County-Wide Drainage Study Using GIS

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Abstract

A county-wide drainage study was conducted for the County of San Joaquin, California, Department of Public Works, for the determination of storm runoff quantities for the planning of flood management facilities, floodplain analysis, and drainage system evaluation. The hydrological analyses were based on a Geographical Information System (GIS) for nearly the entire county. 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.

Introduction

Using GIS to develop a Master Plan of Drainage involves the use of software and a data base system that involves 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. Both rational method and unit hydrograph procedures are combined into a single computerized County-Wide Drainage Model. 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.

Some layers making up the data base were already available in digital form from various local governmental units, and they could be directly incorporated into the GIS with a minimum of effort and cost. Other layers were digitized from maps on which watershed boundaries and stream channel alignments were marked. Additional information was put into digital form by direct drafting using a graphics software package. The entire Master Plan is represented by graphics layers in digital graphics format and thus allows for rapid communication of master plan data and runoff estimates in graphical form.

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The San Joaquin County GIS study 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 the areas within the county administered by the County Department of Public Works. Two procedures are available for the computation of runoff 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 used 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 are applied in the analysis of flow-through and flow-by detention basins.

Geographical Data Base

The hydrologic model is linked to a set of digital graphic layers, each of which represents a hydrologic parameter or an attribute. Some layers provide background information for graphical displays and hard copy maps. The flowing layers were used in the San Joaquin County Hydrologic Model data base.

1. *Base Map*—includes topographic contours, roads, political boundaries, etc.
2. *Subarea Boundaries*—Over 300 individual subbasins were define for the entire county
3. *Flow Paths*—A flow path (the major stream course) was defined for each subarea
4. *Hydrologic Nodal Points*—The inlet node and the outlet node were defined 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 land 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 include land use, hydrologic soil group, rainfall, and hydrologic subarea data such as area, length of water course, and elevation of node points. In addition, maps are used to communicate the data in the data base.

Model Data Base

An example of some of the layers used in the San Joaquin County Hydrologic Model data base are depicted in Figure 1, which shows the areas of the county included in the model, the subareas, and some of the water courses. The southwestern part in the Coast Range and eastern edge of the county in the foothills of the Sierra Nevada have significant relief, and the subarea boundaries 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; 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 is surrounded by levees. The Delta region was not included in the hydrologic model.

The rectangular grid superimposed on the map 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, to allow the viewer of the map to orient various features relative to each other. Although some of the subbasins extend beyond the county boundaries, these areas were included in the model, except for major river basins. Major rivers and streams enter the county on the south (Stanislaus and San Joaquin Rivers) and on the east (Dry Creek, Mokelumne, Calaveras, 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 San Joaquin County Hydrology Manual mentioned above. 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, and the unit hydrograph S-graph type is defined in one of the GIS layers. Appropriate loss rates are computed from land uses and soil type data given in other GIS layers. Rainfall is computed from basin average rainfall determined from the rainfall map for the county which is stored in yet another GIS layer.

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 amounts 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, 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, but the analysis confirmed the appropriateness of using the standard Corps of Engineers S-graphs developed from a much larger data base in Southern

California. The unit hydrographs used in the hydrologic analysis are determined from generalized unit hydrographs in the form of dimensionless S-graphs. The relationships needed to "dimensionalize" the hydrograph are related to the watershed area and unit hydrograph time increment and a timing parameter known as the watershed ***lag.***

The hydrologic modeling approach differs from the typical link-node models in that unit hydrographs are computed for the entire area above a collection point. Some approaches compute the unit hydrograph separately for each subarea and then route flows from node to node, combining hydrographs at the node points. This approach was not used in this model because 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.

Conclusions

Using a Geographical Information System (GIS) for a single computerized County-Wide Drainage Model is an effective tool for this type of hydrological analysis. Incorporating data layers in the GIS data base for 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 permitted complete analysis of the entire system using a single pass of the computer model, Alternative future plans were quickly and easily analyzed by simply changing only the appropriate components of the data base.

