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July 1985

Mr. Jack Ayer
General Manager
San Jacinto River Authority
P.O. Box 329
Conroe, Texas 77305

RE: Transmittal of San Jacinto Upper Watershed Drainage Improvement
and Flood Control Planning Study
WSA Job No. 040-02

Dear Mr. Ayer:

It is with a great deal of pleasure that Wayne Smith & Associates, Inc. transmits herewith to you a copy of the final report for the Upper Watershed Drainage Improvement and Flood Control Planning Study as prepared for your office under TDWR Contract No. 55-41008.

We have provided an engineering and economic assessment of reasonable alternatives for the primary channels including Spring Creek, Lake Creek, Caney Creek, Peach Creek, West Fork of the San Jacinto River, and the East Fork of the San Jacinto River. The results of these analysis and their resultant estimated costs are tabulated herein.

Utilizing existing flood plain water surfaces generated by the Soil Conservation Service and the U.S. Army Corps of Engineers, we have attempted to generate the relative estimated cost of various improvements to reduce urban flood damage. Preliminary designs, based upon 100-year frequency events for desnagging, selective channelization, addition of a lake or reservoir (particularly sites on Lake Creek and East Fork), bridge modification, total channelization, and buy-out of floodplain structures were examined. It should be pointed out that all proposed drainage alternatives investigated were designed to reduce water-surface elevations principally in urban areas.

The Exhibits detail floodplain reduction for the above referenced scenarios. The water surface elevations were generated by hydrologic and hydraulic models of each of the major streams. The reduction of the floodplain due to the projected improvement and its associated estimated cost are the basis for tabulations included in the text. This tabulation projects urban flood damage reduction versus cost of improvement.

Finally, we are providing to the Authority for its use in future analysis and/or design of certain flood control features, computer tapes of all data from each of the watershed models. These tapes will allow the Authority to update the effects of urban land development, project future water surfaces, and develop drainage programs based specifically to each projected development and its downstream impact on the primary channels.

It has been a distinct privilege and pleasure to have assisted the San Jacinto River Authority in the development of this Drainage Planning Study for the Upper Watershed of the San Jacinto River Basin. We look forward to the opportunity of assisting the Authority in any other efforts where our services might be of assistance.

Respectfully submitted,

WAYNE SMITH & ASSOCIATES, INC.

R. Wayne Smith, P.E.

President

RWS/pjh

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DRAINAGE IMPROVEMENT
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PLANNING STUDY

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WAYNE SMITH & ASSOCIATES, INC.

SAN JACINTO UPPER WATERSHED DRAINAGE IMPROVEMENT AND FLOOD CONTROL PLANNING STUDY

Prepared for

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PROJECT BACKGROUND AND ACKNOWLEDGMENTS

Recognizing the critical need for coordinated drainage improvements in the rapidly developing upper San Jacinto River Watershed, the Texas Department of Water Resources through the San Jacinto River Authority on January 10, 1984 commissioned Wayne Smith & Associates, Inc. to perform this Drainage Improvement and Flood Control Study.

Included with the instructions to the Engineer under this Contract was the objective of developing a plan which would provide much needed drainage relief to the residential areas in the upper watershed. The consultant was to conduct flood control planning studies of the major streams (primary channels) for the upper San Jacinto River Watershed in Montgomery, Liberty, San Jacinto, Walker, Grimes, and Waller Counties. The study area was confined to the main natural drainage (primary) channels of Spring Creek, Lake Creek, Caney Creek, Peach Creek, Luce-Tarkington Bayou, West Fork of the San Jacinto River, and the East Fork of the San Jacinto River. The West Fork of the San Jacinto River above Lake Conroe was excluded. Since the focus of the report was drainage relief on residential areas (urban flood reduction) and due to extenuating circumstances (out of basin flow, Luce Bayou Diversion Project, etc.), Luce-Tarkington Bayou was eliminated later in the study. Toward that end and contained herein are the conclusions for drainage improvements of the major streams (primary channels) for the upper watershed. In addition, this report contains descriptions, plan views, profiles, preliminary cost estimates for alternative means of providing drainage in the primary channels for and through the upper watershed.

Wayne Smith & Associates, Inc. wishes to express its sincere appreciation for the cooperation and assistance received from the Director and Staff of the San Jacinto River Authority, Texas Department of Water Resources, Soil Conservation Service, U.S. Corps of Engineers, U. S. Bureau of Reclamation, Harris County Flood Control District, Montgomery County Engineers Office, Cities of Houston, Conroe and Cleveland, Rice University, and the numerous individuals who serve the watershed communities and have assisted and/or made their files available to this study.

SAN JACINTO UPPER WATERSHED DRAINAGE IMPROVEMENT AND FLOOD CONTROL PLANNING STUDY

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CHAPTER 1 - INTRODUCTION

Purpose and Scope

This report presents the results of the drainage improvement and flood control planning study for the primary channels of the Upper Watershed of the San Jacinto River. The purposes of the study were: (1) develop a comprehensive plan to provide storm water drainage by the primary channels for the flows generated by runoff from the existing urban and undeveloped areas of the watersheds, (2) develop drainage improvement recommendations for the watershed, (3) to evaluate alternatives to the rectification of flooding problems on the major streams (primary channels) within the study area, and (4) develop appropriate design criteria to provide area drainage authorities the information necessary for control. The major streams (primary channels) examined were the West Fork of the San Jacinto River, Lake Creek, Spring Creek, East Fork of San Jacinto River, Caney Creek, and Peach Creek.

The scope of the drainage analysis and study for the primary channels of the upper San Jacinto River watershed includes the following elements:

1. The collection of:
 - (a) pertinent field survey data
 - (b) existing flood plain analysis
 - (c) drainage characteristics of the watersheds
 - (d) hydrologic data
 - (e) hydraulic terminations
2. Performance of the necessary surveys:
 - (a) to determine the current information of all existing drainage systems
 - (b) existing cross-sectional data for the primary channels
3. The conduct of hydrologic analysis of the watershed necessary to develop the preliminary designs of the alternatives for primary channel rectification.
4. Conduct of the hydraulic analysis of the existing proposed primary channel system improvements including the alternatives for improving capacity.
5. The analysis of flood damage reduction techniques total channelization, selective channelization, desnagging, bridge modification, buy-out of floodplain structures, and lake reservoir analysis. This analysis includes an estimation of quantities and construction costs.
6. Examination and recommendation of basic design criteria and applicability to Upper San Jacinto River Watershed.

Authorization

Authorization for the drainage improvements and flood control planning study of the Upper Watershed of the San Jacinto River is based on Terms of an Agreement between Wayne Smith & Associates, Inc. and the San Jacinto River Authority dated January 10, 1984.

Arrangement of the Report

The objective of this presentation of the findings is a report which will be convenient reference of drainage information required by laymen, municipal and county officials, and by design engineers. In order that this be as useful a tool as other drainage studies, an attempt has been made to make the structure and the layout presentation similar to the style which has been previously developed in the preparation of previous drainage reports on other watersheds. In the exhibit section of the report, existing conditions and the proposed improvements are shown in plan and profile views. The following summaries describe the contents of each chapter.

Chapter 1—Introduction

Chapter 2—Background Considerations. The limits of the study and the factors that influence drainage in the watershed are described in this chapter.

Chapter 3—Design Concepts and Considerations. The design concepts, design criteria, and the basic data which were used to analyze the drainage facilities are contained in this chapter.

Chapter 4—Presentation of Findings. This chapter presents an inventory of the capability and adequacies of alternatives for storm drainage facilities, a discussion of the alternatives, the affect of the alternatives, and the benefit of the alternatives are also presented in this section.

Chapter 5—Conclusions. This chapter presents in an abbreviated form the final results, determinations, and evaluations of the study.

Chapter 6—Recommended Design Criteria. A basic approach to standardization of drainage design within the study area is presented. Appropriate design criteria is provided for use and adoption by drainage of officials.

Report Designation System

An important element of this study was the development of a designation system for the primary channels and improvements considered in the work. The system used assigns letters (two) to each major study element or watershed, which also becomes the designation of the primary drainage channel within that element. For example, the West Fork (San Jacinto) Watershed is study element WF and West Fork (San Jacinto) primary channel is also designated WF.

Each of the primary channels has been subdivided into stream segments, usually four or five segments. These segments have been identified by number 1 through 4 or 5, with lower numbered segment being the mouth and the higher numbered segment being the headwaters. For instance, the designation WF-1 indicates the lowest (mouth) reach of the West Fork (San Jacinto).

Primary channel existing conditions, improvement concepts, and stream profiles, have been given large case letter identification, A through H. An index to the letter assigned to each improvement follows.

An example is the designation WF-1A. The letter A identifies the exhibit as being the original flood plain plan view prior to any improvement. Hence WF-1A identifies West Fork (San Jacinto) stream segment 1 original flood plain plan view.

Primary Channel Designations

- WF West Fork
- LC Lake Creek
- SC Spring Creek
- PC Peach Creek
- CC Caney Creek
- EF East Fork

Stream Segment

- 1 Segment No. 1, Mouth
- 2 Segment No. 2, Intermediate
- 3 Segment No. 3, Intermediate
- 4 Segment No. 4, Headwaters

Improvement, Concept, Etc.

- A Existing Flood Plain
- B Total Channelization
- C Selective Channelization
- D Desnagging
- E Bridge Modification
- F Buy-Out of Flood Plain Properties
- G Lake — Reservoir
- H Profiles

CHAPTER 2 - BACKGROUND CONSIDERATIONS

Introduction

The Upper San Jacinto River Watershed is an area of 1,200 square miles consisting of all of Montgomery County and parts of Waller, Grimes, Walker, San Jacinto, and Liberty Counties. The southern most boundary of the Upper San Jacinto River Watershed is the Harris County line. The Upper Watershed consists of seven major streams. These streams are the West Fork of the San Jacinto River, Lake Creek, Spring Creek, East Fork of the San Jacinto River, Caney Creek, Peach Creek, and Luce-Tarkington Bayou. In the analysis of the drainage system the primary considerations, were the need to provide adequate outfall capacity for these major streams (primary channels), particularly in urbanized areas. Also, the size and topography of the watershed, standard hydrologic techniques, existing urbanization, and possible primary channel drainage improvements were considered. Two additional but lesser considerations were active ground faulting and subsidence due to groundwater withdrawal.

Topography

The topography of the watershed ranges from rolling hills in the west and north to the flat coastal plain in the south and east. Extreme flow-line elevations range from 120 to 140 feet in the north and west to approximately 35 to 40 feet in the south and east. Average slopes across the watershed are in the range of 0.4 to 0.6 feet per thousand feet, with slopes as low as 0.2 per thousand feet in the south and east to slopes near to 0.6 to 0.7 per thousand feet in the west and north. Generally, this lack of watershed slope in the lower reaches, south and east, has serious impact on abilities of the streams to drain storm water. With little available hydraulic gradient, water velocities are relatively low and, under existing conditions, ponding and flooding in the lower watershed are often widespread after storms. Hydraulic improvements to the drainage system alter natural stream patterns by increasing flow velocities and reducing ponding. Existing channels in the area are narrow meandering coastal stream type incised to a depth of 15 to 20 feet. Even before urban development in the watershed, these type channels did not have adequate capacity to transport the runoff from large storms. However, since the majority of the property or area is rolling hills with tremendous relief between the sides of the hills and the flow line of the streams, the resulted shallow flooding in urbanized areas is limited to those areas currently within the 100 year floodplain. Those areas currently with the largest degree of flooding are those such as River Plantation, below the confluence of the West Fork of the San Jacinto River and Lake Creek, and those urbanized areas along Spring Creek, generally in Harris County.

A local influence on the topography in drainage of the watershed is the existence of geological faults. These faults, many of which were formed by sedimentary loading in the rise of salt domes, maybe stimulated by the withdrawal of oil and underground waters which triggers compaction rates in the sub-surface clays. Generally, the vertical movement of most of these faults in the study areas are on the order of 0.25 to 0.50 inches per year. Active faults in the area move slowly and continuously. The existence and location of faults in the watershed have been documented by the United States Geological Survey Open File. The impact of these faults on storm water drainage is local to the immediate area of the fault. In poorly drained open areas, water may be ponded on the throw-down side of the fault. The differential height of the up-throw and downthrow ranges from approximately 0.33 to 0.67 meters for most recognizable faults in the watershed. This small difference does not significantly impact the overall drainage runoff.

Consideration of faults is most important in development of drainage for areas which straddle or abut the faults. With field investigation, the alignment of earthen ditches or other improvements along fault lines may be considered as an alternative land use to minimize the danger of differential movement which would have little impact on earthen channels.

Climate

The maritime climate of the Gulf Coast Region contributes to the severity of flooding in many of the watersheds. Annually the area receives between 40 and 50 inches of rainfall. Intense rainfall events which generate high peak flows are common. And, in some instances, the uneven distribution of rainfall intensities results in varying depths of runoff between local areas. Unofficial rainfalls range as high as 9.37 inches in a six-hour period. The flat topography of the lower reaches of the watershed can cause the drainage boundaries served by existing streams to vary depending on the distribution of the rainfall intensity.

Flash flooding may accompany extreme rainfall events and is caused by heavy rains falling over small areas where local drainage facilities cannot carry away the excess water without overflow. System floods or basin floods develop more slowly. Runoff from smaller tributaries gather into the larger streams until capacity is exceeded. Water velocity is not the main cause of destruction in river system flooding. The currents within the channels maybe strong, but the damage is caused by floodwater overflow, which has a competitively weak current. Flash flooding is generally responsible for loss of life. River system flooding inundates an extensive area with storm water that may stand on land for several days causing economic loss through property destruction.

In addition to the frequent severe rainfall conditions, seasonal hurricanes are a potential cause of severe flooding problems. Hurricane Carla, the largest recorded tropical storm to come ashore along the Texas Coast, occurred in September of 1961. Rainfall measured in Galveston was 16.23 inches. Rainfall associated with hurricanes is generally very intense resulting in high peak flows. Since all of the property within the study area is above elevation 20, problems associated with a normal hurricane storm surge, which generally is considered to be related to elevations of 20 feet and lower, do not significantly impact the region. In addition, the lower extremities of the study area are protected by Lake Houston from hurricane surge.

Urbanization

Generally, less than five percent of the total land area of the watershed is developed for residential, industrial, and commercial use. Most of the towns and cities within the watershed are relatively small. Exceptions being Huntsville in the northern extremity, Cleveland in the eastern extremity, and Conroe in the south central. An additional large development in the very southern extremity of the area is the unincorporated area of the Woodlands. Because of transportation amenities and prevailing land costs, the southern end of the watershed is one of the fastest urbanizing watersheds in the Country. As more of the land is converted from oil fields and agricultural uses to urban land, the characteristics of flood

hydrographs can be expected to change to reflect greater extent of impervious area and will require a more efficient drainage system to collect and transport runoff.

Higher peak flows associated with greater degrees of urbanization require larger drainage structures to protect against flooding with the same frequency of rainfall as the undeveloped watershed. However, should the subdivisions be planned developments, such as the Woodlands, many of these factors are controlled and discharges from the Woodlands are no higher today than they were years ago in the undeveloped stages. However, it should be pointed out that without the planning efforts done by communities such as the Woodlands and with most of the current development in the southern and eastern extremities of Montgomery County, watershed flooding problems may be greatly enhanced by urbanization.

Historical Subsidence

Land surface subsidence has become a critical factor in many areas of the Gulf Coast Region. To date, subsidence in the watershed has been relatively minor with most subsidence in the southern and eastern extremities. However, as urban development continues to grow, we expect to see greater and greater amounts of ground water withdrawn from the aquifers which will then generate a decrease in subsurface hydraulic pressures. This pressure difference between the sand and clays will cause the water to move from the clay layer draining the clays and compacting them. Most of this compaction is permanent, and less than 10 percent of lost clay volume can be restored even if subsurface water pressure is restored.

We anticipate, with the rapid development and rapid removal of ground water, greater and greater amounts of subsidence in the southern extremities gradually moving north with urbanization. Generally, subsidence levels since 1900 have been less than 4 feet with some areas on the southern extremities along Spring Creek and near Lake Houston in the 4 to 6 foot range. Almost all subsidence has been restricted to the lower extremities of the watershed.

Importance of Adequate Planning

A comprehensive plan of storm water management is essential in providing minimum levels of flood protection in the Upper San Jacinto River Watershed for the following reasons:

1. Urbanization has the potential to increase the peak flows from storm water events and thus increase the potential for greater property damage from flooding.
2. Primary and secondary elements of drainage systems must be analyzed and designed to function dependently in order to achieve the most efficient and effective design. Thus the primary element must be defined and outlined.
3. Right-of-way and reservoir land acquisition should occur while the land is open and available.
4. Establishment of capital requirements allows adequate financial planning by Municipal, County, and State governments.
5. The future development of subdivisions and the approval of the plans for drainage facilities can be reviewed on the basis of a comprehensive plan of action.

CHAPTER 3 - DESIGN CONSIDERATIONS

Introduction

The purpose of this study is to develop a plan of drainage improvements that will result in a unified system throughout the Watershed. Design of the system is to be based on consistent criteria uniformly applied. The basic concepts that led to the formulation of the criteria and define the approach to the study are described in this section of the report.

Basic Data

To implement the study, the following were sources of basic data for the development of analysis of the existing conditions within the Upper San Jacinto Watershed.

1. Soil Conservation Service - 100-year water surface data in Montgomery and Liberty Counties, WSP-2 water surface profile computer model, and TR-20 flood hydrograph computer models.
2. Corps of Engineers - Stream cross-section data, HEC-2 water surface profile computer model, HEC-1 flood hydrograph model, and economic analysis computer model.
3. Bureau of Reclamation - Reservoir data and economic analysis of Lake Creek and East Fork Reservoirs.
4. State Department of Highways and Public Transportation Aerial photography of watershed and adjacent areas at scale 1" = 2,000'. Three separate flights 1978, 1979, 1982.
5. Montgomery County - County wide block maps, land use data, existing drainage improvements, and data on design practices and criteria.
6. Harris County - Existing flood plain data on Spring Creek, land use data, and data on design practices and criteria.
7. City of Houston - Existing data on Lake Houston, expertise on Luce Bayou Diversion, and data on design practices and criteria.
8. Mitchell Development Corp. (Woodlands) - Drainage plans and profiles for existing drainage improvements, and data on proposed improvements and impoundments within the Woodlands.
9. Rice University - Main frame computer modeling, land use computer modeling, rainfall intensity evaluations, and economic analysis evaluations.

Rainfall Runoff Relationships

A fundamental consideration in design of drainage improvements is the determination of the amount of storm water flow that will occur for certain conditions. Drainage improvements are usually designed for the specific rainfall occurrence called a design storm. Since rainfall records for most areas are extensive and available, the pattern amount of rainfall that can be expected to occur at given intervals of time are relatively predictable.

Rain falls on a drainage area and moves over the land surface until it enters a defined drainage channel, and then it flows downstream. The theoretical response of a drainage area to a rainfall is a storm hydrograph, Figure 1. There is a different storm hydrograph for each separate storm or rainfall occurrence.

In addition, physical changes in a drainage area produce changes in the hydrograph for the same occurrence. In order to predict a storm hydrograph resulting from a known rainfall, there must be a fundamental understanding of a rainfall runoff relationship. This relationship is best explained by the theory of unit hydrographs.

A unit hydrograph is the response of a drainage area to a one inch rainfall occurring in a specified period of time called a unit storm or unit rainfall. For example, a rainfall of one inch in one hour would result in a one hour unit hydrograph, Figure 2.

Unit hydrographs can be calculated from records of rainfall and runoff occurrences. However, often the scarcity of rainfall and runoff records along with the need to establish design criteria in areas for which records do not exist have led to the development of the synthetic unit hydrograph. This method relies on establishing a relationship between certain key hydrograph parameters usually the peak flow, time to peak, and physical characteristics of the drainage area. In this way, a unit hydrograph for a drainage area can be established from known drainage area parameter such as area, length of the channel, average slope, shape factors, and so on. Several synthetic hydrograph methods have been developed and used.

The unit hydrograph of a drainage area whether obtained from rainfall, runoff records, or synthetic method can be used to estimate the probable storm hydrograph for any rainfall. This is possible since the storm hydrograph can be viewed as a composite comprising a series of storm hydrographs resulting from successive one hour rainfall amounts, Figure 3. Each overlapping one hour storm hydrograph can be calculated from the unit hydrograph, since the ratio of the storm rainfall amount in each hour of the increment to the unit rainfall amount is the same as the ratio of the corresponding one hour storm hydrograph to the unit hydrograph, Figure 3. The overlapping of one hour storm hydrographs can then be added to produce the composite storm, Figure 4.

Design Storm

The second basic consideration is the selection of the design storm. The significant factors involved are the amount of rainfall, the intensity of the rainfall, and the duration of the storm. Storm pattern is represented by a hyetograph, which is a plot rainfall intensity versus time. The area under the hyetograph represents the total volume of rainfall, Figure 5. Drainage improvements must be designed for a maximum flow that results from the selected design storm. Therefore, the total amount of rainfall over the duration of the storm is not as significant as the intensity of rainfall in effecting the design of drainage improvements. The key consideration, however, is to select a design storm that closely approximates actually observed storm patterns. The severity of storms is usually expressed in terms of the statistical frequency of occurrence or recurrence interval. The recurrence interval of a storm is the average length of time between two equal occurrences. For example, a 10 year storm is one that can be expected to occur on the average of once every 10 years. Recurrence intervals are necessarily based on past records and although there are discernable patterns of weather occurrences an actual storm is unpredictable. This means that while a 10 year storm can be expected to occur 10 times in a hundred year period, more than one could conceivably occur in a single year during the hundred year period.

FIGURE 1
TYPICAL STORM HYDROGRAPH

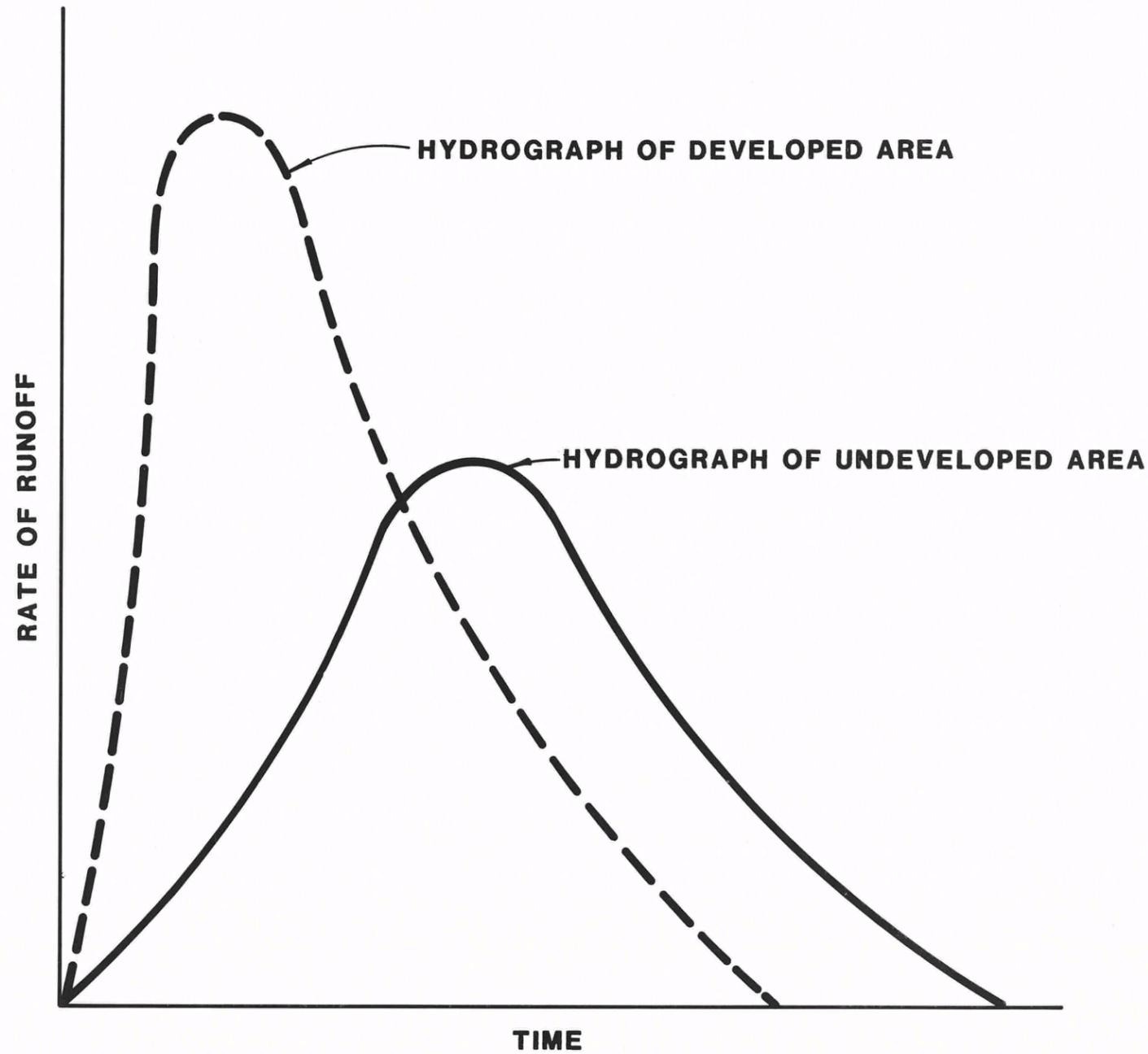


FIGURE 2
ONE HOUR UNIT HYDROGRAPH

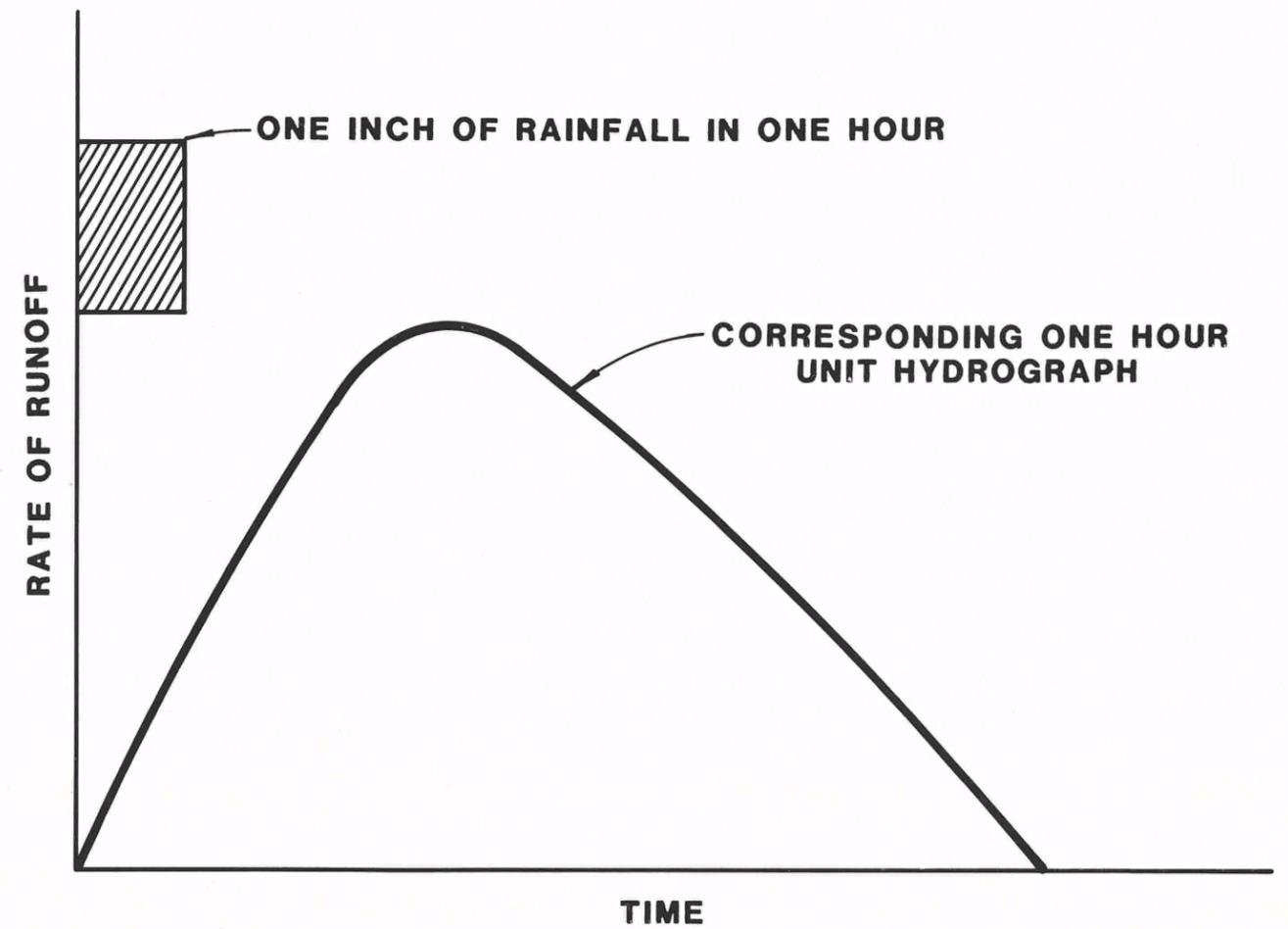


FIGURE 3
STORM HYDROGRAPH

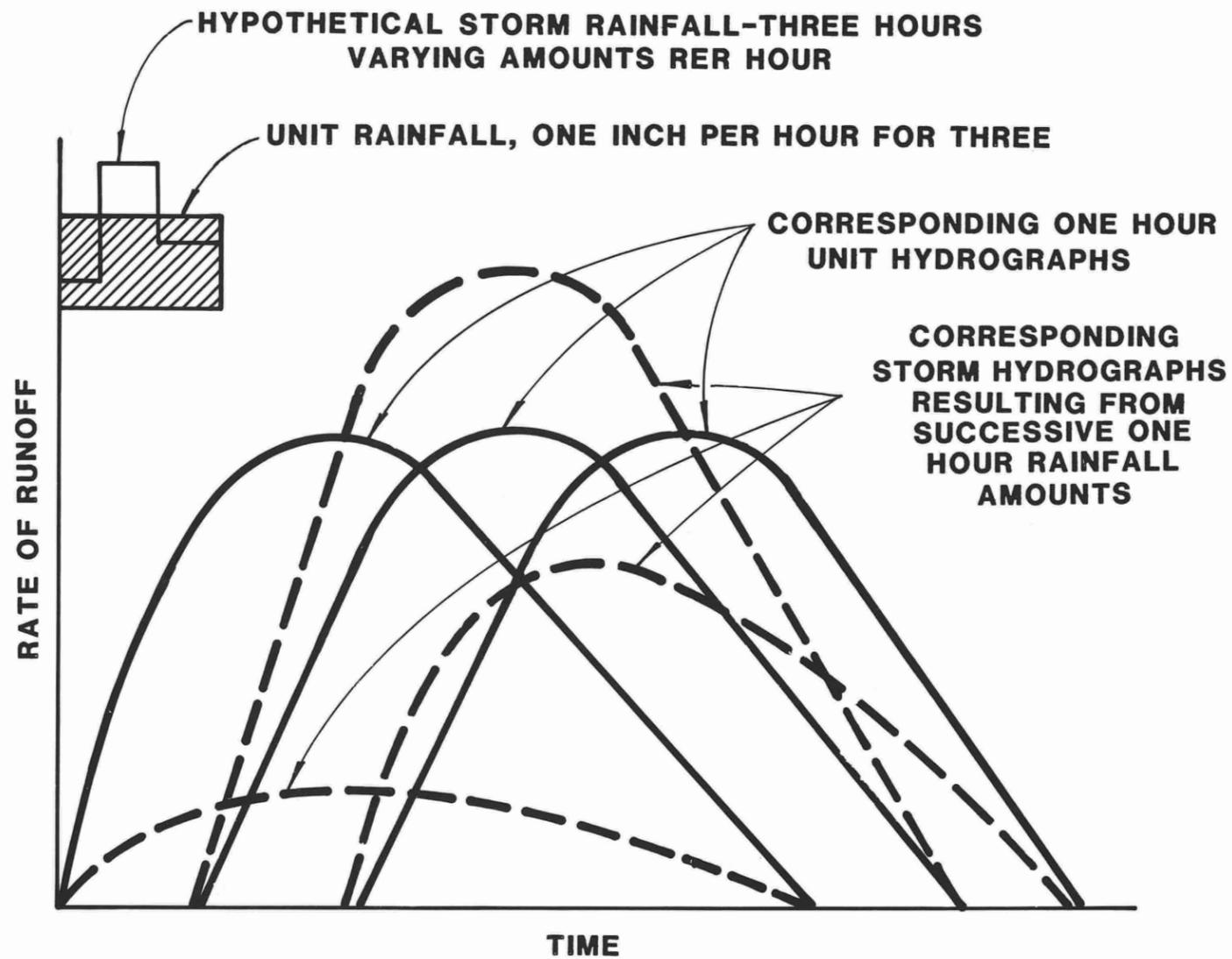


FIGURE 4
COMPOSITE STORM HYDROGRAPH

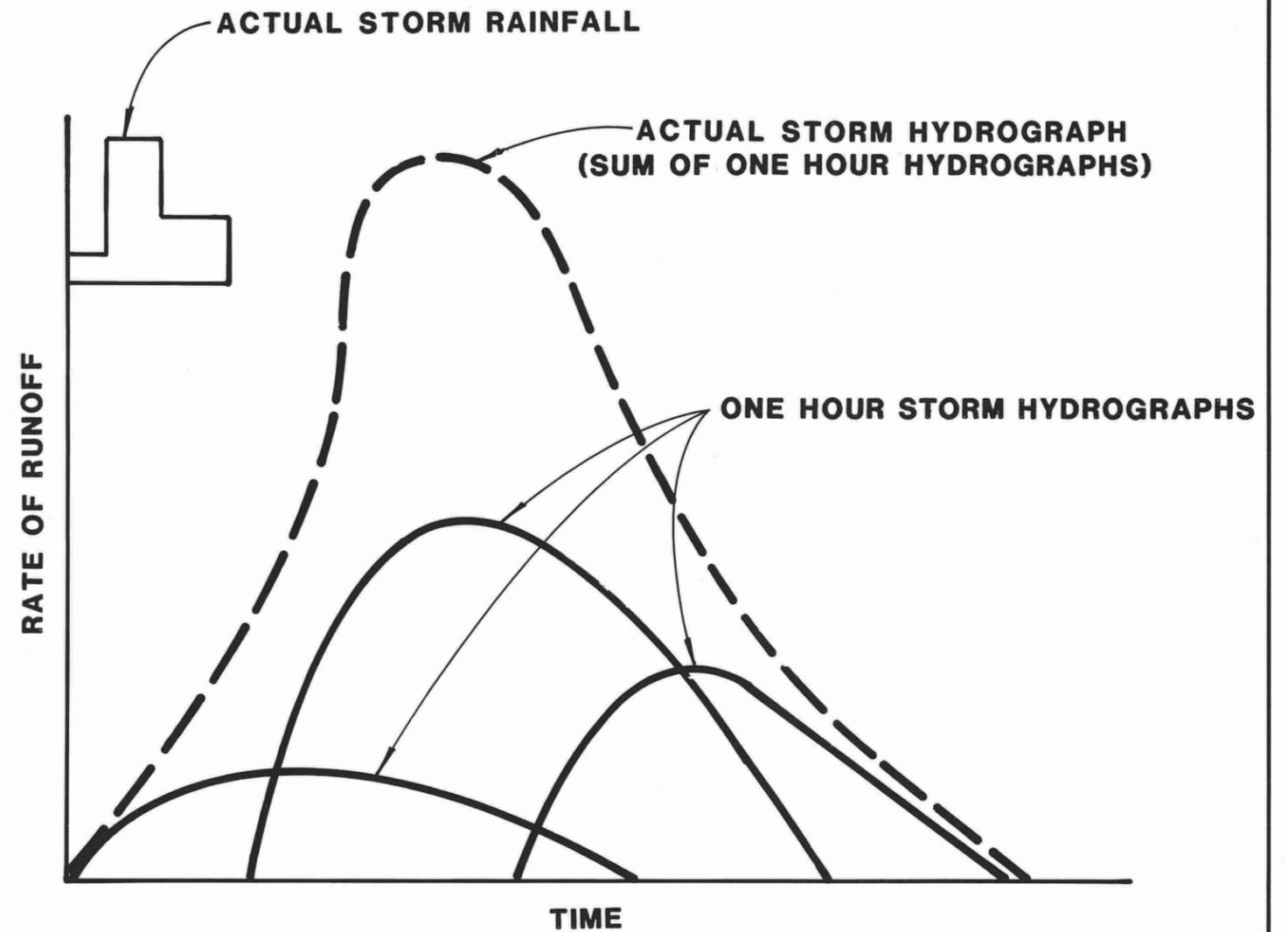
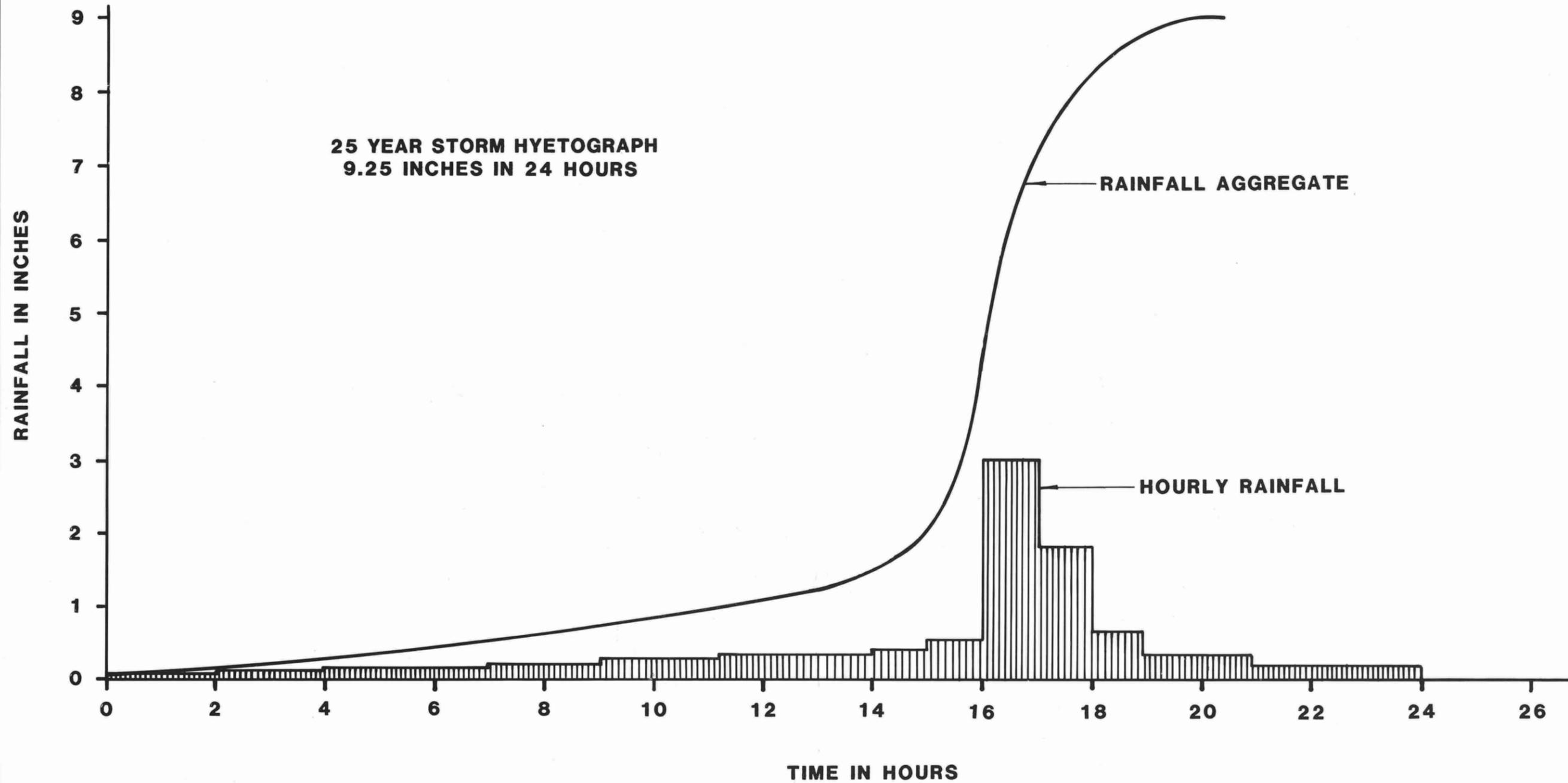


FIGURE 5
DESIGN STORM HYETOGRAPH



Frequency Considerations

Drainage improvements in the Gulf Coast area are commonly designed from storms of 2 to 25 year recurrence intervals depending on the size and significance of the channels storm sewer. More severe occurrences such as the 50 and 100 year storms are considered a flood control problem, and design improvements to handle runoff on these storms is limited to the primary channels. The primary drainage channels considered in this study will form the basic drainage network for the watershed. Furthermore, most recommended improvements will be unlined open channels draining large areas. Under these circumstances and using a conservative basis of design and since all of the drainage improvements will be primary channels, basis for design was considered to be the 100 year storm. It has been a general experience in the Gulf Coast area that open channels designed on this basis facilitate maximum use of storm sewers and laterals. Storm sewers or smaller open channels such as oversized ditches can then be designed for less severe occurrences. Most convenient means of selecting the proper design storm for secondary systems is by size of the drainage area. Table 1 contains a suggestive guideline for the selection of a design storm for secondary drainage systems.

Table 1

SECONDARY DRAINAGE SYSTEM

DESIGN STORM

Area in Acres	Suggested Recurrence Interval of Design Storm
50 and less	2 years
100 to 500	5 years
500 to 1,000	10 years
1,000 and over	25 years

Drainage System Functions

An urban drainage system consists of three basic elements: (1) the primary channels, which include major natural streams and bayous; (2) the lateral outfall channels, which are tributaries of the primary channels and serve smaller areas and together with the primary channels comprise a basic drainage network; and (3) the secondary system of storm sewers, small ditches, roadside ditches, etc. in developed areas. The primary outfall channels are the subject of this study, and all the detailed design of secondary system improvements are not. However, the evaluation of the secondary system requirements both for existing urban areas and for future conditions is often an essential requirement for the design of an adequate

system for primary channels.

The key elements of any drainage system are the primary channels which serve dual functions. As indicated, they are the final collector of storm runoff and as such determine the adequacy of lateral outfall channels and secondary systems. In addition, they perform vital flood control functions since storm runoff for the entire watershed concentrates in the lower reaches of these channels.

Design of primary channel improvements is therefore more complex than the design lateral channel improvements and is complicated by the unique characteristics of each channel. The basis of design for primary channels is described in the following paragraphs.

In general, the pertinent characteristics of the primary channels in the study area can be summarized as follows:

1. Primary channels are natural water courses that drain the large watersheds and have not been significantly altered from their natural state.
2. Natural channels lack sufficient capacity to carry the runoff from generalized storms over the watershed even for undeveloped conditions. Areas adjacent to the channel are then subject to periodic overflow of storm water. Areas subject to such overflow are defined as the floodplain. Included within the floodplain may be an overflow area immediately adjacent to the channel bank. It actually contributes to the channel flow during the storm. This temporary channel area is defined as a floodway. The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment in order that the 100-year flood be carried without substantial increases in flood heights. Minimum standards of the FIA limit such increases in flood heights to one foot, provided that hazardous velocities are not produced.
3. In some instances the primary channel may be characterized by the existence of a well defined high bank. The area below the high bank is frequently referred to as the natural floodplain, since it is subject to frequent overflow.
4. The extent of the floodplain varies depending on the severity of the storm occurrence and the capacity of the channel. Improving the channel will, of course, reduce the extent of the floodplain for a given storm occurrence.
5. The areas along the primary channels remain largely undeveloped or sparsely developed.

These primary channel characteristics, particularly the existence of the natural floodplain, contrasts with the conditions in the remainder of the watershed. Primary channel improvements studied by this report are designed to satisfy the following condition, and that is to avoid flooding of existing urban development by the design storm. The design approach to meet these conditions starts with the definition of the maximum acceptable design water surface along the length of the primary channel. The maximum acceptable water level defined in this way exceeds the low bank of the channel and creates a floodplain defined as the design floodplain, which includes a design floodway along the channel. The objective of the primary channel design can be stated as finding the minimum necessary improvement that will accommodate the runoff from the design storm within the design floodway cross section while reducing the overall floodplain.

The concept of a minimum necessary improvement means that in some instances the existing channel may have adequate capacity and require no improvement. However, in most other instances, improvements must be recommended. The necessary improvements are sized on the basis of backwater computations for the design storm until the minimum necessary improvement which satisfies the design objective is found. It should be emphasized that the recommended minimum necessary improvement is for the design condition defined in this study, the 100 year storm, and that more severe storm occurrences will result in a more extensive floodplain than the one shown in the exhibits, for example: the 500 year storm.

Primary Channel Alternative Considerations

The improvements considered as the basis of this report are: (1) total channelization; (2) selective channelization; (3) desnagging; (4) bridge modification; (5) buy-out of floodplain structures; and (6) lake or reservoir. A general discussion of each of these various improvements follows:

Total Channelization: The most important requirement for total channelization was to maintain the 100 year event water surface within the existing high banks of the primary channel. In order to reduce the amount of right-of-way necessary to handle these magnitude of flows, an arbitrary channel of 300 to 600 feet in width, 3:1 side slopes and approximately 30 feet of depth was selected. Since the value of land (ie. right-of-way) was not considered in the cost analysis, the excavation estimates are reflective of true channel requirements whether the approximate channel be 300 feet by 30 feet or 700 feet by 10 feet.

Selective Channelization: The primary factor impacting selective channelization was urban growth in and/or adjacent to 100 year flood plain. Since it is impractical to deepen the existing primary channel over short segmented distances, the primary channel bottom was established as the existing stream bottom. Establishment of the channel bottom dictated the use of a levee system to form the channel and protect flood plain built structures. Urban secondary drainage systems and tributary streams would require pumping, detention basins, and/or a positive means of preventing backflow during high water conditions in the primary channel. An initial quick cursory review indicated that backflow prevention by flap gates has high potential. However, before any design is undertaken various conditions of rainfall distribution and runoff, including conditions outside the scope of this project, be examined to determine exact timing of the crests along primary channel. This would require that crests of tributary and urban drainage systems be evaluated for the best method of joining tributary streams with the selectively channeled primary stream.

Desnagging: The essence of desnagging is to remove all underbrush and small trees less than 4-inches in diameter within the high bank area of the primary channels. The removal of this growth is to reduce the drag (roughness co-efficient) and thereby speed the rate of flow down the primary channel. As indicated in the presentation of findings, results vary from minor improvement of water levels to minor degradation of water due to peak crest timing impacts downstream.

Bridge Modification: Examination of the flood plains on the various primary channels indicated instances where bridges, railroad and/or highway, appeared to be obstructions to high water flows. These bridges were modified by increasing heights or span lengths or both as applicable to eliminate the obstruction. The impact of this modification was then computer modeled. Generally, bridge modifications have only minor localized effects, some beneficial and some detrimental to downstream developments.

Buy-out of flood plain structures: While not considered a modelable option and obviously having little to no impact on flood plain reduction, buy-out was examined as a viable option for flood damage reduction. Often when large numbers of structures are located deep within the flood plain and are impacted by low level flooding, 3, 5, 10 year frequency events, the most cost effective option, especially with long length primary channels is to buy-out the structures and create recreational and/or park property designed for periodic inundation.

Lake-Reservoir: Creation of a lake or reservoir for flood control purposes or a multipurpose reservoir (water supply, flood control, recreation, etc.) has been a proven method for flood damage reduction. At least one lake-reservoir for each primary channel has been modeled under the scope of this project. When

possible, the lake-reservoir modeled was being considered by others. For example, large scale multipurpose reservoirs on Lake Creek and the East Fork are being examined by the Bureau of Reclamation. Utilizing data provided by the Bureau and with their assistance, a portion of these reservoirs was reserved for flood control for simulation purposes and modeled as such with respect to downstream flood damage reduction. Small reservoirs were modeled on the remaining primary channels. While these small reservoirs have minor impact on 100-year frequency events, smaller storms (5 to 10 year) can often be attenuated and reasonable economic benefits of urban damage reduction attained.

