AN INITIAL INVESTIGATION OF STRUCTURAL AND NONSTRUCTURAL FLOOD CONTROL ALTERNATIVES FOR CYPRESS CREEK, TEXAS

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INTRODUCTION

A preliminary investigation of alternative structural and nonstructural solutions to flood control for Cypress Creek, Texas, was performed in the context of a graduate course offering at the School of Architecture, Rice University, during the spring semester of 1977. It was a multidisciplinary effort involving participation of faculty and students from both the School of Architecture and the Department of Environmental Science and Engineering. The project was funded by a grant from the Galveston District of the U.S. Army Corps of Engineers. Because of the limited time and resources available for the study, the results of the investigation represent conceptual designs for flood control rather than definitive solutions. Many aspects of the proposed alternatives have been accepted by the Corps of Engineers, however, at least as reference designs.

The Cypress Creek watershed is located roughly 20 miles north to northwest of the City of Houston and has a drainage area of about 320 square miles. The main channel is formed by the intersection of Mound and Snake Creeks in Waller County and flows some 54 miles from eastern Waller County through northwestern Harris County to its confluence with Spring Creek immediately west of Lake Houston. The central and eastern portions of the watershed are traversed by two major thoroughfares: Highway 290 and Interstate 45, respectively. In close proximity to Farm Road 1960, the wooded areas of the central and eastern portions of the watershed

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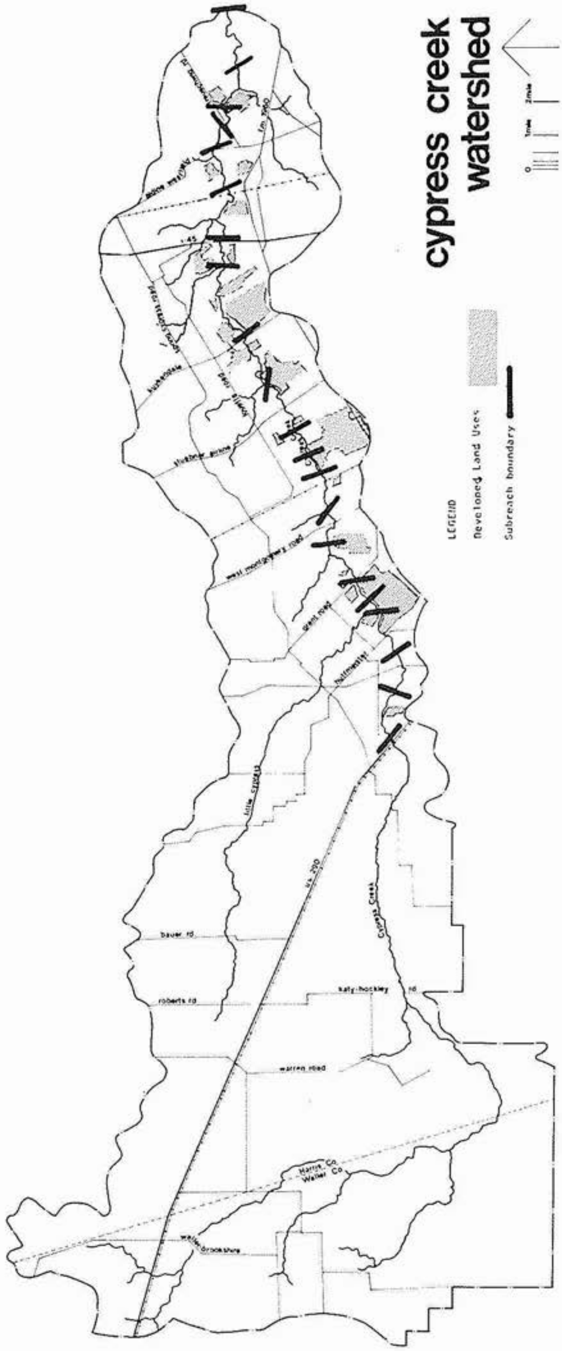


FIG. 1. MAP SHOWING URBAN LAND USES

have recently undergone rapid urbanization. Agricultural land uses are still dominant, however, with about 112,000 acres of cropland located primarily in the western portion of the watershed. In comparison, a recent estimate of urban land uses was about 12,500 acres (figure 1).

From the standpoint of flood protection, the spatial distribution of this urbanization within the watershed causes problems. A considerable amount of residential development has taken place close to the stream channel, in flood-prone areas, where the developers could avail themselves of the natural amenities of the streamside woodlands. Intensive construction activity has also increased the suspended solid loads within the creek and at least temporarily caused the water quality to deteriorate. It is clear that land development within the watershed has aggravated the dual problems of stormwater management, namely flood protection and maintenance of water quality. The scope of this case study, however, was limited to the problem of flood control.