References

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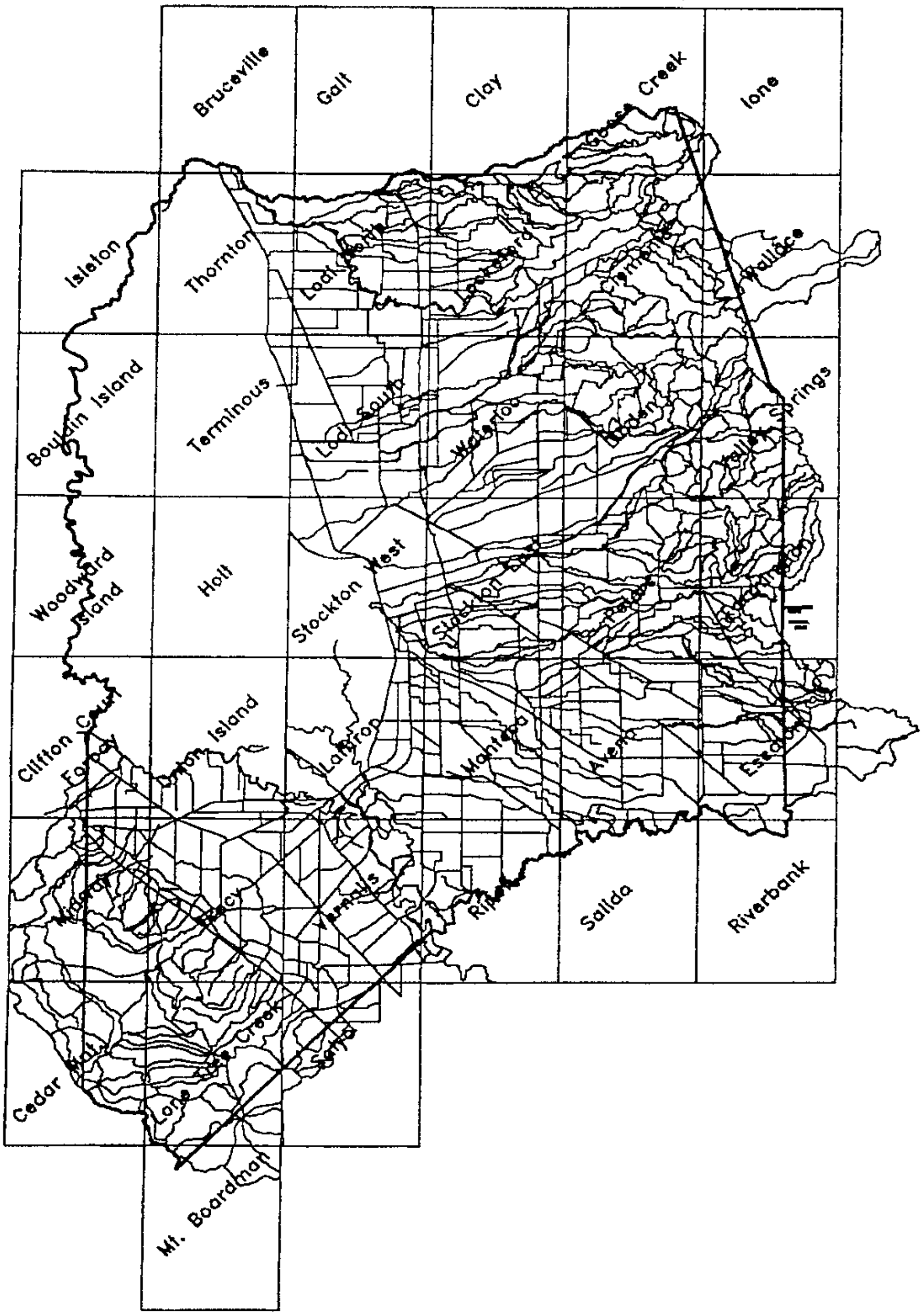

Figure 1. Map of San Joaquin County Showing GIS Information