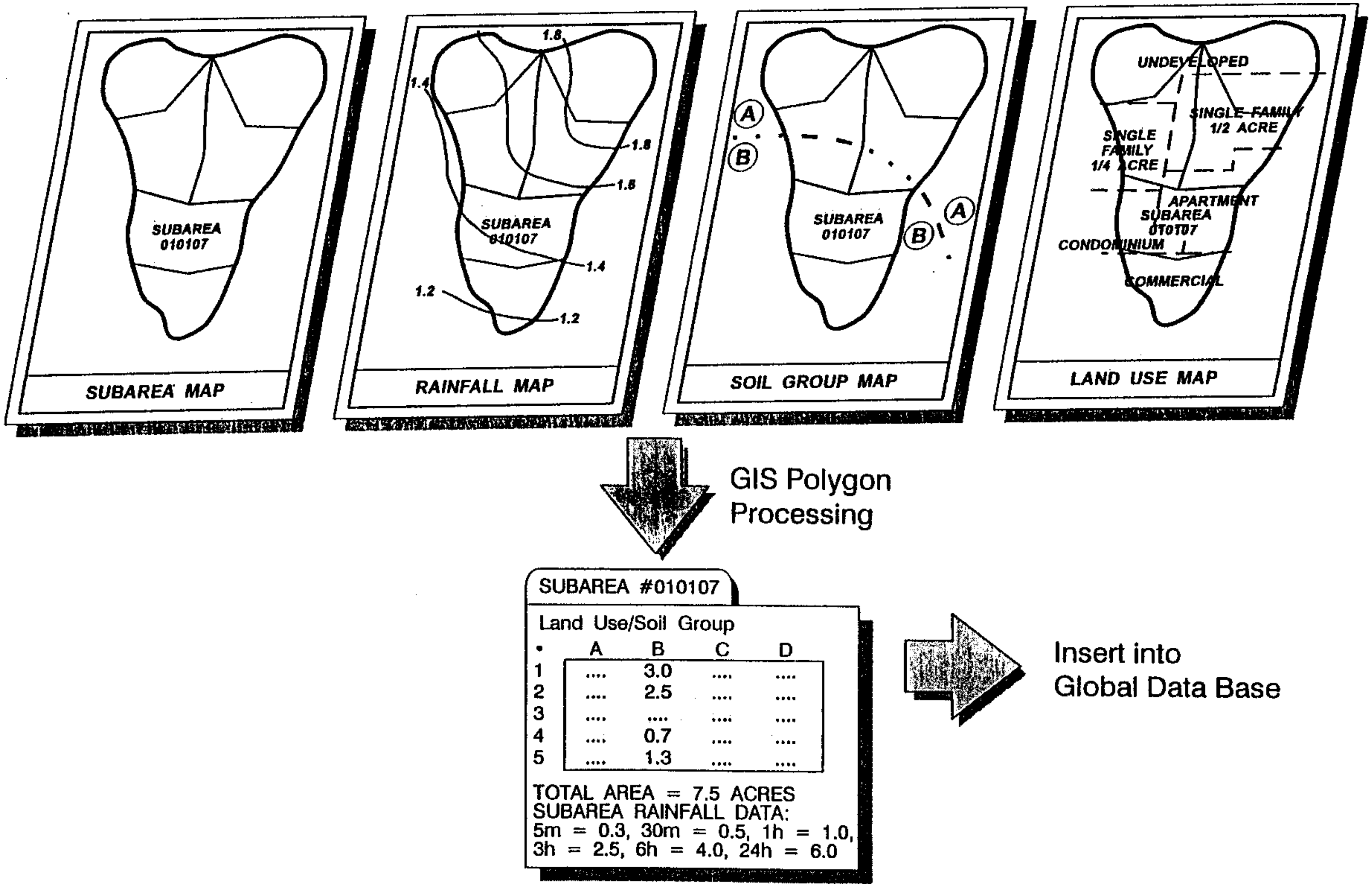


Figure 4. GIS Parameter Definition for Modeling