BASIC APPROACH

The basic approach of the investigation is shown schematically in figure 2. Initially the study was divided into three somewhat independent lines of investigation. They were 1) identification of factors influencing urban growth, and projection of future land uses; 2) modeling the hydrologic response to the watershed under existing and future conditions; and 3) identification of institutional mechanisms and potential structural and nonstructural approaches for flood control. After the preliminary determination of flood-prone areas, the study approach became more integrated.

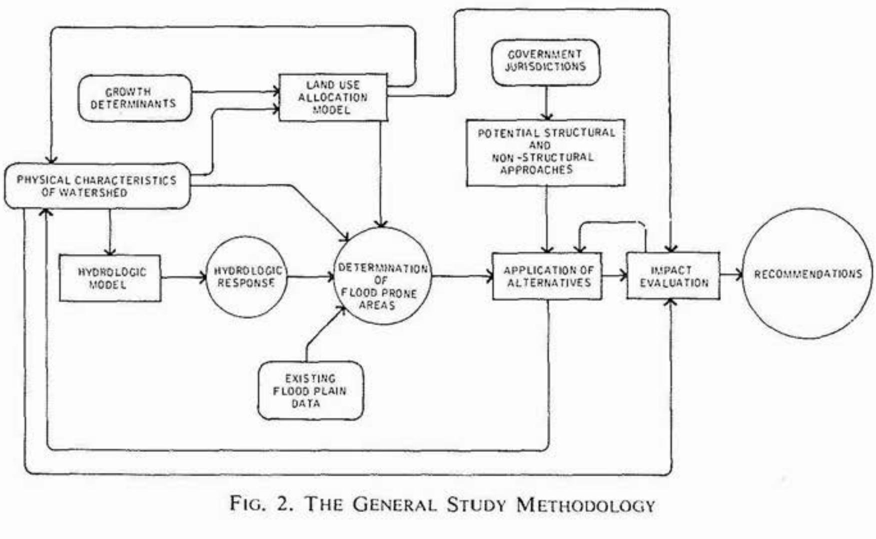


FIG. 2. THE GENERAL STUDY METHODOLOGY

Various flood control strategies were applied to different problem areas within the watershed, and their performance was tested and evaluated against other alternatives to develop a final design and planning strategy.

Many of the study activities, such as the projection of land use and the hydrologic modeling, were supported by information organized in the form of a geographically referenced data base. The data base had the following general characteristics: first, the latitude-longitude system provided the primary form of spatial reference for all the data points; second, a uniform rectangular grid cell system had an individual grid cell size of 70 acres; third, the "attribute data" at each data point primarily described land uses, cover characteristics, and other natural features of the watershed. Also included in the data base were a number of special purpose geocodes, such as census tracts and subwatershed areas. Finally, the natural and man-made cover characteristics within the data base were recorded as the dominant feature in each grid cell. In many areas half cells were used to increase resolution.

The data base was in turn supported by a geographic information system developed at the Rice Architecture Computer Laboratory. In common with other geographic information processors, this data system supports a number of storage-retrieval and display operations. Encoding is performed as a dialogue at a computer terminal and also includes a semi-automated data checking function. A variety of graphic display capabilities is available to the user, including character and gray-tone mapping, *x-y* plots, and linear or tonal contouring. Further details describing this system may be found in Bavinger and Rowe (1978) and Rowe and Bavinger (1979).

LAND USE AND LAND-USE PROJECTIONS

Adequate simulation of the hydrologic response of the watershed required data describing the existing and future type and spatial distribution of land use. Current estimates (1975-76) of population and land use were gathered from several different sources (Martin, 1976; Houston City Planning Department, 1975; Fisher et al., 1975; and James Veltman and Associates et al., 1975). A land use map based on these sources and on an aerial photographic interpretation conducted by the study team was prepared at a scale of 1:1000. The classification used to develop this land-use information was based primarily on Anderson et al. (1972), with some modifications according to local conditions. As we mentioned in the introduction, the predominant existing land use in the watershed is agriculture, with a considerable amount of residential development in the downstream (eastern) half of the watershed. There are very few industrial or commercial developments in the area. The total population was estimated in 1975 to be about 75,000 (Houston-Galveston Area Council, 1976).

Of the available land-use projections, only two were found to be applicable for the entire Cypress Creek watershed. They were both prepared by the Houston-Galveston Area Council (Houston-Galveston Area Council, 1972 and 1976). The 1976 projection was selected because it was more recent and because it was being used in parallel federal stormwater management programs. Another advantage was that the projection included land-use as well as population projections. In any event, comparison between the two Houston-Galveston Area Council projections did show reasonable agreement for most comparable areas (Blackburn et al., 1977).

The 1976 Houston-Galveston Area Council projections were derived for each of the 17 census tracts within the study area using a "shift-share" approach. The population of each census tract was compared to the county population totals. The projected population growth for each tract, over a given time period, was then based on the tract's present share of the county total adjusted in accordance with perceived growth trends over the period. There are, of course, weaknesses with this approach. A tract's proportional future share of total growth is strongly influenced by its present share. The technique does not explicitly account for the impact of future exogenous variables, but rather makes adjustments to a tract's proportional shares based on past trends. However, other projection techniques have weaknesses, too, and the "shift-share" approach is generally one of the more robust. Using the Houston-Galveston Area Council projections as a base, we estimated that the population in the watershed would be about 155,000 by 1990, with most of the increase taking place between 1975 and 1983.