CHAPTER 4 - PRESENTATION OF FINDINGS

Introduction

The study was developed to be a planning level analysis rather than a design study. The large study area, the budget, and time schedule allowed a preliminary examination of 86 different cases. The goal of the project was to identify the most promising flood control alternatives, which could then be examined further during any detailed design work. This project provides a broad examination of the flooding problems in the San Jacinto River Basin.

The scope of the project was considerable. Over 225 miles of stream were analyzed with 369 stream cross sections and 62 bridge crossings. Fortunately, data from the FEMA (Federal Emergency Management Agency) floodplain study was available, decreasing the amount of analysis that had to be developed from original sources. Existing data had to be obtained from several sources, converted to run on the Rice University computer, and then adjusted to match with the official FEMA results.

After matching the existing FEMA floodplains the flood control alternatives were examined. The results were to be judged on two criteria: the effect on lowering the existing 100 year floodplain, and the ratio of economic benefits to the costs of the project.

The effect of each alternative was evaluated by developing floodplain maps showing the change in the 100 year FEMA floodplain. Flooding profiles showing the 100 year flood evaluation versus stream distance were also developed.

The calculation of economic benefits of urban flood reduction required analysis of other types of storms besides the 100 year frequency flood. The 25 year, 10 year, and 2 year storm events were analyzed for each case to determine each alternative's ability to control the smaller, more frequent events. An analysis of the relative contribution of different storm sizes indicated that the smaller storms were responsible for greater annual damages than the 100 year storm when averaged over a long time period.

A graphical method developed in Australia was used to convert the hydrologic, hydraulic, and flood damage data to annual economic benefits from any alternative (Shaw, 1983). For four of the streams, the U.S. Army Corps of Engineers (Corps of Engineers) provided flood damage data from extensive flood damage simulation modeling of the area. For the other two streams, an original method based on recent aerial photographs and topographic maps was employed to obtain flood damage data.

Cost data for each alternative was developed and converted to an annual cost using economic assumptions used by the Corps of Engineers. The annual costs were compared to the economic benefits data to give benefit-cost (B/C) ratios. A B/C ratio greater than 1.0 indicated a positive economic return on the project. A B/C ratio less than 1.0 showed the cost of the project exceeded the economic benefits of the resulting flood control.

These two products, the resulting 100 year floodplain, and the benefit-cost ratios indicate the technical and economic merit of the flood control alternatives for each stream. These results are intended to show which alternatives should be considered first for a detailed evaluation.

For more detail on the technical methods and assumptions used for this project see Appendix A.

Watershed Results

WEST FORK SAN JACINTO RIVER

Description of Watershed and Floodplain:

The West Fork of the San Jacinto River is comprised of four major watersheds: Cypress Creek, Spring Creek, Lake Creek, and the West Fork (Figure 6). Both Cypress and Spring Creeks join the West Fork near Lake Houston and are relatively independent hydrologic systems. Lake Creek joins the West Fork approximately in the middle of the West Fork watershed and is a significant factor in West Fork hydrology. For this project, separate computer models were used for Spring Creek, Lake Creek, and the West Fork (Cypress Creek was not included in the project), and the effect of Lake Creek was accounted for in the West Fork hydrologic model. For this report the term "West Fork" will generally refer to the actual West Fork main channel from Lake Houston to the Lake Conroe dam and not Spring, Cypress, or Lake Creek, which drain into the West Fork.

The West Fork extends from Lake Houston in Harris County to northern Walker County. Most of the 956 square mile watershed (including Lake Creek) lies in western Montgomery County. The two most significant hydrologic features are Lake Creek, the largest tributary with a 327 square mile watershed, and the Lake Conroe reservoir. Lake Creek drains into the West Fork upstream of the I-45 crossing over the West Fork. Lake Conroe is a 31 square mile impoundment that drains 445 square miles of cropland and national forest. The 409,600 acre-ft. of storage are used for municipal and industrial water supply and recreation. The operation of the dam can affect the downstream flowrates for even very large storms, even up to the 100 year return period.

The West Fork watershed is primarily forest land or agricultural land with a small but rapidly growing urban component. The 1970 land use distribution was: (HGAC, 1980):

Land Use	Percentage of Total Area
Forest	79
Pasture	13
Cropland	4
Water	3
Urban	1.2

By 1990 the urban component is projected to increase to 3.1 percent of the total watershed area. Most of the new development is expected to occur in the Southern portion of Montgomery County (Rice Center, 1978).

Soils:

Three major general soil units are found in the West Fork watershed. A thick, fine sandy loam with relatively high permeability is found in most sections of the watershed. A dark, expansive clay outcrops in two wide bands which run east-west across the watershed, the first on the northern edge of the basin in Walker County, and the second running through the Lake Conroe area. These clay bands support most of the pasture land and agricultural land uses, and have a relatively low permeability. The third major soil unit is alluvial soil of the West Fork floodplain. This unit represents a wide mixture of sands and clays with varying infiltration characteristics (Soil Conservation Service, 1982)

Stream Channel Characteristics:

The West Fork stream channel varies from a very wide, shallow channel near the mouth of Lake Houston to a slightly steeper, narrower channel near the Lake Conroe dam. The floodplain is generally very heavily wooded and has a relatively high hydraulic resistance to overbank flows. A typical main channel cross section is from 12 to 25 feet deep and 200 to 600 feet wide. The main channel is flanked by an extensive 100 year floodplain (defined by the FEMA floodplain survey conducted by the Soil Conservation Service) that ranges from 1 to 2 miles in width.

Six bridge crossings affect the hydraulic efficiency of the West Fork channel. At the I-45 crossing three of the bridges are adjacent: the northbound and southbound spans of I-45, and an older railroad trestle downstream of the highway. The railroad trestle was originally thought to be responsible for constricting flood flows and increasing the upstream 100 year floodplain (see Bridge Modification). Results of the study indicate none of the bridges had significant impact.

Hydrologic Characteristics:

During large, infrequent storms the West Fork is dominated by discharges from Lake Conroe dam. The inflow into Lake Conroe is generated by a 445 square mile basin, or 47 percent of the entire West Fork watershed. The other major contributors to the West Fork 100 year storm discharges are Lake Creek (327 square mile drainage area), and Spring Creek (446 square mile drainage area). Figure 6 shows the relative location of the major streams in the San Jacinto River basin.

The Soil Conservation Service (SCS) performed or managed the official West Fork floodplain study for the Federal Emergency Management Agency (the successor to the Federal Insurance Agency). A basic assumption was there would be almost no flood wave attenuation during the 100 year storm. This assumption is the worst case since 5 feet of flood storage is currently available above the conservation pool. The simulation of the worst case assumption showed a peak 100 year discharge of 83,000 cfs just downstream of the dam. At the confluence of Lake Creek, the hydrograph increases the West Fork peak discharge to about 98,000 cfs. This value slowly increases as small downstream tributaries contribute additional flow. Just upstream of the junction with Spring Creek, the West Fork 100 year discharge is 102,000 cfs. Downstream of the Spring Creek junction, this discharge increases to 149,000 cfs.

Description of Critical Flooding Areas:

Aerial photographs taken by the State Department of Highways and Public Transportation (SDHPT) were used to count and map structures in the West Fork 100 year floodplain. Four critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of flood prone property and the average annual damages incurred by flooding. The River Plantation area, for example, is designated critical area 3. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The four critical areas along the West Fork are described further in Table 2 and are shown in Figure 6.

Table 2

WEST FORK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	125	7.5	0.32
2	177	5.5	0.17
3	748	77.4	3.3
4	75	6.5	.65
Total	1,125	96.9	4.5

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling, and the resulting costs and economic benefits are presented below. The alternatives which produced a significant reduction in the floodplain are shown on individual floodplain maps of the West Fork, all alternatives have flood profiles plotted (see exhibits). Appendix A provides more detail on the technical methods and assumptions used for this project.

The changes in the flow and floodplain elevation at each point and for the flood control alternatives are shown in Appendix B. Each table represents a point on the West Fork in the middle of a critical area (defined above).

The costs and economic benefits of each structural alternative (each alternative except property buyout) are presented in Table 3. The affected critical areas, the estimated total cost of the project, and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefits are the reduction in annual flood damages to residential structures and household belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient; a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation follows:

Sample Benefit-Cost Calculation

Average Annual Flood Damages (existing condition):	\$4,500,000
Average Annual Flood Damages (with total channelization)	0
Annual Economic Benefits from Channelization:	\$4,500,000
Total Cost of Channelization:	\$137,000,000
Annual Cost of Servicing Capital Improvement	\$11,200,000
Bonds for Total Cost of Project:	
(Bonds at 8.125 percent interest, 100 year amortization period, from Corps of Engineers assumptions)	

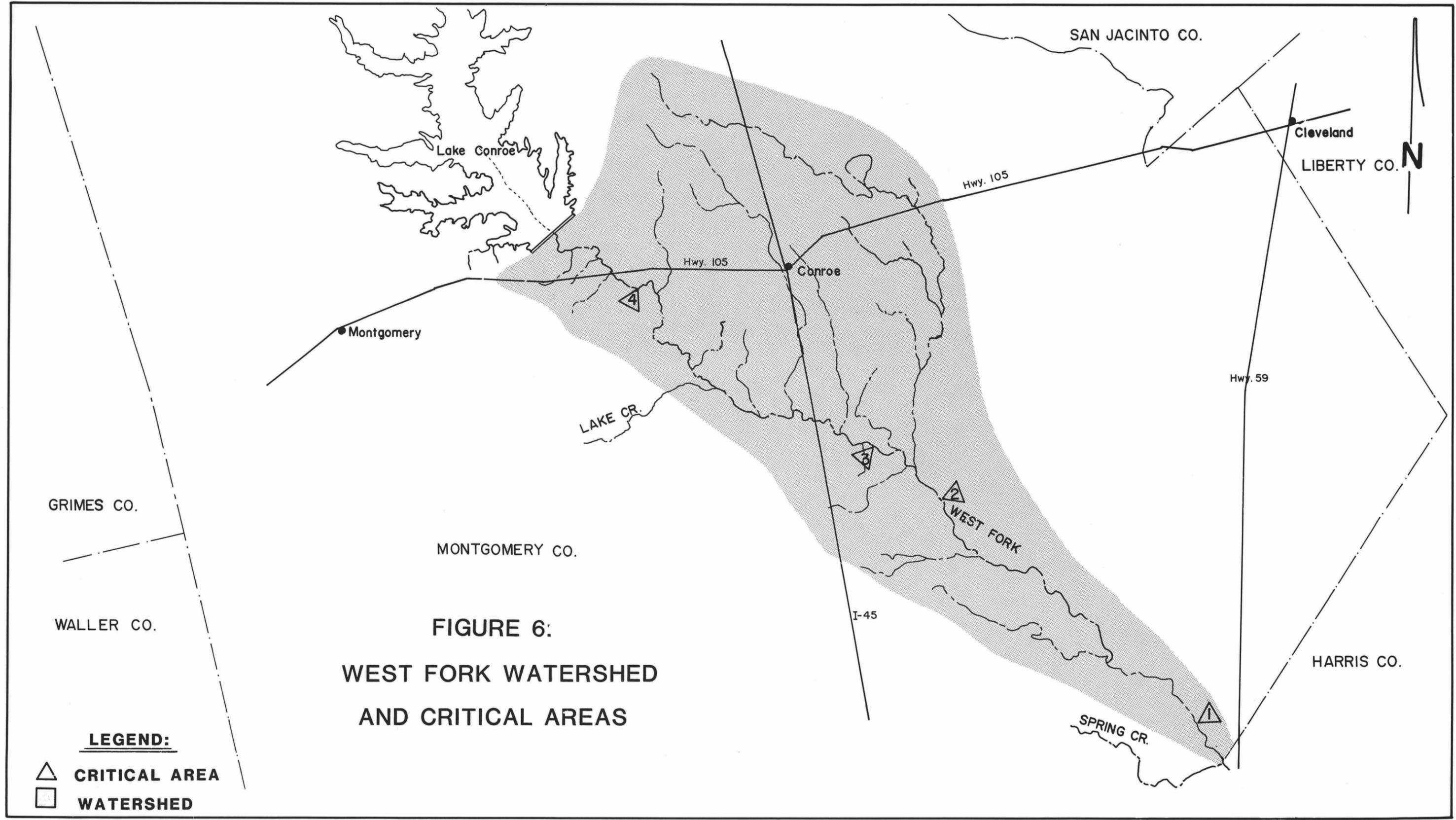


FIGURE 6:
WEST FORK WATERSHED
AND CRITICAL AREAS

LEGEND:

- △ CRITICAL AREA
- WATERSHED

Benefit/Cost Ratio = $(\$4,500,000)/(\$11,200,000) = 0.40$

The benefit/cost ratio of 0.40 indicates the project does not pay for itself with reduced flood damages, even though all existing flood damages are eliminated.

Existing Conditions (no flood control alternatives) (WF-A):

Flow Summary: Results from FEMA floodplain study
 Floodplain Summary: Results from FEMA floodplain study
 Annual Flooding Damages: \$4,500,000

Total Channelization (WF-B):

The existing West Fork channel was replaced with a large grass lined channel from Lake Conroe to the Harris County line (the limit of the study area). A 30 foot deep channel, ranging from 500 to 600 feet top width was required to carry the 100 year flow.

Flow Summary: Increased flows due to channelization
 Floodplain Summary: New floodplain approximately at elevation of existing channel banks
 Total Cost: \$137,000,000
 Annual Cost: \$11,200,000
 Annual Benefits: \$4,500,000
 Benefit/Cost Ratio: 0.40

Selective Channelization (WF-C1, WF-C2, WF-C3, WF-C4, WF-C5):

The existing West Fork channel was replaced with a large grass lined channel at each of the four critical areas. The bottom of the existing channel was assumed to be the bottom of the new channel. Case WF-C1 through WF-C4 corresponded to critical area 1 through critical area 4. Case WF-C5 assumed that a concrete lined channel would be used instead of a grass lined channel for critical area 3 only (the River Plantation area).

Note: Floodplain maps show combined cases other cases not shown.
 Flow Summary: Concrete channel case (WF-C5) increased flows by 2% at most; the other grass channel cases were assumed to have no change.
 Floodplain Summary: Concrete channel (WF-C5) reduced existing 100 year flood depth by up to 5.5 feet in critical area 3 and increased depths slightly downstream. The grass channelization cases reduced the 100 year flood depth to a smaller extent for the other critical areas.
 Total Cost: See Table 3 for each case
 Annual Cost: See Table 3 for each case
 Benefit/Cost Ratio: Ranges from 0.03 to 0.93; both selective grass channelization alternatives for critical areas 3 and 4 had relatively high benefit/cost ratios (0.93 and 0.75 respectively). Concrete channel was very inefficient with B/C ratio of 0.10.

Desnag (WF-D):

The heavy vegetation on the banks of the existing West Fork channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and desnagging was found to cause only a minor change.

Flow Summary: Slight change in flow from existing case Floodplain Summary: Maximum of 1 foot reduction below existing 100 year flood depth
 Total Cost: \$5,700,000
 Annual Cost: \$1,400,000
 Annual Benefit: \$860,000
 Benefit/Cost Ratio: 0.75

Table 3
West Fork Alternative
Cost and Economic Benefits

WEST FORK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
WF-B	Entire stream	137.0	11.2	4.5	0.40
WF-D	Entire stream	5.7	1.4	0.86	0.75
WF-G-1	Below Lake Creek Conf.	13.1	1.1	3.0	2.2
WF-G-2	Entire stream	13.1	1.1	3.3	2.8
WF-C1	1	8.6	0.70	0.023	0.03
WF-C2	2	17.3	1.4	0.44	0.31
WF-C3	3	31.2	2.5	2.4	0.93
WF-C4	4	8.8	0.72	0.54	0.75
WF-C5	3	370.0	30.1	2.9	0.10
WF-D1	1	0.27	0.54	0.0	0.0
WF-D2	2	0.53	0.11	0.035	0.31
WF-D3	3	1.1	0.22	0.55	2.5
WF-D4	4	0.27	0.054	0.12	2.3
WF-E	4	18.5	1.5	0.13	0.085

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir

NOTE: See Figure 7 for location of critical areas.

Selective Desnag (WF-D1), (WF-D2), (WF-D3), WF-D4):

Desnagging was performed along the length of each critical area (from 1-5 miles long). Case WF-D1 is associated with critical area 1, WF-D2 with critical area 2, etc.

Note: No floodplain maps were prepared due to the small change in the floodplain.

Flow Summary: Slight change in flow from existing case Floodplain Summary: Maximum of .6 foot reduction below existing 100 year flood depth.

Total Cost: See Table 3 for summary

Annual Cost: See Table 3 for summary

Benefit/Cost Ratio: Ranges from 0.00 to 2.5; selective desnag in critical areas 3 and 4 had the highest benefit/cost ratios (2.5 and 2.3 respectively).

Bridge Modification (WF-E):

Several bridges were assumed to be hydraulically modified to remove the restrictions to flood flows. All of the bridges along the West Fork were examined and only the Atchinson, Topeka, and Santa Fe Railroad bridge near Highway 105 was found to increase the floodplain elevations in a developed critical area. The other five bridges did not have a major effect on floodplain elevations in developed areas.

Note: No floodplain maps were prepared due to the small change in floodplain.

Flow Summary: Slight change in flow from existing case.

Floodplain Summary: New 100 year flood depth 1.2 feet lower than existing case in critical area 4.

Total Cost: \$18,500,000

Annual Cost: \$1,500,000

Benefit/Cost Ratio: 0.085

Buy-Out of Floodplain Structures (All WF-F25, WF-F100 Alternatives):

The efficiency of buying out floodprone property was analyzed for the entire West Fork, and for each of the four individual critical areas (Table 4). Two types of buy-out were used: buying all structures within the 100 year floodplain (WF-F100), and a subset of this alternative, buying out only those structures in the 25 year floodplain (WF-F25). The buy-outs for the individual critical areas are designated by the number of the critical area; WF-F100-1, for example, refers to the 100 year buy-out of critical area 1.

Flood Damage Assumptions: Corps of Engineers damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Buy-out Cost Assumptions: Corps of Engineers total value data was adjusted to remove contents value and to add approximate land costs.

25 Year Buy-out, Entire Stream (WF-F25)

Total Cost: \$62,000,000

Annual Cost: \$ 5,000,000

Annual Benefit: \$ 3,800,000

Benefit/Cost Ratio: 0.76

100 Year Buy-out, Entire Stream (WF-F100)

Total Cost: \$97,000,000

Annual Cost: \$ 7,900,000

Annual Benefit: \$ 4,500,000

Benefit/Cost Ratio: 0.57

Table 4
West Fork Buy-Out in
25 Year Flood Plain and 100 Year Flood Plain

WEST FORK

Flood Control Alternative	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
WF-F25	Entire Stream	62.0	5.0	3.8	0.76
WF-F25-1	1	4.8	0.39	0.21	0.53
WF-F25-2	2	4.1	0.33	0.12	0.35
WF-F25-3	3	48.0	3.9	2.9	0.73
WF-F25-4	4	5.4	0.44	0.62	1.4
WF-F100	Entire Stream	97.0	7.9	4.5	0.57
WF-F100-1	1	7.5	0.61	0.32	0.52
WF-F100-2	2	5.5	0.45	0.17	0.38
WF-F100-3	3	77.4	6.3	3.3	0.53
WF-F100-4	4	6.5	0.53	0.65	1.22

Although the 100 year buy-out alternative had a higher annual benefit, the 25 year buy-out had a superior benefit/cost ratio. This was true for both the entire stream case and for each of the individual critical areas. More flood damages could be avoided with a 100 year buy-out, but the 25 year alternative is a more efficient use of flood control expenditures.

The ratios for each critical area varied considerably from the average for the entire stream. This indicates some critical areas are much better candidates for buy-outs than others. Critical area 2 had B/C ratios less than .40 for both the 25 and 100 year buy-out, while critical area 4 had B/C ratios greater than 1.0 for both cases.

Buy-out alternatives with B/C ratios greater than 1.0 can occur when the annual flood damages exceed the annual cost to remove the houses. The annual damages to the structure and contents are assumed to occur repeatedly and accumulate over the 100 year period used to calculate the annual costs of a buyout (see sample B/C ratio calculation). If it is assumed the damages will be repaired after a flood and damaged during the next flood, then the annual damages can be very high. High annual damages produce high annual benefits for any project, such as a buyout, that will prevent those damages. In the case of a buy-out B/C ratio greater than 1.0, the annual costs to the structure and the contents are greater than the annual cost of buying the structure plus land.

Different buy-out assumptions will affect the B/C ratios of any buy-out alternative. If one assumes that the future flood damage will not be repaired, then situations where the B/C ratio is greater than 1.0 are much rarer. If a shorter amortization period is used instead of 100 years (the standard Corps of Engineers project lifetime and the amortization period used for this study) the B/C ratios will also be lower. For all the results from this project, however, each buy-out case was calculated assuming that all future flood damage would be repaired and the project lifetime was 100 years.

Reservoirs (WF-G1, WF-G2):

Alternative WF-G1 simulated the impact of the proposed Lake Creek reservoir on the West Fork floodplain downstream of the Lake Creek confluence. The reservoir was assumed to have 3 feet of available flood control storage. Different reservoir operation schemes to protect West Fork property owners were evaluated. For the most effective West Fork flood control, the reservoir should be operated to capture the first portion of the Lake Creek runoff and fill the flood storage several hours before the peak runoff from Lake Creek. This is opposed to a more traditional operational scheme, which is to reduce the peak flow in Lake Creek as much as possible. To utilize the flood storage in a Lake Creek reservoir during an actual storm, however, the operators will need to be able to predict flow and flood elevations in the West Fork, and then coordinate releases with Lake Conroe. The results below reflect a "design storm" instead of an actual storm: the results from an actual storm will depend on the rainfall amount and distribution of rain over time.

- Flow Summary: Average reductions in the West Fork 100 year flow were 14%
- Floodplain Summary: New 100 year flood depth was 2.6 to 4.6 feet lower than the existing case.
- Total Cost: \$13,100,000 (same as case WF-G1)
- Annual Cost: \$1,100,000
- Annual Benefit: \$3,300,000
- Benefit/Cost Ratio: 2.8

LAKE CREEK

Description of Watershed and Floodplain:

Lake Creek flows from northwest to southeast, beginning in Grimes County near Richards, Texas, and ending at its confluence with the West Fork of the San Jacinto River near Conroe, Texas, in Montgomery County. Lake Creek is fed by a number of tributaries, including Garretts Creek, Little Caney Creek, Caney Creek No. 2, Fish Creek, and Mound Creek. Together with its tributaries, Lake Creek extends 47.8 miles in length and drains a watershed that is 327 square miles in area, see Figure 7.

The land in the Lake Creek watershed is predominantly used for raising timber and crops. A very small portion of the basin is used as rangeland or developed as residential and/or commercial tracts. The following table describes the amount and percentage of land devoted to different uses within the watershed. The figures for the table are based on maps published by the Texas Department of Water Resources, drawn from aerial photos taken in 1979.

Land Use	Area (sq.mi.)	Percent of Basin Area
Cropland	187.4	57.3
Forest	137.0	41.9
Rangeland	1.3	0.4
Urban	1.0	0.3

Soils:

The soils in the Lake Creek drainage basin can be grouped into four major classes: the Tuscumbia Association, the Wicksburg-Susquehanna Association, the Conroe Association, and the Ferris-Houston Black-Kipling Association. The Tuscumbia Association soils follow the Lake Creek stream bed and are characterized as poorly drained, very firm clayey flood deposits. The Wicksburg-Susquehanna Association soils are widely distributed through the area to the east and north of Lake Creek and are typically sandy and loamy soils with increasing clay content in lower layers. The Conroe Association soils are scattered in relatively small areas within the lower part of the Lake Creek watershed; Conroe soils underlie much of the Mound Creek and Fish Creek basins, and are also found in the area to the west of Lake Creek and the south of Caney Creek No. 2. Conroe soils are characterized as well drained, sandy soils with clayey lower layers. The last major soil group is called the Ferris-Houston Black-Kipling Association and is found in the middle of the Lake Creek watershed within the Landrum Creek and Caney Creek No. 2 basins. This soil group is made up of mainly clayey soils that are poorly drained.

Stream Channel Characteristics:

The Lake Creek stream channel varies moderately in cross section through its length. In the upstream reaches, the floodplain is roughly 10 feet deep and 340 feet broad. As the stream approaches its confluence with the West Fork of the San Jacinto River, it grows deeper and broader reaching a depth of 18 feet and a width of over 1600 feet.

The channel slope of Lake Creek varies greatly within short segments of the Creek, but in general, keeps close to two average values. In the reaches upstream of river mile 39 (Dacus Road), the Creek follows an average slope of 5.1 feet/mile. In the segment of Lake Creek which is downstream of river mile 39 (Dacus Road), the slope remains close to an average value of 2.4 feet/mile. Within runs of one mile or less, the stream's slope varies from 9.0 feet/mile to 0.0 feet/mile.

Hydrologic Characteristics:

The configuration of the watershed produces a 100 year flow of over 25,000 cfs above Dacus Road and increases to nearly 33,000 in the lower portion of the watershed. The existing 100 year flow near the mouth of Lake Creek near confluence with West Fork is 32,900 cfs. At Highway 149, 21.38 miles above the mouth, the 100 year flow is 33,836 cfs, and at Highway 105 (river mile 32.78) the flow is 29,380 cfs.

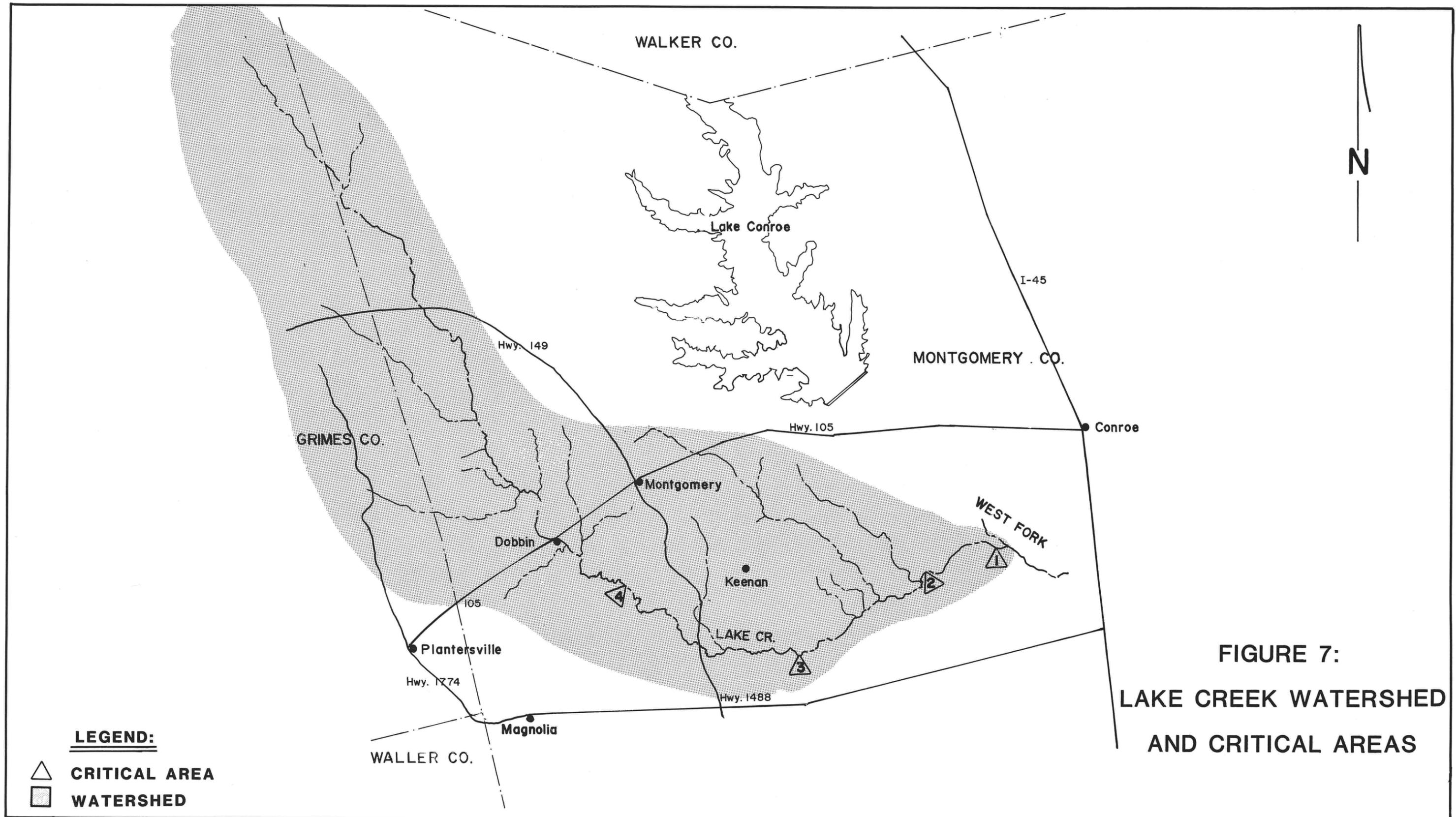
Description of Critical Flooding Areas:

Aerial photographs taken by the SDHPT were used to count and map structures in the Lake Creek 100 year floodplain. Four critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of floodprone property and the average annual damages incurred by flooding. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The four critical areas along Lake Creek are described further in Table 5 and are shown in Figure 7.

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling and the resulting costs and economic benefits are presented below. The alternatives which produced a significant reduction in the floodplain are shown on individual floodplain maps of the Lake Creek and have flood profiles plotted (see Exhibits). Appendix A provides more detail on the technical methods and assumptions used for this report.

Representative changes in the flow and floodplain elevation for each of the flood control alternatives are shown in Appendix B.



**FIGURE 7:
LAKE CREEK WATERSHED
AND CRITICAL AREAS**

Table 5

LAKE CREEK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	8	540	5.1
2	8	150	1.4
3	5	83	0.8
4	18	400	3.7
Total	39	1,173	11.0

The costs and economic benefits of each viable structural alternative (each viable alternative except property buy-out) are presented in Table 6. The affected critical areas, the estimated total cost of the project, and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefit is the estimated reduction in annual flood damages to residential structures and household belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient; a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation is shown in section describing West Fork Flood Control Alternatives.

Existing Conditions (no flood control alternatives) LC-A):

Flow Summary: Results from FEMA floodplain study
 Floodplain Summary: Results from FEMA floodplain study
 Annual Flooding Damages: \$9,600

Total Channelization (LC-B)

The existing Lake Creek channel was replaced with a large grass-lined channel from the junction with the West Fork to a point 43.3 miles upstream. The channel increased in size from upstream to downstream: the far upstream section was 22 feet deep and 260 feet wide, while the section next to the West Fork confluence was 31 feet deep and 670 feet wide.

Flow Summary: Increased flows due to channelization
 Floodplain Summary: New Floodplain approximately at elevation of existing channel banks
 Total Cost: \$126,000,000
 Annual Cost: \$10,600,000
 Annual Benefits: \$9,600
 Benefit/Cost Ratio: <0.001

Table 6

Lake Creek Alternative Costs and Economic Benefits

LAKE CREEK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
LC-B	Entire Stream	126.0	10.6	0.01	<.001
LC-D	Entire Stream	3.1	0.62	0.0	0.0
LC-G1	1A	13.1	1.1	0.0 ¹	0.0
LC-G2	1A	13.1	1.1	0.002 ²	<.001

¹ No Lake Creek Benefits; Large West Fork Benefits (Use WF-G1)

² Lake Creek Benefits Only

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir

Selective Channelization (LC-C)

No site for selective channelization appeared applicable due to diverse locations of flood prone structures. Therefore, no computer modeling was performed and selective channelization was determined to be a non viable option.

Desnag (LC-D)

The heavy vegetation on the banks of the existing channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and was found to cause only a minor change.

Flow Summary: No change in flow was modeled (see Appendix A)
 Floodplain Summary: Maximum of 0.3 foot reduction below existing 100 year flood depth.
 Total Cost: \$3,100,000
 Annual Cost: \$620,000
 Annual Benefits: \$0
 Benefit/Cost Ratio: 0.0 (No economic benefits were observed)

Bridge Modification (LC-E)

Seven bridges over Lake Creek were examined to determine if hydraulic modifications would have any economic effects. Very little urban development was observed upstream of the bridges and no significant benefits would result from bridge modification projects. No detailed modeling was performed.

Buy-out of Floodplain Structures (LC-F25, LC-F100)

The efficiency of buying out floodprone property was analyzed for Lake Creek in Table 7. Two types of buy-out were used: buying all structures within the 100 year floodplain (LC-F100), and a subset of this alternative, buying out only those structures in the 25 year floodplain (LC-F25).

Flood Damage Assumptions: Corps of Engineers damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Buy-out Cost Assumptions: Corps of Engineers total value data was adjusted to remove contents value and to add approximate land costs.

100 Year Buy-out (LC-F100) (Same as 25 year buyout, LC-F25)

Total Cost: \$1,300,000

Annual Cost: \$110,000

Annual Benefit: \$9,600

Benefit/Cost Ratio: 0.09

The 100 year buy-out alternative had the same benefit/cost ratio as the 25 year buy-out, because no additional structures were outside of the 25 year floodplain but still inside the 100 year floodplain.

Table 7

**Lake Creek Buy-Out in
25 Year and 100 Year Flood Plain**

LAKE CREEK

Flood Control Alternative	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
LC-F25	Entire Stream	1.3	.11	0.01	.09
LC-F100	Entire Stream	1.3	.11	0.01	.09

Reservoirs (LC-G1, LC-G2)

These alternatives simulated the impact of the proposed Lake Creek reservoir on the short section of Lake Creek floodplain downstream of the reservoir. The overall beneficial effect of the reservoir on structures in the Lake Creek floodplain was very small. The proposed reservoir site was only three miles upstream of the West Fork confluence and much of the area that would receive benefits from the dam is in

the West Fork floodplain.

The reservoir was assumed to have 3 feet of available flood control storage. Different reservoir operation scheme simulations protect West Fork property owners were evaluated. For the most effective West Fork flood control, the reservoir was modeled to capture the first portion of the Lake Creek runoff and fill the flood storage several hours before the peak runoff from Lake Creek (alternative LC-G1). This operational method produced significant flood control benefits on the West Fork (same as alternative WF-G1) but no benefits to the Lake Creek floodplain. When the peak runoff from Lake Creek reached the reservoir, the flood stage was depleted and no reduction in the 100 year flow occurred. This alternative had more total flood control benefits than case LC-G2 (see below). To achieve the highest level of flood control, a computer simulation model would probably have to be developed to aid the operators of the reservoirs on Lake Creek and Lake Conroe to coordinate releases.

The more traditional operational scheme reduces the peak flow in Lake Creek as much as possible (alternative LC-G2). Some Lake Creek benefits result, but the flood control advantages to the problem areas on the West Fork are lost.

Lake Creek Reservoir (LC-G1) Dam Operation for West Fork Flood Control

Flow Summary: Reductions in the West Fork 100 year flow by 14%. Very little flow reduction on Lake Creek.

Floodplain Summary: No change in Lake Creek floodplain.

Total Cost: See case WF-G1

Annual Cost: See case WF-G1

Benefit/Cost Ratio: No Lake Creek benefits; see alternative WF-G1 for West Fork benefits.

Lake Creek Reservoir (LC-G2) Dam Operation for Lake Creek Flood Control:

Flow Summary: No reduction in the West Fork 100 year flow. Lake Creek 100 year flow reduced by 39%.

Floodplain Summary: Up to 3 foot reduction in short section of Lake Creek floodplain downstream of dam.

Total Cost: \$13,100,000

Annual Cost: \$1,100,000

Annual Benefit: \$2,300

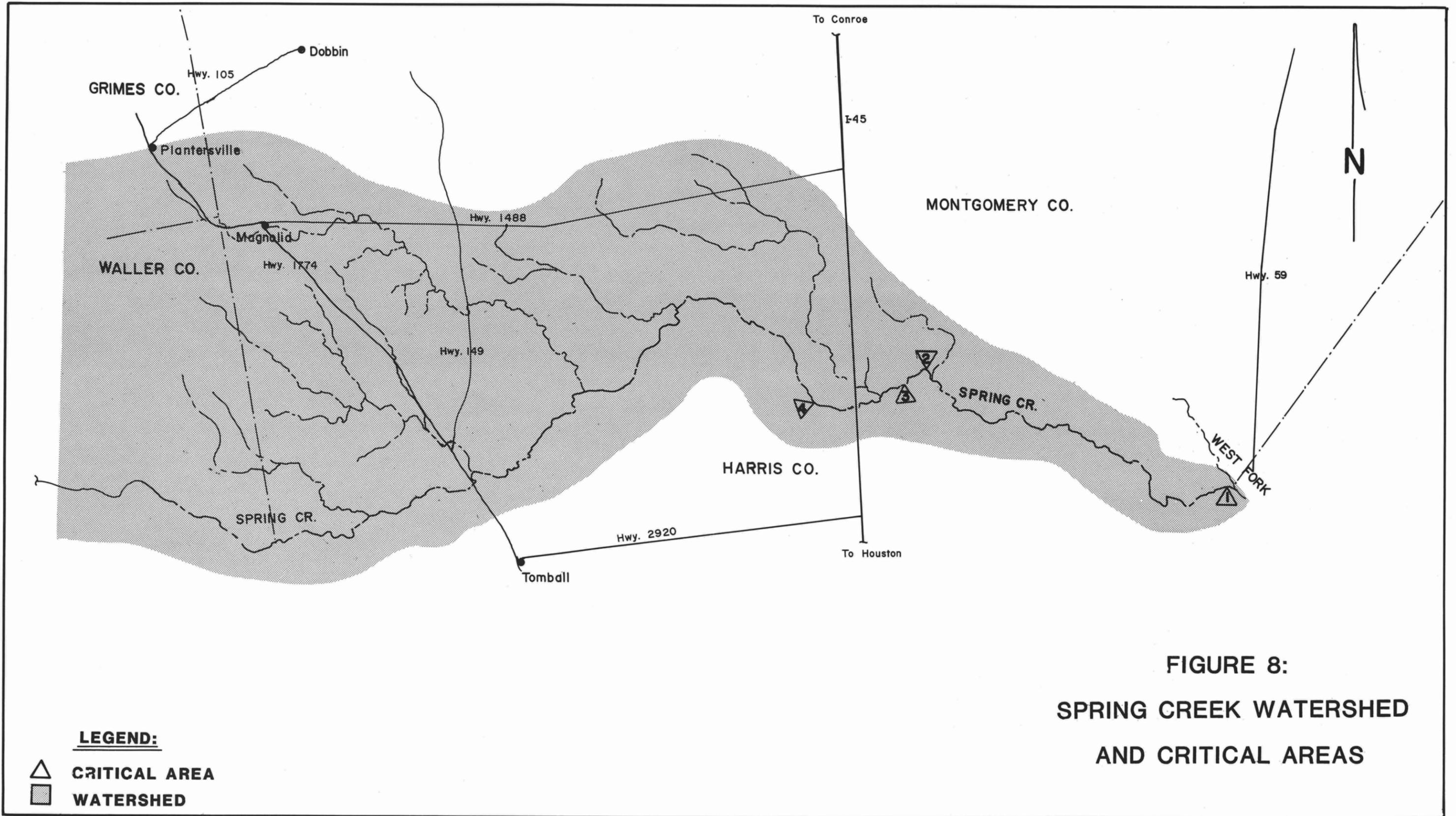
Benefit/Cost Ratio: <.001 (Lake Creek only)

SPRING CREEK

Description of Watershed and Floodplain:

The main channel of Spring Creek represents the boundary between Harris and Montgomery Counties and a section of the boundary between Harris and Waller Counties. A number of tributaries feed the main channel including Kickapoo Creek, Threemile Creek, Brushy Creek, Walnut Creek, Sulphur Branch, Decker Branch, Mill Creek, Dry Creek No. 2, Willow Creek, Panther Branch, Sam Bell Gully, and Cypress Creek. The main channel empties into the West Fork of the San Jacinto River 4 miles east of Lake Houston. The watershed covers parts of Grimes, Waller, Montgomery, and Harris Counties (Figure 8). Excluding the area drained by Cypress Creek, the Spring Creek watershed covers an area of about 446 square miles.

Land use in the Spring Creek watershed is primarily forest land. Smaller amounts of land are devoted to pasture and agricultural use, with the smallest amount devoted to urban development. The percentage of basin area corresponding to each land use appeared as follows based upon the 1970 census (HGAC, 1980):



**FIGURE 8:
 SPRING CREEK WATERSHED
 AND CRITICAL AREAS**

Land Use	Percent of Basin Area
Forest	67.8
Pasture	19.3
Agriculture	11.2
Developed	1.8

A Rice Center Study (1978) predicts that urban development in the Spring Creek basin will grow rapidly, from the value of 2.2 percent of the watershed in 1978 to 5.0 percent in 1990.

Soils:

Along the main channel of Spring Creek, soils are sand and loamy. These soils are found on nearly level to gently sloping land and are typically forested. Moderately drained and moderately permeable soils are found in upstream regions, while in downstream areas below the confluence of Panther Branch with the main channel, poorly drained and slowly permeable soils are found on stream terraces. In regions of the watershed north of Spring Creek and greater than 2-3 miles from the main channel, soils are overall sandier in content and more well-drained. However, in isolated areas around Mostyn, Decker Prairie, and Magnolia, Texas the poorly drained loamy soils again are found South of Spring Creek, loamy soils are more extensive in areas removed from the main channel; in this region of the watershed, nearly level, loamy, prairie soils predominate (SCS, 1972; SCS, 1976).

Stream Channel Characteristics:

The width of the channel containing the 100 year flow varies along the length of Spring Creek. Near the mouth of the creek, the channel has a width of 270 feet, which decreases upstream to a width of 120 feet along the middle portion of the stream length (at river mile 24.1). In the portions of the stream further upstream (at river mile 44.0), the channel has a width of only 60 feet. The depth of the channel remains fairly constant along the length of Spring Creek. At the mouth of the stream, the depth is 27 feet, while at river mile 44.0, the depth is 30 feet. The width of the 100 year floodplain varies more significantly. Interestingly, the width of the floodplain is narrower near the mouth of Spring Creek, approximately 2400 feet while being 4000 feet at river mile 24.1, and 4500 feet at river mile 44.0.

The slope of the main channel is relatively consistent along the length of Spring Creek analyzed in this study. The channel slope is approximately 2.4 feet/mile.

Hydrologic Characteristics:

The peak magnitude of the 100 year flow is 51,692 cfs near the confluence of Spring Creek (river mile 4.1) with the West Fork. At river mile 24.1, the peak flow for the 100 year event is 48,536 cfs and at river mile 44.0, the peak flow is 47,180 cfs (Corps of Engineers, 1984).

Two consulting firms developed 100 year flood flows for Spring Creek in 1976. The results from these studies and the Corps of Engineers results used for this project are listed below:

Location	River Mile	Corps of Engineers (CFS)	Turner, Collie & Braden, 1976 (CFS)	Farner & Winslow, 1976 (CFS)
Mouth	0.0	76,800	113,590	84,480
Above Cypress Creek	3.1	51,600	78,520	59,780
Riley-Fussel Road	13.16	52,900	---	---
I-45	16.75	---	75,000	57,100
Below Willow Creek	21.60	51,700	---	---
Below Dry Creek	30.65	48,100	---	---
Above Mill Creek	37.28	42,400	56,500	43,020
Below Walnut Creek	44.04	47,200	---	---
Above Brushy Creek	49.19	---	26,380	20,090

Significant differences in the 100 year flows predicted by the three studies can be seen. This illustrates some of the uncertainty inherent in developing hydrologic data for floodplain studies. For this project, the Corps of Engineers data were used because it is the basis for the FEMA floodplains.

Description of Critical Flooding Areas:

Aerial photographs taken by the State Department of Highway and Public Transportation were used to count and map structures in the Spring Creek 100 year floodplain. Four critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of flood-prone property and the average annual damages incurred by flooding. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The four critical areas are described further in Table 8 and are shown in Figure 8.

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling, and the resulting costs and economic benefits are presented below. The alternatives which produced significant reductions in the floodplain are shown on individual floodplain maps and flood profiles of Spring Creek (see Exhibits). Appendix A details the technical methods and assumptions used in this project.

Representative changes in the flow and floodplain elevation for each of the flood control alternatives are shown in Appendix B.

The costs and economic benefits of each structural alternative (each alternative except property buy-out) are presented in Table 9. The affected critical areas, the estimated total cost of the project and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefit is the reduction in annual flood damages to residential structures and household belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient; a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation is provided in section West Fork Flood Control Alternatives.

Table 8

SPRING CREEK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	48	3,110	54
2	105	4,448	172
3	188	8,314	281
4	97	2,108	16
Total	438	17,980	523

Existing Conditions (no flood control alternatives) (SC-A):

Flow Summary: Results from FEMA floodplain study
 Floodplain Summary: Results from FEMA floodplain study
 Annual Flooding Damages: \$520,000

Total Channelization (SC-B):

The existing Spring Creek channel was replaced with a large grass lined channel from the confluence with the West Fork to a point 48.2 miles upstream. The channel increased in size upstream to downstream: the upstream section was 14 feet deep with a 200 foot top width while the most downstream section was 35 feet deep with a 500 foot top width.

Flow Summary: Increased flows due to channelization
 Floodplain Summary: New floodplain approximately at elevation of existing channel banks.
 Total Cost: \$190,800,000
 Annual Cost: \$ 15,500,000
 Annual Benefit \$520,000
 Benefit/Cost Ratio: 0.03

Selective Channelization (SC-C):

No site for selective channelization appeared applicable due to the diverse locations of floodprone structures. Therefore, no computer model simulation was performed and selective channelization was determined to be a non-viable option.

Desnag (SC-D):

The heavy vegetation on the banks of the existing channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and was found to cause only a

minor change.

Flow Summary: A slight increase in flow was observed. The downstream portion of Spring Creek showed a 10% increase over existing conditions after "desnagging".

Floodplain Summary: The average reduction in the 100 year flood depth was around 1.0 feet.

Total Cost: \$4,700,000
 Annual Cost: \$380,000
 Annual Benefit: \$52,000
 Benefit/Cost Ratio: 0.14

Table 9

Spring Creek Alternative Costs and Economic Benefits

SPRING CREEK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
SC-B	Entire Stream	190.8	15.5	0.52	0.03
SC-D	Entire Stream	4.7	0.38	0.052	0.14
SC-F1	Downstream of Reservoir — (Dry Creek) 1, 4, 5, 6	6.5	0.53	~0.0	~0.0
SC-F2	Downstream of Reservoir — (Walnut Creek) 1, 4, 5, 6, 8	41.0	3.3	0.30	0.09
SC-E1	4, 5	10.0	0.81	~0.0	~0.0
SC-E2	4, 5	19.0	1.5	~0.0	~0.0

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir

NOTE: See Figure 7 for location of critical areas.

Bridge Modification (SC-E1, SC-E2, SC-E3):

Three Spring Creek bridge modification alternatives were performed to determine if any hydraulic modifications would produce any reduction of flood damages. Alternative SC-E1 assumed three upstream bridges would be improved: HuffsmithConroe Road (river mile 35.44), Missouri Pacific Railroad bridge at river mile 37.28, and the Chicago and Pacific Railroad bridge at river mile 38.54. Alternative SC-E2 assumed the Missouri Pacific Railroad bridge on the downstream portion of Spring Creek was improved (river mile 13.17). Alternative SC-E3 simulated the improvement of the SC-E2 bridge along with the modification of the two I-45 spans over Spring Creek (river mile 16.83, 16.89).

Each alternative lowered the 100 year flood depth to some degree. These alternatives simulated the best possible result if the existing bridges were replaced with bridges with very efficient hydraulic characteristics. The economic effects of bridge improvement were negligible because only a short distance upstream (usually less than a mile) was affected.