For the purposes of the hydrologic modeling and later development of flood-control strategies, it was appropriate to represent the spatial distribution of future land-uses for both subwatersheds and grid cells, although they had been originally estimated for census tracts.

The first step in this process was to convert the census tract projections to subwatershed projections. As there was little or no spatial congruence between the boundaries of census tracts and subwatershed areas, the conversion process required grouping portions of census tracts together. A "shift-share" approach, similar to that used for the Houston-Galveston Area Council 1976 projections, was used to allocate existing and projected land use from the census tracts to the subwatershed areas (Blackburn et al., 1977).

Distributing land uses at the level of a grid cell was accomplished with a simple land-use allocation model. In essence, this model attempted to duplicate the land development process, in which location, accessibility, existing land use, and the presence or absence of natural or man-made encumbrances strongly influence the location of development. Allocation of land uses among the grid cells was based on the relative attractiveness of cells for particular types of land use. Initially, the allocation process involved assign-

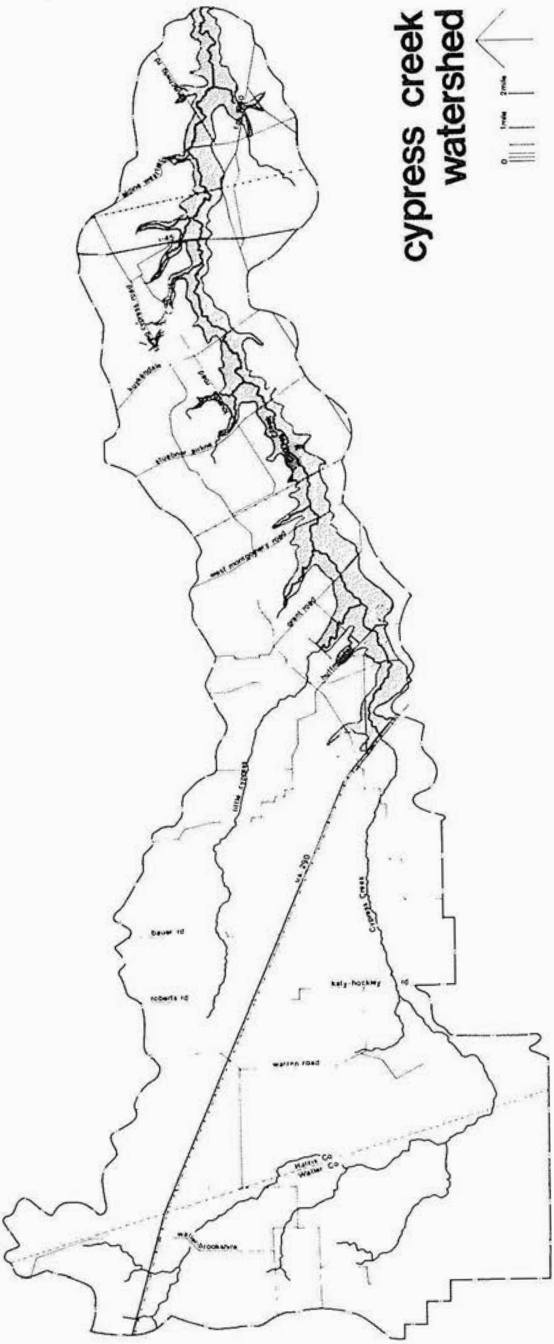


FIG. 3. MAP SHOWING THE U.S. ARMY CORPS OF ENGINEERS PRELIMINARY DETERMINATION OF THE 100-YEAR FLOODPLAIN

ing each cell in a subwatershed an "attractiveness score" for each possible use. For instance, location in the floodway would preclude a cell's use for most development purposes because of its low attractiveness score. During the actual allocation, the cells with the highest attractiveness scores for a particular use received the first allotments of the projected increase assigned to a subwatershed area for a particular time period. Allocation continued until the land use increment to be assigned for the period was totally distributed or "cleared." The same process was repeated for successive time periods.

The results of the land-use allocation indicated that the eastern portion of the watershed would continue to undergo rapid urbanization, adding about 5,000 acres of urban land uses between 1975 and 1990. For the most part, this urban development can be expected to be predominantly residential. By contrast, hardly any change in land use was indicated for the rural western sector of the watershed.

HYDROLOGIC ANALYSIS

A preliminary floodplain study by the Galveston District of the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1972), data from the U.S. Geological Survey, and the work of the Federal Insurance Agency (F.I.A.) formed the primary base for the hydrologic analysis of Cypress Creek. Both the U.S. Army Corps and F.I.A. floodplain studies (figure 3) indicated substantial areas of urban development within the floodplains of the 100-year flood and the Standard Project Flood, particularly between Highway 290 and the confluence with Spring Creek (figure 4).

A statistical analysis of historical flow records on Cypress Creek from the U.S. Geological Survey yielded some unexpected results. By using a Log-Pearson Type III analysis on 39 years of flow data gauged at the I-45 crossing, a maximum flow rate of 20,000 c.f.s. was indicated. Further analysis showed that rainfall amounts and flood flows between 1967 and 1976 were generally lower than for the total period from 1945 to 1976 (Blackburn et al., 1977). Flood-flow patterns have been less than "normal" during the time of greatest urbanization within the watershed.

The U.S. Army Corps of Engineers, using the HEC-1 unit hydrograph, obtained a predicted flow of 34,420 c.f.s. at the I-45 gauge for the 100-year flood. Predictions were also made by the U.S. Army Corps of the backwater profile for different flood flows (10-year, 100-year, and SPF) from the Highway 290 crossing to the confluence with Spring Creek.

In addition to using the results from these earlier studies, the Rice group attempted to model the hydrologic response to the watershed using the HLAND model (Bedient et al., 1977). HLAND is based on a daily water balance of rainfall and evaporation, where surplus water is allowed to run

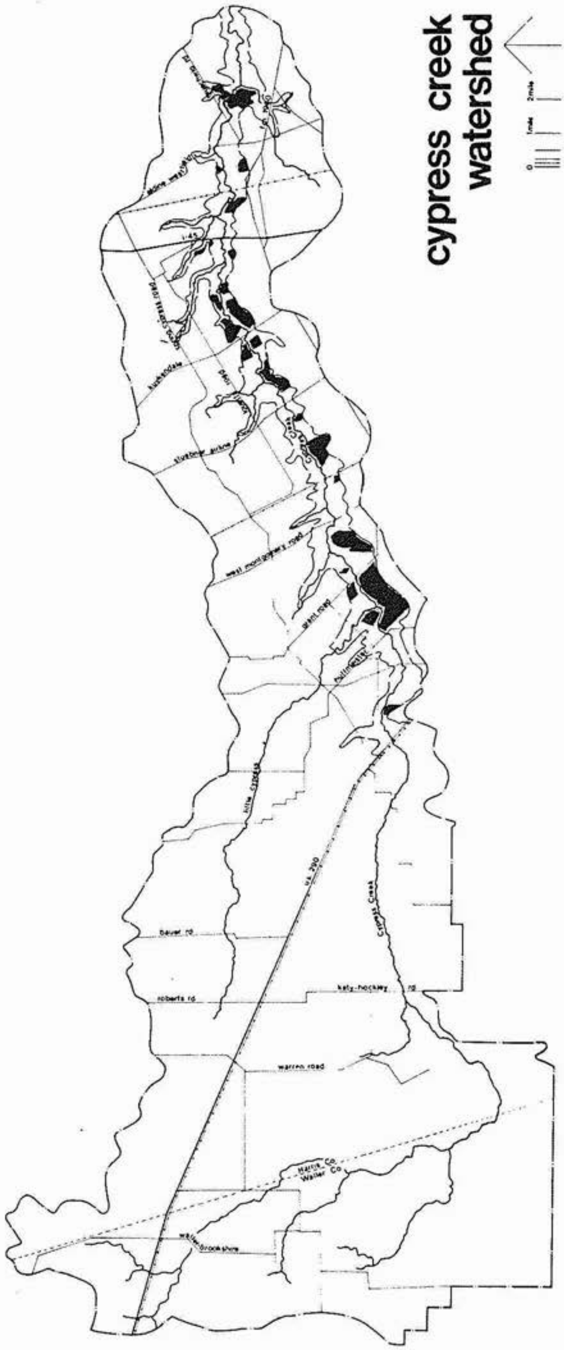


FIG. 4. MAP SHOWING URBAN LAND USES WITHIN THE 100-YEAR FLOODPLAIN

off at specified rates depending on land-use cover characteristics and soil types. The approach places primary emphasis on soil storage changes between and during rainstorms, and is well suited for modeling watersheds with relatively flat slopes and large retention storage, which are typical of many coastal areas of the southern United States.

In order to apply HLAND, the Cypress Creek watershed was subdivided into 31 subwatershed areas. Appropriate land-use cover and soil data were then gathered for each subwatershed. During the HLAND simulation, the total predicted runoff from a storm for each subwatershed was routed through the main stream channel using the Muskingum Flood Routing Method. Appropriate selection of routing time and storage coefficients allowed for the simulation of a variety of channel configurations. Calibration of the HLAND model for Cypress Creek was performed by comparing measured and predicted daily flows at the I-45 gauging station. The results of this comparison indicated that the HLAND prediction tended to overestimate the measured values by about 20%. A closer fit would have required changes in parameters outside their reasonable range and was not attempted.