Bridge Modification (Three bridges between river mile 36.0 and 39.0) (SC-E1):

Flow Summary: No change in flow was modeled (see Appendix A)
 Floodplain Summary: Reduction in the 100 year flood depth of up to 0.8 feet immediately upstream of bridges.
 Total Cost: \$10,000,000
 Annual Cost: \$810,000
 Annual Benefit: \$0 (no measurable reduction in flood damage)
 Benefit/Cost Ratio: 0.00

Bridge Modification (Mo. Pac. railroad bridge at river mile 13.17) (SC-E2):

Flow Summary: No change in flow was modeled (see Appendix A)
 Floodplain Summary: Reduction in the 100 year flood depth of up to 0.2 feet immediately upstream of bridges.
 Total Cost: \$19,000,000
 Annual Cost: \$1,500,000
 Annual Benefit: \$0 (no measurable reduction in flood damage)
 Benefit/Cost Ratio: 0.00

Bridge Modification (Same as SC-E2 plus I-45 bridges at river mile 16.8) (SC-E3):

Flow Summary: No change in flow was modeled (See Appendix A)
 Floodplain Summary: Reduction in the 100 year flood depth of up to 0.5 feet immediately upstream of bridges.
 Total Cost: Not calculated
 Annual Cost: Not calculated
 Annual Benefit: \$0 (no measurable reduction in flood damage)
 Benefit/Cost Ratio: 0.00

Buy-Out of Floodplain Structures (All SC-F25, SC-F100 Alternatives):

The efficiency of buying out floodprone property was analyzed for Spring Creek (Table 10). Two types of buyout were used: buying all structures within the 100 year floodplain (SC-F100), and a subset of this alternative, buying out only those structures in the 25 year floodplain (SC-F25). The buy-outs for the individual critical areas are designated by the number of the critical area; SC-F100-1, for example, refers to the 100 year buy-out of critical area 1.

Flood Damage Assumptions: Corps of Engineers damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Buy-out Cost Assumptions: Corps of Engineers total value data was adjusted to remove contents value

and to add approximate land costs.
 25 Year Buy-out Entire Stream (SC-F25):
 Total Cost: \$6,300,000
 Annual Cost: \$510,000
 Annual Benefit: \$430,000
 Benefit/Cost Ratio: 0.84
 100 Year Buy-out Entire Stream (SC-F100)
 Total Cost: \$18,000,000
 Annual Cost: \$1,500,000
 Annual Benefit: \$520,000
 Benefit/Cost Ratio: 0.36

Table 10
Spring Creek Buy-Out
in 25 Year and 100 Flood Plain
SPRING CREEK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
SC-F25	Entire Stream	6.3	0.51	0.43	0.84
SC-F25-1	1	0.75	0.061	0.024	0.39
SC-F25-2	2	1.2	0.095	0.14	1.5
SC-F25-3	3	4.3	0.35	0.27	0.75
SC-F25-4	4	0.0	0.0	0.0	0.0
SC-F100	Entire Stream	18.0	1.5	0.52	0.36
SC-F100-1	1	4.1	0.25	0.054	0.21
SC-F100-2	2	5.8	0.36	0.17	0.47
SC-F100-3	3	10.9	0.68	0.28	0.42
SC-F100-4	4	2.7	0.17	0.016	0.09

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir

NOTE: See Figure 9 for location of critical areas.

Although the 100 year buy-out alternative had a higher annual benefit, the 25 year buy-out had a superior benefit/cost ratio. Most of the flood damage occurred within the 25 year floodplain, indicating the 139 structures that are within the 25 year floodplain represent the worst flood problems on Spring Creek.

The 299 structures outside of the 25 year floodplain but within the 100 year floodplain are responsible for only a small fraction of the average annual damages from Spring Creek.

The ratios for the critical areas varied considerably around the average for the entire stream, indicating some critical areas are better candidates for buy-outs than others. Critical area 4 had a very low B/C for the 100 year buy-out and no benefits at all for the 25 year buy-out. This was because all of the 97 structures in this critical area were outside of the 25 year floodplain but still within the 100 year floodplain. Critical area 2 had the best B/C ratios, and for the 25 year buy-out case the B/C was greater than 1.0.

Buy-out alternatives with B/C ratios greater than 1.0 can occur when the annual flood damages exceed the annual cost to remove the houses. The annual damages to the structure and contents are assumed to occur repeatedly, and accumulate over the 100 year period used to calculate the annual costs of a buy-out (see sample B/C ratio calculation). If it is assumed that the damages will be repaired after a flood, and damaged during the next flood, then the annual damages can be very high. High annual damages produce high annual benefits for any project, such as a buy-out, that will prevent those damages. In the case of a buy-out B/C ratio greater than 1.0, the annual costs to the structure and the contents are greater than the annual cost of buying the structure plus land.

Different buy-out assumptions will affect the B/C ratios of any buy-out alternative. If one assumes that the future flood damage will not be repaired, then situations where the B/C ratio is greater than 1.0 are much rarer. If a shorter amortization period is used instead of 100 years (the standard Corps of Engineers project lifetime and the amortization period used for this study) the B/C ratios will also be lower. For all the results from this project, however, each buy-out case was calculated assuming that all future flood damage would be repaired and the project lifetime was 100 years.

Reservoirs (SC-G1, SC-G2):

This alternative simulated the impact of two flood control reservoirs on Spring Creek. Alternative SC-G1 simulated a reservoir proposed near the Woodlands at river mile 26.42 (downstream of the confluence with Dry Creek). This is a small 1000 acre pool with 5 feet of flood storage for large storms. The small size of the reservoir and the location in the downstream portion of Spring Creek limit its usefulness as a flood control structure. Other uses for the reservoir include recreation and possibly water supply.

Alternative SC-G-2 simulated a larger reservoir located upstream on Walnut Creek, which joins the main branch of Spring Creek at river mile 49.19. This reservoir was modeled as a structure similar to Barker and Addicks reservoirs in Houston, where there is no permanent pool and all the storage is committed for flood control. This reservoir had an area 3643 acres and a storage capacity of 47,661 acre-feet.

Spring Creek Reservoir (Woodlands Reservoir) (SC-G1):

Flow Summary: Reductions of the 100 year flow in Spring Creek by 0.5% to 1.6%.

Floodplain Summary: Maximum of 0.2 foot reduction in 100 year flood depth.

Total Cost: \$6,500,000

Annual Cost: \$530,000

Annual Benefit: \$0 (No measureable reduction in flood damages)

Benefit/Cost Ratio: 0.00

Spring Creek Reservoir (Walnut Creek Reservoir) (SC-G-2):

Flow Summary: Reductions of the 100 year flow near the mouth of Spring Creek by 33% and a 41% reduction at the reservoir.

Floodplain Summary: An average of a 3 foot reduction in the 100 year flood depth.

Total Cost: \$41,000,000

Annual Cost: \$3,300,000

Annual Benefit: \$300,000

Benefit/Cost Ratio: 0.09

PEACH CREEK

Description Of Watershed And Floodplain:

Peach Creek flows in a southeastern direction from the southeastern corner of Walker County, Texas and empties into Caney Creek 0.8 miles north of the Montgomery-Harris County line (Figure 9). Tributaries of Peach Creek include: Duck Creek, Lawrence Creek, Jayhawker Creek, Hightower Branch, Gully Branch and Waterhole Branch. The watershed drained by Peach Creek covers an area of 166 square miles, with the main tributary extending upstream a distance of 40.4 miles from its confluence with Caney Creek.

The Peach Creek watershed consists primarily of forest lands, with smaller areas of dry cropland and urban or developed land. The following table, derived from data collected by the HoustonGalveston Area Council (HGAC, 1980), lists the percentage of basin area devoted to each land use in 1970:

Land Use	Percent of Basin Area
Forest	95.6
Pasture	3.0
Developed	1.4

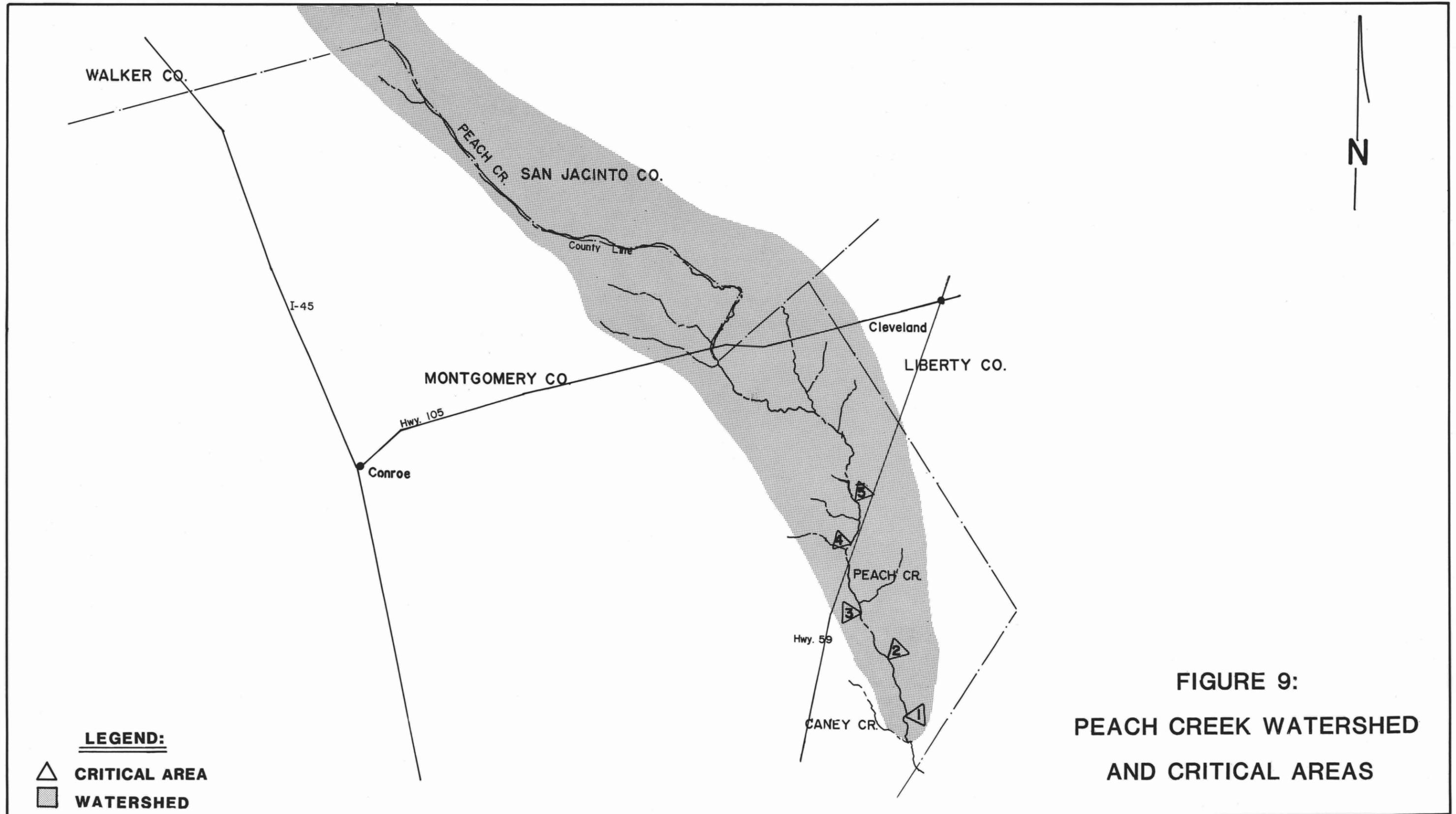
The Rice Center for Community Design and Research found that developed land rose to 2.1 percent of the total basin area in 1978. Projections made in the same report (Rice Center, 1978) predicted a further rise in percentage development from 2.5 percent in 1980 to 3.8 percent in 1990.

Soils:

Soils in the Peach Creek drainage basin vary from sandy, well-drained soils in the northern portion of the watershed to loamy, poorly drained soils in the southern portion. The division in soil types occurs at a point approximately halfway down the river length, near the confluence of Duck Creek and the main tributary of Peach Creek. North of this point, soils in the watershed belong to the Conroe association and consist of moderately well-drained to well-drained sandy soils with clayey lower layers. In the downstream southern portion of the watershed, soils belonging to Splendora-Boy-Segno association are found along the main tributary of the creek. These are poorlydrained to well-drained, loamy and sandy soils, in which loam content increases with depth. In regions 1-2 miles from the stream bed, particularly in the downstream areas near Splendora, Texas, soils belong to the Sorter association. Soils of this association are poorly drained and loamy throughout (SCS, 1972).

Stream Channel Characteristics:

The cross-sectional profile of Peach Creek varies along the length of the main tributary. Near its confluence with Caney Creek, the channel has a width of 650 feet. At river mile 12.5, the channel is 52 feet wide and at river mile 36.4, 33 feet wide. The width of the 100 year floodplain also varies accordingly, being approximately 3740 feet wide at the mouth of the creek, 1850 feet wide along the middle length of the creek, and 36 feet wide along the upstream length of the creek. Depths for the 100 year flow vary along



**FIGURE 9:
PEACH CREEK WATERSHED
AND CRITICAL AREAS**

Peach Creek from approximately 24.8 feet at the mouth, 10.9 feet along the middle length, and 3.7 feet along the upstream length.

Channel slope also varies along the length of Peach Creek. In the downstream portion of the creek, near its mouth and extending north to river mile 24, the channel slope is 4.1 feet/mile. In the middle length of the creek, between river miles 24 and 35.2, the slope steepens to 7.4 feet/mile. In the uppermost portion of the creek, north of river mile 35.2, the channel slope is approximately 18 feet/mile.

Hydrologic Characteristics:

Near the mouth of Peach Creek at river mile 2.3, the existing 100 year flow has a magnitude of 42,800 cfs. In the middle length of the creek, at river mile 12.5, the existing 100 year flow is 35,700 cfs, while in upstream lengths, at river mile 36.4, the flow is 7,400 cfs.

Peach creek empties into Caney Creek 3.1 miles above Lake Houston.

Description Of Critical Flooding Areas:

Aerial photographs taken by the SDHPT were used to count and map structures in the Peach Creek 100 year floodplain. Five critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of floodprone property and the average annual damages incurred by flooding. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The five critical areas are described further in Table 11 and are shown in Figure 9.

Table 11

PEACH CREEK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	35	1,409	191
2	22	885	27
3	34	1,369	245
4	106	4,267	229
5	39	1,570	316
Total	236	9,500	1,008

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling, and the resulting costs and economic benefits are presented below. The alternatives which produced significant reductions in the floodplain are shown on individual floodplain maps of Peach Creek and have flood profiles plotted (see Exhibits). Appendix A details the technical methods and assumptions used in this project.

Representative changes in the flow and floodplain elevation for each of the flood control alternatives are shown in Appendix B.

The costs and economic benefits of each structural alternative (each alternative except property buy-out) are presented in Table 12. The affected critical areas, the estimated total cost of the project, and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefit is the reduction in annual flood damages to residential structures and household belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient; a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation is provided in section describing West Fork Flood Control Alternatives.

Existing Conditions (no flood control alternatives) (PC-A):

Flow Summary: Results from FEMA floodplain study
 Floodplain Summary: Results from FEMA floodplain study
 Annual Flooding Damages: \$1,000,000

Total Channelization (PC-B):

The existing Peach Creek channel was replaced with a large grass lined channel from the confluence with Caney Creek to a point 40.4 miles upstream. The channel varied in size: the farthest upstream section was 10 feet deep and 100 feet wide, while the section near the mouth was 20 feet deep and 450 feet wide.

Flow Summary: Increased flow due to channelization
 Floodplain Summary: New floodplain approximately at elevation of existing channel banks.
 Total Cost: \$37,500,000
 Annual Cost: \$3,100,000
 Annual Benefit: \$1,000,000
 Benefit/Cost Ratio: 0.33

Selective Channelization (PC-C):

No site for selective channelization appeared applicable due to the diverse locations of floodprone structures. Therefore no computer model was performed and selective channelization was determined to be a non-viable option.

Desnag (PC-D):

The heavy vegetation on the banks of the existing channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and was found to cause only a minor change.

Table 12

**Peach Creek Alternative
Costs and Economic Benefits**

PEACH CREEK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
PC-B	Entire Stream	37.5	3.1	1.0	0.33
PC-D	Entire Stream	4.3	0.86	0.038	0.04
PC-G1	Downstream of Reservoir — All Critical Points	3.5	0.29	0.23	0.80
PC-G2	Downstream of Reservoir — All Critical Points	8.0	0.65	0.26	0.40
PC-E	Upstream of Bridges	---	---	0.	---

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

Flow Summary: No change in flow was modeled (See Appendix A)

Floodplain Summary: The average reduction in the 100 year flood depth was around 0.5 feet, although a 1.3 foot reduction was observed in one location. The largest improvements occurred upstream of bridge crossings, where the overflow areas around the bridges were desnagged, increasing flow capacity.

Total Cost: \$4,300,000
Annual Cost: \$860,000
Annual Benefit: \$38,000
Benefit/Cost Ratio: 0.04

Bridge Modification (PC-E):

Three Peach Creek bridges were examined to determine if hydraulic modifications would have any economic effects. Appian Way (river mile 5.2), an unnamed road (river mile 7.1), and FM 2090 (river mile

9.4) were modeled assuming no backwater effects from the two bridges. This represents the best possible result if the existing bridges were replaced with bridges with very efficient hydraulic characteristics. The economic effects of bridge improvement were negligible, however, because bridge improvement only affects a short section of channel (usually less than a mile).

Flow Summary: No change in flow was modeled (See Appendix A)

Floodplain Summary: Improvement of the Appian Way bridge would decrease the 100 year flood depth by 0.4 feet immediately upstream of the bridge. Improvement of the unnamed road at river mile 7.1 would provide a 1.2 foot decrease, while modification of the FM 2090 bridge would show a 0.6 foot reduction.

Total Cost: Not Calculated
Annual Cost: Not Calculated
Benefit/Cost Ratio: 0.00

Buy-Out Of Floodplain Structures (All PC-F25, PC-F100 Alternatives):

The efficiency of buying out floodprone property was analyzed for Peach Creek in Table 13. Two types of buyout were used: buying all structures within the 100 year floodplain (PC-F100), and a subset of this alternative, buying out only those structures in the 25 year floodplain (PC-F25). The buy-outs for the individual critical areas are designated by the number of the critical area; PC-F100-1, for example, refers to the 100 year buy-out of critical area 1.

Flood Damage Assumptions: Rice University damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Buy-out Cost Assumptions: Rice University total value data was adjusted to remove contents value and to add approximate land costs.

25 Year Buy-out Entire Stream (PC-F25):

Total Cost: \$6,200,000
Annual Cost: \$510,000
Annual Benefit: \$940,000
Benefit/Cost Ratio: 1.90

100 Year Buy-out Entire Stream (PC-F-100):

Total Cost: \$9,500,000
Annual Cost: \$770,000
Annual Benefit: \$1,000,000
Benefit/Cost Ratio: 1.30

Although the 100 year buy-out alternative had a higher annual benefit, the 25 year buy-out had a superior benefit/cost ratio. Most of the flood damage occurred within the 25 year floodplain, indicating that the 155 structures within this area represent the worst flood problems on Peach Creek. The 81 structures outside of the 25 year floodplain but within the 100 year floodplain are responsible for only a small fraction of the average annual damages from Peach Creek.

Both the 25 year and 100 year buy-out benefit/cost ratios were greater than 1.0. Buy-out alternatives with B/C ratios greater than 1.0 can occur when the annual flood damages exceed the annual cost to remove the houses. The annual damages to the structure and contents are assumed to occur repeatedly, and accumulate over the 100 year period used to calculate the annual costs of a buy-out (see sample B/C ratio calculation). If it is assumed that the damages will be repaired after a flood, and damaged during the next flood, then the annual damages can be very high. High annual damages produce high annual benefits for any project, such as a buy-out, that will prevent those damages. In the case of a buy-out B/C ratio greater than 1.0, the annual costs to the structure and the contents are greater than the annual cost of buying the structure plus land.

Different buy-out assumptions will affect the B/C ratios of any buy-out alternative. If one assumes that the future flood damage will not be repaired, then situations where the B/C ratio is greater than 1.0 are much rarer. If a shorter amortization period is used instead of 100 years (the standard Corps of Engineers project lifetime and the amortization period used for this study) the B/C ratios will also be lower. For all the results from this project, however, each buy-out case was calculated assuming that all future flood damage would be repaired and the project lifetime was 100 years.

The ratios for the critical areas varied considerable around the average for the entire stream, indicating some critical areas are better candidates for buy-outs than others. Critical areas 4 and 5 had the best B/C ratios, while critical areas 2 and 3 had the lower B/C ratios under 1.0.

Table 13

**Peach Creek Buy-Out in
25 Year and 100 Year Flood Plain**

PEACH CREEK

Flood Control Alternative	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
PC-F25	Entire Stream	6.2	0.51	0.94	1.9
PC-F25-1	1	0.68	0.056	0.018	3.3
PC-F25-2	2	2.5	0.20	0.20	0.97
PC-F25-3	3	0.40	0.033	0.017	0.53
PC-F25-4	4	1.4	0.12	0.31	2.7
PC-F25-5	5	1.3	0.10	0.24	2.3
PC-F100	Entire Stream	9.5	0.77	1.0	1.3
PC-F100-1	1	1.4	0.12	0.19	1.7
PC-F100-2	2	4.3	0.35	0.23	0.67
PC-F100-3	2	0.89	0.072	0.027	0.37
PC-F100-4	4	1.6	0.13	0.32	2.5

NOTE: See Figure 9 for location of critical areas.

Reservoirs (PC-G1, PC-G2):

This alternative simulated the impact of two "dry" flood control reservoirs on upper Peach Creek. Two reservoirs were modeled to determine if the increased costs of a larger reservoir were justified. Alternative PC-G1 simulated a moderate sized reservoir located at river mile 25.8, while alternative PC-G2 simulated a larger reservoir located at river mile 30.0. Both reservoirs were modeled as structures similar to Barker and Addicks reservoirs in Houston, where there is no permanent pool and all the storage is committed for flood control. The smaller reservoir had an area of 626 acres and a storage capacity of 6150 acre-feet. Alternative PC-G2 had an area of 1371 acres and 25.170 acre-feet of capacity.

Peach Creek Reservoir (PC-G1):

Flow Summary: The 100 year flow at the mouth of Peach Creek reduced by 10% and a 50% reduction at the reservoir.

Floodplain Summary: 0.8 foot reduction in 100 year flood depth at mouth; 4.5 foot reduction immediately downstream of the reservoir.

Total Cost: \$3,500,000
Annual Cost: \$290,000
Annual Benefit: \$230,000
Benefit/Cost Ratio: 0.80

Peach Creek Reservoir (PC-G2):

Flow Summary: The 100 year flow at the mouth of Peach Creek reduced by 15% and a 67% reduction at the reservoir.

Floodplain Summary: 1.1 foot reduction of 100 year flood depth at mouth; 6.9 foot reduction immediately downstream of the reservoir.

Total Cost: \$8,000,000
Annual Cost: \$650,000
Annual Benefit: \$260,000
Benefit/Cost Ratio: 0.40

CANEY CREEK

Description of Watershed and Floodplain:

Caney Creek, one of the major tributaries of the San Jacinto River at Lake Houston, extends from the northern part of Montgomery County to the upstream portion of Lake Houston in Harris County. Most of the 201 square mile watershed lies in eastern Montgomery County.

The majority of the land use along Caney Creek consists of forest with very little urban development. Land use in the watershed in 1970 (HGAC, 1980) is listed below:

Land Use	Percent of Basin Area
Forest	79.6
Pasture	16.4
Cropland	2.0
Urban	2.0

Urban development is expected to rise to 6.0 percent by the year 1990 with most of the development to occur in southern Montgomery County (Rice Center, 1978).

Soils:

Two basic soil types occur along Caney Creek. A moderately well-drained, sandy soil with clayey lower layers occurs upstream, while a loamy, sandy soil with varying permeability can be found for much of the downstream reach. At the uppermost end of the watershed are two small bands of loamy, sandy, and clayey soils which support much of the pasture land activities (SCS, 1972).

Stream Channel Characteristics:

The shape of the Caney Creek channel varies from wide and shallow near Lake Houston to narrower and steeper further upstream. Main channels run from 5 to 15 feet deep and 40 to 100 feet wide. An extensive 100 year flood plain (defined by FEMA floodplain survey conducted by the Soil Conservation Survey) flanks the main channel.

Hydrologic Characteristics:

Near the mouth of Caney Creek at river mile 3.9, the existing 100 year flow has a peak magnitude of 27,405 cfs. In middle reaches of the creek, at river mile 21.0, the existing 100 year peak flow is 26,671 cfs, while further upstream, at river mile 39.4, the peak flow is 21,322 cfs.

Description of Critical Flooding Areas:

Aerial photographs taken by the SDHPT were used to count and map structures in the Caney Creek 100 year floodplain. Five critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of floodprone property and the average annual damages incurred by flooding. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The five critical areas are described further in Table 14 and are shown in Figure 10.

Table 14

CANEY CREEK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	21	845	78
2	34	1,369	91
3	9	362	20
4	36	1,449	118
5	14	564	132
Total	114	4,589	439

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling, and the resulting costs and economic benefits are presented below. The alternatives which produced significant reductions in the floodplain are shown on individual floodplain maps and flood profiles of Caney Creek (see Exhibits). Appendix A provides more detail on the technical methods and assumptions used for this project.

Representative changes in the flow and floodplain elevation for each of the flood control alternatives are shown in Appendix B.

The costs and economic benefits of each structural alternative (each alternative except property buy-out) are presented in Table 15. The affected critical areas, the estimated total cost of the project, and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefit is reduction in annual flood damages to residential structures and household belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient; a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation is provided in section West Fork Flood Control Alternatives.

Table 15

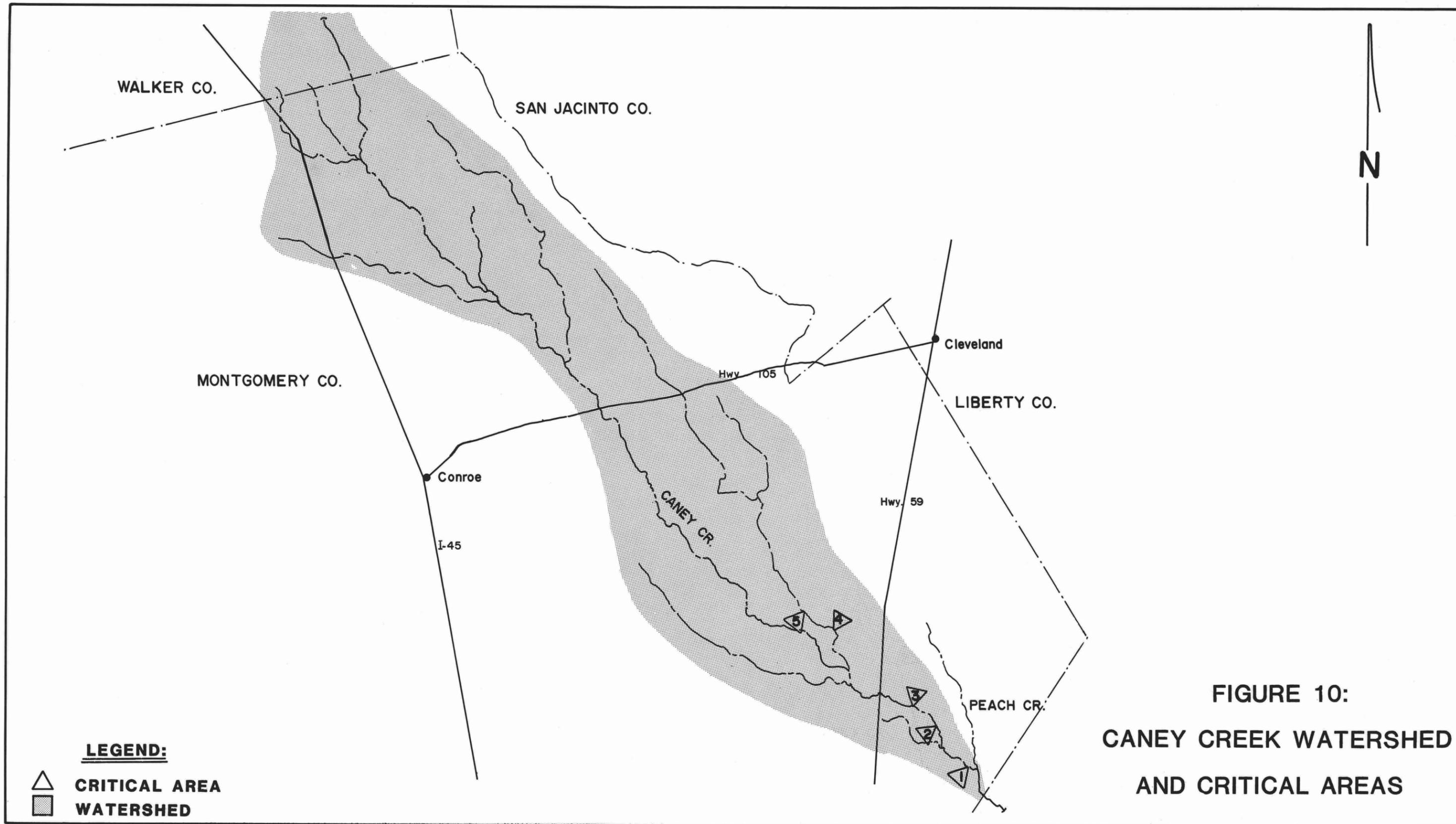
Caney Creek Alternative Costs and Economic Benefits

CANEY CREEK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
CC-B	Entire Stream	73.0	5.9	.51	0.09
CC-D	Entire Stream	3.4	0.68	0.053	0.08
CC-G1	Downstream of Reservoir — All Critical Points	5.7	0.46	0.24	0.51
CC-E	Upstream of Bridges	---	---	0.0	---

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir



**FIGURE 10:
CANEY CREEK WATERSHED
AND CRITICAL AREAS**

Existing Conditions (no flood control alternatives) (CC-A):

Flow Summary: Results from FEMA floodplain study
Floodplain Summary: Results from FEMA Floodplain study
Annual Flooding Damages: \$510,000

Total Channelization (CC-B):

The existing Caney Creek channel was replaced with a large grass-lined channel from the Montgomery-Harris county line to a point 46.1 miles upstream. The channel varied in size, from 14 feet deep with a 200 foot top width upstream, to 30 feet deep with a 460 foot top width down stream.

Flow Summary: Increased flows due to channelization
Floodplain Summary: New Floodplain approximately at elevation of existing channel banks.
Total Cost: \$73,000,000
Annual Cost: \$5,900,000
Annual Benefit: \$510,000
Benefit/Cost Ratio: 0.09

Selective Channelization (CC-C):

No site for selective channelization appeared applicable due to the diverse locations of floodprone structures. Therefore, no computer model was performed and selective channelization was determined to be a non-viable option.

Desnag (CC-D):

The heavy vegetation on the banks of the existing channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and was found to cause only a minor change.

Flow Summary: No change in flow was modeled (see Appendix A)
Floodplain Summary: Up to a 2.7 foot reduction in the existing 100 year flood depth was observed. Most of the large differences occurred in the undeveloped upstream portion of the stream and near bridge crossings. The bridge crossing effect was caused by the improved flow capability of the overbank areas where high flows went around and over bridges.
Total Cost: \$3,400,000
Annual Cost: \$680,000
Annual Benefit: \$53,000
Benefit/Cost Ratio: 0.08

Bridge Modification (CC-E):

Two Caney Creek bridges were examined to determine if hydraulic modifications would have any economic effects. Sycamore Drive (river mile 12.31) and Fire Tower Road (river mile 13.45) were modeled assuming no backwater effects from the two bridges. This represents the best possible result if the existing bridges were replaced with bridges with very efficient hydraulic characteristics. The economic effects of bridge improvement were negligible, however, because bridge improvement only affects the floodplain a short distance upstream (usually less than a mile).

Flow Summary: No change in flow was modeled (See Appendix A)
Floodplain Summary: Improvement of the Sycamore Drive bridge would decrease the 100 year flood depth by 0.4 feet immediately upstream of the bridge. Improvement of the Fire Tower Road bridge would provide a 0.6 foot decrease immediately upstream of the bridge.
Total Cost: Not calculated
Annual Cost: Not calculated

Annual Benefit: \$0.0 (no reduction in flood damages)
Benefit/Cost Ratio: 0.0

Buy-Out Of Floodplain Structures (All CC-F25, CC-F100 Alternatives):

The efficiency of buying out floodprone property was analyzed for Caney Creek in Table 16. Two types of buy-out were used: buying all structures within the 100 year floodplain (CC-F100), and a subset of this alternative, buying out only those structures in the 25 year floodplain (CC-F25). The buy-outs for the individual critical areas are designated by the number of the critical area: CC-F100-1, for example, refers to the 100 year buy-out of critical area 1.
Flood Damage Assumptions: Rice University damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Table 16

**Caney Creek Buy-Out in
25 Year and 100 Year Flood Plain**

CANEY CREEK

Flood Control Alternative	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
CC-F25	Entire Stream	1.9	0.15	0.41	2.7
CC-F25-1	1	0.24	0.020	0.069	3.5
CC-F25-2	2	0.52	0.043	0.086	2.0
CC-F25-3	3	0.12	0.010	0.020	2.0
CC-F25-4	4	0.60	0.049	0.11	2.1
CC-F25-5	5	0.40	0.033	0.129	3.9
CC-F100	Entire Stream	4.6	0.37	0.43	1.2
CC-F100-1	1	0.85	0.069	0.078	1.13
CC-F100-2	2	1.4	0.11	0.091	0.81
CC-F100-3	3	0.36	0.029	0.020	0.69
CC-F100-4	4	1.5	0.12	0.12	1.0
CC-F100-5	5	0.56	0.046	0.13	2.9

NOTE: See Figure 10 for location of critical areas.

Buy-out Cost Assumptions: Rice University total value data was adjusted to remove contents value and to add approximate land costs.

25 Year Buyout Entire Stream (CC-F25):

Total Cost: \$1,900,000
 Annual Cost: \$150,000
 Annual Benefit: \$410,000
 Benefit/Cost Ratio: 2.70

100 Year Buy-out Entire Stream (CC-F100):

Total Cost: \$4,600,000
 Annual Cost: \$370,000
 Annual Benefit: \$430,000
 Benefit/Cost Ratio: 1.20

Although the 100 year buy-out alternative had a higher annual benefit, the 25 year buy-out had a superior benefit/cost ratio. Most of the flood damage occurred within the 25 year floodplain, indicating the 47 structures that are within this area represent the worst flood problems on Caney Creek. The 67 structures outside of the 25 year floodplain but within the 100 year floodplain are responsible for only a small fraction of the average annual damages from Caney Creek.

Both the 25 year and 100 year buy-out benefit/cost ratio were greater than 1.0. Buy-out alternatives with B/C ratios greater than 1.0 can occur when the annual flood damages exceed the annual cost to remove the houses. The annual damages to the structure and contents are assumed to occur repeatedly, and accumulate over the 100 year period used to calculate the annual costs of a buy-out (see sample B/C ratio calculation). If it is assumed that the damages will be repaired after a flood, and damaged during the next flood, then the annual damages can be very high. High annual damages produce high annual benefits for any project, such as a buy-out, that will prevent those damages. In the case of a buy-out B/C ratio greater than 1.0, the annual costs to the structure and the contents are greater than the annual cost of buying the structure plus land.

Different buy-out assumptions will affect the B/C ratios of any buy-out alternative. If one assumes that the future flood damage will not be repaired, then situations where the B/C ratio is greater than 1.0 are much rarer. If a shorter amortization period is used instead of 100 years (the standard Corps of Engineers project lifetime and the amortization period used for this study) the B/C ratios will also be lower. For all the results from this project, however, each buyout case was calculated assuming that all future flood damage would be repaired and the project lifetime was 100 years.

Reservoirs (CC-G1):

This alternative simulated the impact of a "dry" flood control reservoir on upper Caney Creek at river mile 34.71. The reservoir was modeled as a structure similar to Barker and Addicks reservoirs in Houston, where there is no permanent pool and all the storage is committed for flood control. The Caney Creek reservoir had 15,400 acre-feet of flood control storage, was 671 acres in area and had a maximum water depth of 45 feet when full to capacity. This design was large enough to hold all the upstream runoff from a 100 year storm.

Caney Creek Reservoir (CC-G1):

Flow Summary: Reductions of the 100 year flow at the mouth Caney Creek by 16% . No flow released from reservoir during 100 year storm; complete storage of all runoff.

Floodplain Summary: 1.1 foot reduction of the 100 year flood depth at mouth; 14 foot reduction in floodplain immediately downstream of reservoir.

Total Cost: \$5,700,000
 Annual Cost: \$460,000

Annual Benefit: \$240,000
 Benefit/Cost Ratio: 0.51

EAST FORK

Description of Watershed and Floodplain:

The East Fork of the San Jacinto River as it was modeled hydrologically in this study includes Winters Bayou and the main tributary of the river which originates in San Jacinto County between Oakhurst and Willow Springs, Texas. Streams feeding the main tributary of the East Fork include Cobb Creek and Miller Creek. Winters Bayou, which originates south of Phelps, Texas in Walker County and which empties into the main tributary north of Cleveland, Texas is fed by several streams including Gourd Creek and Nebletts Creek. The East Fork drains a watershed of 371 square miles and empties into Lake Houston near River Terrace, Texas.

Land use in the East Fork watershed consists primarily of forest and pasture, with significantly smaller areas devoted to urban development and agriculture. Land uses in 1970 and corresponding watershed areas were delineated by the HoustonGalveston Area Council (HGAC, 1980) as follows:

Land Use	Percent of Basin Area
Forest	83.6
Pasture	14.3
Agriculture	1.5
Developed	0.6

Developed areas in the watershed are expected to increase from 0.6% of the total basin area to 1.3% of the basin area in 1990 (Rice Center, 1978).

Soils:

Most of the soils in the East Fork consist of a high permeability sand which permits recharge particularly in the southern part of the watershed. Isolated areas of expansive, low permeability clay are also found in the downstream portion of the basin. In the northern half of the watershed, a mixture of clay and sandy soils outcrop in a band between Hawthorne and Laurel Hill, Texas. These soils are moderately to highly expansive in the clayey portions and have a low to moderate permeability. In stream beds and in flood prone areas along Winters Bayou and the main East Fork tributary, soils consist of sand, gravel, and mud.

Stream Channel Characteristics:

The stream channel cross-section varies significantly along the length of the tributary. Upstream from the mouth of the East Fork Tributary at Lake Houston (river mile 9.4), the stream channel has a width of 450 feet and a depth of 22 feet.

At the San Jacinto - Hardin County line (river mile 30.4), below the confluence of Winters Bayou with the main tributary, the channel has a width of 85 feet and a depth of 27 feet. The width of the 100 year floodplain also varies along the length of the tributary, from approximately 3300 feet wide at river mile 9.4 and 850 feet wide at river mile 30.4.

Channel slope varies between approximately 1.6 feet/mile and 4.8 feet/mile.

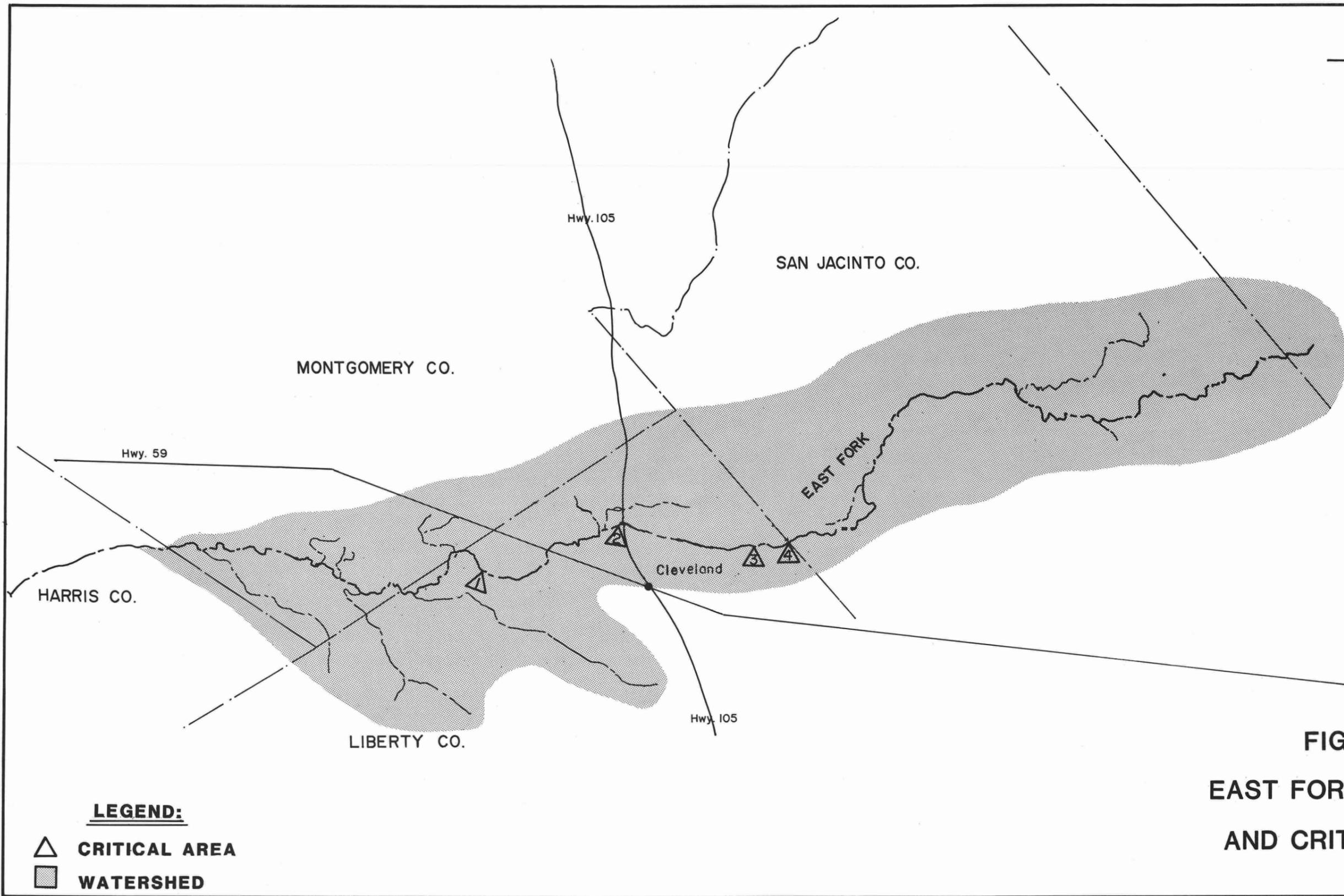


FIGURE 11:

**EAST FORK WATERSHED
AND CRITICAL AREAS**

LEGEND:

- △ CRITICAL AREA
- WATERSHED

Hydrologic Characteristics:

Downstream from the confluence of Winters Bayou with the main East Fork tributary, the existing 100 year flow has a peak magnitude of 53,728 cfs. Near the mouth of the tributary at Lake Houston the flow has a magnitude of 55,433 cfs.

Description of Critical Flooding Areas:

Aerial photographs taken by the SDHPT were used to count and map structures in the East Fork 100 year floodplain. Four critical areas with high concentrations of floodprone structures were defined and studied in detail to determine the current value of floodprone property and the average annual damages incurred by flooding. The beneficial effects of the series of flood control alternatives were determined for each of the critical areas. The four critical areas are described further in Table 17 and are shown in Figure 11.

Table 17

EAST FORK CRITICAL AREAS

Critical Area	Number of Structures in 100 yr Floodplain	Total Value of Structures (mil \$)	Annual Flooding Damages (mil \$)
1	99	2,643	59
2	23	667	76
3	59	2,348	42
4	37	1,047	103
Total	218	6,705	280

Flood Control Alternatives:

A short description of each alternative, the assumptions used for the technical modeling, and the resulting costs and economic benefits are presented below. The alternatives which produced significant reductions in the floodplain are shown on individual floodplain maps and flood profiles of the East Fork (see Exhibits). Appendix A details the technical methods and assumptions used in this project.

Representative changes in the flow and floodplain elevation for each of the flood control alternatives are shown in Appendix B.

The costs and economic benefits of each structural alternative (each alternative except property buy-out) are presented in Table 18. The affected critical areas, the estimated total cost of the project, and the annualized costs and economic benefits of each flood control alternative are presented. The annual cost of the project is the total cost of the project translated to an annual cost for servicing any capital improvement bonds. The annual benefit is the reduction in annual flood damages to residential structures and household

belongings that arise from a particular flood control project. The benefit/cost ratios show if an alternative is economically efficient: a B/C ratio greater than 1.0 results if the annual economic benefits exceed the annual costs. A B/C less than 1.0 indicates the project is more expensive than the reduction of flood damages related to the project. A sample calculation is provided in section West Fork Flood Control Alternatives.

Table 18

East Fork Alternative Costs and Economic Benefits

EAST FORK

Flood Control Alternative*	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
EF-B	Entire Stream	48.7	4.0	0.28	0.07
EF-D	Entire Stream	7.4	1.5	0.003	0.002
EF-G	Downstream of Reservoir — All Critical Points	44.3	3.6	0.26	0.07
EF-E1	1	~3.0	~0.24	0.020	0.08
EF-E2	4	3.0	0.24	0.006	0.02

***Alternatives:**

- A. Existing channel
- B. Total channelization
- C. Selective channelization
- D. Desnag
- E. Bridge modification
- F. Buy-out
- G. Reservoir

Existing Conditions (no flood control alternatives) (EF-A):

Flow Summary: Flows from the FEMA study were available for downstream 5.5 miles (Montgomery County). The upstream 15.6 miles, the Liberty County portion, were not analyzed by FEMA when this project was performed: the flows were developed from an original Rice University analysis and should not be considered official FEMA floodplains.

Floodplain Summary: Same as flow summary above: the Montgomery County FEMA floodplain study was used for the downstream 5.5 miles. The Liberty County section was analyzed using a recently completed SCS floodplain model with the Rice University flows, producing a floodplain that should be considered only an estimate of the final FEMA floodplain for Liberty County. The San Jacinto County section was not analyzed because floodplain land is primarily National Forest with little urban development.

Annual Flooding Damages: \$280,000

Total Channelization (EF-B):

The existing East Fork channel was replaced with a large grass lined channel from the Harris County line (river mile 9.3) to the San Jacinto County line at river mile 30.4. This represents the downstream third of the East Fork. The channel was 20 feet deep and the top width varied from 480 feet at the upstream section to 530 feet at the far downstream section near Lake Houston.

Flow Summary: Increased flows due to channelization

Floodplain Summary: New floodplain approximately at elevation of existing channel banks.

Total Cost: \$48,700,000

Annual Cost: \$4,000,000

Annual Benefits: \$280,000

Benefit/Cost Ratio: 0.07

Selective Channelization (EF-C):

No site for selective channelization appeared applicable due to the diverse locations of floodprone structures. Therefore, no computer model was performed and selective channelization was determined to be a non-viable option.

Desnag (EF-D):

The heavy vegetation on the banks of the existing channel was assumed to be removed along the entire length of the channel to increase the hydraulic efficiency. This was simulated by lowering the channel roughness factors in the hydraulic model. The effect on flow was examined and was found to cause only a minor change.

Flow Summary: A slight increase in flow was observed. The downstream portion of East Fork showed a 4% increase over existing conditions after desnagging.

Floodplain Summary: Very little effect was observed: the average reduction in the 100 year flood depth was 0.1 feet.

Total Cost: \$7,400,000

Annual Cost: \$1,500,000

Annual Benefit: \$3,000

Benefit/Cost Ratio: 0.03

Bridge Modification (EF-E1, EF-E2):

Two East Fork bridge modification alternatives were performed to determine if any hydraulic modifications would produce any reduction of flood damages. Alternative EF-E1 modeled the improvement of the FM 1485 bridge near the Harris County line, while alternatively EF-E2 assumed the Highway 105 bridge near Cleveland would be improved. Each alternative lowered the 100 year flood depth to some degree. These alternatives simulated the best possible result if the existing bridges were replaced with bridges with very efficient hydraulic characteristics. The economic effects of bridge improvement were small, however, because bridge improvement only effects the floodplain a short distance upstream (usually less than a mile).

Bridge Modification (FM 1485 Bridge) (EF-E1):

Flow Summary: No change in flow was modeled (see Appendix A). Floodplain Summary: Reduction in the 100 year flood depth of up to 1.6 feet immediately upstream of bridges.

Total Cost: \$3,000,000 (approximate)

Annual Cost: \$240,000

Annual Benefit: \$20,000

Benefit/Cost Ratio: 0.08

Bridge Modification (Highway 105 Bridge) (EF-E2):

Flow Summary: No change in flow was modeled (see Appendix A).

Floodplain Summary: Reduction in the 100 year flood depth of up to 1.2 feet immediately upstream of bridges.