The results of the HLAND simulations for the two future land-use conditions considered in the analysis (1983 and 1990) indicated marginal increases in total flow volumes. These findings can be explained by at least two factors: first, while the projected increase in urbanization alone was fairly substantial (5,000 acre increase by 1990), the relative change in the cover characteristics of the entire watershed was comparatively slight; second, even in a natural state, the surface of the watershed consists of impermeable soils with low water-absorption capacities.

For design purposes, the 100-year flood with a flow rate of 34,420 c.f.s. at I-45 was used. On the basis of the backwater elevations estimated using HEC-2, and channel cross-section data from Highway 290 to the confluence, a floodplain covering some 4,000 acres was delineated. Currently about 50% of the land within this floodplain is either developed or being developed, with a total estimated value of $96 million (Blackburn et al., 1977). Although new development activity appears to be taking place outside the 100-year floodplain, the magnitude and extent of the existing flood protection problem clearly required consideration.

ALTERNATIVE FLOOD CONTROL STRATEGIES

During the initial stages of the project, an independent investigation was made of potential flood control mechanisms and the institutional strategies that would be required for their implementation. For the purposes of this investigation, a solution to the problem of flood control was considered to be one where development in flood-prone areas would obtain relief from flooding and where flood-prone areas would not be enlarged in the future. In this regard, three interrelated lines of reasoning were pursued. One was concerned solely with maintaining the floodplain as a natural environmental system within the watershed. The second was concerned with examining a standard flow prediction model, such as HLAND, to determine which variables influence flooding and which can be incorporated in a flood control strategy. The third line of reasoning was concerned with protection or relief for land development located in flood-prone areas. As shown in figure 5, these lines of reasoning were further subdivided into the environmental and developmental characteristics affecting flood control, the environmental changes involved in putting various flood control strategies into practice, and the strategies themselves. In essence, the flood control mechanisms shown in figure 5 represent the list from which alternatives were developed.

Perhaps a more common way of characterizing potential flood control solutions is to differentiate between structural and nonstructural approaches. Generally, structural approaches are those requiring physical alteration of the drainage system, usually along the stream channel, to increase flood storage or flow capacities. The various forms of channelization and detention devices are clear examples. On the other hand, nonstructural approaches make use of regulatory control powers, special grant-in-aid programs, land acquisition, and the improvement of public access to information, all for the purposes of discouraging development from taking place in flood-prone areas and of providing relief to flood-prone developments. The exercise of traditional local regulatory control powers, such as subdivision plat approval and building regulations, can in principle be used for floodplain management. Public acquisition of flood-prone areas and government-sponsored insurance programs already have been frequently used to reduce the direct costs of flood damage.

FORMULATION OF FLOOD CONTROL SOLUTIONS

In the final formulation of flood control solutions for the Cypress Creek watershed, two basic strategies were pursued simultaneously. They were 1) on-site stormwater detention in upland areas of the watershed, and 2) reduction in size of flood-prone areas affecting development adjacent to the stream channel.

The examination of on-site stormwater detention in upland areas was considered to be important for at least two reasons. First, impoundment of water at the subdivision level offers protection from local "sheet" flooding. Second, the long-term effectiveness of stream channel solutions can be better guaranteed if runoff from future upland developments is controlled.

A number of structural mechanisms may be used to impound stormwater runoff in subdivisions. These devices would include roof-top pond-

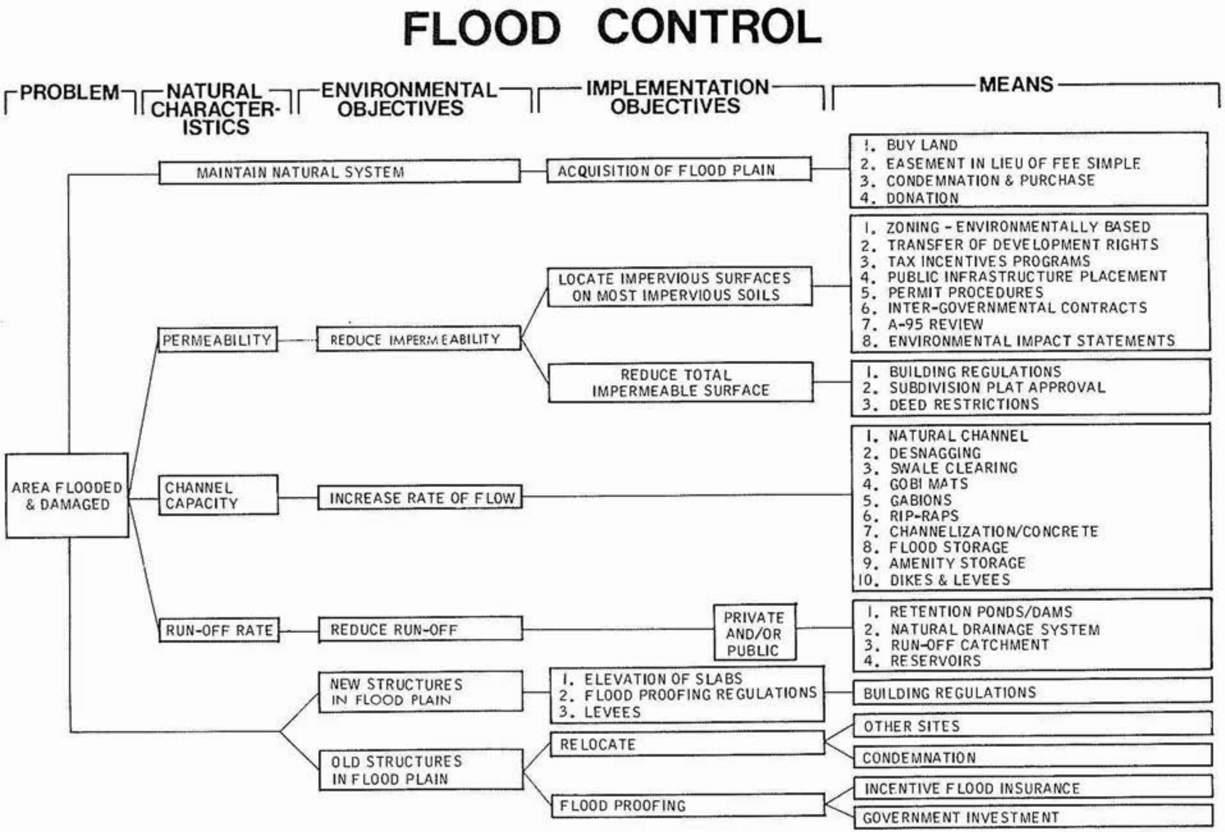


FIG. 5. ALTERNATIVE FLOOD CONTROL STRATEGIES

ing, swales on individual lots, grasscrete or permeable pavement, French drains, natural swales, amenity ponds, and golf course ponds. The costs and effectiveness of such controls are poorly documented.

In order to evaluate the practicability of on-site detention at the subdivision level, the researchers answered a straightforward sequence of questions. Initially, the scales and types of residential development that are typical of the study area were identified and described. Here the scale ranged from the property of individual lot owners (one acre or less) to the more typical subdivision tract of 100 to 250 acres. Few developers were found to be developing tracts in excess of 500 acres. Using the rational runoff equation, we estimated the amount of rainfall runoff to be expected from developments of various sizes. Here 6-inch and 11-inch storms were assumed. A series of schematic landscape and site plans was designed with the objective of detaining on-site as much of the estimated rainfall runoff as possible. In almost all cases a combination of flood control devices was proposed. For instance, street-front swales were combined with some roof-top ponding, back yard swales, and greenway lake systems. As might be expected, the group found that the scale of the development strongly influenced the flexibility with which various flood control techniques could be effectively combined. As a general rule, large amenity lakes were clearly not feasible for smaller developments. Estimates of the costs and stormwater detention capacities of the various proposals were then made and costs compared with those of conventional drainage systems. Finally, the issues of implementation and payment or repayment were addressed (Blackburn et al., 1977.)

The results of these preliminary investigations suggest that a mix of subdivision-level flood control mechanisms could achieve reasonable amounts of on-site detention, or at least a substantial reduction in the rate of runoff for storms of about 6 inches of rainfall per hour. Depending of course on the extensiveness and detailed design of the system, expectations for effective detention of a 100-year event were smaller. Preliminary economic analyses suggested that the development costs for the more highly diversified proposals were financially feasible. Single solutions in the form of large lakes or extensive drainage swales were found to be uneconomical.

In theory at least, one could rely on the subdivision plat approval process and issuance of building permits to enforce the use of on-site stormwater devices. However, exercising these police powers for such a purpose would require the prior establishment of performance standards specifying at least the amount of runoff requiring detention for subdevelopments of various sizes and types. Alternatively, prescriptive standards describing when and under what circumstances various devices should be incorporated into a subdevelopment would require specification. In view of the current lack of knowledge in this area, attempts to legislate such an approach to flood control would be premature indeed. Further investigation of the issue of on-site detention should be encouraged.

Two analyses were made in designing solutions to reduce the extent of flood-prone areas adjacent to the stream channel. The first was the spatial distribution of land uses within flood-prone areas, and the second was the comparison of the channel's current capacity with that needed to contain a given amount of rainfall.