Total Cost: \$3,000,000

Annual Cost \$240,000

Annual Benefit \$6,000

Benefit/Cost Ratio: 0.03

Buy-out of Floodplain Structures (All EF-F25, EF-F100 Alternatives):

The efficiency of buying out floodprone property was analyzed for the East Fork and presented in Table 19. Two types of buy-out were used: buying all structures within the 100 year floodplain (EF-F100), and a subset of the alternative, buying out only those structures in the 25 year floodplain (EF-F25). The buyouts for the individual critical areas are designated by the number of the critical area; EF-F100-1, for example, refers to the 100 year buy-out of critical area 1.

Flood Damage Assumptions: Corps of Engineers damage data incorporated structure plus contents damage for residential structures. No other damage was included.

Buy-out Cost Assumptions: Corps of Engineers total value data was adjusted to remove contents value and to add approximate land costs.

25 Year Buy-out Entire Stream (EF-F25):

Total Cost: \$3,400,000

Annual Cost: \$280,000

Annual Benefit: \$230,000

Benefit/Cost Ratio: 0.81

100 Year Buy-out Entire Stream (EF-F100):

Total Cost: \$4,500,000

Annual Cost: \$360,000

Annual Benefit: \$280,000

Benefit/Cost Ratio: 0.77

Although the 100 year buy-out alternative had a higher annual benefit, the 25 year buy-out had a superior benefit/cost ratio. Most of the flood damage occurred within the 25 year floodplain, indicating the 125 structures that are within the 25 year floodplain represent the worst flood problems on East Fork. The 93 structures outside of the 25 year floodplain but within the 100 year floodplain are responsible for only a small fraction of the average annual damages from the East Fork. The ratios for the critical areas varied considerably around the average for the entire stream, indicating some critical areas are better candidates for buy-outs than others. Critical area 3 had a very low B/C for both buy-out alternatives. Critical areas 2 and 4 had the best B/C ratios, and for both the 100 year and the 25 year buy-out cases the B/C was greater than 1.0.

Buy-out alternatives with B/C ratios greater than 1.0 can occur when the annual flood damages exceed the annual cost to remove the houses. The annual damages to the structure and contents are assumed to occur repeatedly, and accumulate over the 100 year period used to calculate the annual costs of a buy-out. If it is assumed that the damages will be repaired after a flood, and damaged during the next flood, then the annual damages can be very high. High annual losses produce high annual benefits for any project, such as a buy-out, that will prevent those losses. In the case of a buy-out B/C ratio greater than 1.0, the annual costs to the structure and the contents are greater than the annual cost of buying the structure plus land.

Different buy-out assumptions will affect the B/C ratios of any buy-out alternative. If one assumes that the future flood damage will not be repaired, then situations where the B/C ratio is greater than 1.0

Table 19

**East Fork Buy-Out in
25 Year and 100 Year Flood Plain**

EAST FORK

East Fork Reservoir (EC-G1):

Flow Summary: 80% to 90% reductions in the 100 year flow in the Montgomery County and Liberty county sections of the East Fork: from 55,000 cfs to less than 10,000 cfs.

Floodplain Summary: A 9 foot reduction in 100 year flood depth occurred.

Total Cost: \$44,300,000

Annual Cost: \$4,000,000

Annual Benefit: \$260,000

Benefit/Cost Ratio: 0.07

Flood Control Alternative	Affected Critical Points	Total Cost (mil \$)	Annual Cost (mil \$)	Annual Benefits (mil \$)	BENEFIT Cost Ratio
EF-F25	Entire Stream	3.4	0.28	0.23	0.81
EF-F25-1	1	1.4	0.11	0.035	0.31
EF-F25-2	2	0.4	0.033	0.069	2.1
EF-F25-3	3	0.78	0.063	0.028	0.45
EF-F25-4	4	0.90	0.073	0.096	1.3
EF-F100	Entire Stream	4.5	0.36	0.28	0.77
EF-F100-1	1	2.6	0.22	0.060	0.28
EF-F100-2	2	0.68	0.054	0.076	1.4
EF-F100-3	3	2.3	0.19	0.042	0.22
EF-F100-4	4	1.1	0.085	1.0	1.2

NOTE: See Figure 11 for location of critical areas.

are much rarer. If a shorter amortization period is used instead of 100 years (the standard Corps of Engineers project lifetime and the amortization period used for this study) the B/C ratios will also be lower. For all the results from this project, however, each buy-out case was calculated assuming that all future flood damage would be repaired and the project lifetime was 100 years.

Reservoirs (EF-G1):

This alternative simulated the impact of a proposed multi-purpose reservoir near the junction of the East Fork and Winters Bayou in San Jacinto County. Reservoir data was provided by the Bureau of Reclamation and was modeled assuming a 29,000 acre controlled pool area and 84,000 acre-feet of flood storage. This was based on the assumption that 3 feet of the available 5 feet of flood storage was available for active flood control of the 100 year storm, and the remainder was used as a safety factor and for inefficiencies in managing the storage of large storms.

CHAPTER 5 - CONCLUSIONS

There are approximately 2170 structures in the 100 year floodplains of the major streams in the San Jacinto Basin: the West Fork, Lake Creek, Caney Creek, Peach Creek, the East Fork, and Spring Creek. The West Fork accounts for 52 percent of these structures, followed by Spring Creek with 20 percent. Lake Creek has only 39 structures in the floodplain and has a much smaller flood problem than any of the other five streams (Table 20).

Table 20
**Summary of Floodplain
Structures and Annual Damages**

Watershed	Number of Structures	Annual Flood Damage (Thous. dollars)
West Fork	1125	4500
Lake Creek	39	11
Spring Creek	438	623
Peach Creek	236	1008
Caney Creek	114	439
East Fork	218	280
	<u>2170</u>	<u>6861</u>

Average annual flooding damages were calculated for 26 floodprone areas ("critical areas") on the six major streams. Average annual flooding damage accounts for damages caused by small, frequent floods (floods occurring on the average every 2 years), and for the larger but less frequent floods, up to the flood that occurs on the average once every 100 years. The average annual flood damage from the six main streams is estimated to be \$6,861,000. The West Fork is responsible for 66 percent of this total, with the River Plantation area alone accounting for \$3,300,000 in annual damages. Peach Creek had \$1,007,000 of annual flood damages and Spring Creek showed \$623,000 of annual damages.

The economic benefits and cost of several flood control alternatives were determined for each of the six streams. This calculation incorporated hydrologic, hydraulic, and economic modeling of the entire San Jacinto River Basin. The economic benefits of each alternative were defined as the annual flooding damages that would be prevented with the flood control alternative in place. The total capital costs of each

alternative were estimated and converted to an annual cost using U.S. Army Corps of Engineers assumptions (8.125 percent interest rate and a 100 year amortization period). Benefit/cost ratios were calculated for most of the alternatives; a B/C ratio greater than 1.0 indicates the project had a positive economic benefit, while a B/C ratio less than 1.0 indicated the costs of the project were greater than the resulting economic benefits (Table 21).

Table 21
Summary of Benefit/Cost Ratios of Alternatives

Basin	Total Channelization	Desnag	Reservoirs		100-yr Buyout	25-yr Buyout
			Alt. 1	Alt. 2		
West Fork	0.40	0.75	2.2 ¹	2.8 ²	0.57	0.76
Lake Creek	<0.001	0.0	0.0 ¹	<0.001 ³	0.09	0.09
Spring Creek	0.03	0.14	0.0	0.09	0.36	0.84
Peach Creek	0.33	0.04	0.80	0.40	1.3	1.9
Caney Creek	0.09	0.08	0.51	---	1.2	2.7
East Fork	0.07	0.002	0.07	---	0.77	0.81

¹ = Lake Creek Reservoir operated for controlling West Fork floods.

² = Lake Creek Reservoir and new Lake Conroe operation assumption.

³ = Lake Creek Reservoir operated for controlling Lake Creek floods.

Total Channelization:

This alternative modeled the construction of a grass lined channel down the entire length of each stream. The channel was designed to carry the 100 year flood. This alternative had the greatest effect on the 100 year floodplain; it reduced the 100 year flood elevation to the level of the existing stream banks. The benefit/cost ratios for each stream were less than 1.0, however, and the most economically efficient project (on the West Fork) only paid back 40 percent of the project costs in reduced flood damage. The economic analysis also did not account for the large environmental impact that channelization projects produce.

The scope of this project was concerned only with analyzing the cost effectiveness of a channel large enough to carry the 100 year flood. A channel designed to carry a smaller flood, such as the 25 year flood, would probably be more cost-effective.

Selective Channelization:

Channelization of short sections of the stream was determined to be viable and examined for the four critical areas of the West Fork. The B/C ratios were much more favorable than for total channelization. A 30 foot deep channel with a 550 foot top width through the River Plantation area was estimated to have a B/C ratio of 0.93, almost at the break even point.

Desnag:

Removal of trees and heavy vegetation along the stream channels was examined for each stream. This alternative assumed no dredging or change in the channel configuration, only the reduction in the hydraulic friction of the channel. The West Fork showed a relatively high B/C ratio of 0.75, while the other streams all had B/C ratios less than 0.14.

Selective desnag projects through the West Fork critical areas were also examined. As with the selective channelization alternative, desnag through River Plantation area had a high B/C ratio, as did selective desnag of the West Fork near Highway 105. The benefits from both selective desnag projects were calculated to be over twice the cost of the project. In the desnag cases, the clearing operation was assumed to be repeated every five years.

The environmental impact of the desnagging operation was not considered in this analysis. Removal of most trees and all brush from the 500 foot channel section would have a large effect on the appearance of the area and on some of the wildlife. These impacts would need to be considered in any detailed design analysis of this alternative.

Bridge Modification:

Improvement of bridges that restricted flow in the floodplains were examined for the six major streams. No bridge modification project was cost effective in reducing flood damages, and the highest B/C ratio was 0.10. The reason for the low economic benefits of these projects was the reduction in the existing 100 year floodplain only extended a short distance upstream of the bridges.

Buy-out of Floodprone Property:

The buy-out alternatives generally produced high B/C ratios, and several of the projects had B/C ratios greater than 1.0. A B/C ratio greater than 1.0 can occur when the flooding damages are assumed to be prevented for more than one flood. Buy-out analysis were performed for each critical area, and the B/C ratios ranged from 0.0 to 3.9, indicating some critical areas were much better buy-out candidates than others.

Two types of buy-outs were evaluated: a buy-out of all the houses in the 100 year floodplain, and a buy-out of just those structures in the 25 year floodplain. In all cases, the 25 year buy-out case had superior B/C ratios, indicating the bulk of the flood damages are caused by the group of houses that are flooded frequently by smaller storms rather than by the 100 year flood.

Reservoirs:

Three types of reservoir alternatives were performed: evaluation of large, multi-purpose reservoirs on Lake Creek and the East Fork, optimization of the flood control potential of Lake Conroe, and considerations of "dry" flood control reservoirs such as Addicks and Barker dams in Houston, Texas.

The West Fork-Lake Creek system was evaluated for two main alternatives involving the proposed Lake Creek reservoir and the existing Lake Conroe. The first alternative assumed the Lake Creek reservoir would be operated for West Fork flood control purposes only, instead of controlling the Lake Creek floodplain. This distinction was important, as the analysis suggested that two different operational methods were required to protect Lake Creek and to protect the West Fork. Since the West Fork has over 400 times as much flood damage as Lake Creek, the West Fork flood protection alternative was the most cost effective. The overall B/C ratio for using the available flood control storage in the Lake Creek reservoir was 2.2, a very cost effective alternative (WF-G1).

The second West Fork alternative (WF-G2) evaluated the actual flood control capabilities of Lake Conroe combined with the Lake Creek reservoir. The Federal Emergency Management Agency (FEMA) floodplain study assumed the worst case, that the flood storage in Lake Conroe was used very inefficiently.

Alternative WF-G2 assumed the operators of Lake Conroe would be able to manage the existing storage to provide more flood control than was assumed in the FEMA study. (The San Jacinto River Authority is now developing a computer model of the watershed draining into Lake Conroe to aid in the operation of the reservoir). The assumption of different Lake Conroe operation combined with the Lake Creek reservoir produced a B/C ratio of 2.8 and a \$3,300,000 reduction in annual flood damages. This was the highest annual benefit of any flood control alternative.

The only two other reservoirs with a B/C ratio greater than 0.50 were the "dry" flood control reservoirs on Peach Creek (B/C at 0.80) and Caney Creek (B/C at 0.51). A comparison of two sizes of "dry" flood control structures on Peach Creek indicated that a medium sized reservoir was more cost effective than a large one. This corresponds to the results from the buyout analysis, which suggested it was more cost effective to control only the most serious flooding in the 100 year floodplain, rather than rectify all of the flood problems in the 100 year floodplain.

CHAPTER 6 - EXAMINATION & RECOMMENDATION OF BASIC DESIGN CRITERIA FOR WATERSHED

Introduction:

This review is intended to provide a general guide for recommended hydrologic and hydraulic design methods in Upper Watershed. A summary of the existing hydrologic models of the Upper Watershed streams is provided along with the basic assumptions used in the models. This section is not intended to be used for specific runoff design methodology; rather it includes a broad outline of design procedures, the data and tools available to governmental entities, planners, and engineers for watershed analysis.

Hydrology:

It has long been recognized that urban development has a pronounced effect on the rate of runoff from a given rainfall. The hydraulic efficiency system generally is improved by urbanization, thereby increasing the speed of runoff and reducing the storage capacity of a watershed. The reduction of a watershed's storage capacity is a direct result of the elimination of porous surfaces, small ponds, and natural holding areas. This comes about by parking lots, sidewalks, and by construction of buildings and other facilities characteristic of urban development. More importantly, the improved hydraulic efficiency of storm sewers, curb-and-gutter streets, and open ditch systems, both earthen and concrete-lined, increases the speed at which runoff drains from a developed area. Over the years a number of methods have been used for discharge determination in the design and analysis of flood control facilities. The methods included various forms of the Rational Method, synthetic unit hydrograph analysis using existing stream gaging records and computer programs developed by the Soil Conservation Service, Corps of Engineers, U.S. Geological Survey generalized regression equation developed for the area, and drainage area discharge curves developed for specific watersheds.

The hydrologic methodology used in the design and analysis of flood control and drainage facilities in the San Jacinto watershed should be such that the methodology utilized would be consistently used by developers, planners, and engineers, and was the basis of the Federal Emergency Management Agency (FEMA) hydraulic studies establishing the limits of the 100-year flood plain in the watershed. In this case, 100-year floodplain was determined utilizing SCS TR-20 and therefore is the logical choice to utilize for large drainage systems.

Any drainage system can be divided into two categories: the minor system and the major system. The minor system refers to small drainage basins: several drainage districts have used 25 to 100 acres to delineate a minor drainage system. Design of grass swales, storm sewers, curbs and gutters, and small culverts can be performed using the Rational Method and input data based on traditional design criteria.

The major system refers to design and management of runoff in larger drainage systems. Hydrograph analysis methods are very useful, it not necessary, to analyze how large drainage projects impact downstream flows particularly in the major drainage system.

Rainfall:

The design rainfalls used for drainage projects should account for the worst case for runoff calculation. The SCS used 48 hour Type I design storm distribution for all the watersheds except Peach and Caney Creeks, where they used a 24 hour Type I design storm distribution. The selection of a Type I storm is unusual as this distribution was developed to describe storms occurring in Asaska, Hawaii, and the far West Coast. The SCS used a Type I distribution instead of Type II distribution (representing a North American thunderstorm distribution) in order to match the types of peak flows recorded by gauges in the streams of the San Jacinto watershed. Rainfall amounts were adjusted from the National Weather Service statistical design rainfalls (TP-40) in addition to the rainfall distribution to match the stream gauge records.

The SCS adjustments complicate the decision of which design rainfalls to use for future watershed planning and design purposes. One alternative is to require a traditional worst case design rainfall for projects affecting the major hydrologic system: a 100 year 24 hour design rainfall volume from the National Weather Service's Technical Publication 40 (TP-40), distributed over the 24 hours using the traditional Type II distribution. If the proposed project appears to have a major effect on the main streams or tributaries, then an analysis using the SCS assumptions can be performed to see if the second set of assumptions will have a larger effect. The largest impact from the two sets of assumptions can then be used for the impact of the proposed project.

Runoff:

"Runoff volume" or "rainfall excess" is the direct runoff from a storm event. The volume of runoff is highly dependent on rainfall volume and rate, but is also affected by antecedent soil moisture, depression storage, interception, infiltration, and evaporation. The impact of these factors is variable from basin to basin and is dependent on basin characteristics, hydrologic conditions, and season. Three of the factors generally considered most important in determining the resulting runoff volume are antecedent soil moisture, depression storage, and infiltration.

Modeling:

Two SCS techniques are available to provide stream hydrograph analysis. The SCS TR-55 is a "desktop" calculation method that can provide hydrographs from watersheds up to 20 square miles in area. The computerized version of the SCS methodology, the TR-20 model, is available on either mainframe computers or microcomputers. Both of these methods have the advantage of relatively simple input requirements and ease of use.

The SCS has modeled each of the six major streams and most of the tributaries using TR-20. As a result of this project, all of the Montgomery County FEMA study input data is now available on tape from the San Jacinto River Authority. Most of the data is ready for use; some data was not available from the SCS in tape or card form and had to be transcribed by hand from paper copies. All of the transcribed data for the six main watersheds were checked until the results matched the original SCS results from the 1975 FEMA study. The data for the smaller watersheds were not used for this project, and although transcribed from the paper copies but was not checked and verified. This data, which is marked on the tape, will require debugging and checking against the SCS floodplain data.

Hydraulics:

The hydraulic design of a channel or structure is of primary importance to insure that flooding and erosion problems are not aggravated or created.

All major open channels should be designed to contain the runoff from the 100 year frequency storm within the right-of-way, except where channel improvements are necessary to offset increased flows from a proposed development. In those cases, the 100 year flood profile under existing conditions of development should not be increased. Additionally, the channel must provide sufficient freeboard during the more frequent design storm (25 year frequency) to provide for adequate drainage of lateral storm sewers.

In areas served by closed systems, storm water runoff should be removed during the 100 year frequency storm without flooding of structures. This is accomplished through the design of the street system and the storm sewer system in combination as well as increases in the design capacity of the closed conduit.

Several methods exist which can be used to compute water surface profiles in open channels. The methodology selected depends on the complexity of the hydraulic design and the level of accuracy desired.

For an existing or proposed channel with flow confined to uniform cross-sections, either a hand calculated normal depth or direct step computation is sufficient. Manning's equation should be used for computing normal depth. For evaluating non-uniform channels for existing conditions or designing a proposed channel with flow in the overbanks, the standard step method is recommended.

Two computer programs are available which make use of the standard step method; HEC-2 developed by the U.S. Army Corps of Engineers and WSP-2 developed by the Soil Conservation Service.

WSP-2 hydraulic backwater models utilizing FEMA input data are available for each of the six major streams and for many of the tributaries in the San Jacinto watershed. As with the hydrologic data, all of this data is now available on a tape from the San Jacinto River Authority. The data was obtained in two forms from the SCS: actual computer tape and paper copies. The data for the six main streams were checked and verified against the actual results from the SCS floodplain study. All of the tributary data on paper were copied to magnetic tape; this data was not checked against the SCS results and needs to be checked for accuracy and correctness. The index to the data tape lists the data and whether the data should be checked or not.

Effects of Urbanization:

Drainage authorities have recognized that urban development will increase the 100 year peak flow over existing conditions. This can greatly enlarge the 100 year floodplain, and make the existing 100 year floodplain maps outdated. Property initially outside the original floodplain can actually be inside the 100 year floodplain when urbanization increases the runoff from the watershed.

One mechanism to account for the widening floodplain is to develop criteria on how much an increase in the 100 year flow is permissible based on how important it is to the regulatory agency to keep the existing

floodplain from expanding. A stream with significant development just on the fringe of the floodplain would merit different consideration than one where a larger floodplain would have a minor impact.

The criteria could be developed using hydrologic simulation models and would be in the form of recommended development densities (percentage impervious areas) for different portions of the watershed. One area, for example, might be able to support high development densities in a hydrologically "insensitive" portion of the watershed, and yet have the same impact as low density development in a "sensitive" area. The simulation modeling could provide the general development guidelines for different areas of each watershed based on hydrologic timing, proximity to the stream and to major problem areas, and to the topography and soils of the basin.

Structural Considerations:

The structural design of flood control facilities encompasses all aspects of the design of modifications from reducing runoff by retention/detention to altering existing channels and streams, building new channels, selecting side slopes for earthen channels, and building major structures, such as bridges, culverts, drop structures, and retaining walls. Hydraulic structures should convey stormwater safely, control erosion, be cost effective, require minimal maintenance, and add safety and esthetics to the drainage system.

It is beyond the scope of this project to develop detailed structural requirements, however, future development of this criteria by the eventual governmental entity responsible should be considered. Retention/detention has limited usefulness for an overall stream. However, when retention/detention is properly applied, especially in the upper reaches of watersheds, substantial benefits and results are achieved.

Detention ponds are useful to reduce the impacts of urban development to downstream areas. Stormwater detention can be divided into two main groups: on-site detention and regional detention. On-site detention refers to small basins, usually constructed by a developer, that control runoff from individual subdivisions or commercial developments. Regional detention refers to larger structures on a major drainage systems that control runoff from several developments.

The advantage to an on-site located detention facility is the capital costs are carried by a developer, and a drainage district or municipality with no available capital funds can get detention installed into the drainage system. The key to a successful onsite detention program is detailed design criteria and performance standardp with a strong maintenance clause. Many cities and counties have experienced severe maintenance problems with on-site detention. When considering the large number of potential basins, it is very important to establish who is going to provide the money and effort to maintain the system in order for it to be effective.

Regional detention has been shown in many cases to be more technically efficient and more cost effective than on-site detention. Developers usually favor regional detention, even if they have to pay a shared portion of the construction costs. A regional detention policy can be very cost effective, especially if land is reserved for detention before the best basin sites are committed for development. The Harris County Flood Control District is now developing an innovative regional detention system for White Oak Bayou; this system is based on the concept of user's fees, where upstream developers contribute funds to the Flood Control District to help defray some of the costs for regional detention basins.

Non-Structural Considerations:

Often steps taken by governmental entities on their own initiative or in conjunction with other agencies can have a profound affect on reduction of flood damages. Ordinances, regulations, and/or laws can regulate development within the floodplain boundary. These actions are usually based upon FEMA

floodplain boundary maps. Development of this plan of attack is highly recommended to assist in the control of future flood damages. Among the steps recommended are:

1. Initiate one central group or agency to control, monitor, remedy, and finance flood control for the watershed. Since the entire watershed ties together in Lake Houston, a coordinated flood control management is most important in the upper watershed.

2. Control development within the 100 year floodplain by laws and ordinances prohibiting development within the floodway and limiting development within the floodplain. These laws may control through numerous governmental agencies: the entities in charge of flood control, building permits, plan approvals, commissioner's court rulings, etc.

3. Establish minimum building slab elevations in floodprone areas. These slab elevations should conform to the requirements outlined by the Federal Housing Administration and apply to all structures.

4. Limit placement of fill within the floodplain without the approval of the flood control entity and/or county government. Require appropriate compaction testing and data along with hydrologic and hydraulic data with emphasis on impact on downstream and surrounding water surfaces.

5. Develop guidelines and procedures to follow when allowing development within the 100 year flood plain. Among the factors to be considered are: provide adequate passage of adjacent waterway through development, limit land fill, limit structures to not obstruct the 100 year flood flow unless offsetting conveyance capacity is provided and limit floodway encroachment.

6. Finally, develop general criteria, procedures, and requirements for downstream impact analysis. Include the specific analysis, procedures, type model, depth of detail, and all other such factors. This specific design criteria is necessary in order to compare Development A with Development B and to analyze these combined effects.

APPENDIX A

TECHNICAL METHODS

A. HYDROLOGIC AND HYDRAULIC MODELING

Existing Floodplain

The hydrologic and hydraulic simulations of the six major streams in the San Jacinto River basin were performed using different computer models and different sources of input data:

Stream	Hydrologic Model	Input Data Source	Hydraulic Model	Input Data Source
West Fork	TR-20	SCS	WSP2	SCS
Lake Creek	TR-20	SCS	WSP2	SCS
Caney Creek	TR-20	SCS	WSP2	SCS
Peach Creek	TR-20	SCS	WSP2	SCS
East Fork	HEC-1*	Rice U.	WSP2	SCS
Spring Creek	HEC-1**	COE, Rice U. Calibration	HEC-2	COE

*-1981 version **-1973 version

Data Sources:

SCS—Soil Conservation Service, Temple, Texas

Rice U.—Rice University Department of Environmental Science and Engineering

COE—U. S. Army Corps of Engineers, Galveston District, Texas

All elevations are based on the National Geodetic Vertical Datum of 1973.

The West Fork, Lake Creek, Caney Creek, and Peach Creek were modeled for existing conditions by the SCS during the Montgomery County FEMA (Federal Emergency Management Agency, the successor to the FIA, The Federal Insurance Administration) study. The FEMA hydrology and hydraulics were matched exactly after the data was converted to the Rice University computer. This task required considerable effort because of the different types of data available from the SCS and the need to load several computer simulation models into the Rice University computer.

Several trips were made to the SCS office in Temple, Texas to discuss how the FEMA study was performed and to obtain the input data for all the computer models. The SCS provided support in setting up the data bases which although not used for several years were the input for this project. The summary

sheets, the hydrologic and hydraulic methodology, and the various maps, profiles, and cross-section cross references were obtained. The SCS had the input data for the WSP2 and TR-20 models in two forms: about half of the data was available on computer tape and half was only available on original paper copies. The data on paper was examined, copied, and then entered by hand into the Rice University computer.

Four computer models (TR-20, WSP2, HEC-2, and the 1973 version of HEC-1) were obtained from four different sources and were set up on the Rice University AS-9000 mainframe computer. Extensive effort was required to alter the models from the form they were received to a form compatible with the Rice computer.

After the input data and the models were entered in the Rice computer, the output results were checked against the FEMA floodplain flows and elevations. The data obtained on tape matched very well; only in a few instances were changes in computer hardware reflected in the results. The input data entered by hand was more difficult to debug. The inevitable typing errors had to be tracked down and corrected based on any anomalies in the output data.

Once the input data and simulation models were adjusted to reproducing the FEMA results, program changes were made to make the analysis of alternatives easier. One major change was to have the hydraulic models produce rating tables rather than calculate specific profiles for selected flows. Other changes included the addition of data for the other storm sizes and removing tributary sections not to be included in this analysis from the working data base. Once all of these changes were made, the West Fork, Lake Creek, Caney Creek, and Peach Creek flood control alternatives were examined and compared to existing conditions.

The SCS did not have a hydrologic model prepared for the East Fork and an original HEC-1 simulation was developed by Rice University from existing land use, topographic, and soils maps. East Fork rainfall data was developed using the procedure employed by the SCS in the other watersheds: a 48 hour type I rainfall distribution was used with total rainfall adjusted to match a known flow. In this case, the known flow was the short section of the lower East Fork included in the Montgomery County FEMA study. The Rice University flows were used with the existing Montgomery County WSP2 model for the East Fork and with a recent Liberty County WSP2 model (January, 1985) to provide an estimated floodplain for this project. This floodplain should only be used as a reference to evaluate the efficiency of various flood control alternatives. A FEMA floodplain is now being developed by the SCS.

The Spring Creek hydrologic simulation proved to be difficult to match against the FEMA flowrates. The COE provided a version of the HEC-1 input data with precipitation data that did not correspond to the actual FEMA study. The original data was not available. A calibration was performed to match the HEC-1 output to the FEMA flows. All flows were eventually matched to within 10 percent by manipulating the uniform rainfall over the watershed and the hydrologic routing parameters. The HEC-2 flows for each alternative were calculated based on the percentage change in HEC1 flows with and without the alternative.

Complete Channelization Case:

The Channelization alternative simulated the construction of an excavated, grass-lined channel large enough to carry the 100 year flood. The increase in peak channel flow was also simulated using the hydrologic models, so the final channel design for each stream actually had a design flow in excess of the existing 100 year flood. The increase in flowrate caused by channelization varied between streams:

Stream	100 year flow at mouth after channelization (cfs)	Percentage Increase Over FEMA Flow %	Notes
West Fork	116,694	18%	(Above Cypress Creek)
Lake Creek	108,694	230%	
Caney Creek	69,340	153%	
Peach Creek	80,562	50%	
East Fork	58,300	5%	(Only downstream third channelized)

The small increase for the West Fork upstream of Cypress Creek was due to Lake Conroe. No channelization was performed upstream of the lake, leaving only about half of the stream channelized in this case. Interestingly, the channelized flow of the West Fork downstream of the Cypress Creek was lower than the existing flow. This was due to the nature of the timing of the hydrographs: the West Fork hydrograph caused by channelization peaked earlier than the Cypress Creek hydrograph, hence the combined channelized flow was lower.

The small increase in the East Fork channelization run was due to a similar effect as the West Fork: only the Montgomery and Liberty County portions were channelized (approximately the downstream third of the stream).

Channelization was simulated using the following assumptions:

- * Trapezoidal configuration with 4:1 side slopes.
- * Grass-lined channel with Manning's n of 0.035. This value is used by the Harris County Flood Control District for large improved streams.
- * No backwater effect from existing bridges.
- * Channel slope based on the general slope of existing low bank of the stream.
- * No drop structures were considered to decrease high water velocities.

The actual configuration varied from stream to stream and changed from upstream to downstream for each stream. Table A.1 summarizes representative channel configurations.

Table A.1
Average Configuration of Channelization to Carry 100-Year Flood

Stream	Representative Upstream Section			Representative Downstream Section		
	Depth (Ft)	Top Width (Ft)	Channel Slope (Ft/Ft)	Depth (Ft)	Top Width (Ft)	Channel Slope (Ft/Ft)
West Fork	30	600	0.00074	30	600	0.00071
Spring Creek	28	524	0.00045	34	772	0.00045
Lake Creek	24	460	0.00081	26	620	0.00049
Caney Creek	20	365	0.00085	22	460	0.00089
Peach Creek	20	350	0.00078	20	450	0.00076
East Fork	20	485	0.00065	20	530	0.00049

Selective Channelization:

Five selective channelization projects, all on the West Fork, were analyzed. Four projects were grass channels, ranging from 2.5 to 5.5 miles long, with the same general configuration as the complete channelization case. The bottom of the selective channelization projects were set to the existing bottom, producing simulated levees around the critical areas. No consideration was given for providing a diversion or storage for any local tributary flow behind the levees.

One selective channelization project with a concrete lining rather than a grass lining was performed to analyze the better hydraulic efficiency of concrete against the lower cost of a grass channel. In this case, a Manning's n value of .015 was used for the 5.46 miles of concrete lining.

The effect of the concrete channel on West Fork hydrology was evaluated and was found to increase peak flows by less than 2 percent. The impact on downstream hydrology of the grass channels would be less than the concrete channel and was considered negligible.

Desnag:

Desnagging was simulated by lowering the Manning's n value of the channel sections from the existing condition to a value of 0.045 (Table A.2). The channels usually ranged from 200 to 400 feet wide and represented only a small portion of the floodplain. In general, the effects of desnagging were relatively small.

Table A.2

**Manning's "n" Factor for Channels
Before and After Desnag Alternative**

Stream	Manning's "n" Factor	
	Before Desnag	After Desnag
West Fork	0.06	.045
Spring Creek	0.06 to 0.08	.045
Lake Creek	0.04 to 0.06	.045
Caney Creek	0.04 to 0.065	.045
Peach Creek	0.04 to 0.065	.045
East Fork	0.05 to 0.07	.045

The hydrologic effects of desnagging were evaluated for all the streams except for Lake Creek, Caney Creek, and Peach Creek. In these cases, the hydrologic routing employed in the TR-20 model used a constant "C" value for the Convex routing method. This prevented using the subtle changes in routing that were reflected in storage-discharge relationships. An attempt was made to change the "C" factors, which are a function of velocity, to reflect a desnag condition. The trial proved the routing to be very sensitive to the "C" factors and showed the difficulty in determining the change in overall channel and overbank velocity when only the channel hydraulics had changed. These problems suggested the conservative course of action was to use the existing flows for the desnag hydraulic modeling. These flows were shown to be fairly close to desnag flows in cases where a more accurate analysis was possible.

Bridge Modification:

The bridge modification alternatives simulated the change in the floodplain when restrictive bridge structures were removed from the hydraulic simulation. In most cases, the change was very small, and only a few cases showed any effect on critical areas.

Reservoirs:

Lake Creek Reservoir and Lake Conroe Eight reservoir cases were modeled on the six streams (Table A.3). The proposed Lake Creek reservoir was simulated using the assumption that a 3 foot flood storage pool was available to attenuate the 100 year storm. Different operational characteristics of the reservoir were examined and two methods were modeled: storage of the rising limb of the Lake Creek hydrograph, and maximum attenuation of the peak flow of the hydrograph.

Storage of the rising limb flows was found to be the most effective method to reduce flooding in the lower West Fork. A significant reduction in West Fork peak flows occurred (see West Fork summary tables, case WF-G1) even though there was no reduction in the Lake Creek peak flow. The simulation indicated the Lake Creek reservoir flood storage would be used before the peak of the Lake Creek

hydrograph, and little reduction in Lake Creek peak flow would occur. This reservoir operation scheme did trap the portion of the Lake Creek runoff that combines directly with the discharges from Lake Conroe on the West Fork and was very effective in reducing West Fork flood damages.

Table A.3

**San Jacinto Flood Control Project
Reservoir Data**

Reservoir	Reservoir Type	Alternative	Affected Streams	Area (Acres)	Flood Control Depth (Ft)	Flood Control Storage (A-ft)	Range of Pool Elevation (Ft M.S.L.)
Lake Conroe	Multi-purpose	WF-E2	West Fork	21,500	3.5	79,400	201-204.5
Lake Creek	Multi-purpose	WF-E1 WF-E1 LC-E1 LC-E2	West Fork, Small Section of Lake Creek	17,500	3.0	55,350	165-168
Spring Creek Reservoir 1 (Woodlands)	Amenity Flood Control	SC-E1	Spring Creek	1,000	5.0	5,000	125-130
Spring Creek Reservoir 2	Flood Control— No Permanent Storage	SC-E2	Spring Creek	3,643	45.0	47,661	160-205
Caney Creek Reservoir 1	Flood Control— No Permanent Storage	CC-E1	Caney Creek	671	45.0	15,400	195-230
Peach Creek Reservoir 1	Flood Control— No Permanent Storage	PC-E1	Peach Creek	626	25.0	6,150	165-190
Peach Creek Reservoir 2	Flood Control— No Permanent Storage	PC-E2	Peach Creek	1,371	45.0	25,170	195-240
East Fork	Multi-Purpose	EF-E1	East Fork	28,000	3.0	84,000	240-243

A more traditional reservoir operation scheme was also evaluated for Lake Creek reservoir. The peak flow was reduced as much as possible (Lake Creek summary tables, case LC-G2) to provide maximum benefits to downstream Lake Creek land uses. The benefits were very small compared to the benefits from the West Fork for the operational method described above (case WF-G1).

The final West Fork-Lake Creek reservoir simulation involved both Lake Conroe and the proposed Lake Creek reservoir (West Fork, case WF-G2). The Lake Creek reservoir was operated to capture the rising limb of the Lake Creek hydrograph to provide maximum downstream benefits. The assumptions used by the SCS for the FEMA floodplain study were also changed to show the potential effect of Lake Conroe. The SCS used a very conservative assumption that the operators of Lake Conroe would not discharge any runoff until the reservoir's flood storage was exhausted. After this point, all runoff was translated through the Lake with no reduction in peak flow. This produced almost no reduction in the 100 year peak flow which occurred despite considerable "flood storage" available in Lake Conroe.

The Lake Conroe flood storage represents 3.5 feet of storage above the normal operating level of the reservoir. This level is currently available to store flood waters. Alternative WF-G2 evaluated the potential benefits of the existing available flood control storage.

Alternative WF-G2 assumed the operators of the reservoir could predict the inflow into the reservoir and could adjust the outflow to maximize the benefits from the reservoir's flood storage pool. The technical requirements for this assumption are fairly simple: a hydrologic simulation model would assist the operators on how best to adjust the outflow from the reservoir to match the size and type of storm creating the runoff. (At this time the San Jacinto River Authority is developing a hydrologic predictive system to aid in managing reservoir outflows.) The storage in the Lake Creek reservoir, combined with the assumption that the existing available Lake Conroe storage could be used for flood control, proved to be one of the most effective flood damage reduction control alternatives examined in this project.

East Fork Reservoir:

The reservoir on the East Fork was evaluated using data provided by the Bureau of Reclamation. The proposed reservoir was simulated for multi-purpose operation using 3 feet of flood control storage above the proposed normal water level. Because of the large size of the reservoir almost all of the 100 year storm was trapped in the reservoir. Two factors affecting this result were: calibration of the 100 year storm runoff reduced the total rainfall and the Bureau of Reclamation evaluating reservoir design with more flood storage.

The calibration procedure reduced the rainfall used for the 100 year run to 9.6 inches, which is less than the actual 24 hour 100 year rainfall of 12.7 inches. This probably causes the reservoir simulation to underpredict the amount of runoff to be handled. The overall error seems to be small, however, since the runoff needed to be corrected and calibrated downward in the same way as the peak flow. No runoff figures were available and the East Fork model was only calibrated against peak flow.

The Bureau of Reclamation is considering other flood storage in the East Fork reservoir to maximize the benefit-cost ratio for the project. The final design could have more than 3 feet of flood control storage and provide even more flood control protection than evaluated for this project.

Peach Creek and Caney Creek Reservoirs:

Two reservoirs on Peach Creek and one reservoir on Caney Creek were evaluated as normally dry basins that were devoted entirely to flood control (Table A.3). These structures would be designed and operated like the Addicks and Barker reservoirs on Buffalo Bayou in Houston, Texas. Potential sites were located, measured for flood storage and incorporated in the hydrologic models to predict reduction in peak runoff. On Peach Creek a large reservoir (Peach Creek case PC-G2) and a smaller reservoir (case PC-G1) were modeled to compare the cost effectiveness of a small versus large structure. On Caney Creek, a moderately sized reservoir was designed.

To account for extra land space required for the reservoirs and some unavoidable inefficiencies in operation, the final reservoir design was assumed to be 25 percent greater than the amount utilized in the simulation. The locations for these reservoirs represent only possible locations, not proposed sites for a flood control project. If a reservoir is to be built, other sites may prove to be more cost effective.

Spring Creek Reservoirs:

Two Spring Creek reservoirs were simulated: a small amenityflood control reservoir downstream of the Dry Creek confluence, (Woodland Reservoir), and a normally dry flood control structure far upstream on Walnut Creek. The Woodlands reservoir is being evaluated by outside interests Woodlands Corporation, who provided the technical data for incorporating the structure into the hydrologic model. This reservoir had only minimal effect on downstream flows and floodplain elevations because of its small size and location in the lower portion of the watershed (case SCG1).

The second reservoir was designed to capture all of the runoff from the Walnut Creek watershed (SC-G2). As with the Peach Creek and Caney Creek reservoirs the location is only a possible site for a Barker-Addicks type structure located in the upper Spring Creek watershed.

B. ECONOMIC BENEFIT CALCULATIONS

Definition of Critical Areas:

Each stream was divided into a series of reaches ranging from 2 to 5 miles long. The reaches were compared to determine "critical reaches", or the reaches where the highest flood damages occurred. The comparison was based on elevation-damage data provided by the Corps of Engineers or on the number of structures in the 100 year floodplain if no Corps data was available.

Each stream except Lake Creek had from 4 to 6 critical areas, and the final selected critical areas usually represented over 85 percent of the damage to structures in the entire stream. The Lake Creek analysis was not accomplished in the same detail as the other streams because of the relatively undeveloped nature of the Lake Creek 100 year floodplain.

Stream	Critical Areas	Percentage of 100 Year Flood Damage Included in Critical Areas
West Fork	1,2,3,4	99%
East Fork	1,2,3,4,5	87%
Spring Creek	1,2,3,4	88%
Caney Creek	1,2,3,4,5	89%
Peach Creek	1,2,3,4,5	100%

A separate economics benefit calculation was performed for each critical area using a graphical method referred to in this report as the chart method (Shaw, 1983). This method used hydrologic, hydraulic, and flood damage data to construct a plot yielding annual economic benefits for any flood control alternative.

Hydrologic and Hydraulic Data:

The hydrologic and hydraulic data for each alternative were obtained from the modeling described previously. For each critical area, two relationships were reduced from the data: a probability vs. flow plot and an elevation vs. flow plot. Four storms (the 100, 25, 10, and 2 year events) were used to construct the plots. These plots were then used directly in the chart method (described later) to calculate economic benefits.

Elevation-Damage Data:

The chart method required a stage-damage curve for each critical area to represent the amount of damage sustained when flood waters reach different elevations. To obtain these curves a definition of appropriate damages for this study was developed: urban residential damages included structures together with the contents. No other types of damages were considered in this project. Two sources of data were used to develop these curves: existing Corps of Engineers economic data and original estimates generated by a subcontractor, Environmental Planning and Design.

The Corps of Engineers had performed economic modeling on the West Fork, Lake Creek, the East Fork, and Spring Creek and generously provided detailed input and output data from their work. The data included an elevation-total damage table. For this study, the combined single-family and multi-family data used; commercial, agricultural, utility, and transportation damages were not considered.

Chart Method to Calculate Damages:

The chart method used the data described previously to calculate annual flood damages at a critical area for the existing condition and with any flood control alternative. The benefits of an alternative were calculated by taking the difference between the annual damages from the existing conditions and the annual damages after the project is in place.

The chart method requires three types of curves to generate a fourth curve:

Input curves: Annual Probability-Flow Curve
 Elevation-Flow Curve
 Elevation-Damage Curve

Resulting curve: Annual Probability - Damage Curve

Figure A.1 shows a representative chart with the position of the four curves. By drawing a rectangle with three corners on the three input curves, the fourth corner represents one point on the resulting curve. By drawing several rectangles, an entire annual probability-damage curve can be constructed. The area under this curve can be measured and converted to dollars damage per year.

A flood control alternative is represented by changes in one or more of the input curves:

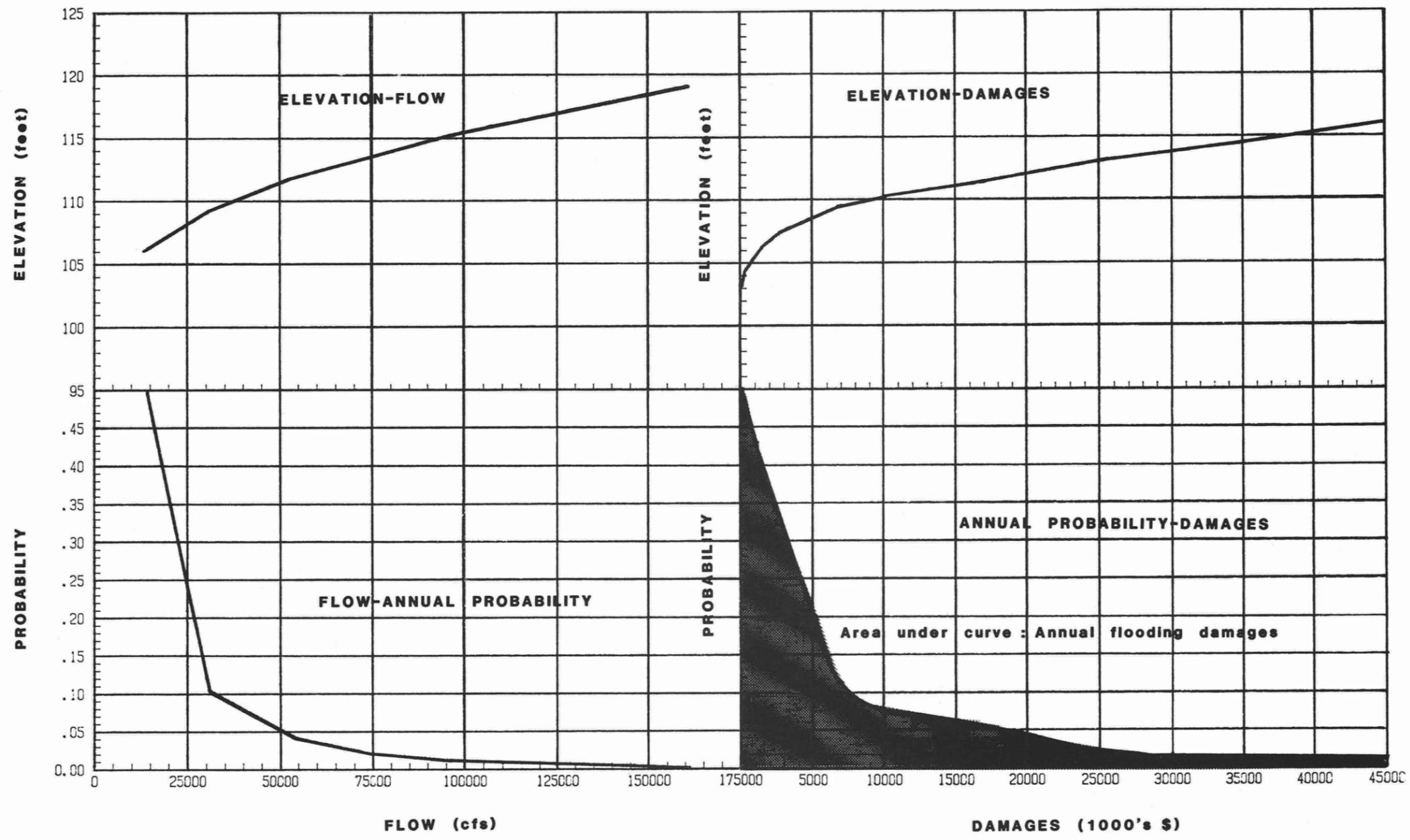
Flood Control Alternative	CHANGE IN INPUT CURVES		
	Annual Prob.-Flow Curve	Elevation-Flow Curve	Elevation-Damage Curve
Reservoir	Lowers	Same	Same
Channelization	Raises	Lowers	Same
Desnag	Same or minor raising	Lowers	Same
Bridge Modific.	Same	Lowers	Same
Buy-out	Same	Same	Raises (higher elev. for same damage)

An alternative will change one or more input curves and will usually lower the annual probability-damage curve. The annual benefit from the alternative can be determined directly by measuring the area between the two curves and converting to dollars benefit per year. A second method is to calculate annual damages for both alternatives and subtract to get annual benefits from a project.

A detailed analysis of one critical area indicated that using four storms (the 100, 25, 10, and 2 year events) would yield results as accurate as using six storms (the four listed above plus the 500 and 50 year storms). Benefit calculations were performed using all six storms, four storms, and three storms. The three storm case gave results 10 percent lower than the six storm case, while the four storm case was within 1 percent. Most of the annual damages seemed to be caused by the smaller storms between the 2 and 25 year level. These results led to the selection of the 100, 25, 10 and 2 year storms for the graphical method used in this study.

C. COST OF ALTERNATIVES AND CALCULATION OF BENEFIT/COST RATIOS

Total costs for each alternative were calculated and then converted to an annual cost using a mortgage payout assumption. The annual costs were then compared to the annual benefits described above to generate benefit/cost ratios for each alternative.



**WEST FORK
CRITICAL AREA 3**

**FIGURE A.1
GRAPHICAL METHOD**

Annual costs for each alternative except desnaging were calculated from total costs according to Corps of Engineers economic criteria. Costs were assumed to be amortized over a 100 year period using a 8.125 percent interest rate. A mortgage program was used to obtain annual costs from total costs based on these assumptions.

Desnag annual costs were calculated by assuming the desnag operation would have to be repeated every five years to maintain an acceptable level of hydraulic efficiency. Annual costs were assumed to be equal to one fifth the total cost for the desnag alternative.

A sample calculation of a benefit/cost ratio is provided in section West Fork Flood Control Alternatives.

D. BUY-OUT ASSUMPTIONS

The economic costs and benefits of buying out affected properties in flood prone areas was examined extensively in this project. The benefit/cost ratios show whether the one time costs of buying property in each critical area are smaller than the recurring costs caused by flooding. Two cases were examined: buying out the property in the 100 year floodplain and the property in the 25 year floodplain.

Two sources of data were used to develop the buy-out data: the Corps of Engineers economic data was used for the West Fork, Lake Creek, the East Fork, and Spring Creek. Environmental Planning and Design and Rice University Department of Environmental Science and Engineering data were used for Caney Creek and Peach Creek.

Costs were derived from the Corps of Engineers "total value" data for combined single-family and multi-family residential dwellings. The "total value" represented the value of the structure and contents, but did not include land costs. Structure costs were assumed to be roughly equivalent to two thirds the total value. Land costs were assumed to be equal to 15 percent of the structure value. Only residential structures were used in the analysis; to simplify the calculation no commercial structures were included.