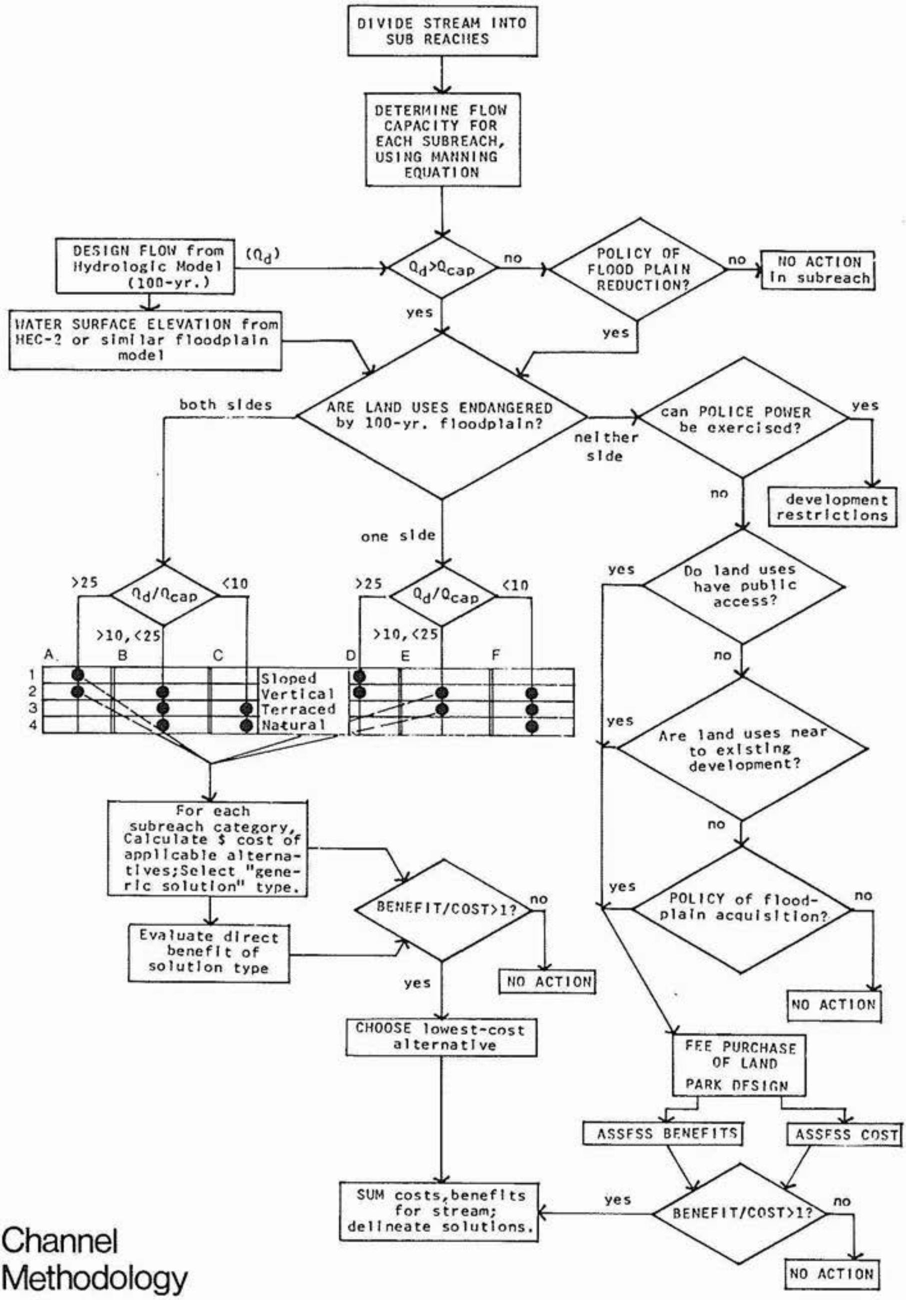
Initially the stream channel from Highway 290 to the confluence was divided into 20 subreaches. The principal criterion for delineating the subreaches was the stream's deviation from a straight path. Of the 20 subreaches, 8 were classified as having severe meanders, 7 were classified as having appreciable meanders, and 5 were classified as having only minor meanders. The subreach segments ranged in length from 4500 feet to 14,300 feet.

The present capacity of each subreach was determined using a variation of the Manning equation (Blackburn et al., 1977). The values for the equation coefficients were provided by the U.S. Army Corps of Engineers. The roughness coefficient (n) was estimated using a technique documented in Chow (1964). The results of this computation revealed flow capacities ranging from as low as 594 c.f.s. to a high of 14,637 c.f.s.

Again on the basis of data furnished by the U.S. Army Corps of Engineers, our group estimated the channel capacities needed to convey floodwaters through the subreaches for the 10-year, 25-year, and 100-year storms. For the 100-year storm, these flows ranged from 17,806 c.f.s. to over 34,000 c.f.s.

As shown in figure 6, the next step in the study was to compute a ratio between the needed capacity (Q_d) and the stream segment's existing capacity (Q_{cap}). If Q_d was not greater than Q_{cap}, then no channel modification would be necessary. If, however, Q_d was greater than Q_{cap}, then flooding would occur. Under existing conditions, Q_d was invariably greater than Q_{cap}.