For Caney and Peach Creeks, the benefit and cost data were obtained from an analysis based on aerial photos and topographic maps. The elevation of each residential structure was estimated using a linear representation of the channel cross section and counting houses at each elevation. The house count was then adjusted to the elevation of an index point for that critical area. Elevation-damage curves were constructed assuming each structure was valued at \$35,000 and contents were valued at \$15,000. The \$35,000 structure value was obtained by taking the average structure value for all of the creeks from Corps of Engineers data, minus the structures in the high-value River Plantation area.

Buy-out costs were calculated using the \$35,000 structure cost with 15 percent additional cost for land.

The Caney Creek and Peach Creek data is probably not as accurate as the Corps of Engineers data for the other streams because there is no individual assessment of structure value in different locations. The accuracy of the alternate method is considered good enough for a broad planning analysis of this type.

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APPENDIX B

FLOOD REDUCTION ALTERNATIVE IMPACT ON FLOW AND FLOOD ELEVATION

Drainage Improvement Flood Control Planning Study Hydrologic and Hydraulic Summary

Stream WEST FORK
River mile 13.60
Critical point 1

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
WF-A	99,220	69.4	---
WF-B	116,694	50.6	- 18.8
WF-G1	85,381	67.6	- 1.8
WF-G2	69,000	65.4	- 4.0
WF-C1	99,220	69.3	- 0.1
WF-C5	101,242	69.6	+ 0.2
WF-D1	99,220	69.1	- 0.3
WF-E	100,400	69.2	- 0.2

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

Drainage Improvement Flood Control Planning Study Hydrologic and Hydraulic Summary

Stream WEST FORK
River mile 29.55
Critical point 2

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
WF-A	101,539	104.8	---
WF-B	112,103	86.2	- 18.6
WF-D	100,451	104.0	- 0.8
WF-G1	87,700	103.7	- 1.1
WF-G2	67,000	102.2	- 2.6
WF-C2	101,539	102.0	- 2.8
WF-C5	103,631	104.9	+ 0.1
WF-D1	101,539	104.2	- 0.6
WF-E	102,166	104.6	- 0.2

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream WEST FORK
 River mile 34.25
 Critical point 3

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
WF-A	99,384	115.5	---
WF-B	104,292	99.1	- 16.4
WF-D	98,580	114.8	- 0.7
WF-G1	85,545	114.5	- 1.0
WF-G2	61,000	112.6	- 2.9
WF-C3	99,384	113.6	- 1.9
WF-C5	100,308	110.0	- 5.5
WF-C2	99,384	115.2	- 0.3
WF-D3	99,384	115.1	- 0.4
WF-D2	99,384	115.4	- 0.1

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream WEST FORK
 River mile 48.00
 Critical point 4

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
WF-A	86,683	150.1	---
WF-B	84,792	136.8	- 13.3
WF-D	83,600	149.7	- 0.4
WF-G1	83,684	150.1	0
WF-G2	41,000	145.5	- 4.6
WF-C4	83,683	146.5	- 3.6
WF-D4	83,600	149.7	- 0.4
WF-D3	83,600	150.0	- 0.1
WF-E	83,683	148.9	- 1.2

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream LAKE CREEK
 River mile 1.79
 Critical point 1

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
LC-A	32,923	135.2	---
LC-B	108,694	124.44	- 10.8
LC-D	32,923	135.1	- 0.1
LC-G1	32,923	135.2	0.0
LC-G2	20,007	132.11	- 3.1

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream SPRING CREEK
 River mile 15.78
 Critical point 2

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
SC-A	53,679	104.63	---
SC-B	80,562	84.2	- 20.4
SC-D	57,014	103.93	- 0.7
SC-F1	53,237	104.56	- 0.1
SC-F2	36,177	101.56	- 3.1
SC-E1	53,679	104.63	0.0
SC-E2	53,679	104.43	- 0.2
SC-E3	53,679	104.58	- 0.1

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream **SPRING CREEK**
 River mile **38.546**
 Critical point **4**

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
SC-A	43,443	158.78	---
SC-B	43,451	141.83	- 17.0
SC-D	42,646	157.65	- 1.1
SC-F1	42,646	158.78	0.0
SC-F2	25,846	155.00	- 3.8
SC-E1	43,443	158.65	- 0.1
SC-E2	43,443	158.78	0.0
SC-E3	43,443	158.78	0.0

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream **PEACH CREEK**
 River mile **5.61**
 Critical point **2**

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
PC-A	42,232	91.4	---
PC-B	57,390	78.3	- 13.1
PC-D	42,232	90.4	- 1.0
PC-E1	37,761	90.7	- 0.7
PC-E2	35,203	90.3	- 1.1

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream CANEY CREEK
River mile 16.40
Critical point 4

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
CC-A	26,266	128.7	—
CC-B	44,713	115.7	-13.0
CC-D	26,266	128.2	-0.5
CC-G-1	10,978	124.0	-4.7
CC-E	26,266	128.7	0.0

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream EAST FORK
River mile 9.3
Critical point 1

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
EF-A	55,524	69.3	—
EF-B	58,300	59.4	-9.9
EF-D	57,837	69.6	+0.3
EF-G	9,751	59.8	-9.5
EF-E	55,524	68.6	-0.7

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream PEACH CREEK
 River mile 12.52
 Critical point 5

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
PC-A	35,502	117.7	---
PC-B	45,185	106.1	- 11.6
PC-D	35,694	117.4	- 0.3
PC-E1	29,709	116.5	- 1.2
PC-E2	22,419	114.9	- 2.8

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

Stream CANEY CREEK
 River mile 4.56
 Critical point 1

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
CC-A	27,457	72.9	---
CC-B	69,340	58.6	- 14.3
CC-D	27,457	72.9	0.0
CC-E1	22,897	71.7	- 1.2
CC-E	27,457	72.9	0.0

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

**Drainage Improvement Flood Control Planning Study
Hydrologic and Hydraulic Summary**

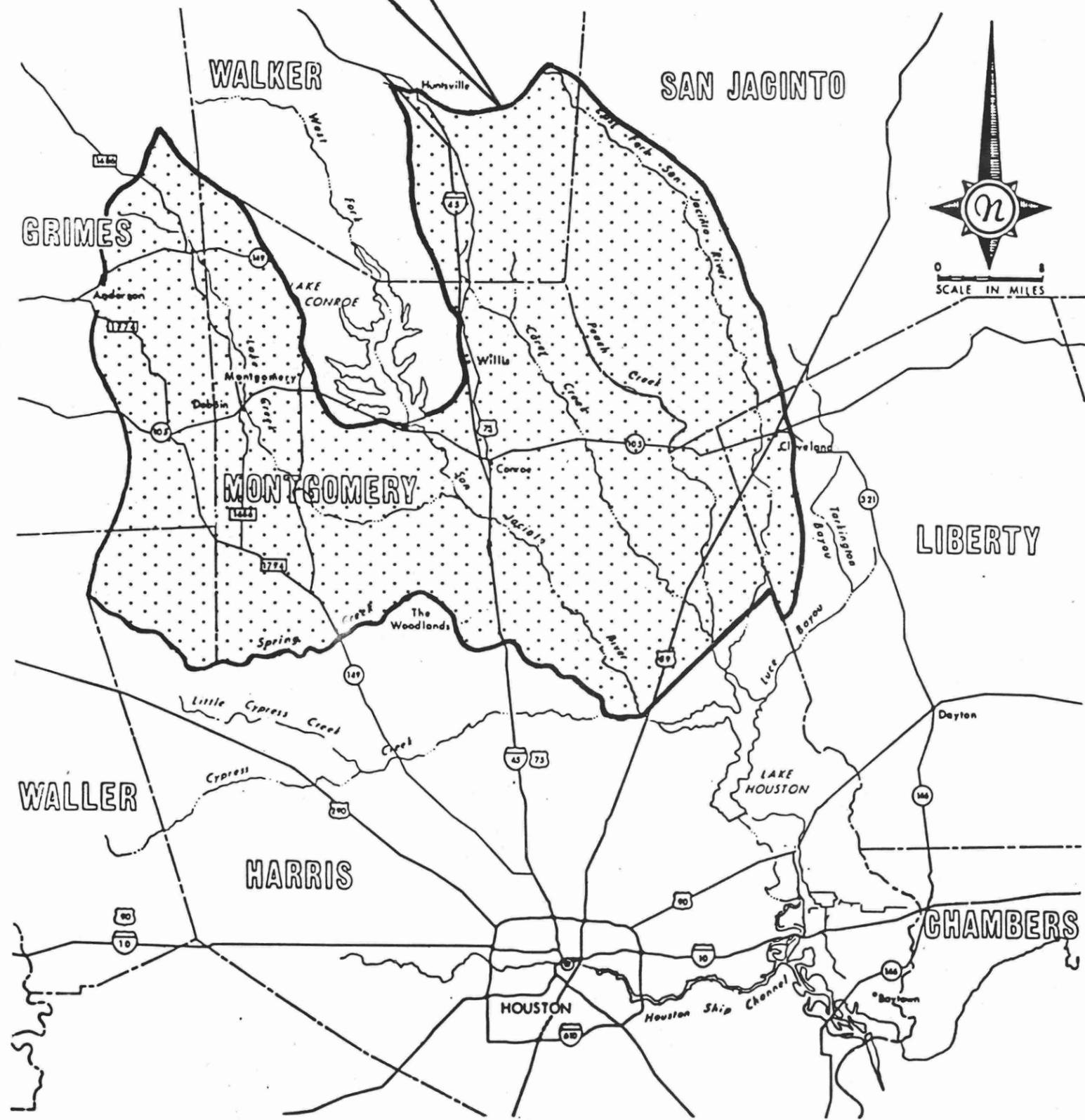
Stream EAST FORK
 River mile 28.1
 Critical point 4

Flood Control Alternative*	100-year Peak Flow (CFS)	100 yr Flood Elevation (Ft MSL)	Change from Existing Condition (Ft)
EF-A	53,728	134.0	---
EF-B	53,700	121.7	- 12.3
EF-D	54,833	134.1	+ 0.1
EF-F	5,905	125.1	- 8.9
EF-E	53,728	133.2	- 0.8

***Alternatives:**

- | | |
|-----------------------------|------------------------|
| A. Existing channel | E. Bridge modification |
| B. Total channelization | F. Buy-out |
| C. Selective channelization | G. Reservoir |
| D. Desnag | |

STUDY AREA



EXHIBITS

EXPLANATION OF EXHIBITS

This report is arranged so that the user can examine the text and exhibits, which illustrate the drainage improvements, at the same time. In addition, the exhibits are organized and indexed so that a user can locate an area of interest from the existing stream, road, and street patterns.

INDEX EXHIBITS

--- Exhibit Locator Map

WF-1A West Fork, Stream Segment 1, Existing 100 yr. Flood Plain
WF-2A West Fork, Stream Segment 2, Existing 100 yr. Flood Plain
WF-3A West Fork, Stream Segment 3, Existing 100 yr. Flood Plain
WF-1B West Fork, Stream Segment 1, Total Channelization
WF-2B West Fork, Stream Segment 2, Total Channelization
WF-3B West Fork, Stream Segment 3, Total Channelization
WF-1C West Fork, Stream Segment 1, Selective Channelization
WF-2C West Fork, Stream Segment 2, Selective Channelization
WF-3C West Fork, Stream Segment 3, Selective Channelization
WF-1G-1 West Fork, Stream Segment 1, Reservoir 1
WF-2G-1 West Fork, Stream Segment 2, Reservoir 1
WF-1G-2 West Fork, Stream Segment 1, Reservoir 2
WF-2G-2 West Fork, Stream Segment 2, Reservoir 2
WF-3G-2 West Fork, Stream Segment 3, Reservoir 2
WF-1H West Fork, Stream Segment 1, Profile
WF-2H West Fork, Stream Segment 2, Profile
WF-3H West Fork, Stream Segment 3, Profile
WF-4H West Fork, Stream Segment 4, Profile

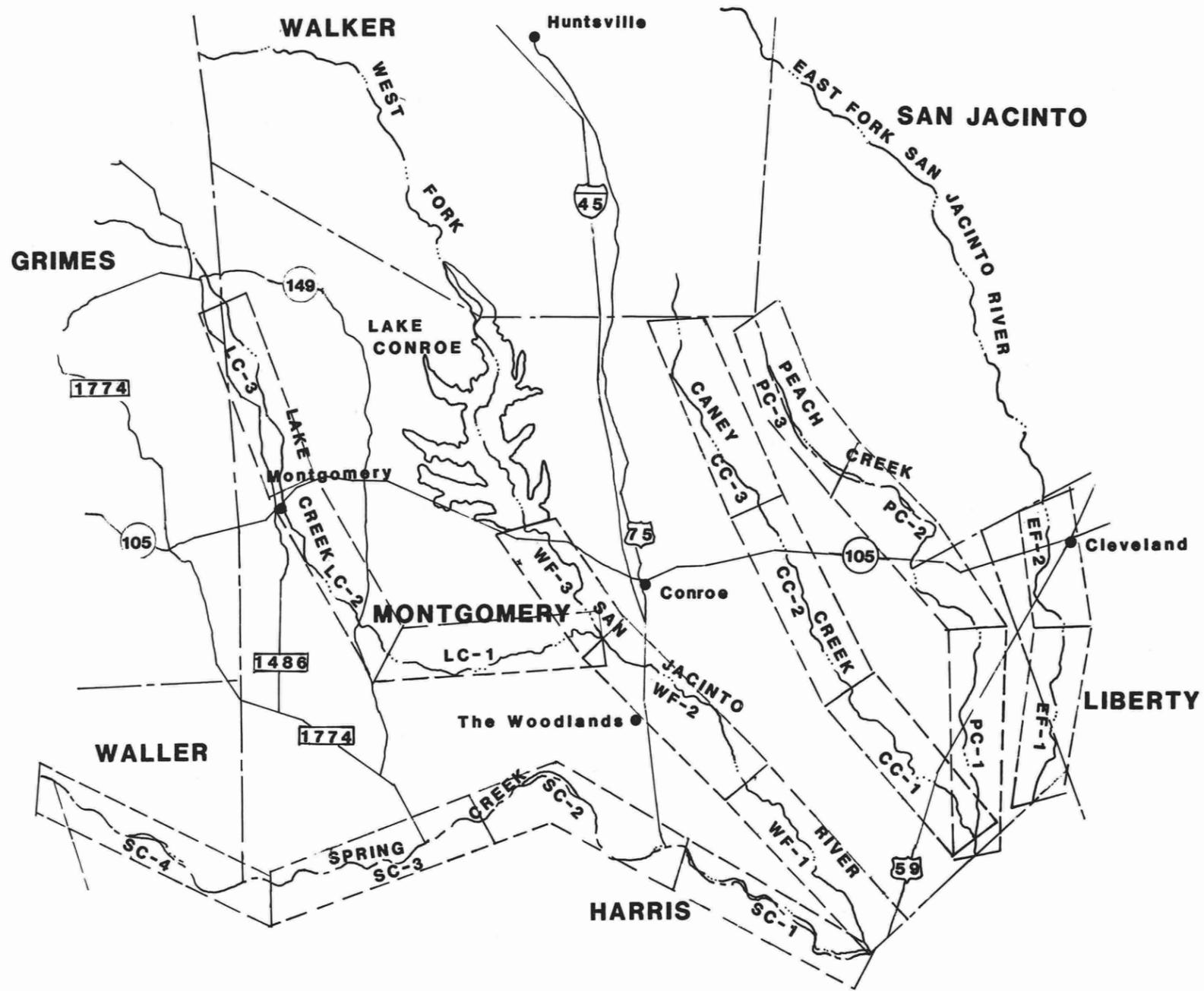
LC-1A Lake Creek, Stream Segment 1, Existing 100 yr. Flood Plain
LC-2A Lake Creek, Stream Segment 2, Existing 100 yr. Flood Plain
LC-3A Lake Creek, Stream Segment 3, Existing 100 yr. Flood Plain
LC-1B Lake Creek, Stream Segment 1, Total Channelization
LC-2B Lake Creek, Stream Segment 2, Total Channelization
LC-3B Lake Creek, Stream Segment 3, Total Channelization
LC-1G Lake Creek, Stream Segment 1, Reservoir
LC-1H Lake Creek, Stream Segment 1, Profile
LC-2H Lake Creek, Stream Segment 2, Profile
LC-3H Lake Creek, Stream Segment 3, Profile
LC-4H Lake Creek, Stream Segment 4, Profile

SC-1A Spring Creek, Stream Segment 1, Existing 100 yr. Flood Plain
SC-2A Spring Creek, Stream Segment 2, Existing 100 yr. Flood Plain
SC-3A Spring Creek, Stream Segment 3, Existing 100 yr. Flood Plain
SC-4A Spring Creek, Stream Segment 4, Existing 100 yr. Flood Plain
SC-1B Spring Creek, Stream Segment 1, Total Channelization
SC-2B Spring Creek, Stream Segment 2, Total Channelization
SC-3B Spring Creek, Stream Segment 3, Total Channelization
SC-4B Spring Creek, Stream Segment 4, Total Channelization
SC-2G-1 Spring Creek, Stream Segment 2, Reservoir 1
SC-1G-2 Spring Creek, Stream Segment 1, Reservoir 2
SC-2G-2 Spring Creek, Stream Segment 2, Reservoir 2
SC-3G-2 Spring Creek, Stream Segment 3, Reservoir 2
SC-4G-2 Spring Creek, Stream Segment 4, Reservoir 2
SC-1H Spring Creek, Stream Segment 1, Profile
SC-2H Spring Creek, Stream Segment 2, Profile
SC-3H Spring Creek, Stream Segment 3, Profile
SC-4H Spring Creek, Stream Segment 4, Profile

PC-1A Peach Creek, Stream Segment 1, Existing 100 yr. Flood Plain
PC-2A Peach Creek, Stream Segment 2, Existing 100 yr. Flood Plain
PC-3A Peach Creek, Stream Segment 3, Existing 100 yr. Flood Plain
PC-1B Peach Creek, Stream Segment 1, Total Channelization
PC-2B Peach Creek, Stream Segment 2, Total Channelization
PC-3B Peach Creek, Stream Segment 3, Total Channelization
PC-1G-1 Peach Creek, Stream Segment 1, Reservoir 1
PC-2G-1 Peach Creek, Stream Segment 2, Reservoir 1
PC-2G-2 Peach Creek, Stream Segment 2, Reservoir 2
PC-3G-2 Peach Creek, Stream Segment 3, Reservoir 2
PC-1H Peach Creek, Stream Segment 1, Profile
PC-2H Peach Creek, Stream Segment 2, Profile
PC-3H Peach Creek, Stream Segment 3, Profile
PC-4H Peach Creek, Stream Segment 4, Profile

CC-1A Caney Creek, Stream Segment 1, Existing 100 yr. Flood Plain
CC-2A Caney Creek, Stream Segment 2, Existing 100 yr. Flood Plain
CC-3A Caney Creek, Stream Segment 3, Existing 100 yr. Flood Plain
CC-1B Caney Creek, Stream Segment 1, Total Channelization
CC-2B Caney Creek, Stream Segment 2, Total Channelization
CC-3B Caney Creek, Stream Segment 3, Total Channelization
CC-1G Caney Creek, Stream Segment 1, Reservoir
CC-2G Caney Creek, Stream Segment 2, Reservoir
CC-3G Caney Creek, Stream Segment 3, Reservoir
CC-1H Caney Creek, Stream Segment 1, Profile
CC-2H Caney Creek, Stream Segment 2, Profile
CC-3H Caney Creek, Stream Segment 3, Profile
CC-4H Caney Creek, Stream Segment 4, Profile

EF-1A East Fork, Stream Segment 1, Existing 100 yr. Flood Plain
EF-2A East Fork, Stream Segment 2, Existing 100 yr. Flood Plain
EF-1B East Fork, Stream Segment 1, Total Channelization
EF-2B East Fork, Stream Segment 2, Total Channelization
EF-1G East Fork, Stream Segment 1, Reservoir
EF-2G East Fork, Stream Segment 2, Reservoir
EF-1H East Fork, Stream Segment 1, Profile
EF-2H East Fork, Stream Segment 2, Profile



LEGEND

Exhibit Number

NOTE:

See Index Of Exhibits For Exhibit Number And Exhibit Title

EXHIBIT LOCATOR MAP

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

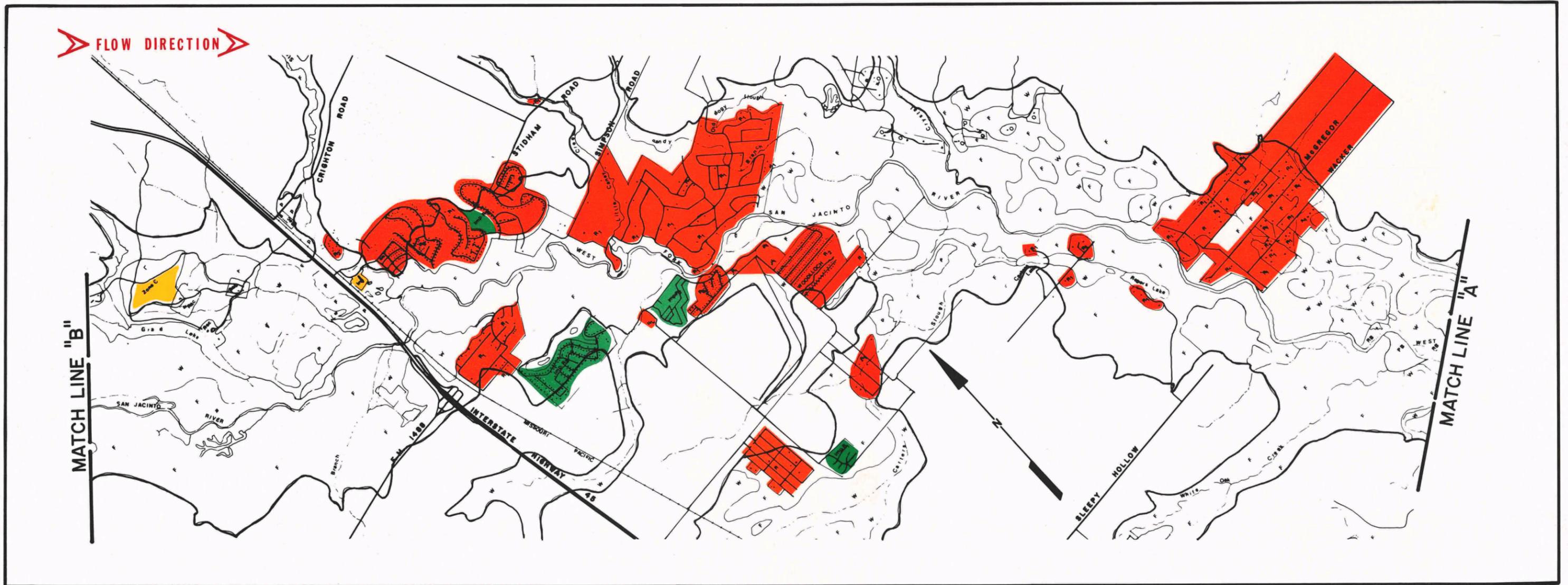


**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-1A



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
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**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2A



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1		Gas Well
	School		Improved Land For Development Imp/R2		Recreational
			Wetland		Flood Plain Reclamation

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information
Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp.
1:2000 ft. 1976 — 1982

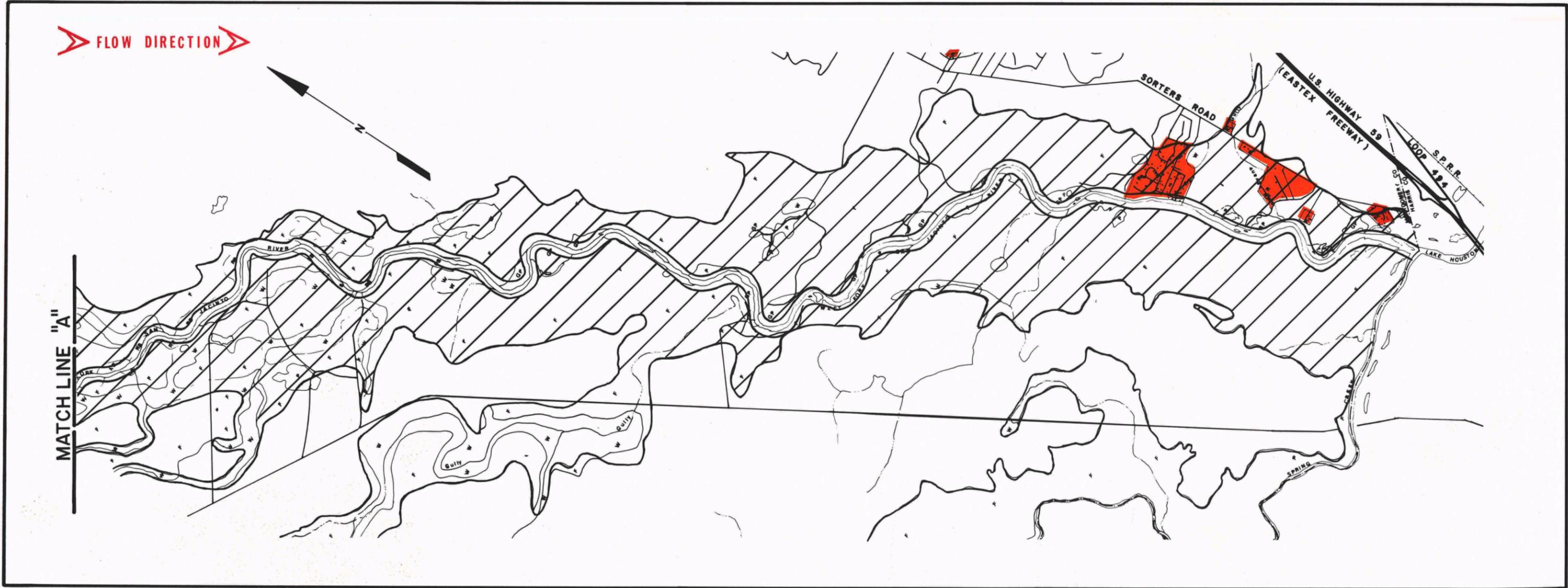


**WEST FORK OF SAN JACINTO
STREAM SEGMENT 3
EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-3A



Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential — R1 | | Forest | | Sewage Disposal |
| | Residential — R2 | | Pasture | | River Bottom |
| | Residential — M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1/R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

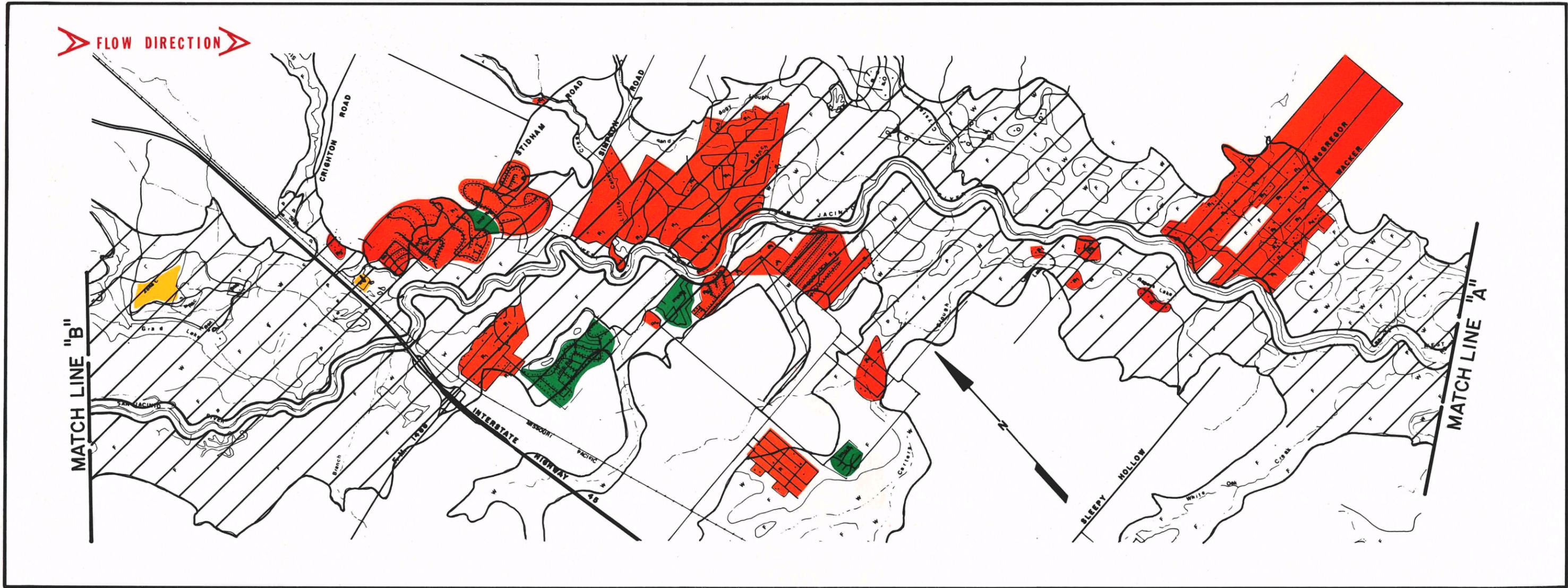
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-1B



Legend

- | | | | | | |
|--|--------------------|--|--|--|-------------------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forest | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1, R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | | | Flood Plain Reclamation |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

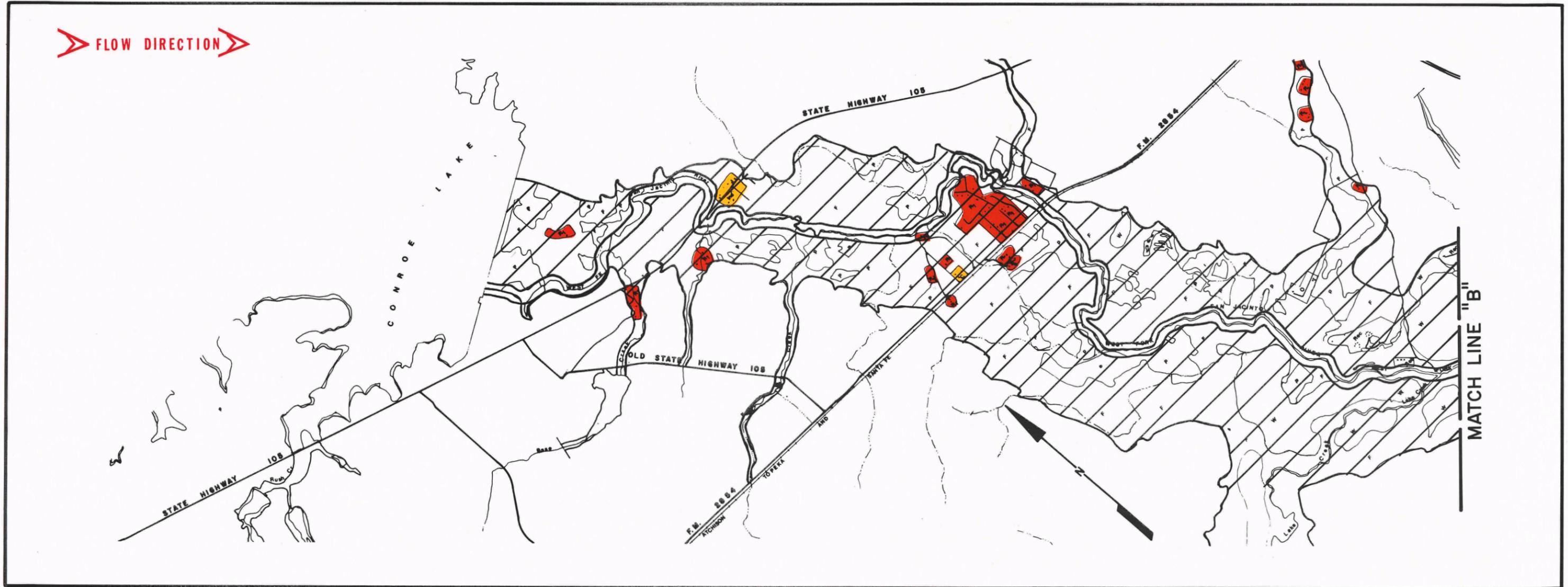
- Sources
1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp _{R1} R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
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 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982

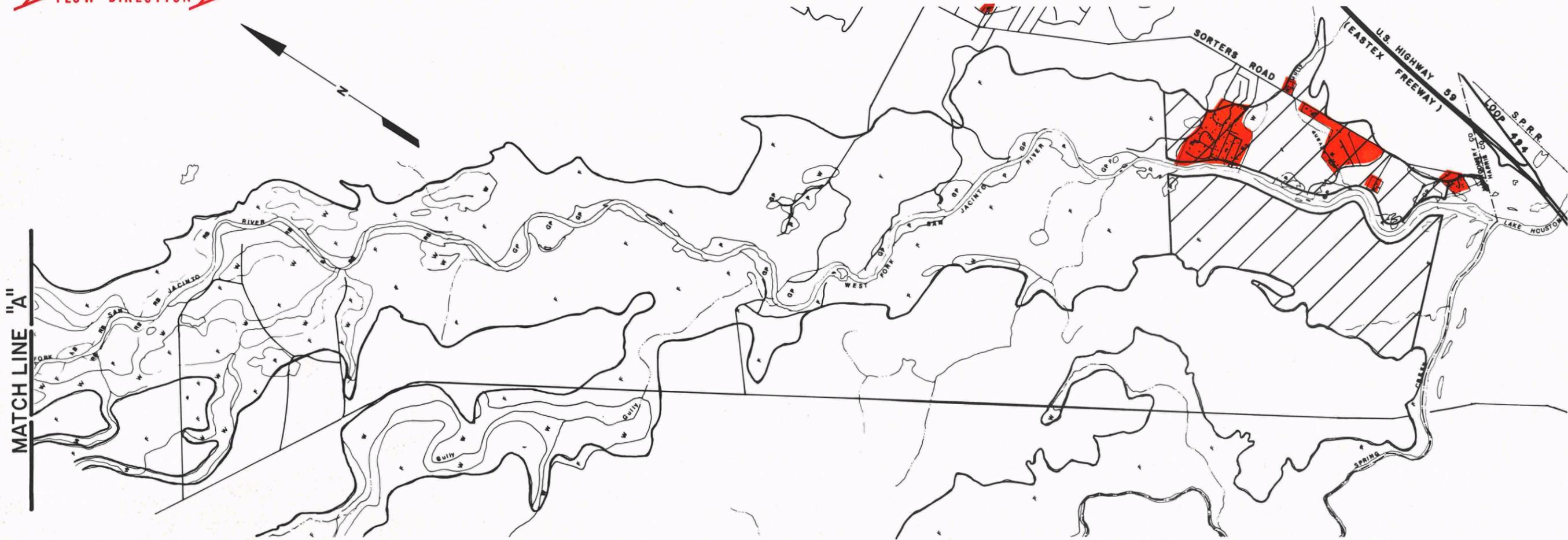


**WEST FORK OF SAN JACINTO
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-3B

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map—USGS 1:24000—1959-1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976—1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
SELECTIVE CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-1C



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

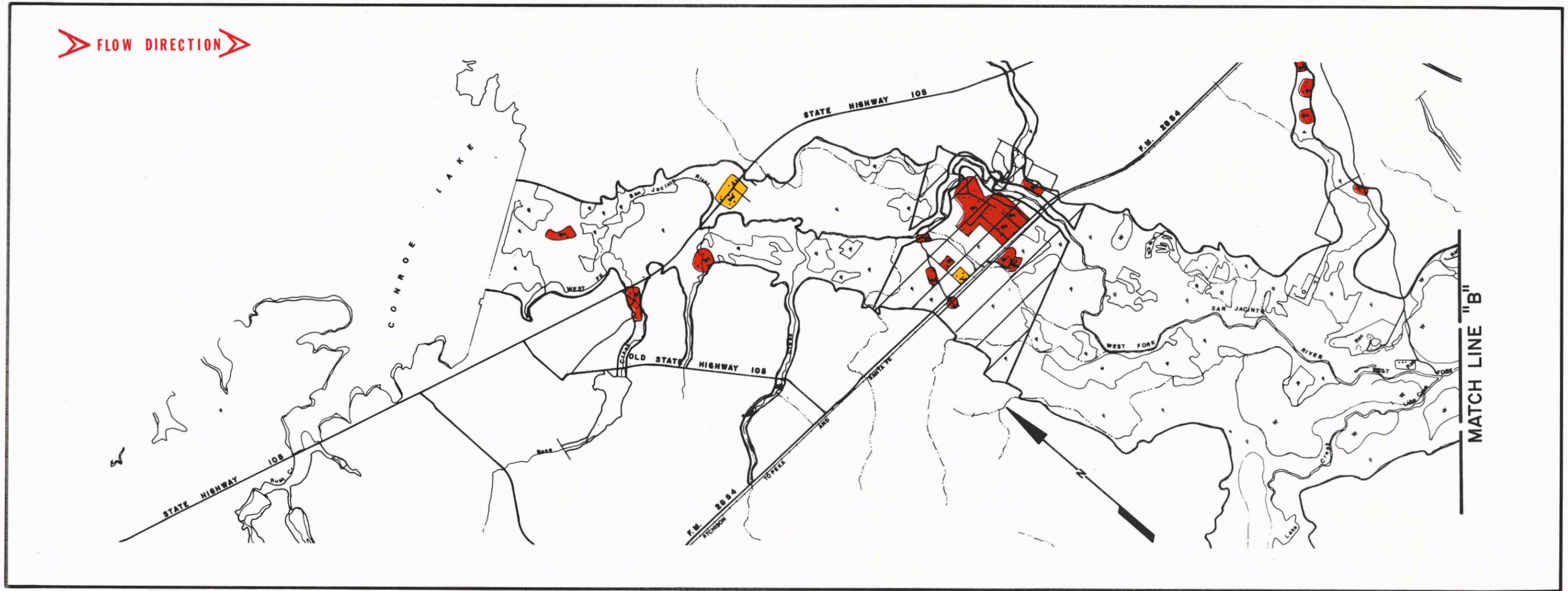
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**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
SELECTIVE CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2C



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

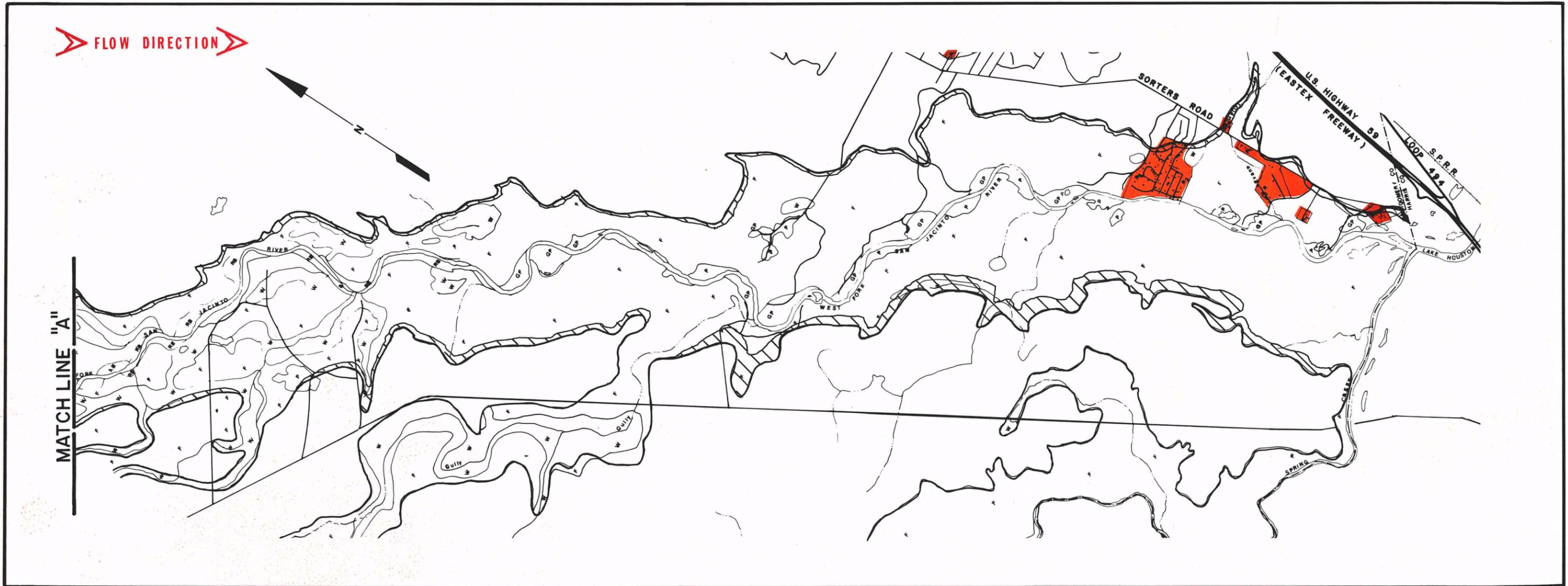
1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
SELECTIVE CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-3C



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp _{R1} R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

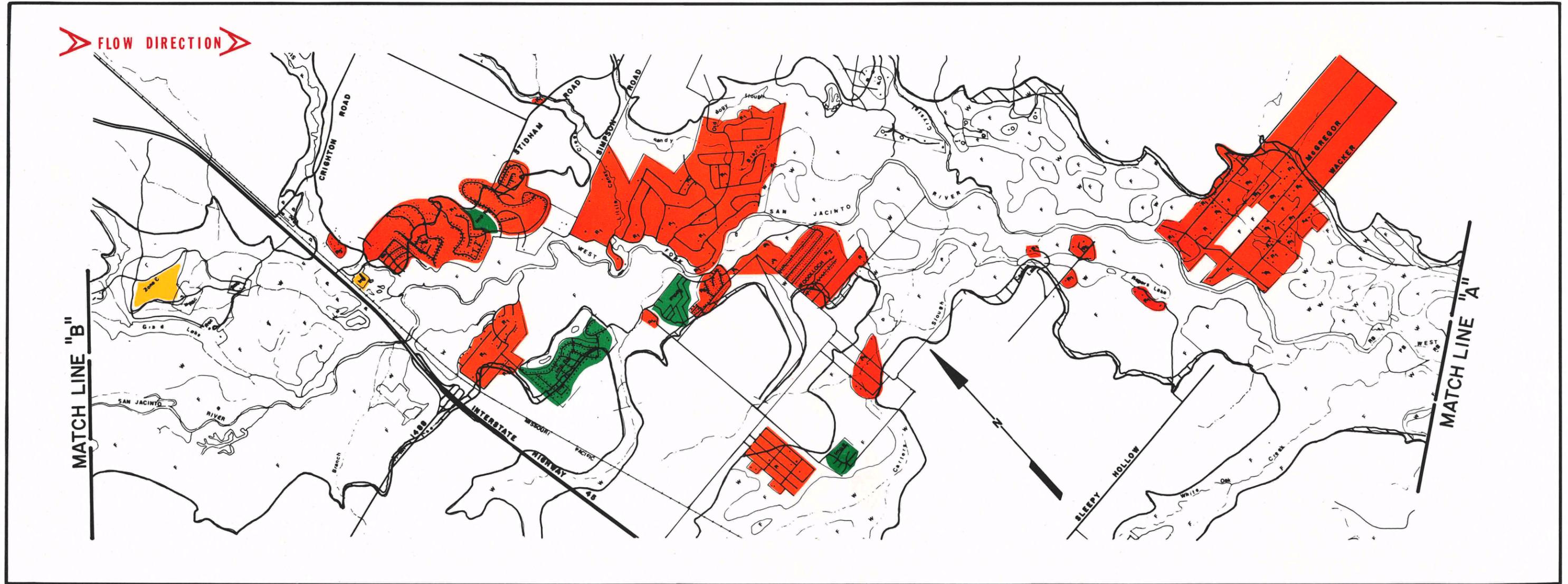


**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 1**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-1G-1



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 1**

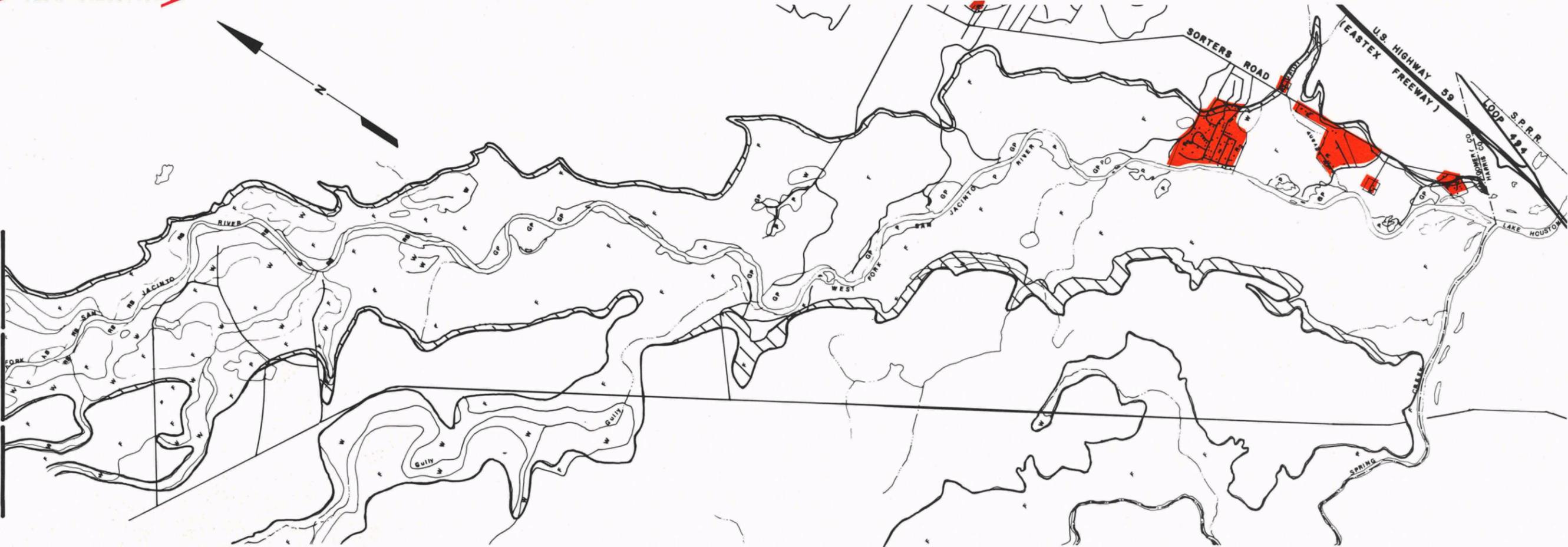
WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2G-1

▶ FLOW DIRECTION ▶



MATCH LINE "A"



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp _{R1} R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

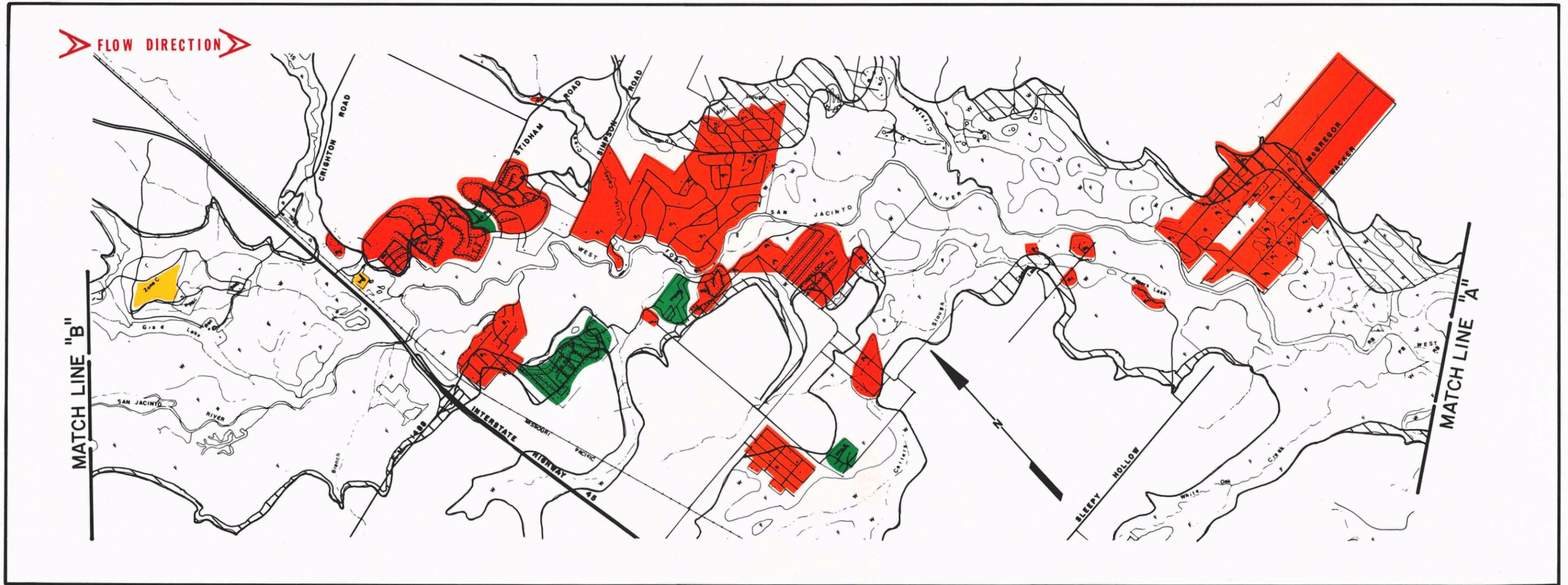
Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-1G-2



Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential — R1 | | Forest | | Sewage Disposal |
| | Residential — R2 | | Pasture | | River Bottom |
| | Residential — M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1/R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



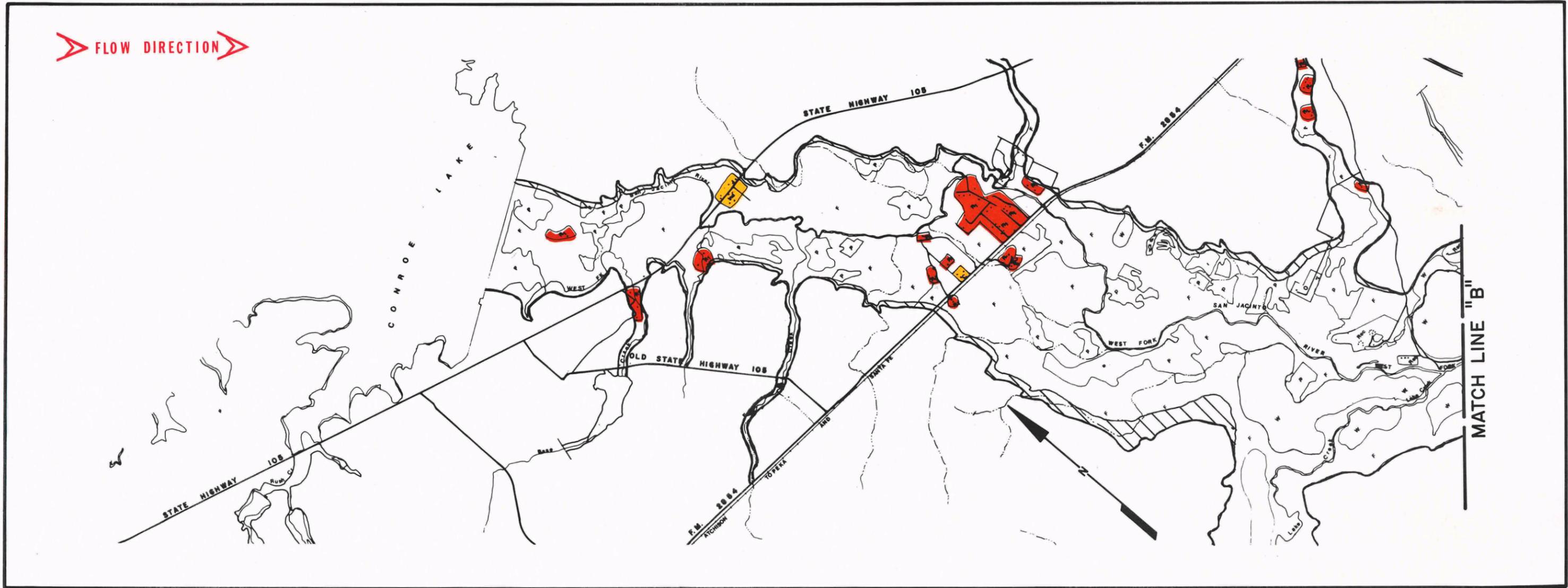
**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2G-2

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

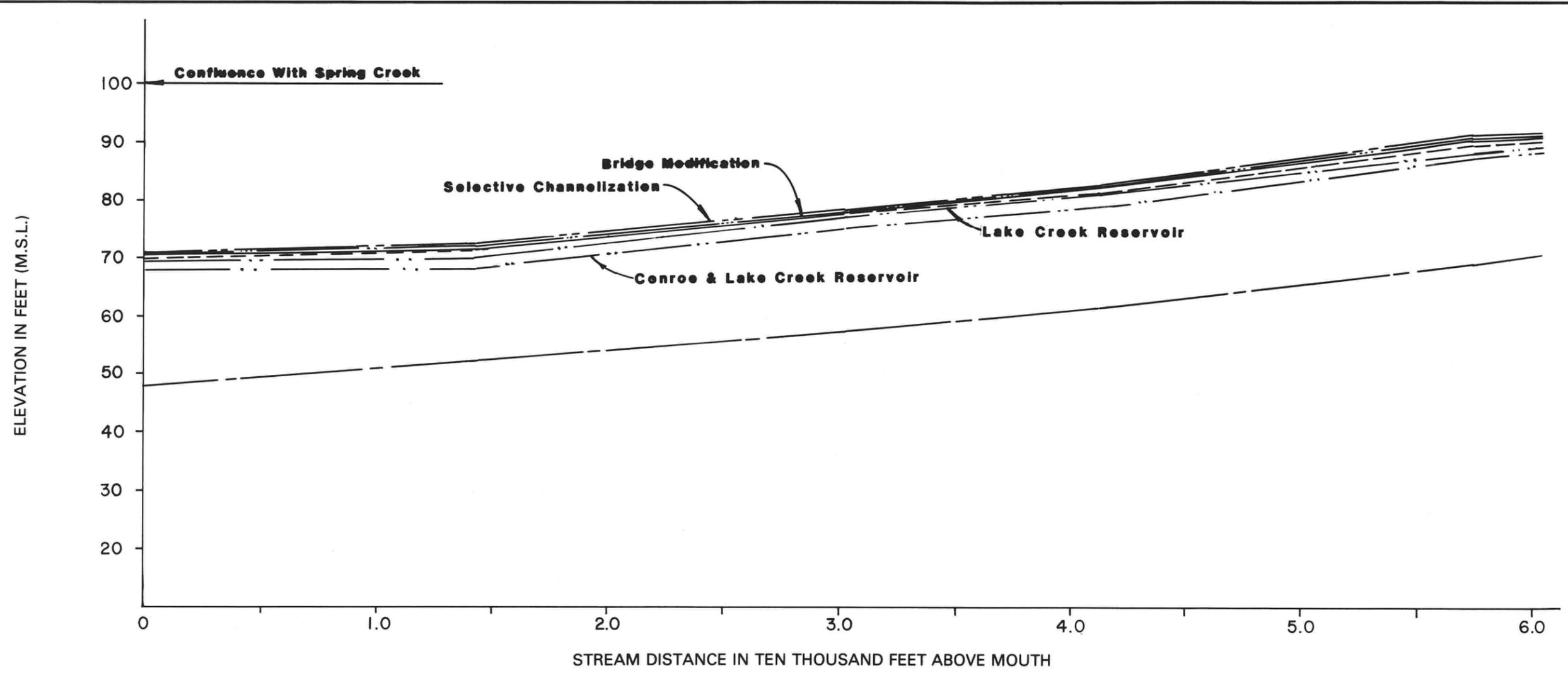
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**WEST FORK OF SAN JACINTO
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS



LEGEND

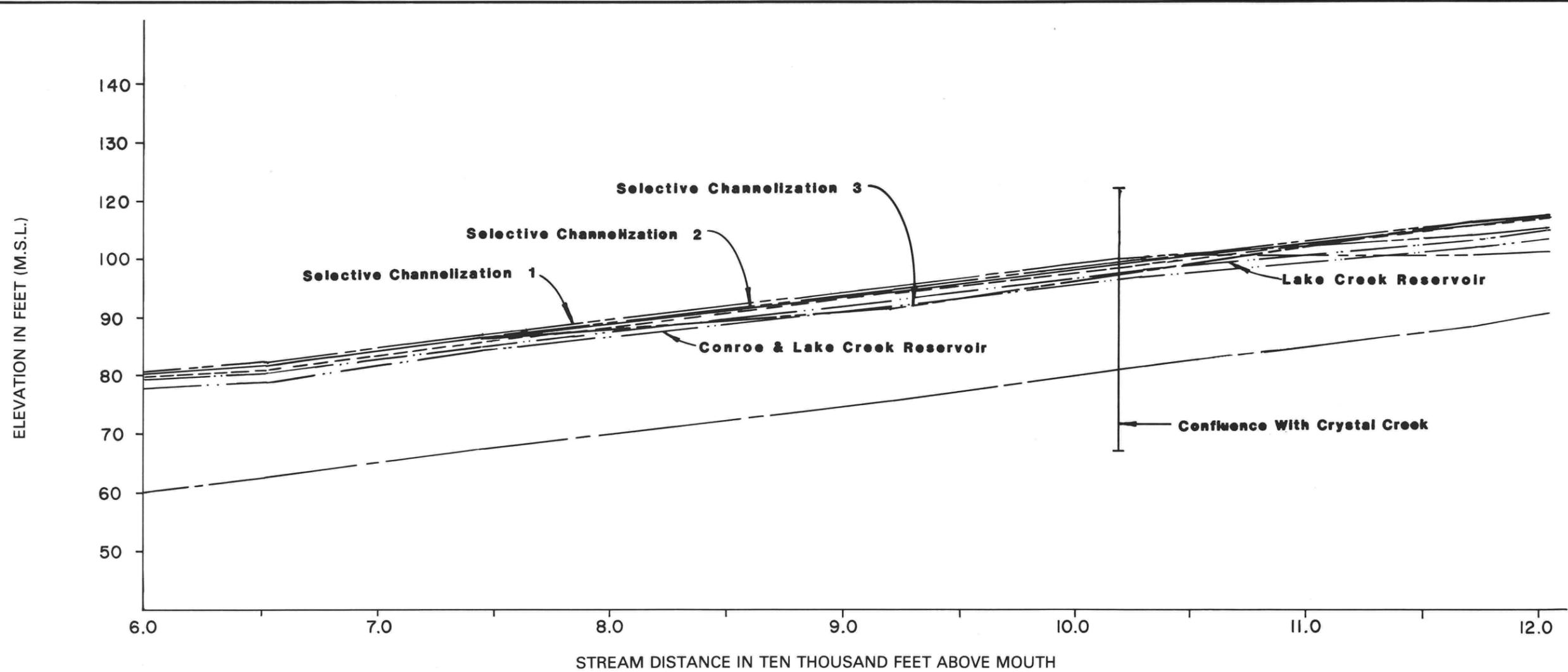
- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- - - - - DESNAGGING
- · · · - RESERVOIR
- · · · - BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**WEST FORK OF SAN JACINTO
STREAM SEGMENT 1
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT WF-1H



LEGEND

- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- · · · · DESNAGGING
- - - - - RESERVOIR
- · · · - BRIDGE MODIFICATIONS

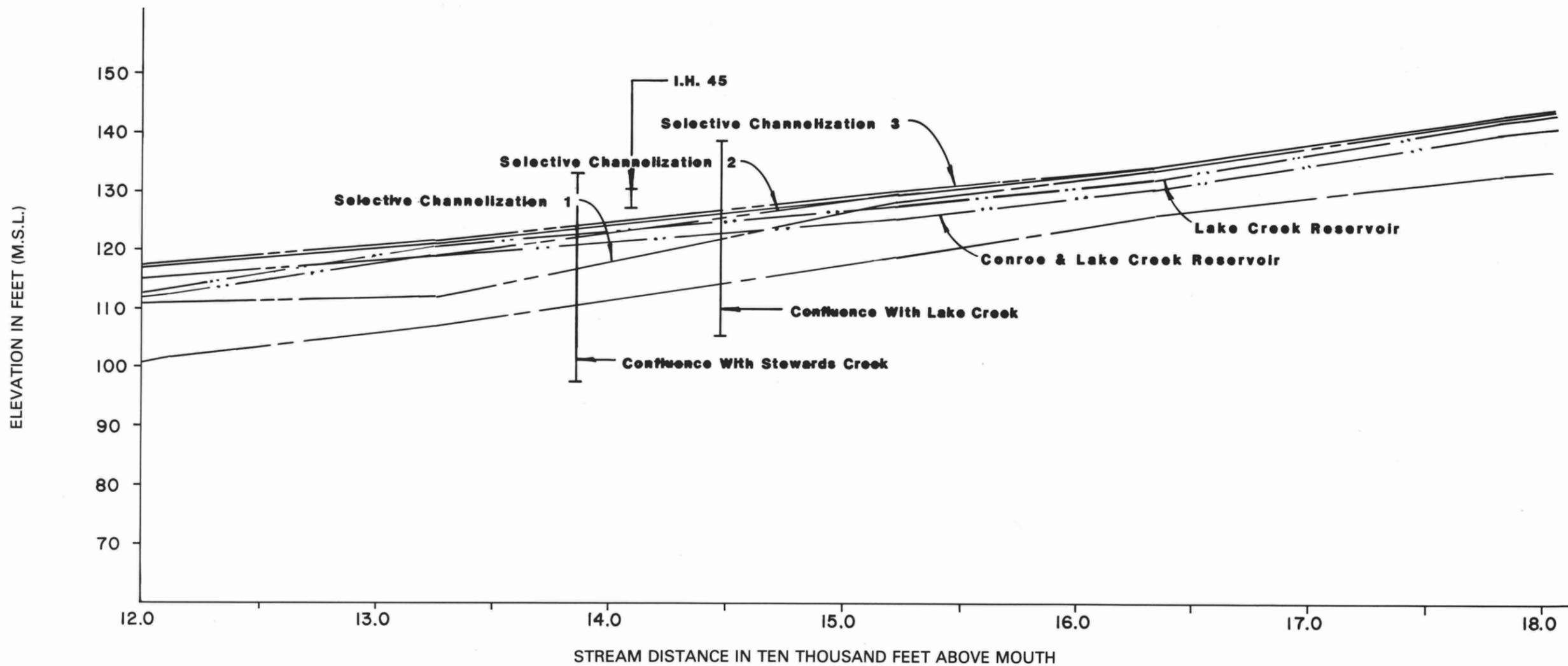
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**WEST FORK OF SAN JACINTO
STREAM SEGMENT 2
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-2H



LEGEND

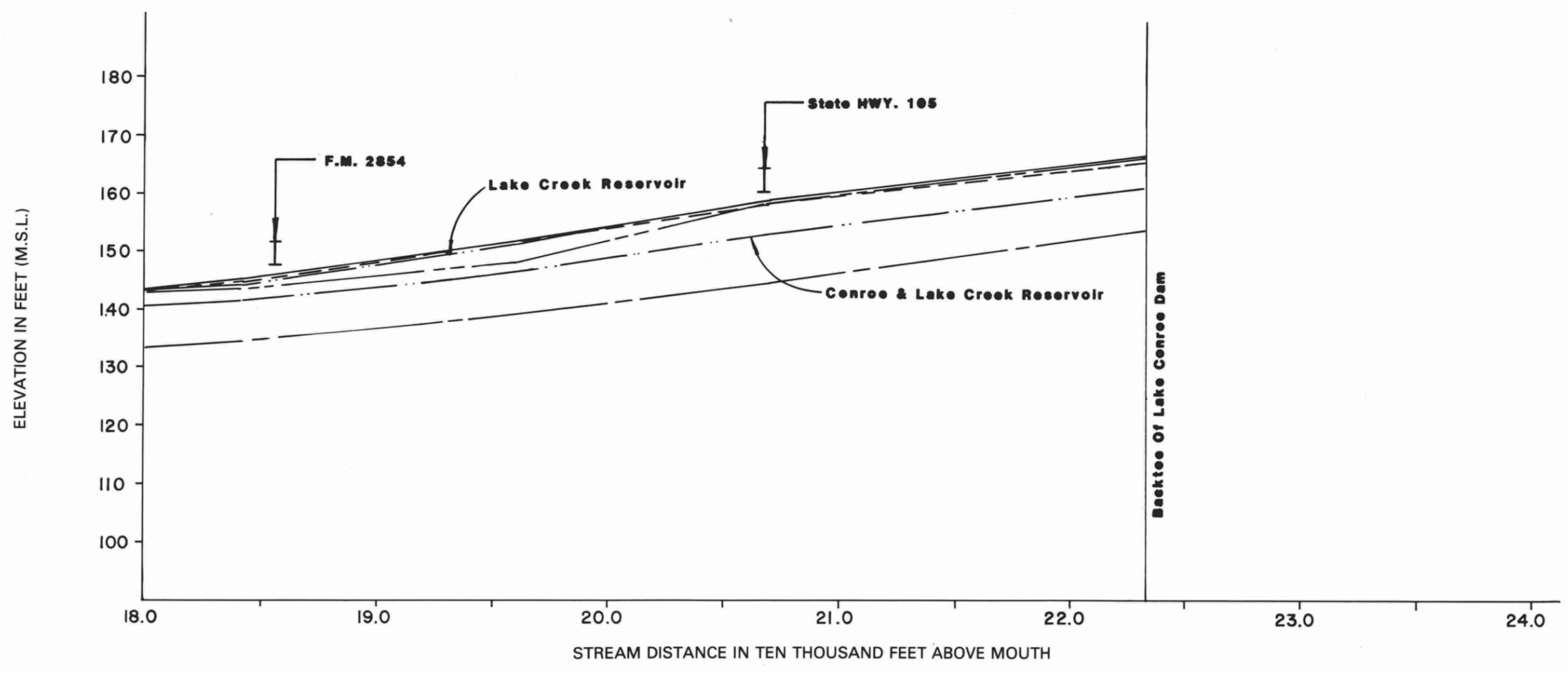
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- - - - - DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**WEST FORK OF SAN JACINTO
STREAM SEGMENT 3
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT WF-3H



LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- . - . - . SELECTIVE CHANNELIZATION
- DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**WEST FORK OF SAN JACINTO
STREAM SEGMENT 4
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT WF-4H

▶ FLOW DIRECTION ▶

MATCH LINE "A"



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study. 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

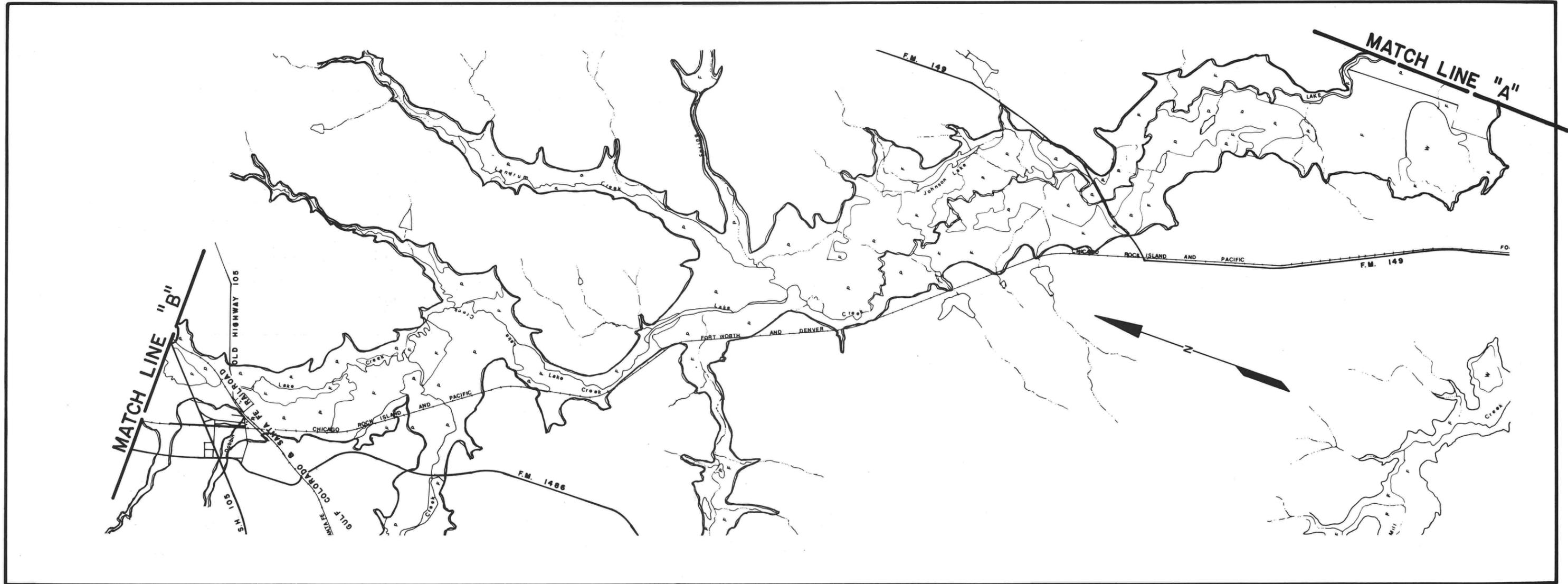


**LAKE CREEK
STEAM SEGMENT 1
EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-1A



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

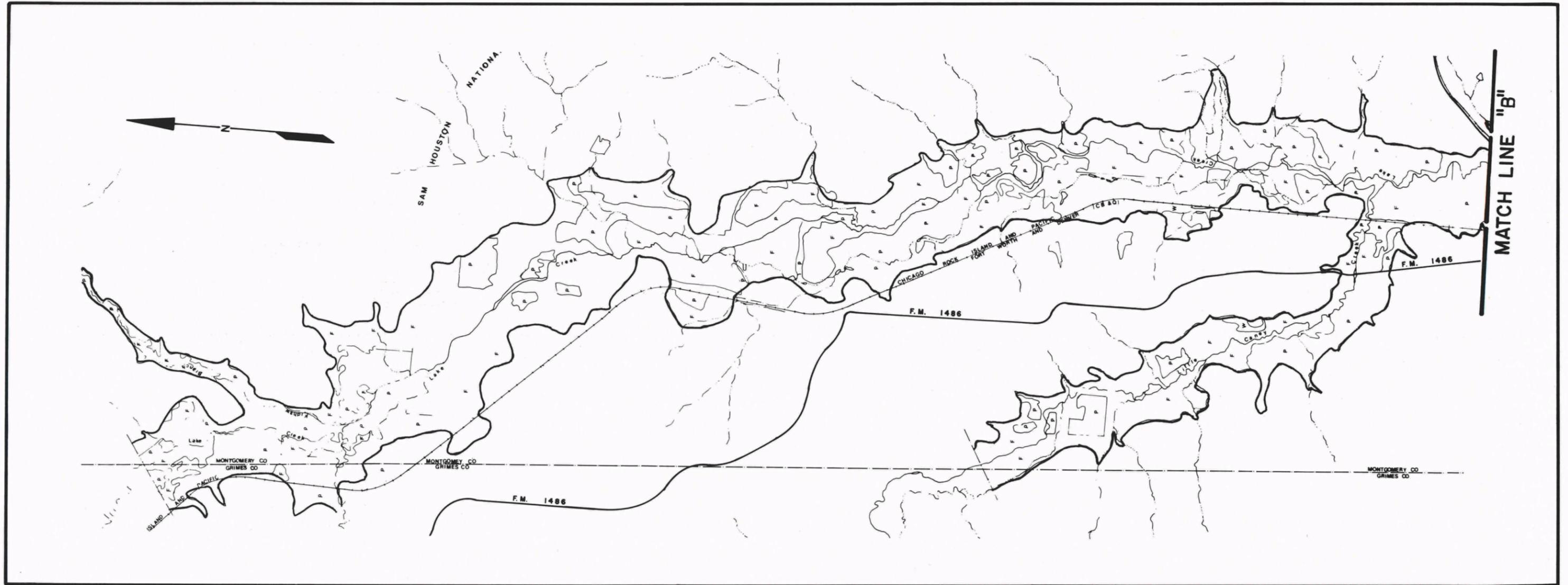
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982.



**LAKE CREEK
STREAM SEGMENT 2
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-2A



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**LAKE CREEK
STREAM SEGMENT 3
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-3A

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

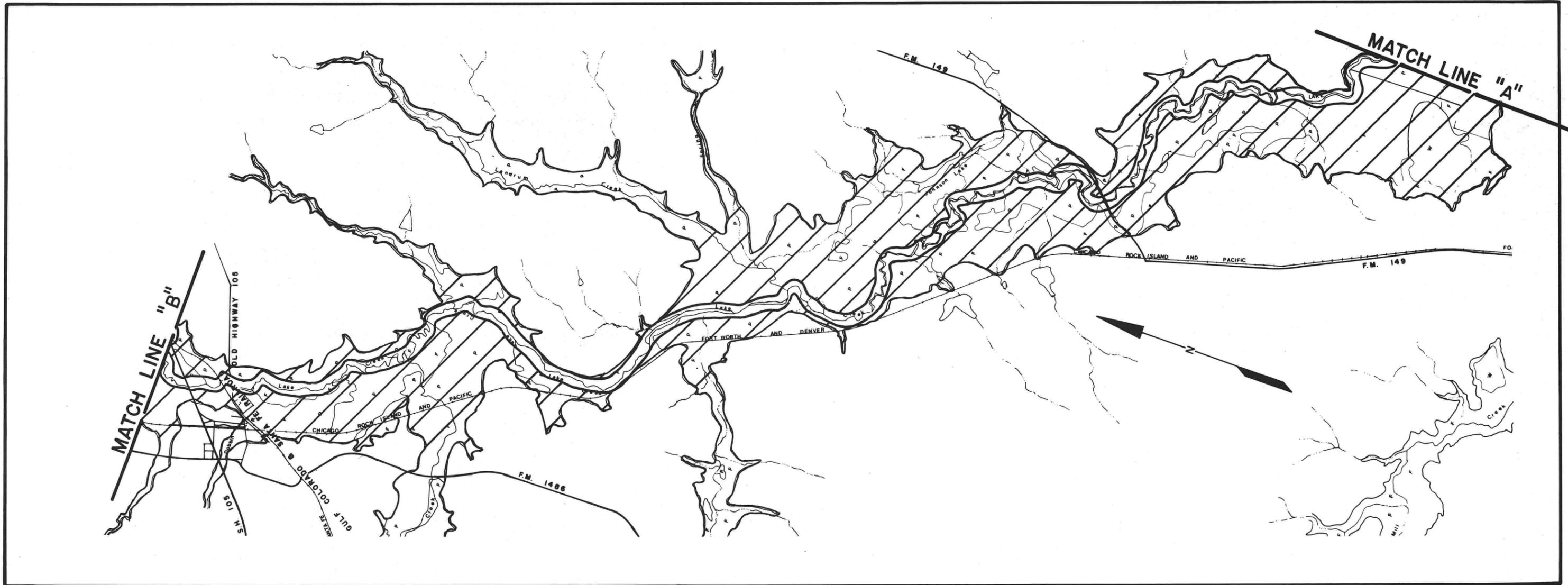
1. Base Map—USGS 1:24000—1959-1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976—1982.



**LAKE CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-1B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1		Gas Well
	School		Wetland		Recreational
					Flood Plain Reclamation

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

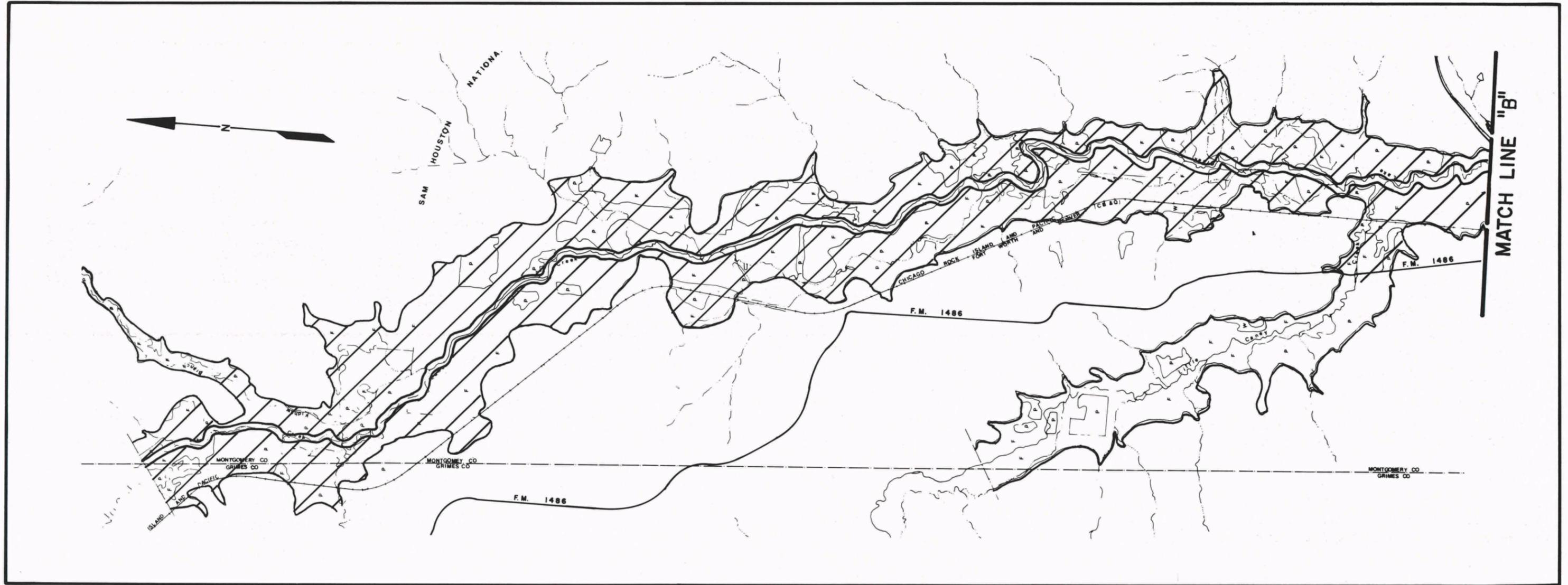
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**LAKE CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-2B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

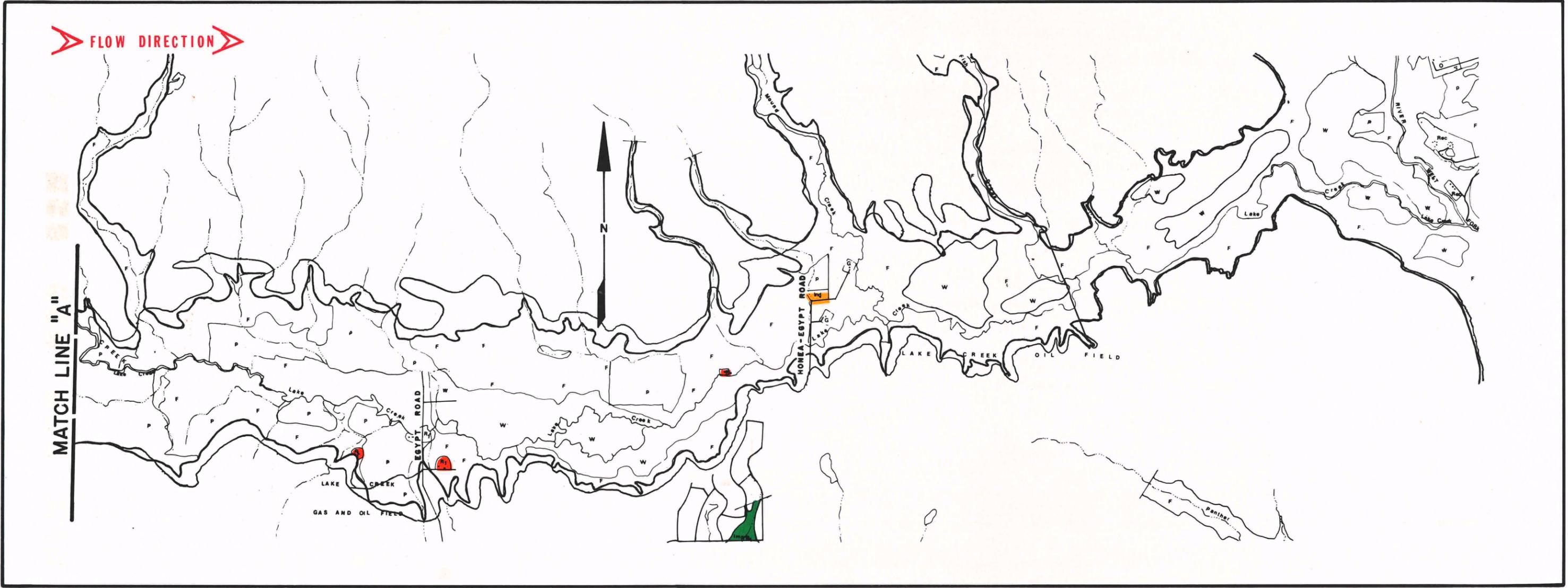
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**LAKE CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-3B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
					Flood Plain Reclamation

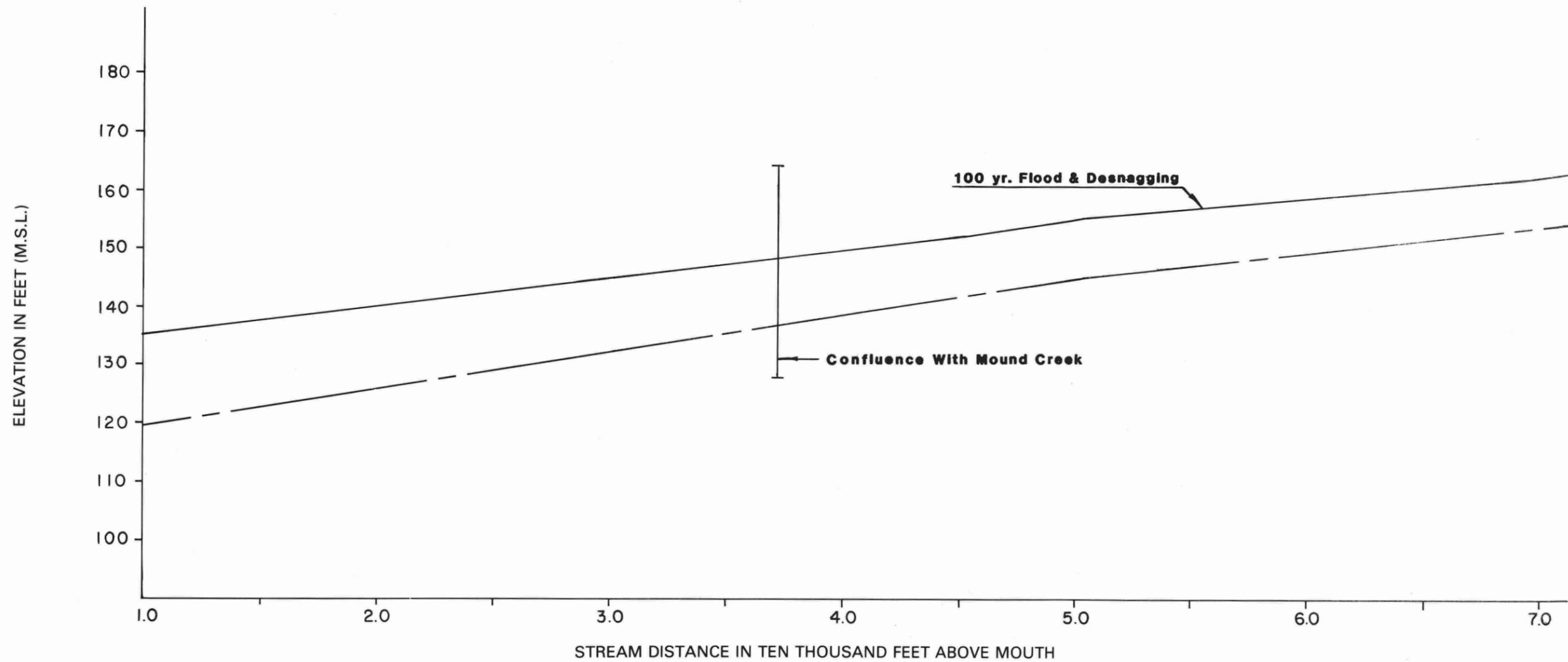
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**LAKE CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR**

WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS



LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- SELECTIVE CHANNELIZATION
- DESNAGGING
- · — · — RESERVOIR
- · · — · — BRIDGE MODIFICATIONS

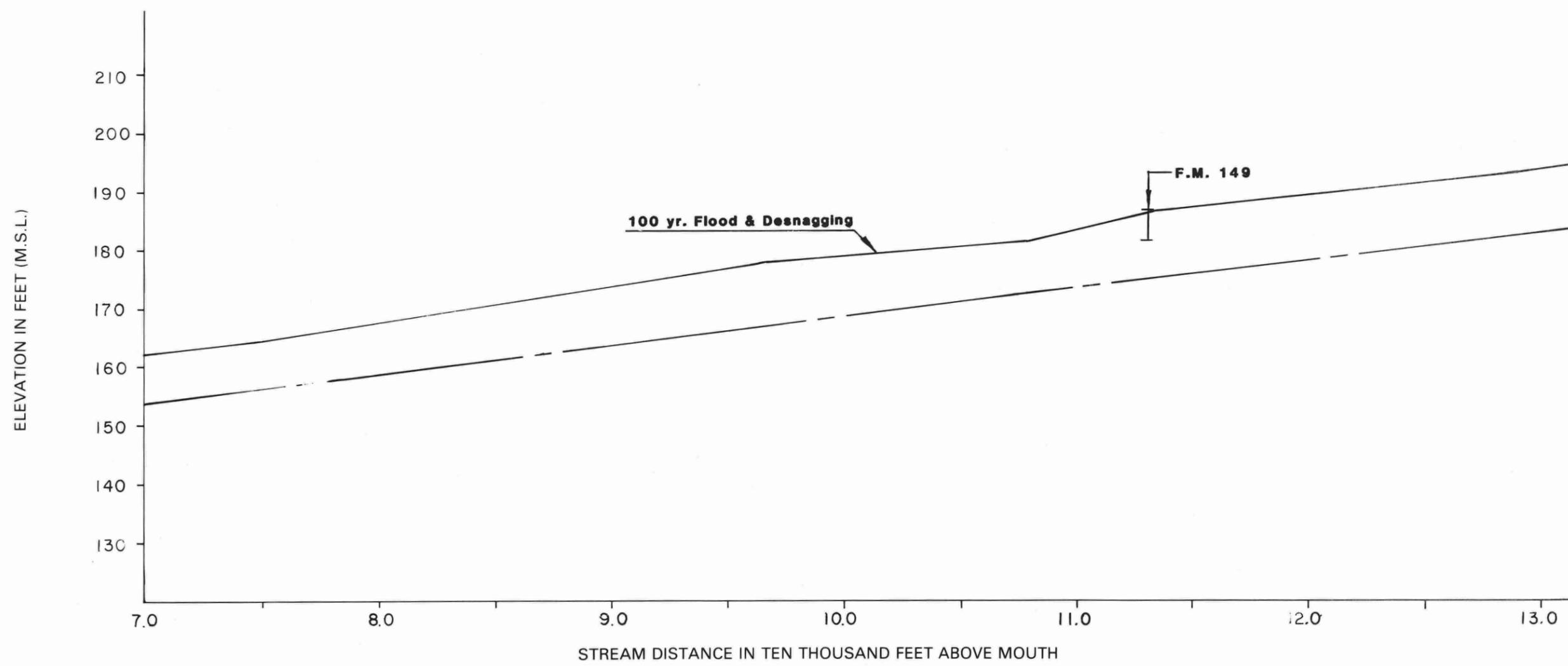
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**LAKE CREEK
STREAM SEGMENT 1
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT LC-1H



LEGEND

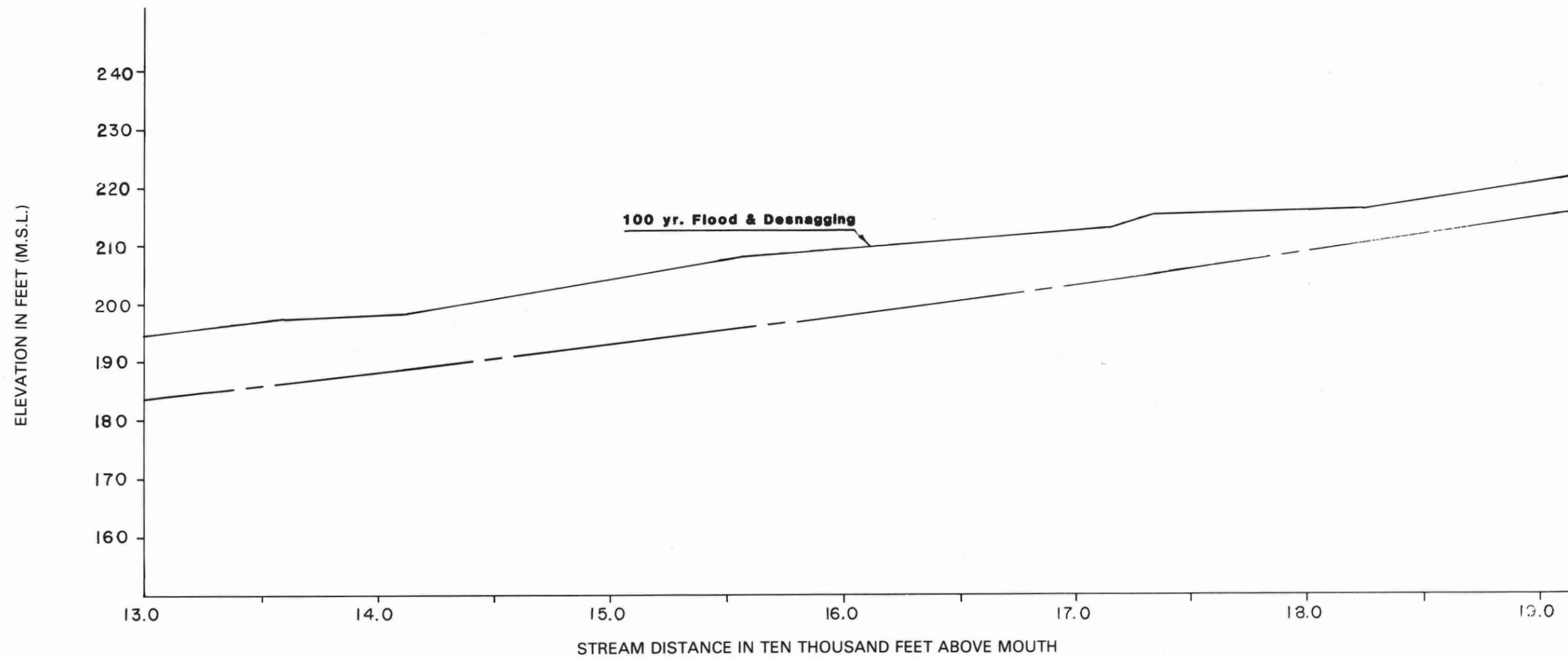
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- SELECTIVE CHANNELIZATION
- DESNAGGING
- · — · — RESERVOIR
- · · — · — BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**LAKE CREEK
STREAM SEGMENT 2
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT LC-2H



LEGEND

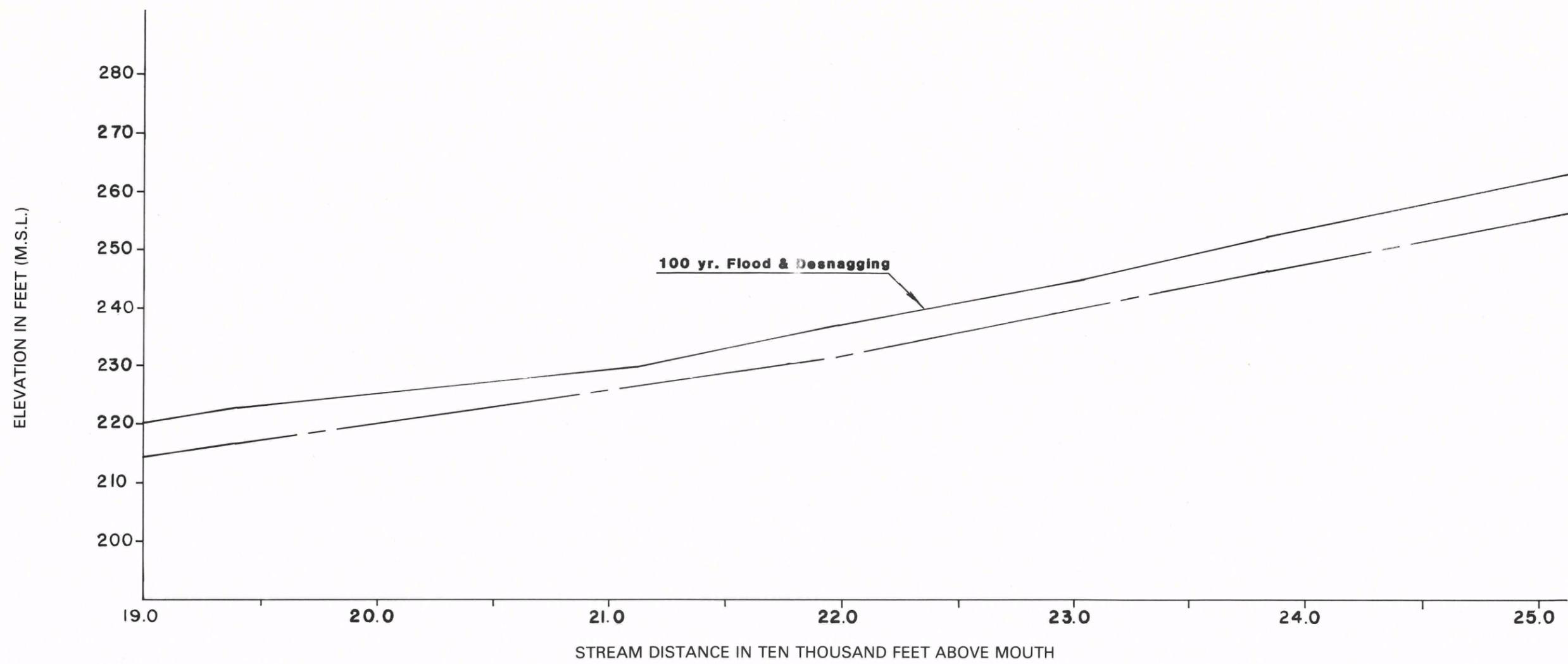
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- - - - - DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**LAKE CREEK
STREAM SEGMENT 3
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT LC-3H



LEGEND

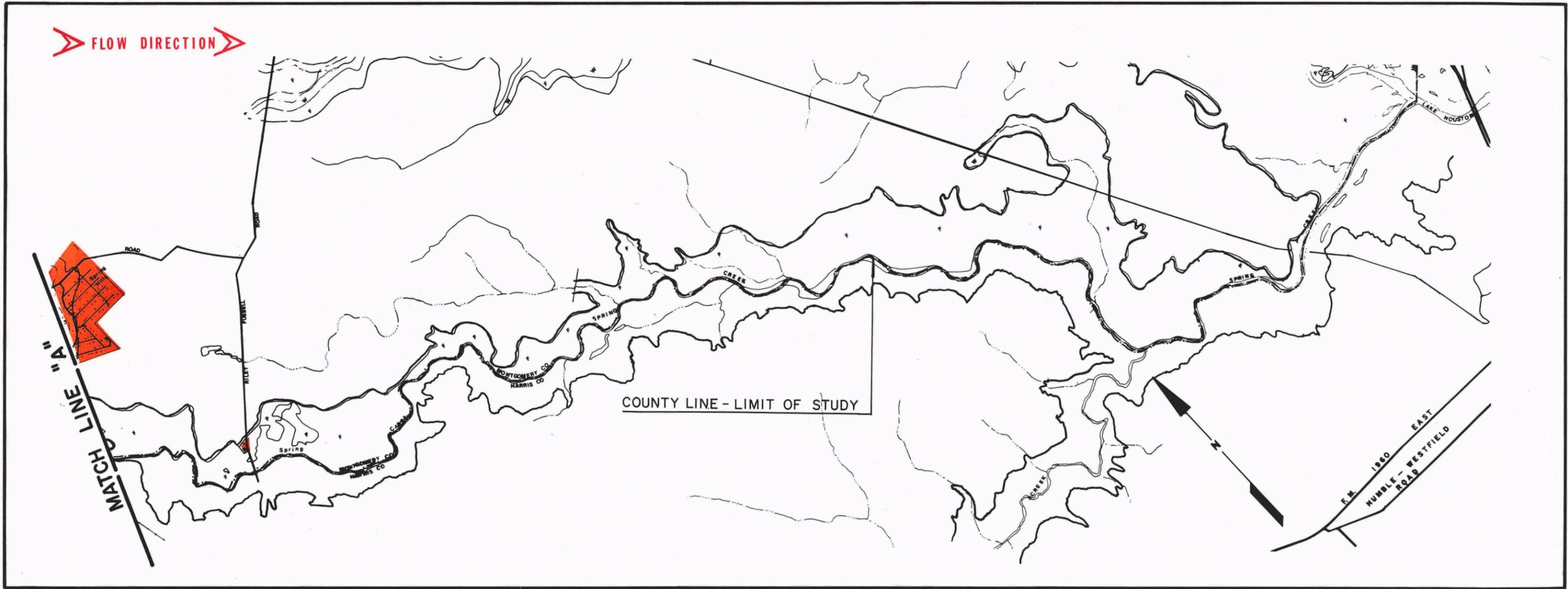
- 100 YR. FLOOD
- — — — TOTAL CHANNELIZATION
- — — — SELECTIVE CHANNELIZATION
- - - - - DESNAGGING
- · · — · · RESERVOIR
- · · · · · BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**LAKE CREEK
STREAM SEGMENT 4
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT LC-4H



Legend

- | | | | | | |
|--|--------------------|--|---|--|-------------------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forcst | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp R1 R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | | | Flood Plain Reclamation |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

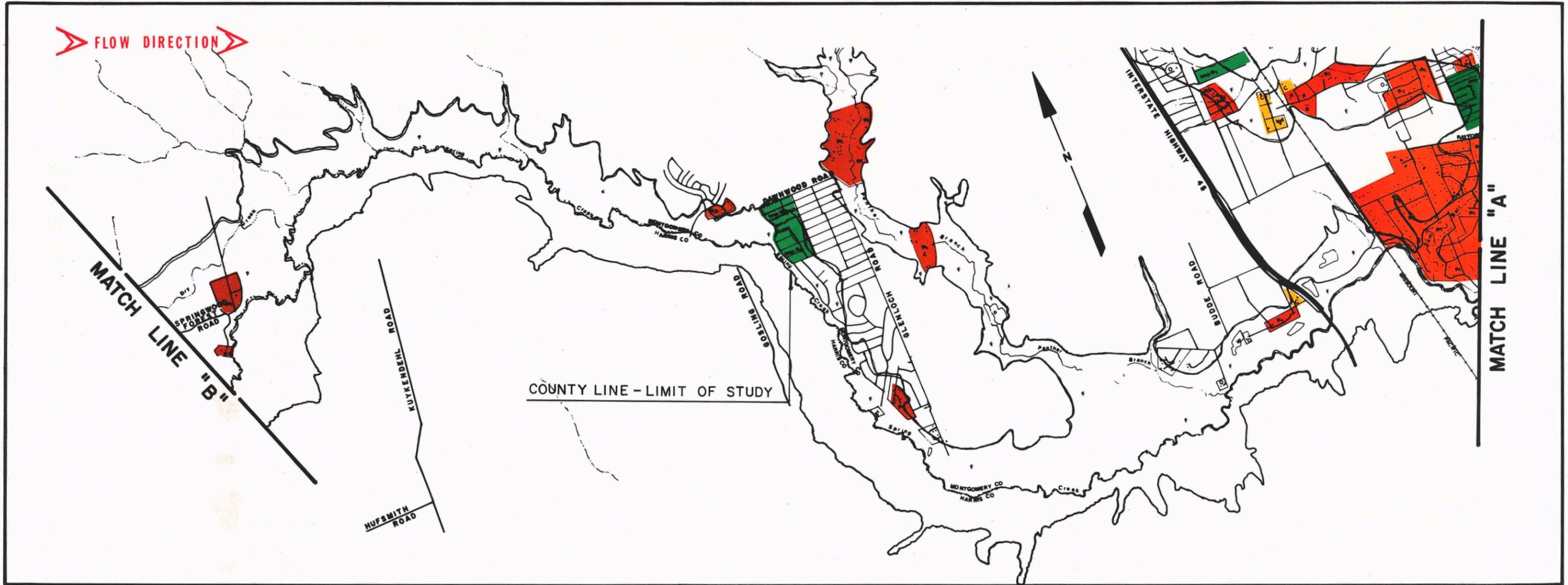
- Sources
1. Base Map - USGS 1:24000 - 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



**SPRING CREEK
STREAM SEGMENT 1
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-1A



Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forcst | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp R1 R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

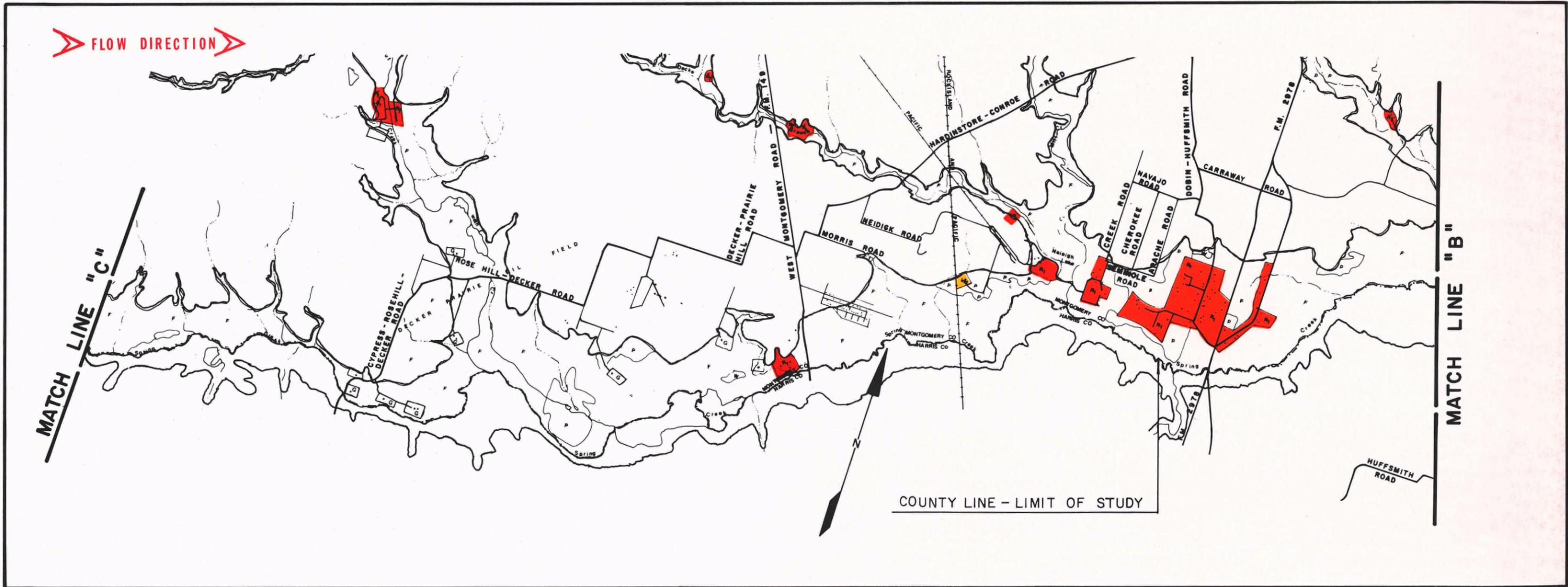
1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



**SPRING CREEK
STREAM SEGMENT 2
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-2A



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study. 1982.
2. Land Use. Aerial Photog. Interp. 1:2000 ft. 1976 — 1982.



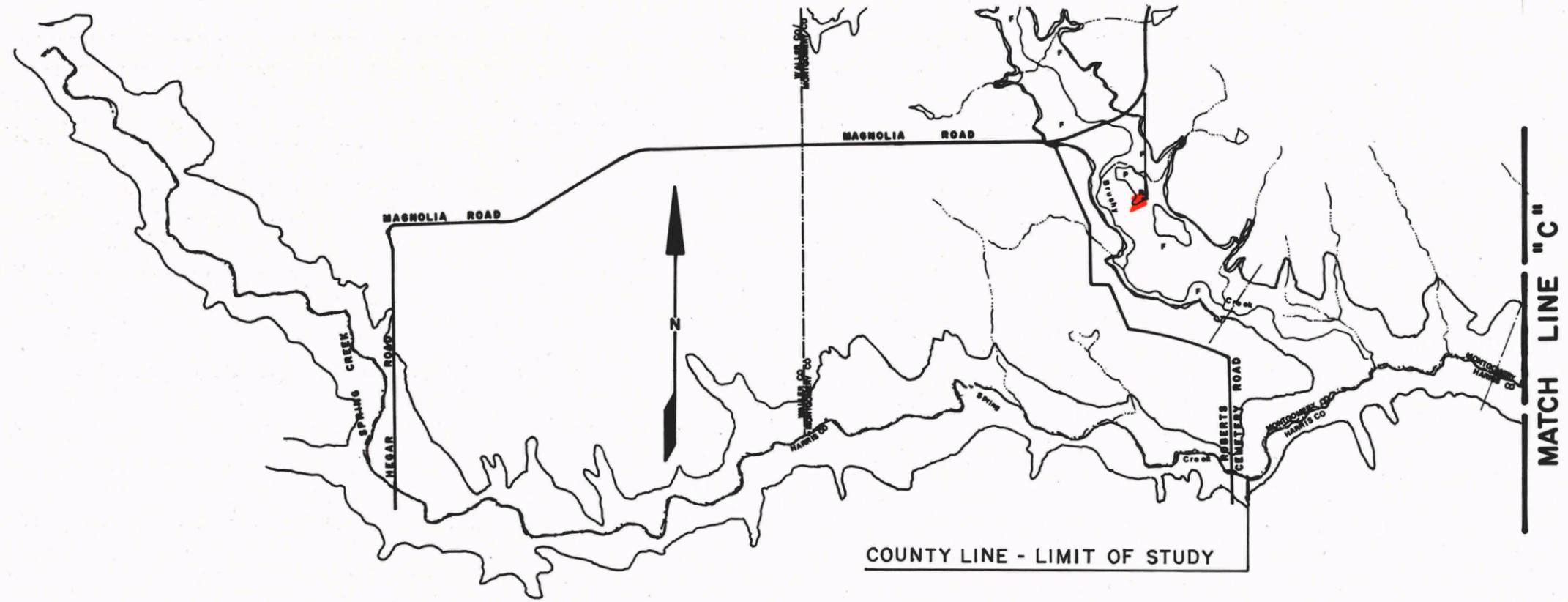
SPRING CREEK
STREAM SEGMENT 3
EXISTING 100yr. FLOOD PLAIN



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-3A

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forcst		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

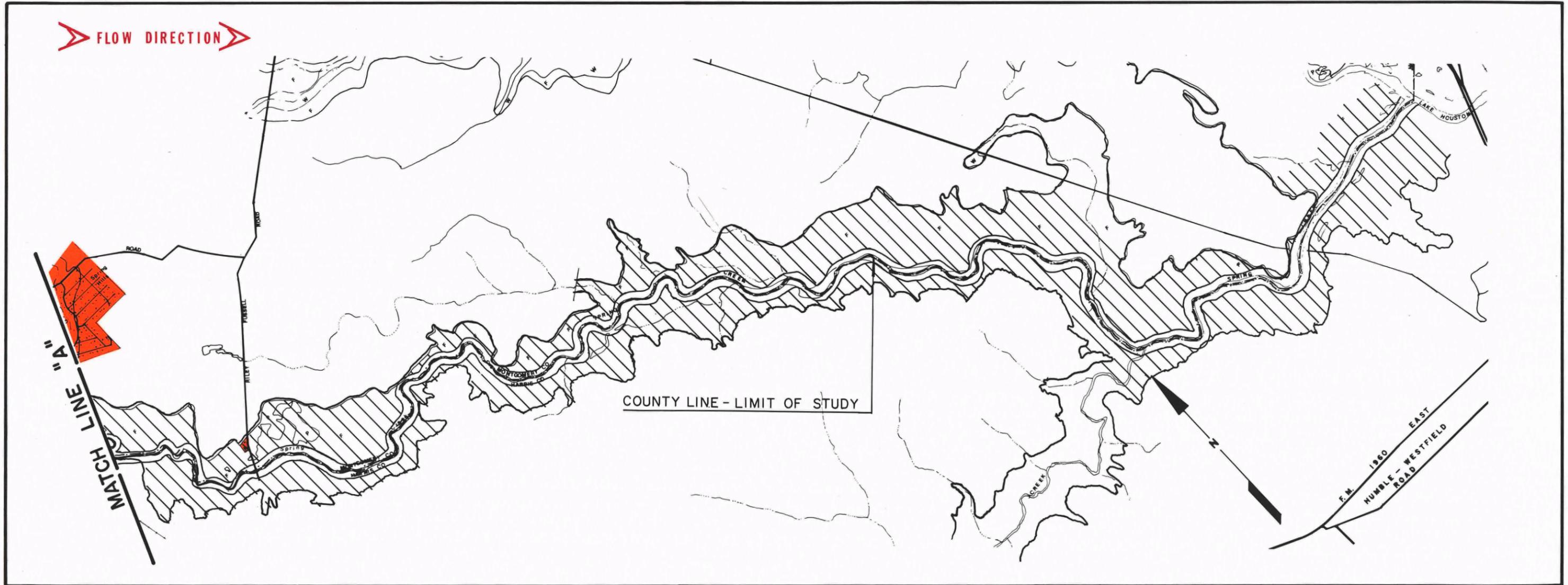
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**SPRING CREEK
STREAM SEGMENT 4
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-4A



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use. Aerial Photog. Interp. 1:2000 ft. 1976 - 1982

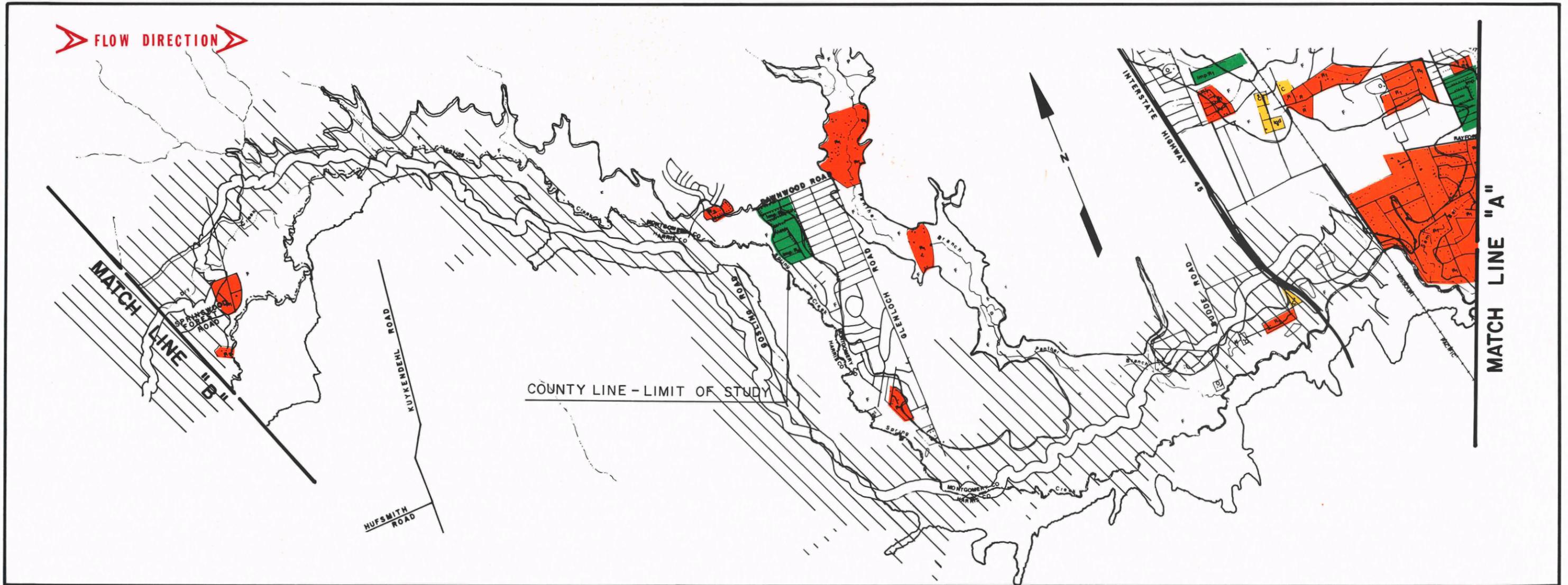
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**SPRING CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-1B



Legend

- | | | | | | |
|--|--------------------|--|--|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forest | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp R1, R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

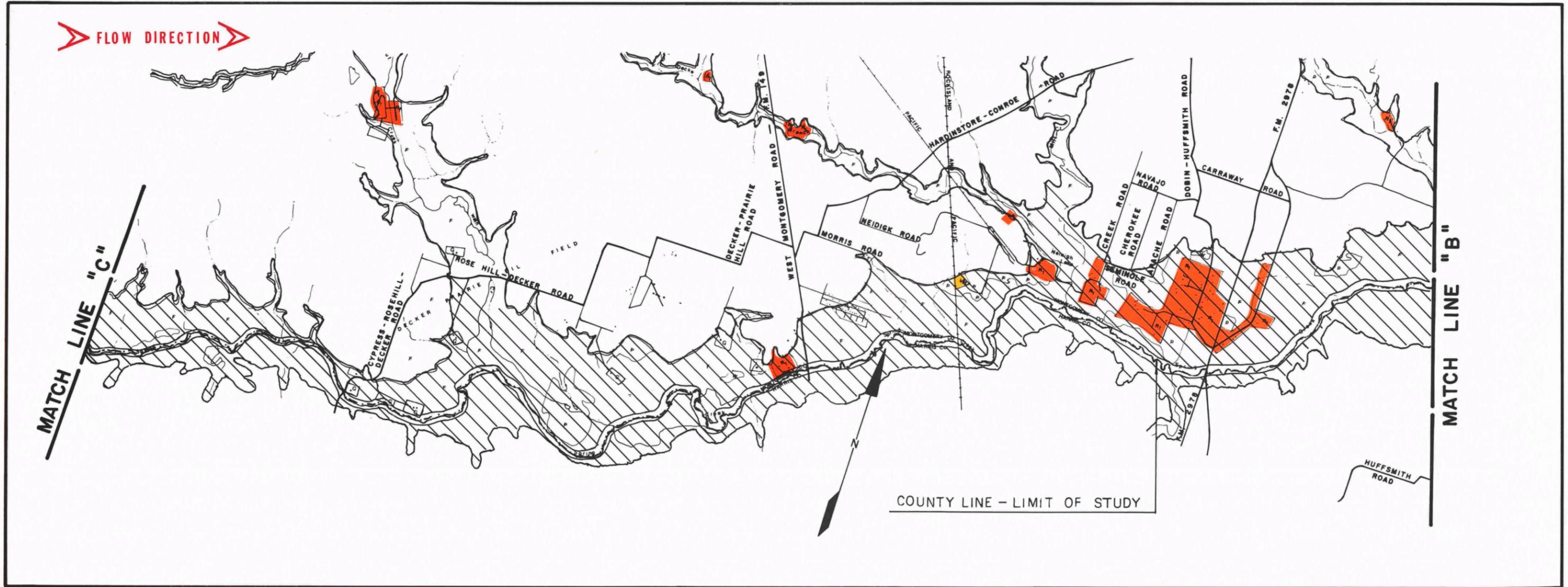
Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982.



**SPRING CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS
EXHIBIT SC-2B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



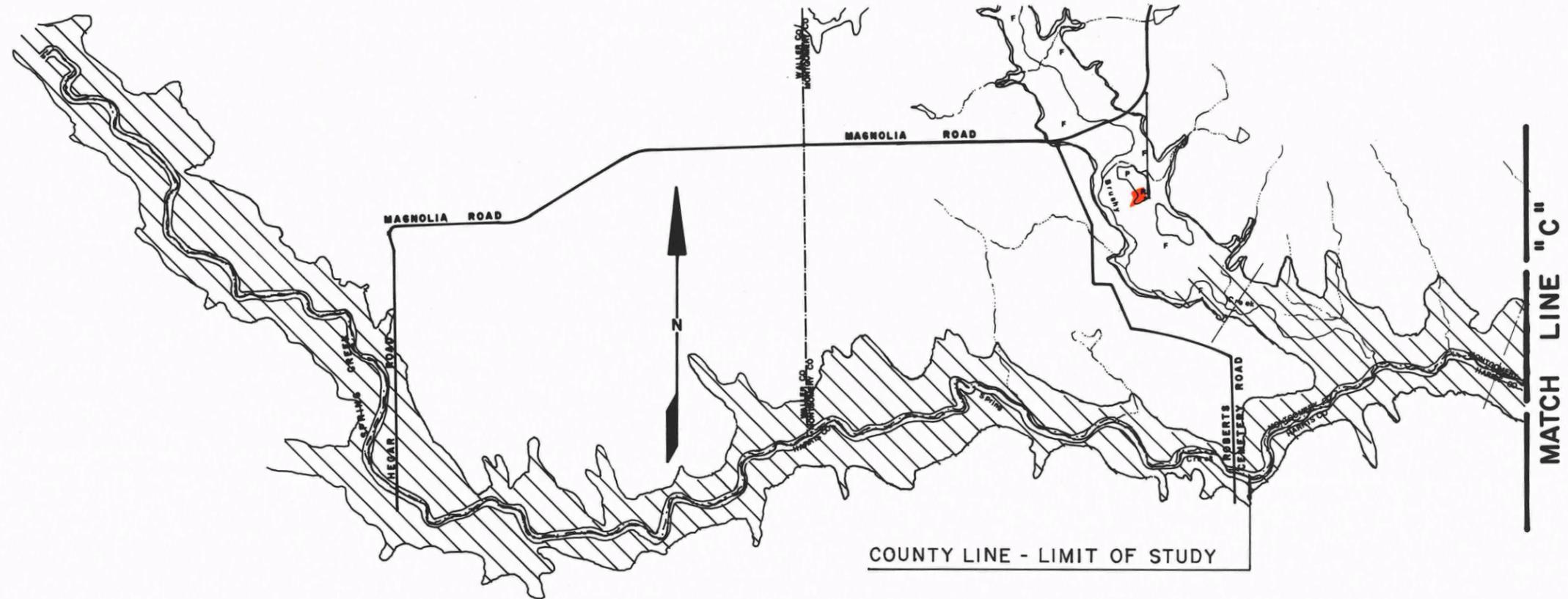
**SPRING CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-3B

➤ FLOW DIRECTION ➤



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

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2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

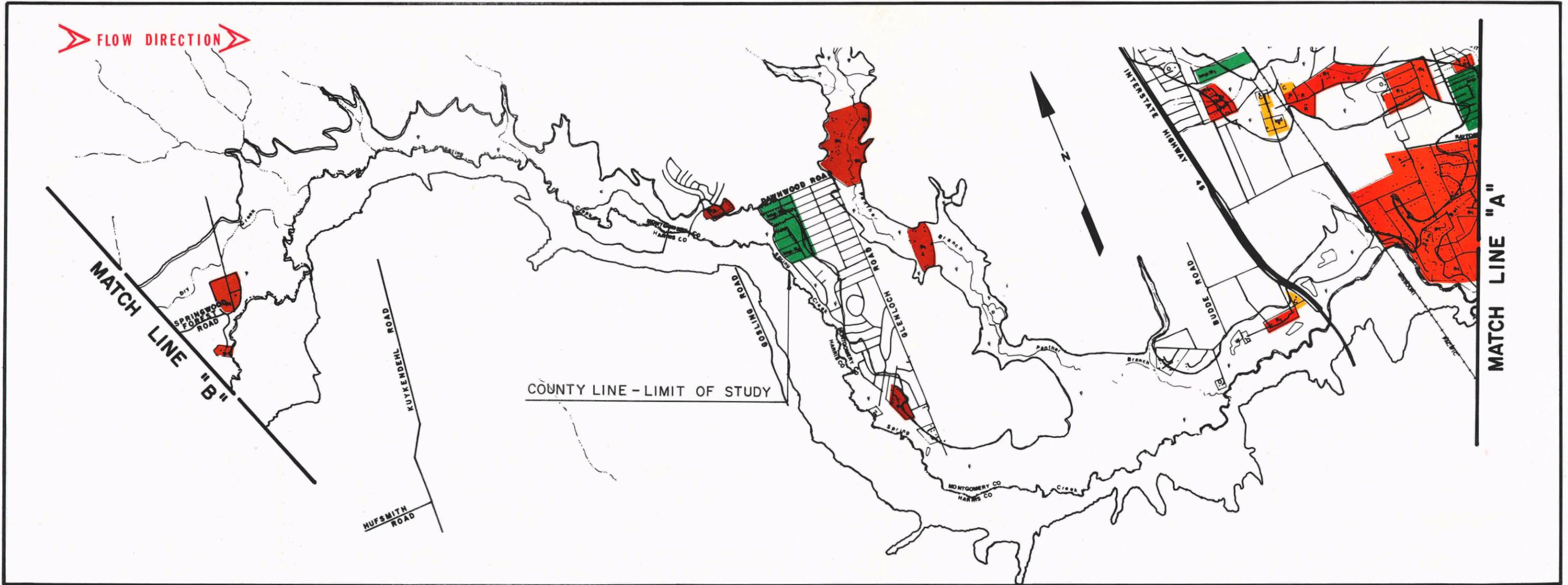


**SPRING CREEK
STREAM SEGMENT 4
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-4B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
					Flood Plain Reclamation

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

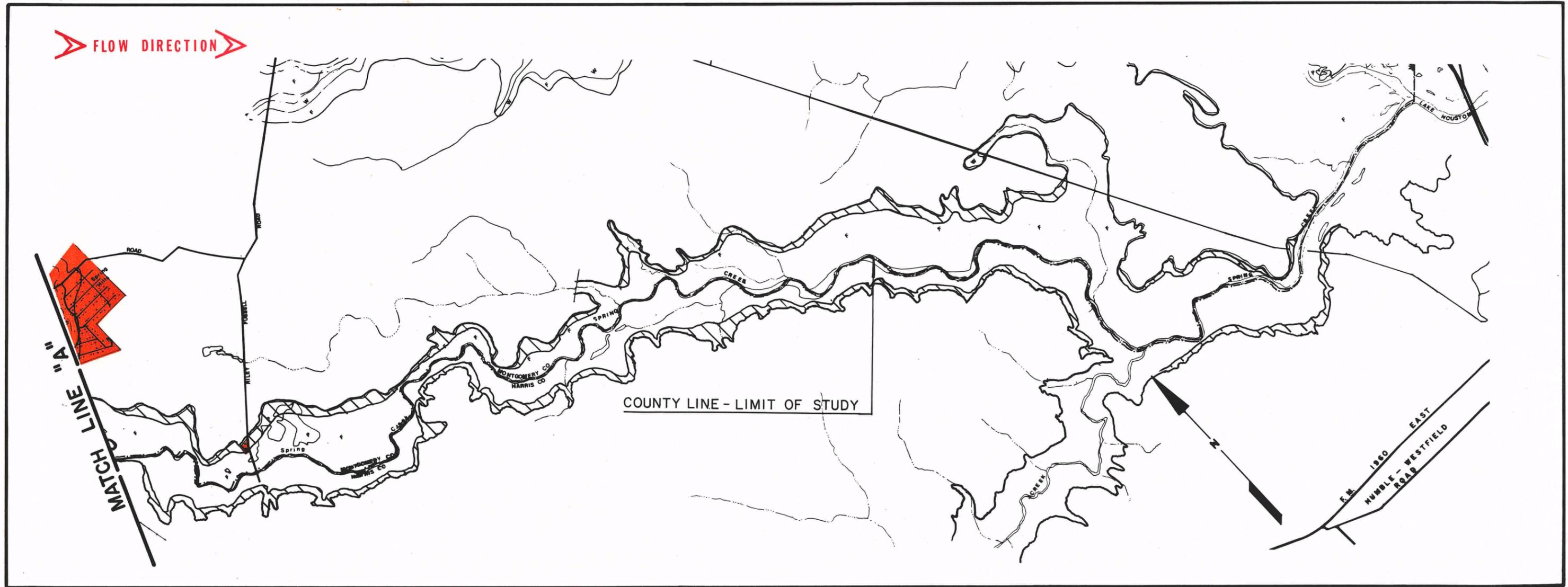
Sources
 1. Base Map - USGS 1:24000 - 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 - 1982.



**SPRING CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 1**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-2G-1



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

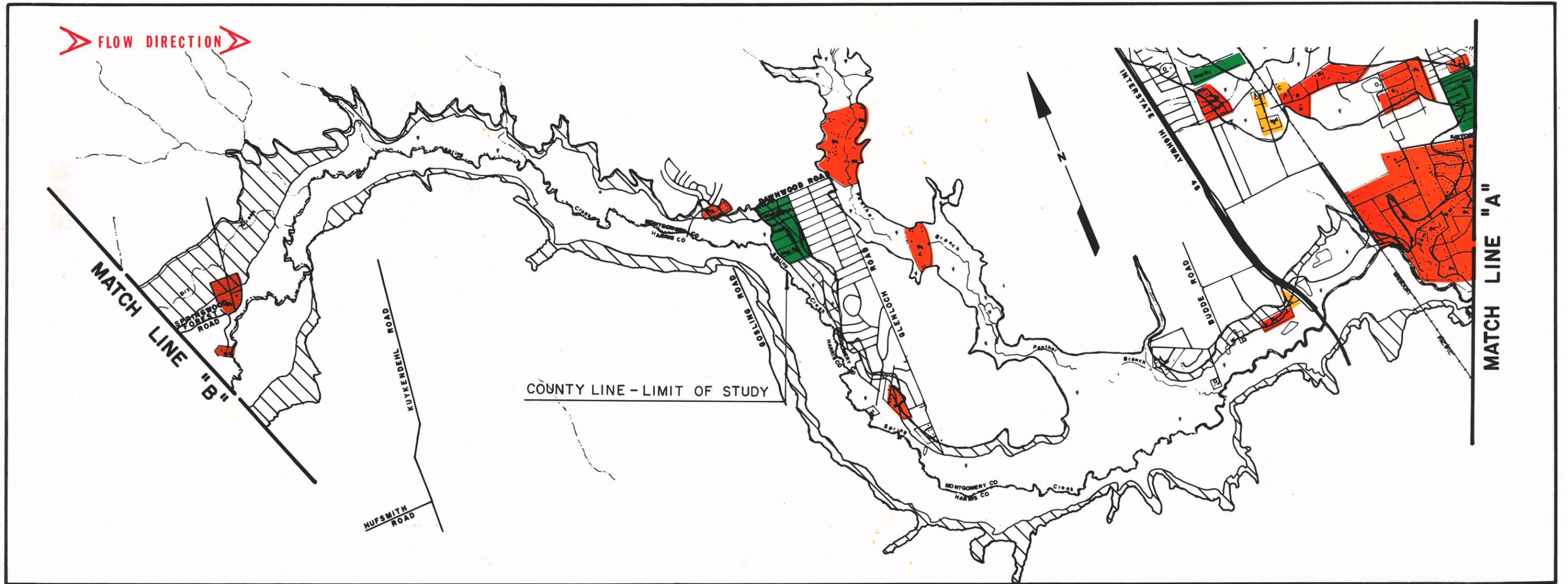


**SPRING CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-1G-2



Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forest | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp R1 R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

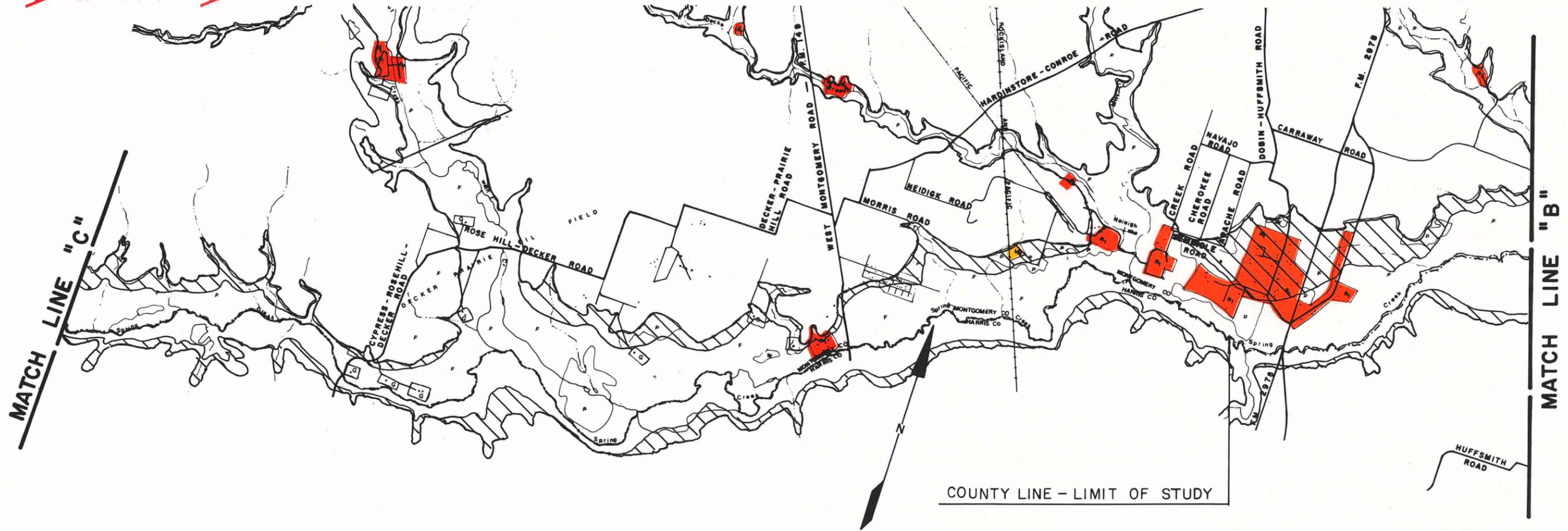
- Sources
1. Base Map - USGS 1:24000 - 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



SPRING CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-2G-2



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982.



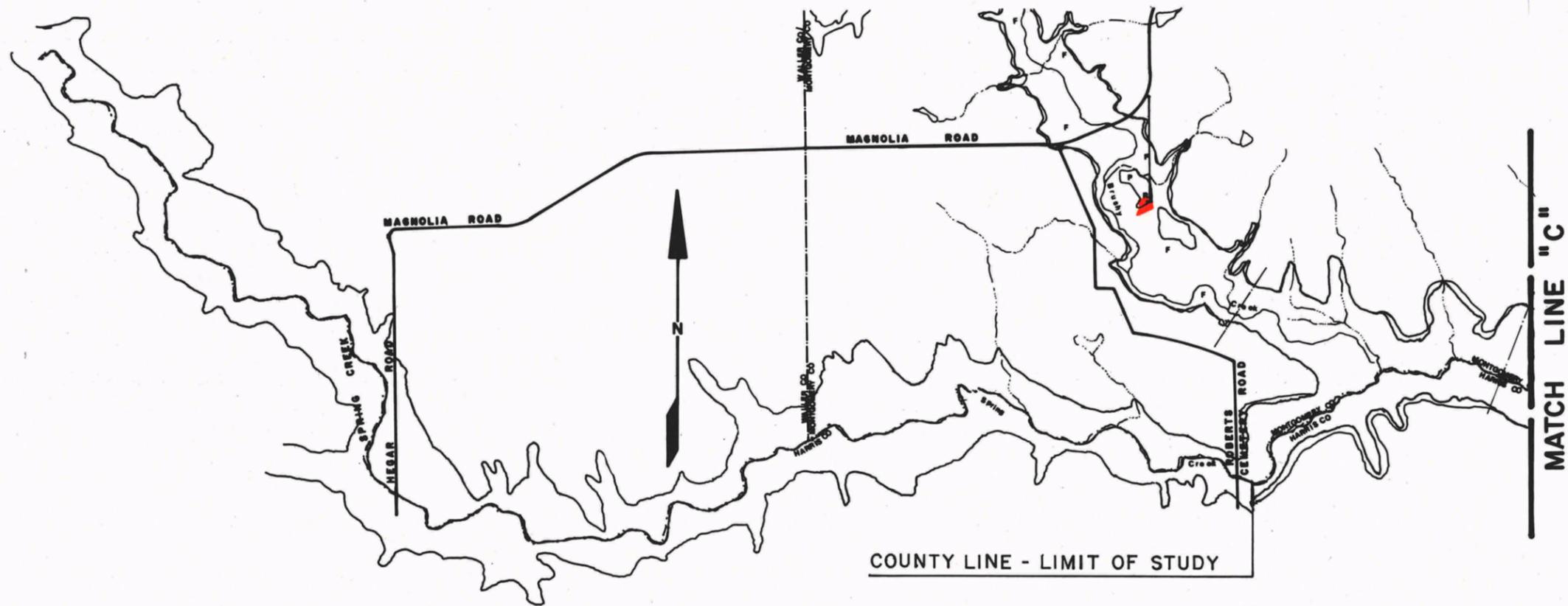
**SPRING CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-3G-2

▶ FLOW DIRECTION ▶



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forcst		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

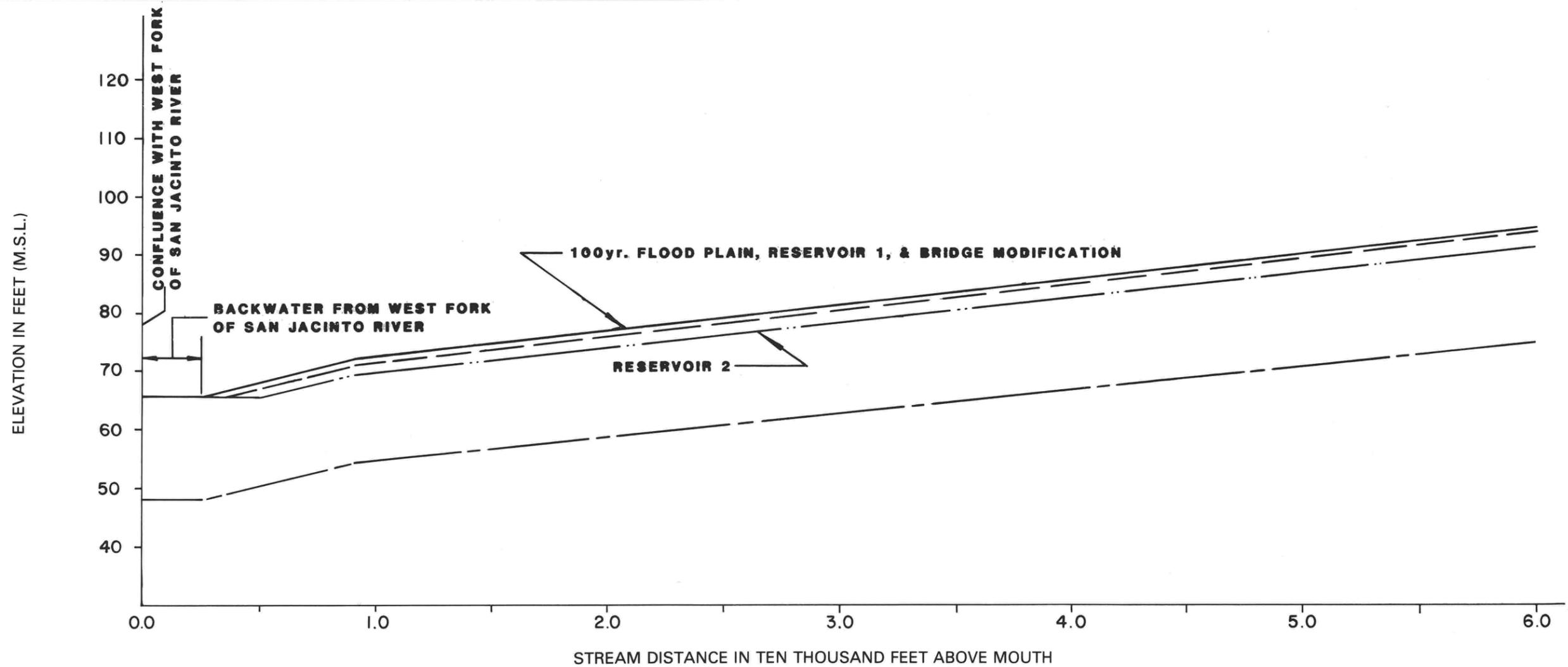
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**SPRING CREEK
STREAM SEGMENT 4
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-4G-2



LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- · - · - DESNAGGING
- · — · — RESERVOIR
- · · — · — BRIDGE MODIFICATIONS

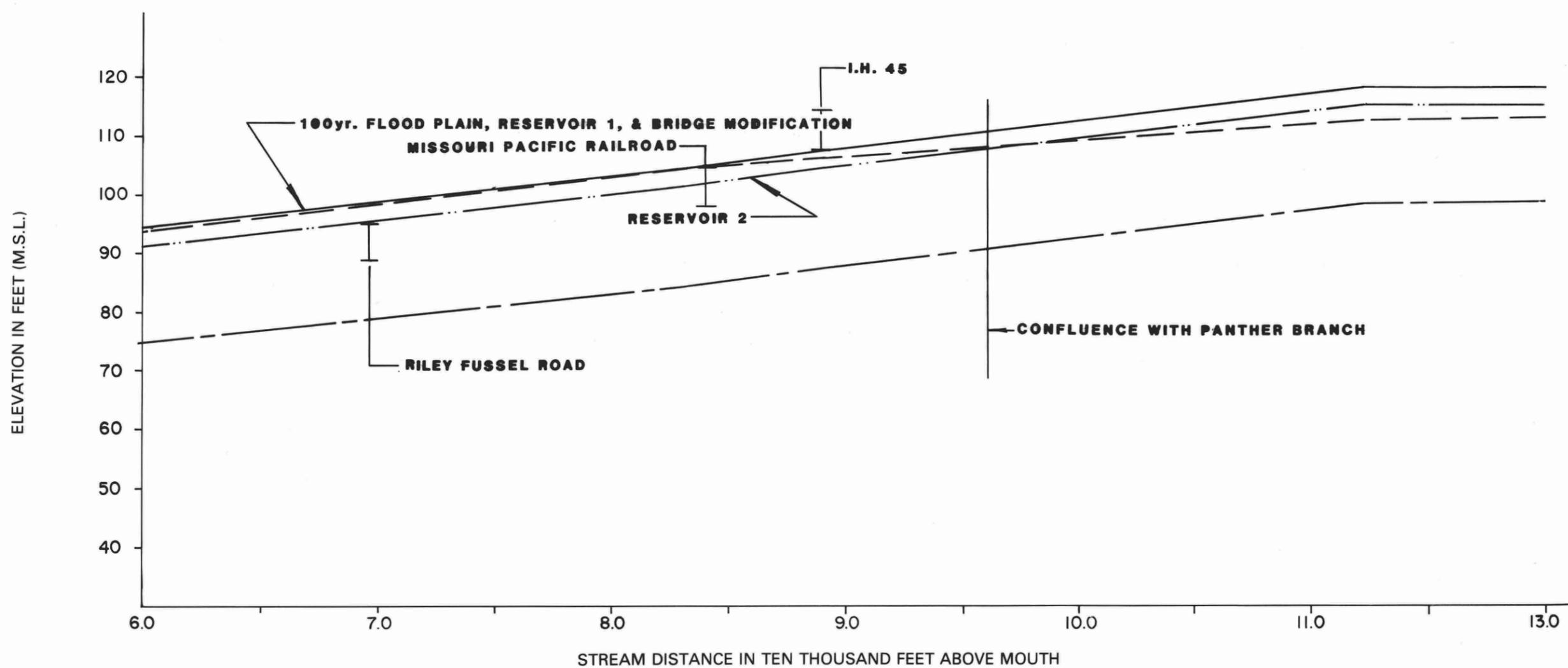
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**SPRING CREEK
STREAM SEGMENT 1
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-1H



LEGEND

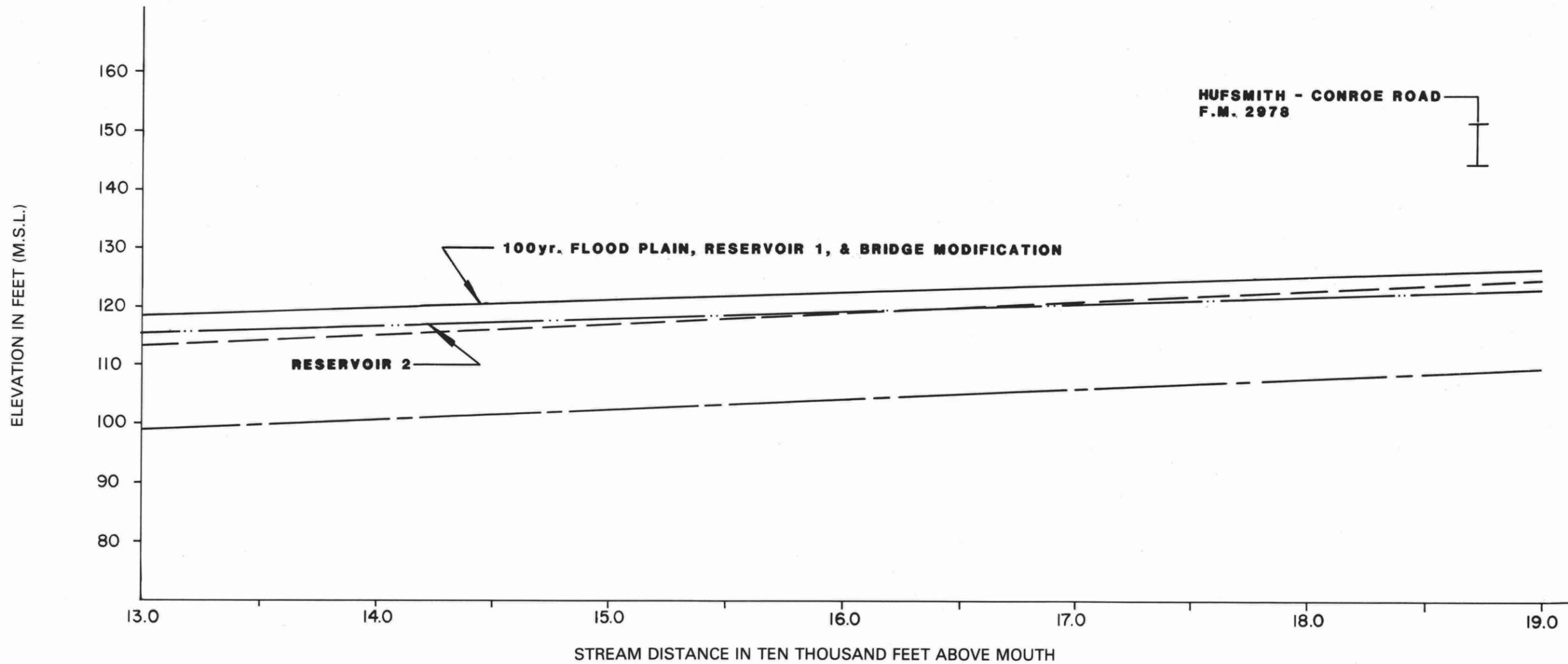
- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- · - · - DESNAGGING
- - - - - RESERVOIR
- · · · - BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**SPRING CREEK
STREAM SEGMENT 2
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT SC-2H



LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- . - . - . SELECTIVE CHANNELIZATION
- DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