Each subreach was analyzed to determine which stream segments had adjacent flood-prone land developments. If there were no land-use conflicts, then we recommended that no channel modification be made, unless further study showed a need to provide transitional areas between modified channel segments. Where land-use conflicts did occur, either a "one-sided" or "two-sided" channel modification was recommended. The "one-sided" option was reserved for those situations where flood-prone land uses were found on only one side of the stream channel. If the ratio of Q_d to Q_{cap} for a stream segment was greater than 25:1, more traditional "sloped" or "vertical" channel sections were selected. With ratios of Q_d to Q_{cap} equal to or less than 10:1, more "natural" and "terraced" channel sections were proposed. Clearly, as the Q_d to Q_{cap} ratio decreases, less modification of the channel section will be required. In flood-prone areas where no channel modifications appeared necessary, we recommended public land acquisition or ease-



Channel Methodology

FIG. 6. FLOW CHART OF THE CHANNEL DESIGN RECOMMENDATIONS

ment dedication. This also applied to proposed "one-sided" channel modifications.

The final channel solution combined structural and nonstructural approaches. In retrospect, the location of the nonstructural elements among the subreaches was found to coincide fairly well with current and proposed acquisitions of the Cypress Creek Parkway Project sponsored by Harris County. A total of 41% of the stream channel required structural modification. The total costs of the project were estimated to be about $54 million, giving a benefit to cost ratio of 1.8:1.0. The average annual charges of such a project were further estimated to be about $5 million, with an accrual of average annual benefits of approximately $8.9 million. On the basis of this preliminary investigation, the Galveston District of the U.S. Army Corps of Engineers is conducting further studies.

CONCLUSIONS

It is difficult to make any general comments about floodplain management based on a single study. However, several tentative conclusions can be drawn from our experience. First, results of the hydrologic modeling suggest that the influence of urbanization on flooding in watersheds with flat terrain and relatively impermeable soils is more pronounced with respect to increases in runoff rate than to increases in runoff volume. Second, considerably more engineering and economic research is required concerning on-site stormwater detention. The results of this preliminary investigation suggest that diversified and decentralized combinations of flood control techniques at the subdivision level show the most promise. Third, controlling the discharge of upland stormwater in conjunction with stream channel modifications lessens the risk of instituting flood controls that may become ineffective at some future date. Finally, especially in developing watersheds, careful consideration of adjacent land uses in the process of channel design can facilitate the integration of structural and nonstructural flood control approaches and the provision of recreational open space.

REFERENCES CITED

ANDERSON, J. R. et al., 1972. *A Land Use Classification System for Use With Remote-Sensor Data*. U.S. Geological Survey Circular No. 671, U.S. Government Printing Office, Washington, D.C.

BAVINGER, B. A. and P. G. ROWE, July 1978. "User-Oriented Applications of Speakeasy in the Analysis and Management of Geographic Information," *Proceedings, International Users Conference on Computer Mapping Software and Data Bases: Application and Dissemina-*

tion. Harvard University Laboratory for Computer Graphics and Spatial Analysis.

BEDIENT, P. B., W. C. HUBER, and J. P. HEANY, Nov. 1977. "Environmental Model of the Kissimmee River Basin," *Journal of Water Resources Planning and Management Division, American Society of Civil Engineers* **103**, no. WRZ: 241-256.

BLACKBURN, J. B., P. G. ROWE, et al., Sept. 1977. *A Preliminary Investigation of Structural and Nonstructural Flood Control Alternatives for Cypress Creek, Texas*. A Report to the Galveston District, U.S. Army Corps of Engineers. Prepared by the School of Architecture, Rice University, Houston, Texas.

CHOW, V. T., 1964. *Handbook of Applied Hydrology*. New York: McGraw-Hill.

FISHER, W. L. et al., 1975. *Texas Coastal Geologic Atlas: Houston-Galveston Area*. Bureau of Economic Geology, University of Texas, Austin, Texas.

HOUSTON CITY PLANNING DEPARTMENT, Feb. 1975. *Harris County Population Study*. Houston City Planning Department, Houston, Texas.

HOUSTON-GALVESTON AREA COUNCIL, April 1972. *Population Projections, 1970-2020 for the Gulf Coast Planning Region*. Houston, Texas: Houston-Galveston Area Council.

HOUSTON-GALVESTON AREA COUNCIL, July 1976. *Population and Land Use*. Houston, Texas: Houston-Galveston Area Council.

JAMES VELTMAN AND ASSOC. et al., 1975. *Cypress Creek Basic Watershed Management Plan*. Texas A & M University, College Station, Texas.

MARTIN, H. N., ed., 1976. *Population, Households and Dwelling Units in Harris County Census Tracts*. Houston Chamber of Commerce, Houston, Texas.

ROWE, P. G. and B. A. BAVINGER, 1979. "Constructing a Geographic Information System for Watershed Management," *Rice University Studies* **65**, no. 1:109-123.

U.S. ARMY CORPS OF ENGINEERS, 1972. *Flood Plain Information, Cypress Creek, Texas*. Galveston District, U.S. Army Corps of Engineers, Galveston, Texas.