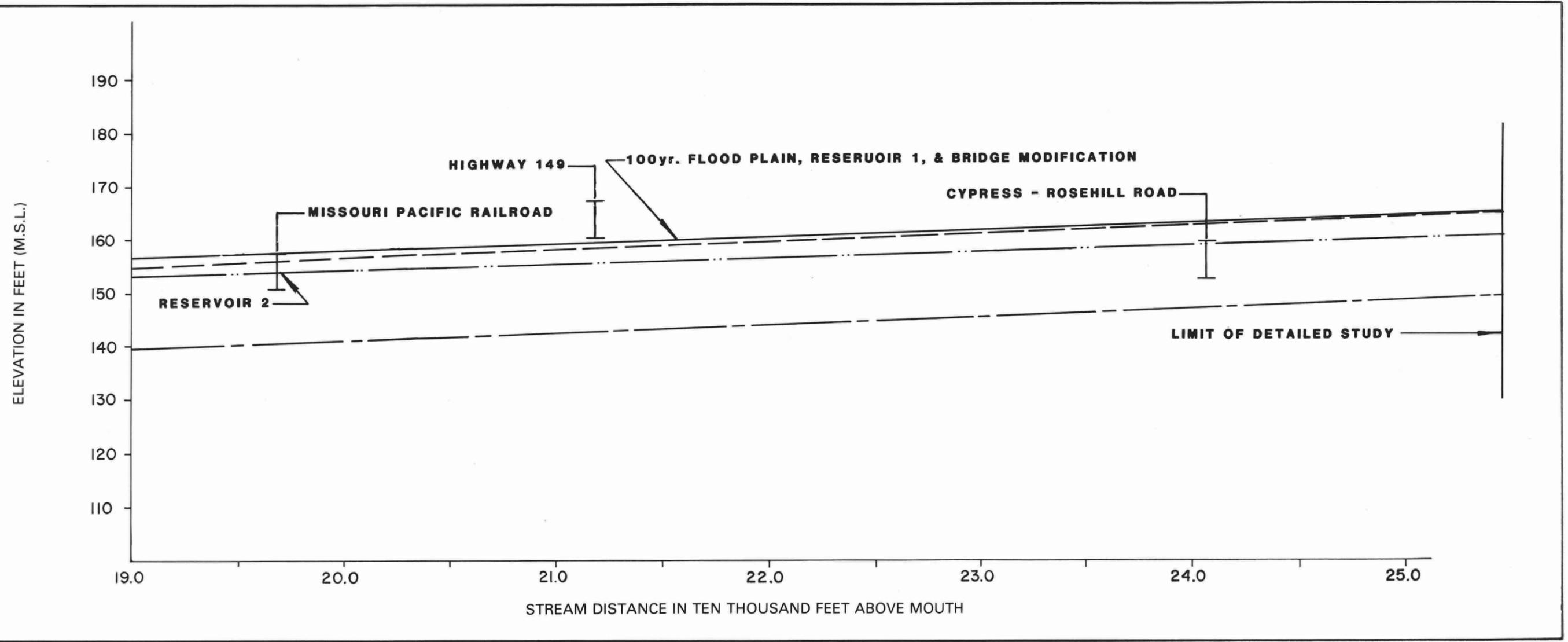
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**SPRING CREEK
STREAM SEGMENT 3
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT SC-3H



LEGEND

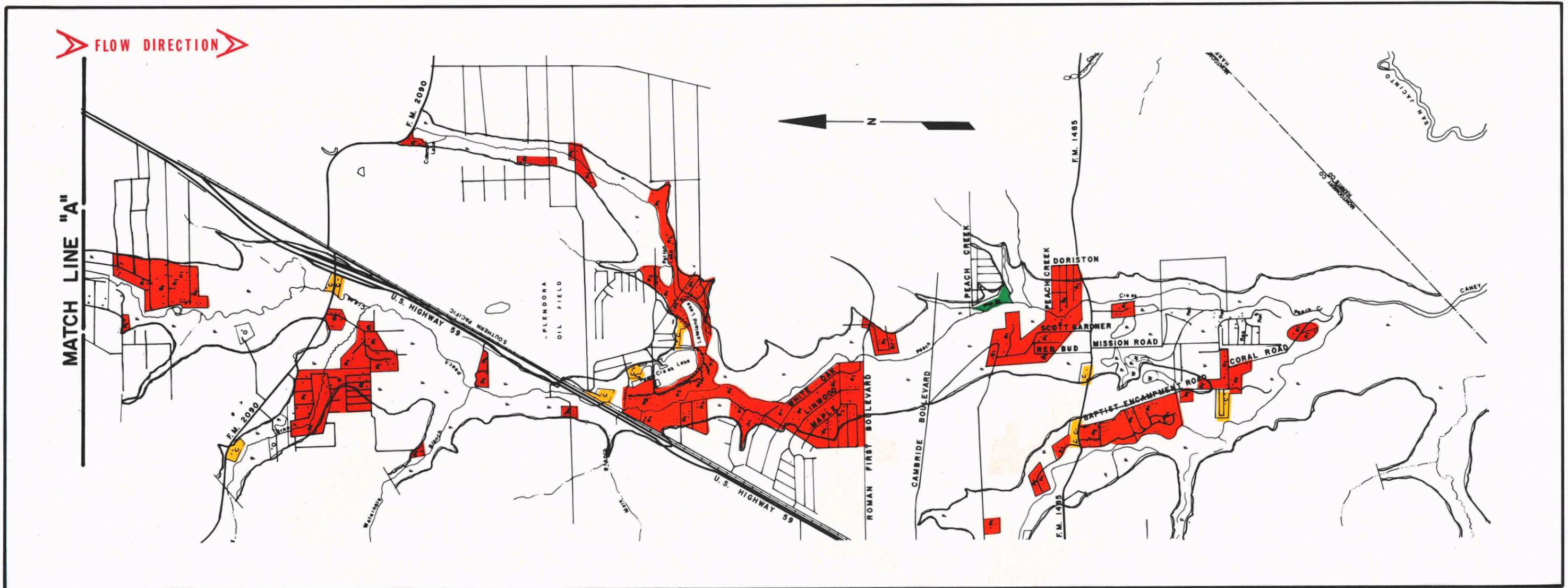
- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- · - - - DESNAGGING
- - - - - RESERVOIR
- · · · - BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**SPRING CREEK
STREAM SEGMENT 4
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT SC-4H



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1, R2		Gas Well
	School		Wetland		Recreational
					Flood Plain Reclamation

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

Sources

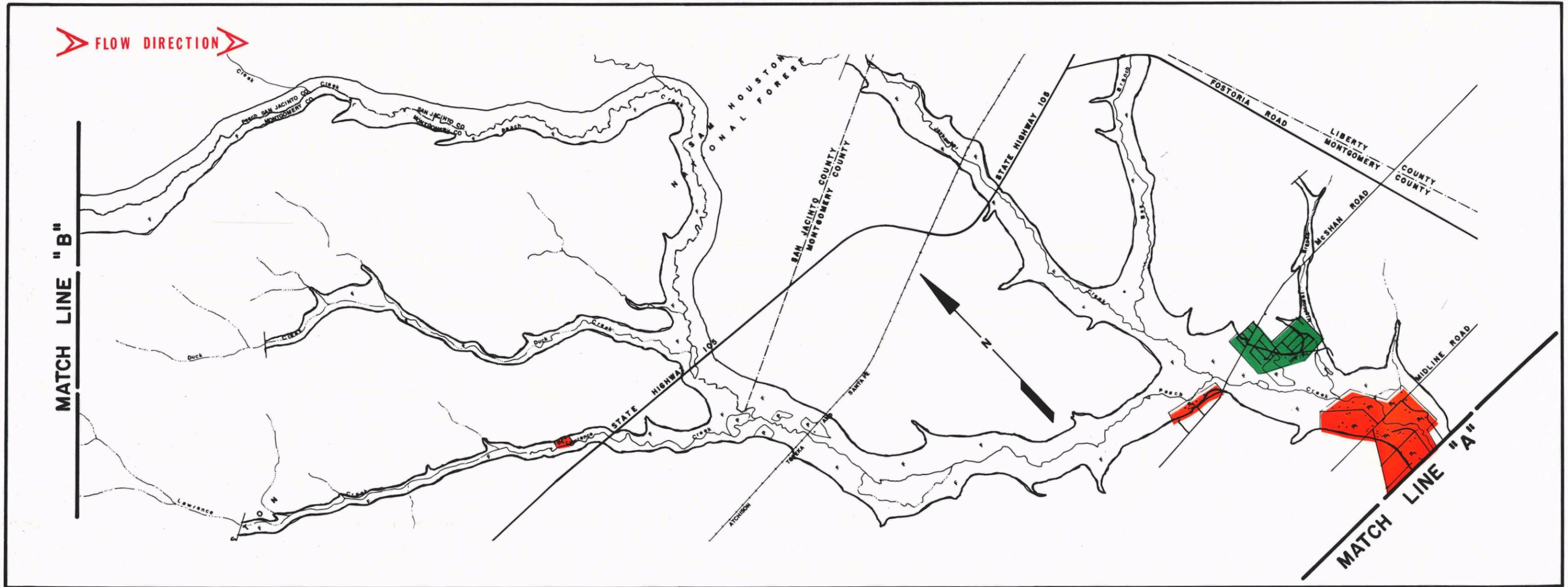
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



PEACH CREEK
STREAM SEGMENT 1
EXISTING 100yr. FLOOD PLAIN

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-1A



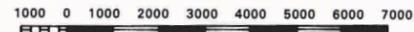
Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study. 1982.
3. Land Use. Aerial Photog. Interp. 1:2000 ft. 1976 - 1982

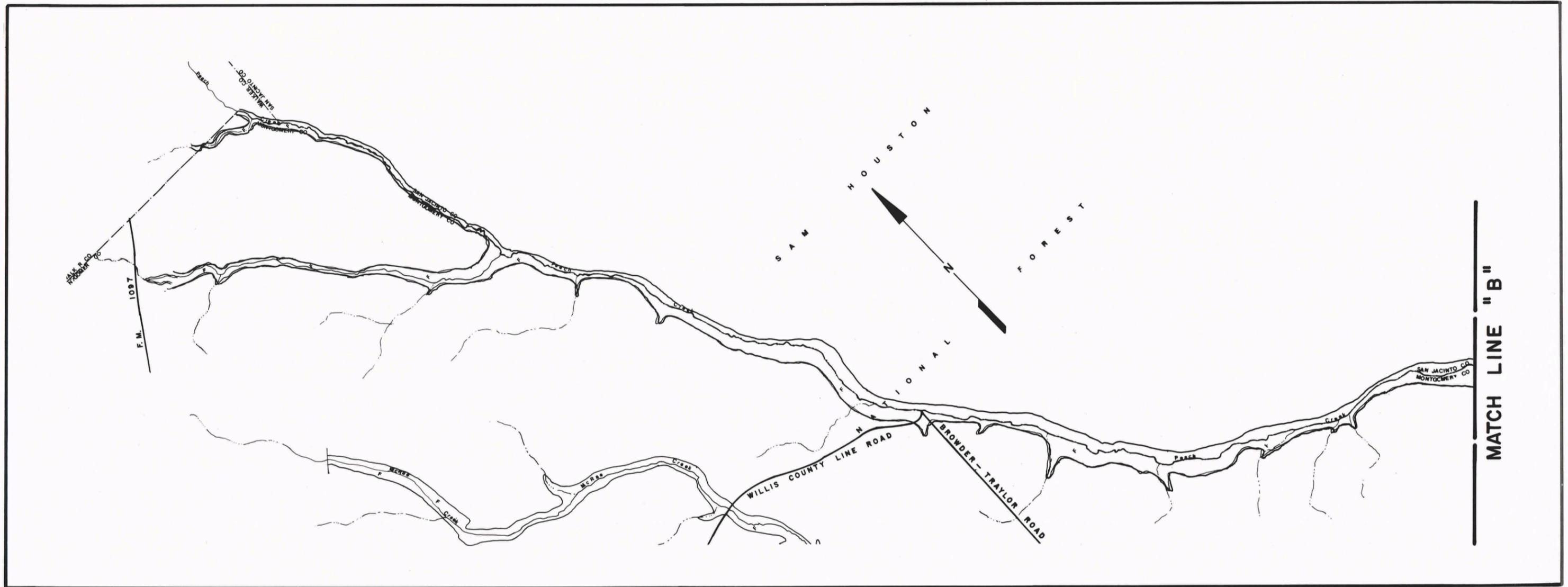


**PEACH CREEK
STREAM SEGMENT 2
EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-2A



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp _{R1} R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982.



**PEACH CREEK
STREAM SEGMENT 3
EXISTING 100yr. FLOOD PLAIN**

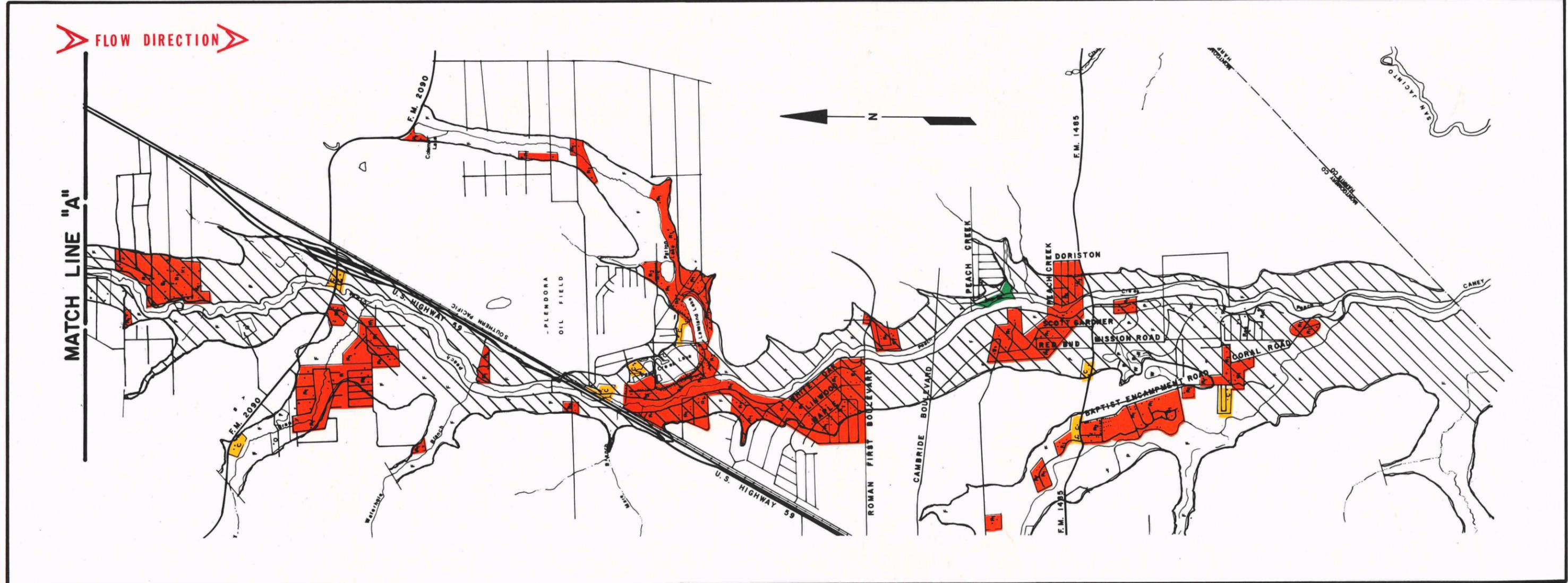
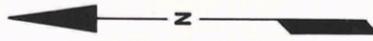


WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-3A



MATCH LINE "A"



Legend

- | | | | | | |
|--|--------------------|--|--|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forest | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1
R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

- Sources
1. Base Map - USGS 1:24000 - 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982.



**PEACH CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

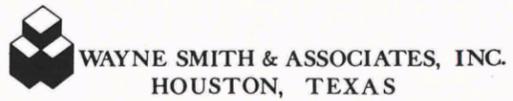
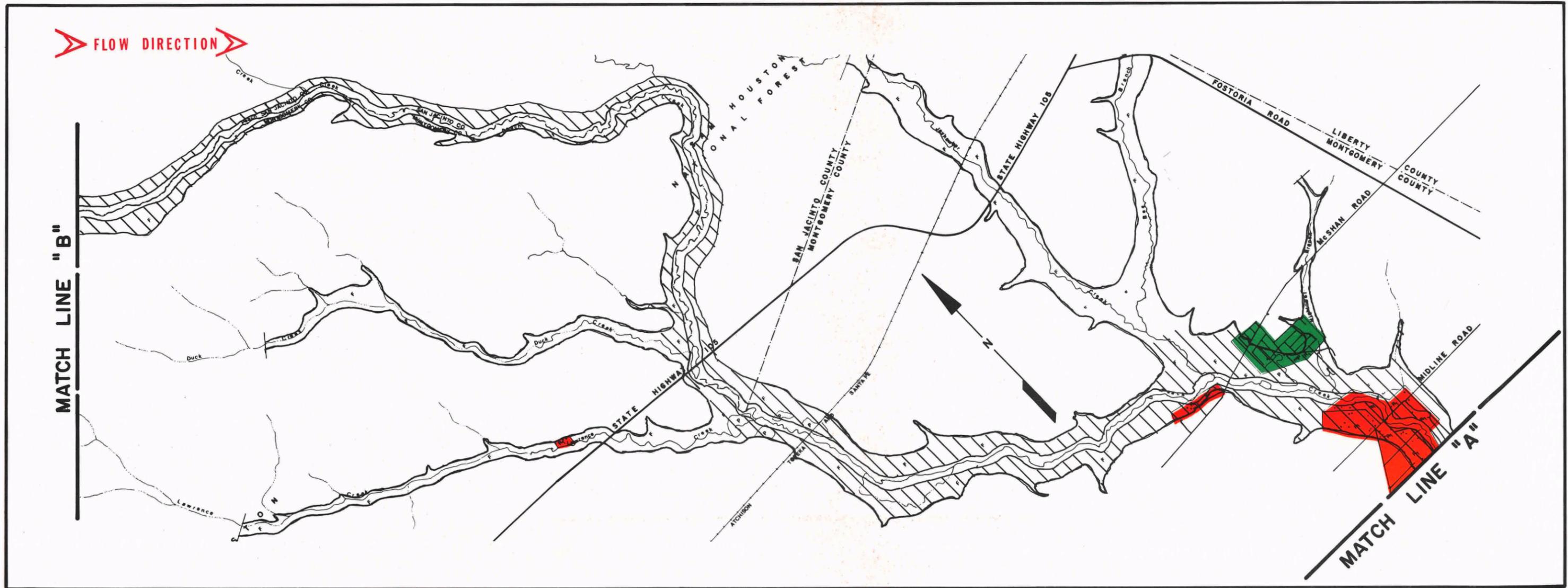


EXHIBIT PC-1B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

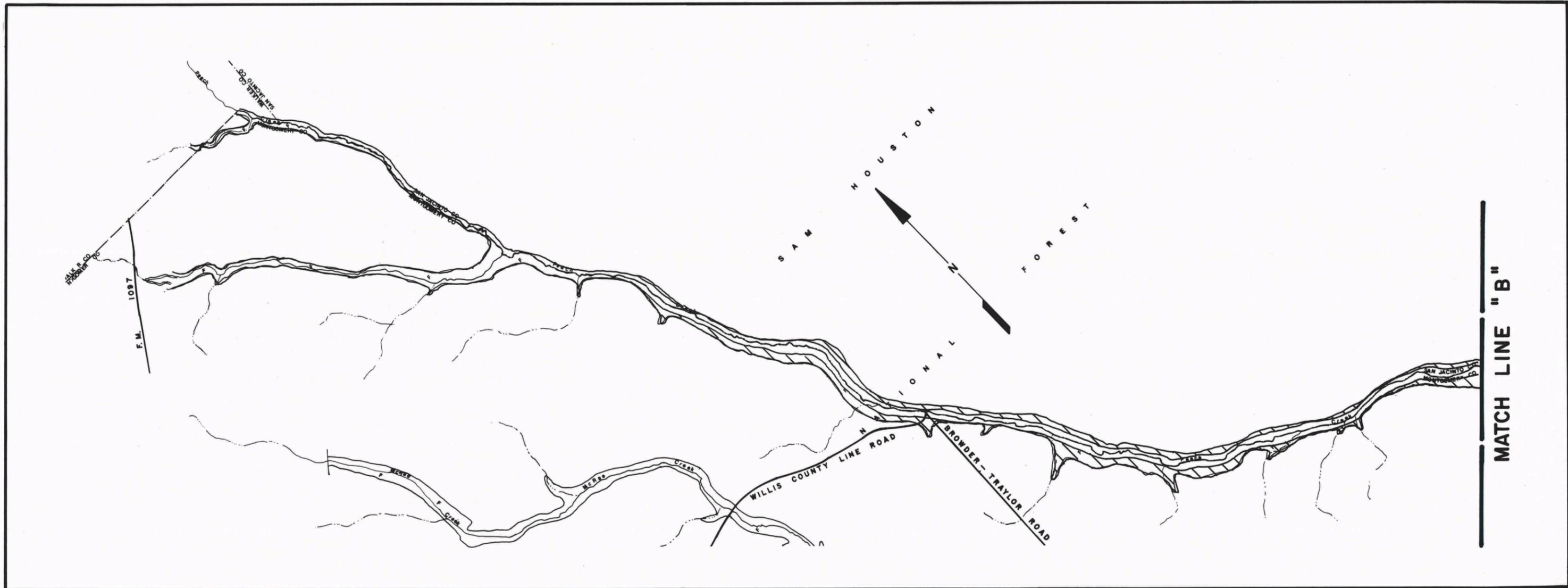


**PEACH CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-2B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
					Flood Plain Reclamation

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982

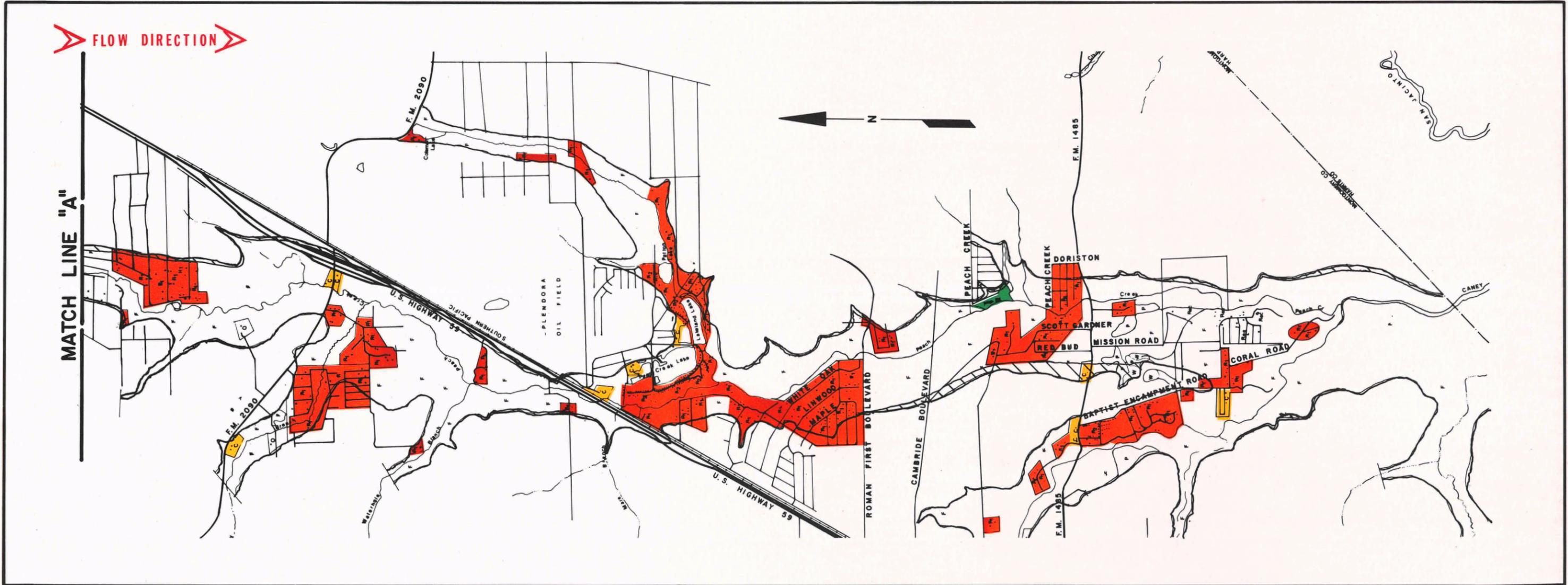


**PEACH CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-3B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
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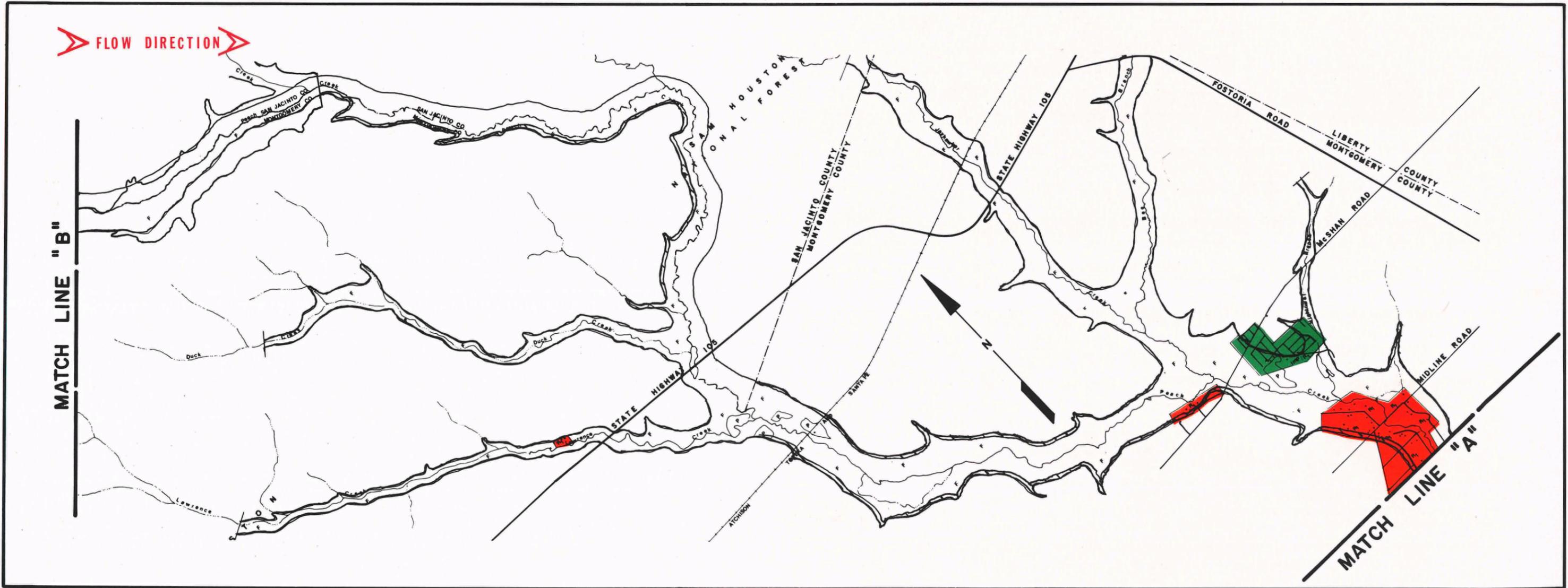


PEACH CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 1



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-1G-1



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

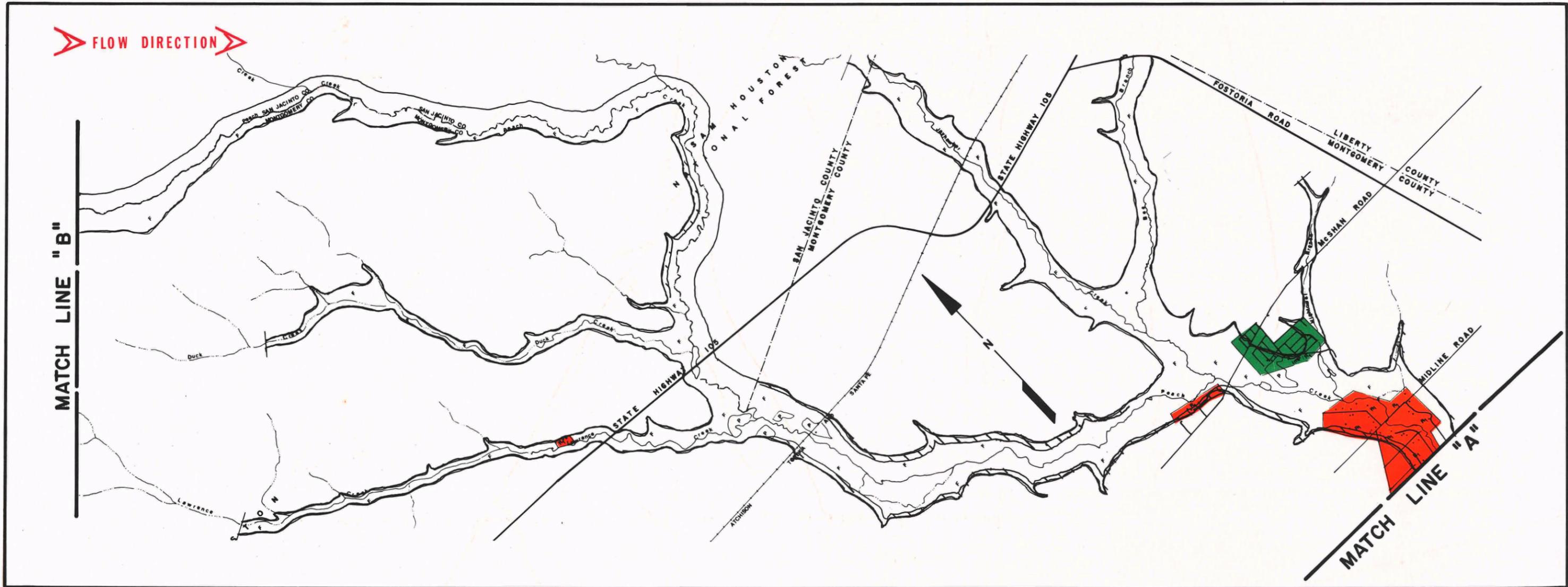
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982

1000 0 1000 2000 3000 4000 5000 6000 7000

**PEACH CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 1**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

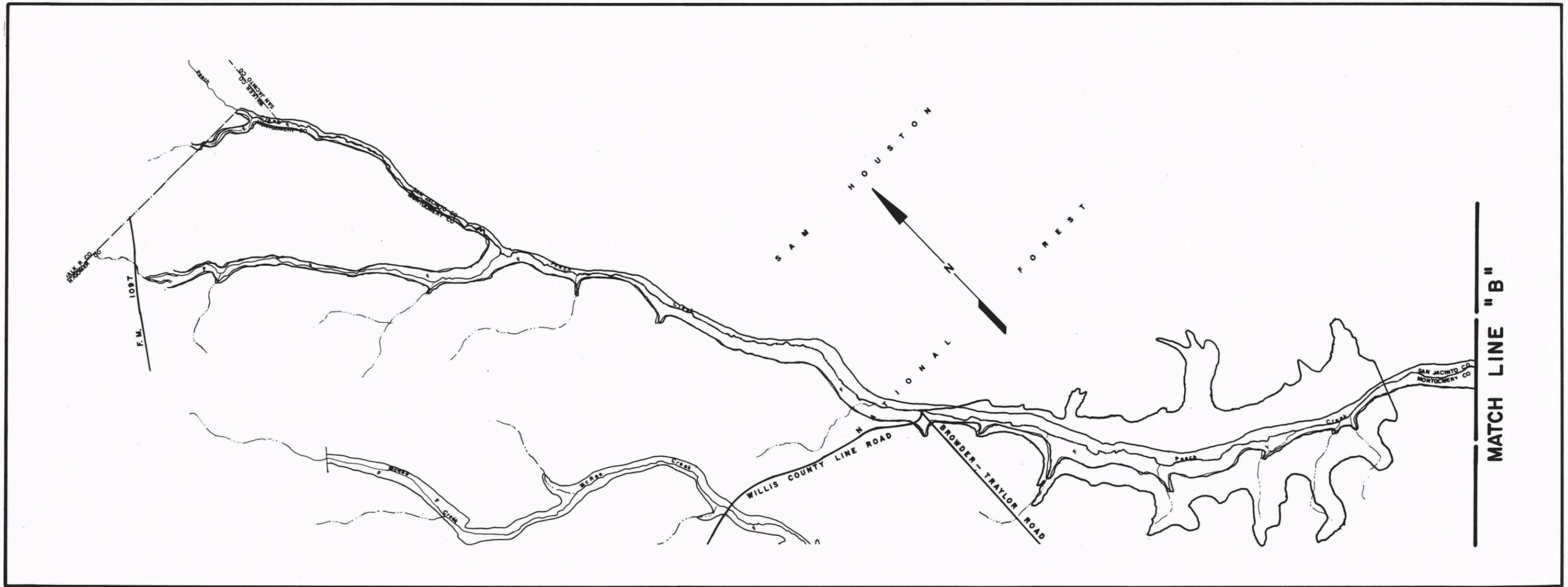
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**PEACH CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

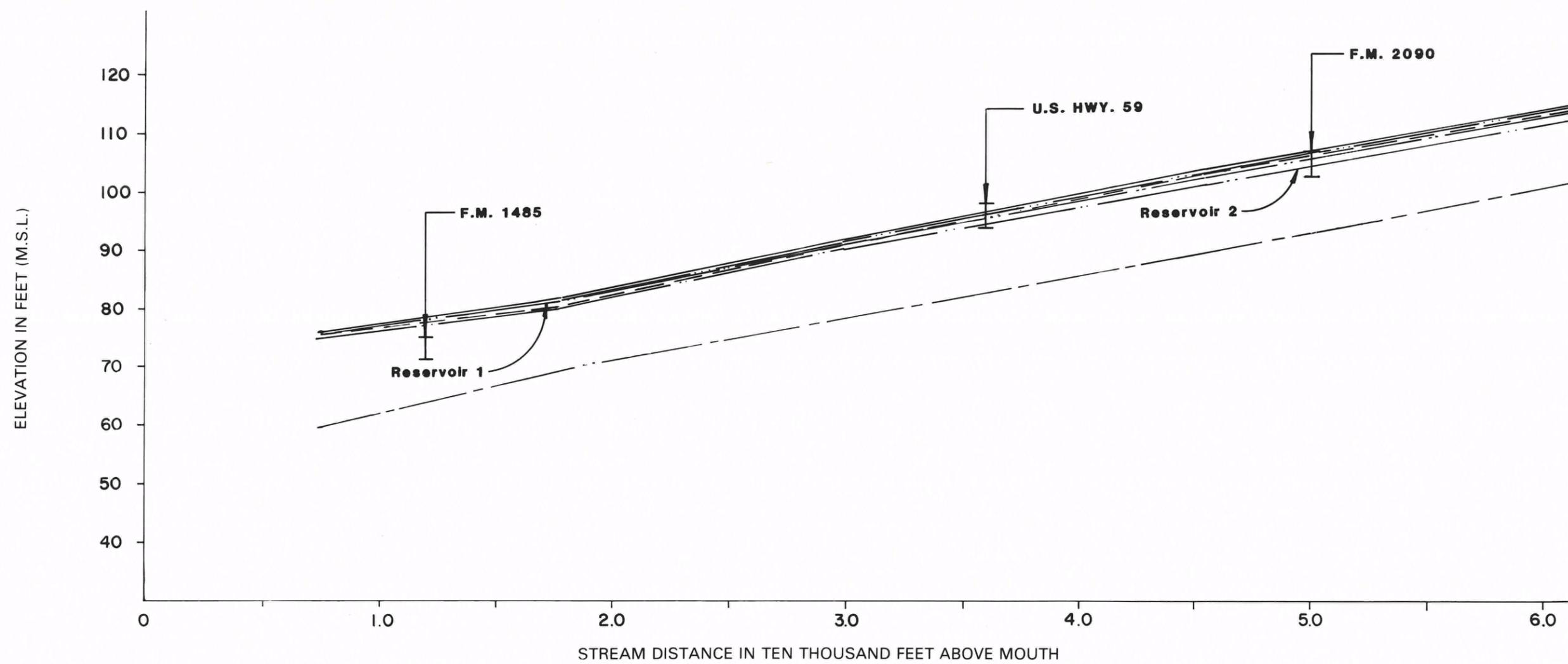
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources
 1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**PEACH CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR 2**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS



LEGEND

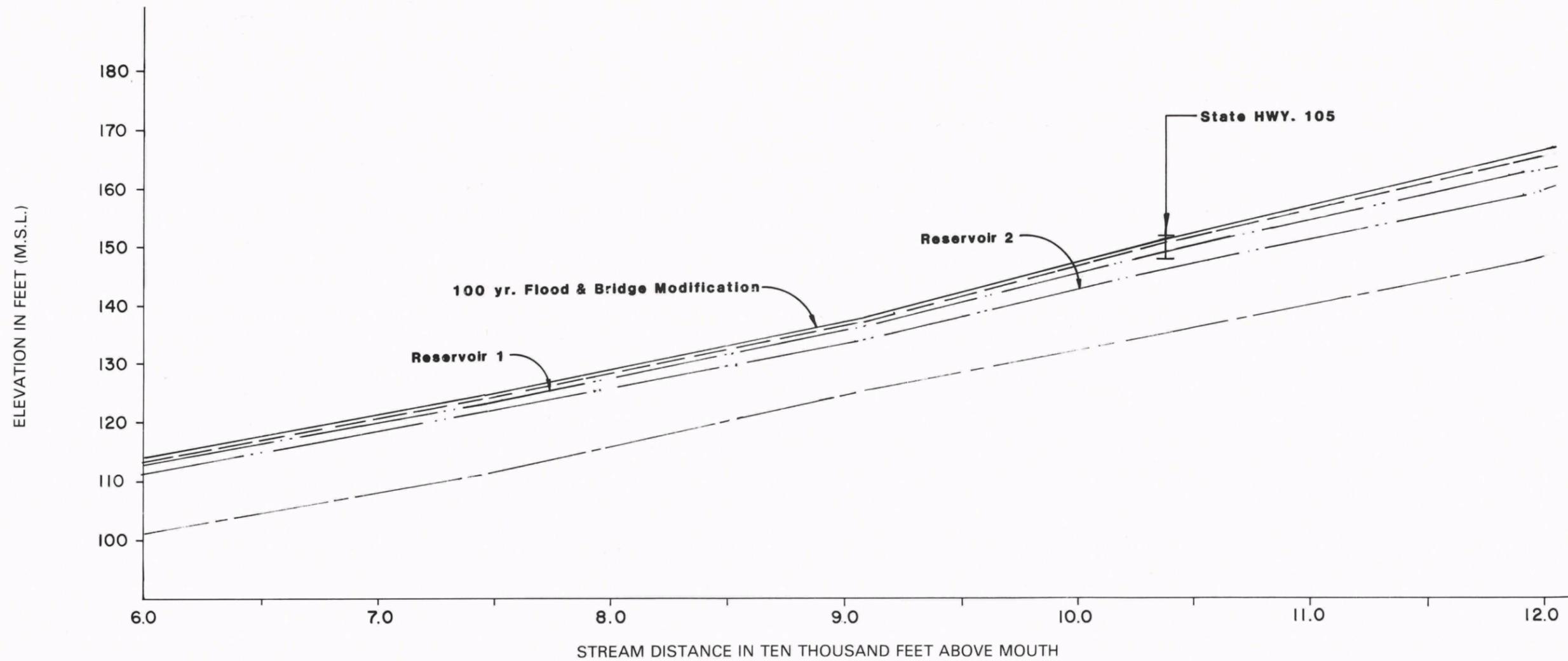
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- . - . - DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**PEACH CREEK
STREAM SEGMENT 1
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT PC-1H



LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- - - - - DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

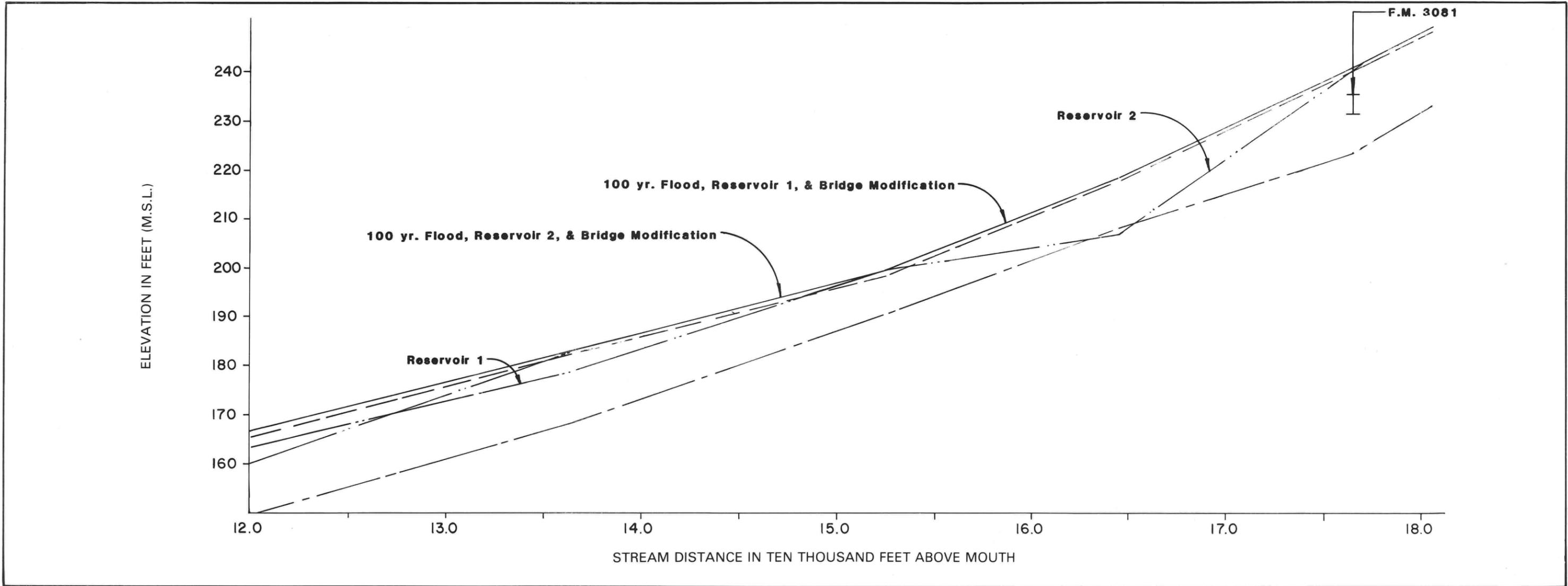
**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**PEACH CREEK
STREAM SEGMENT 2
PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-2H



LEGEND

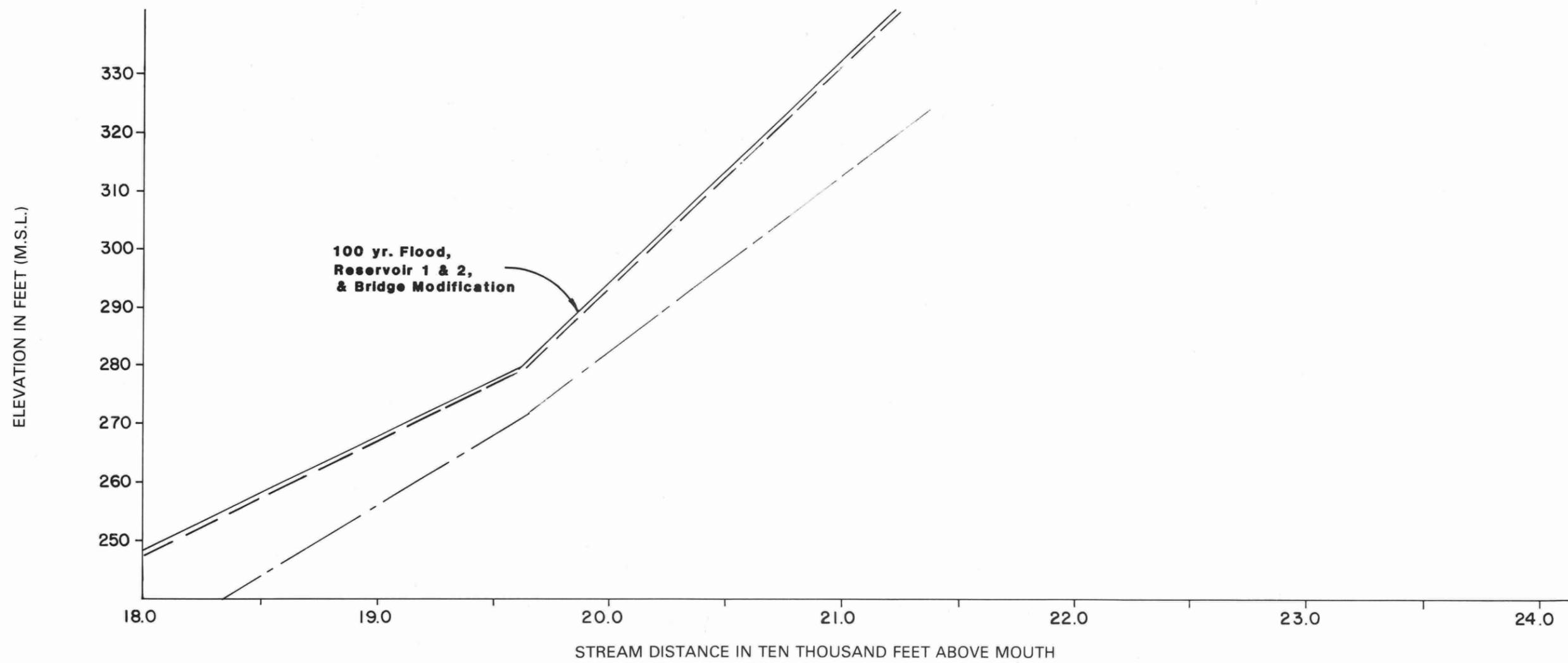
- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- · · · · DESNAGGING
- · — · — RESERVOIR
- · · — · BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**PEACH CREEK
STREAM SEGMENT 3
PROFILE**

 WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT PC-3H



LEGEND

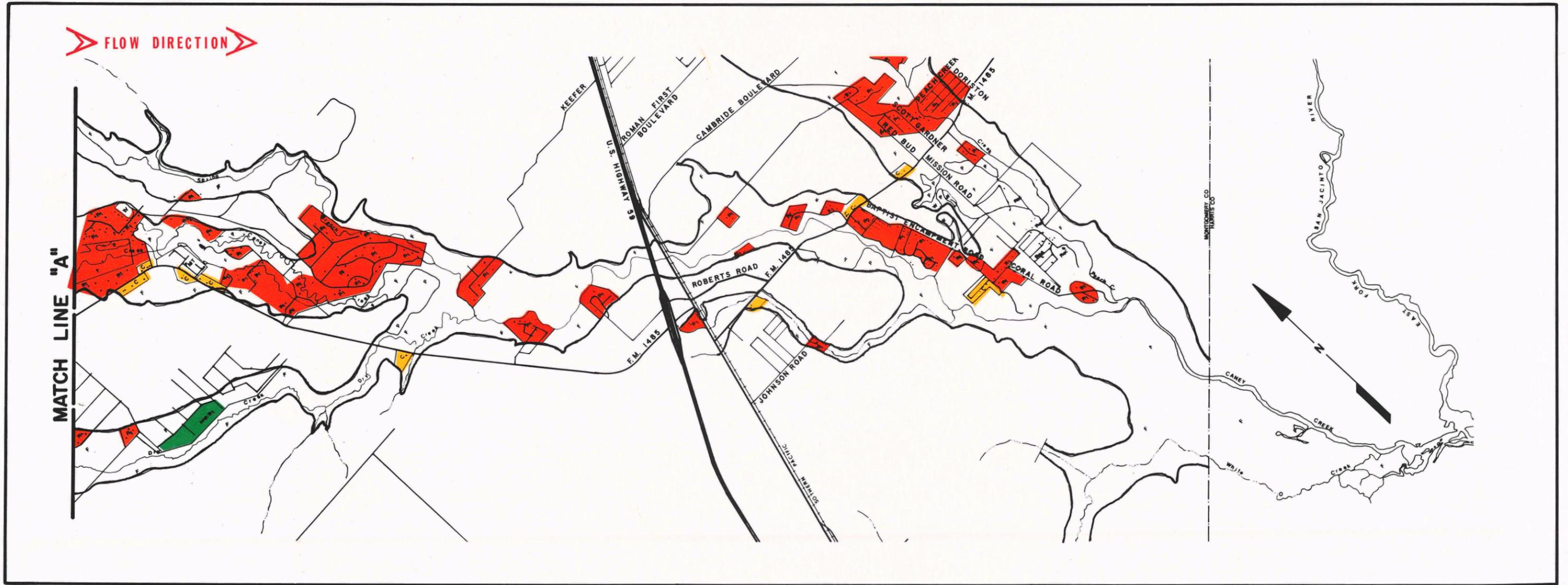
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- DESNAGGING
- · · — RESERVOIR
- · · — BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**PEACH CREEK
STREAM SEGMENT 4
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT FC-4H



Legend

- | | | | | | |
|--|--------------------|--|---|--|-------------------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential - R1 | | Forest | | Sewage Disposal |
| | Residential - R2 | | Pasture | | River Bottom |
| | Residential - M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1/R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | | | Flood Plain Reclamation |

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

Sources

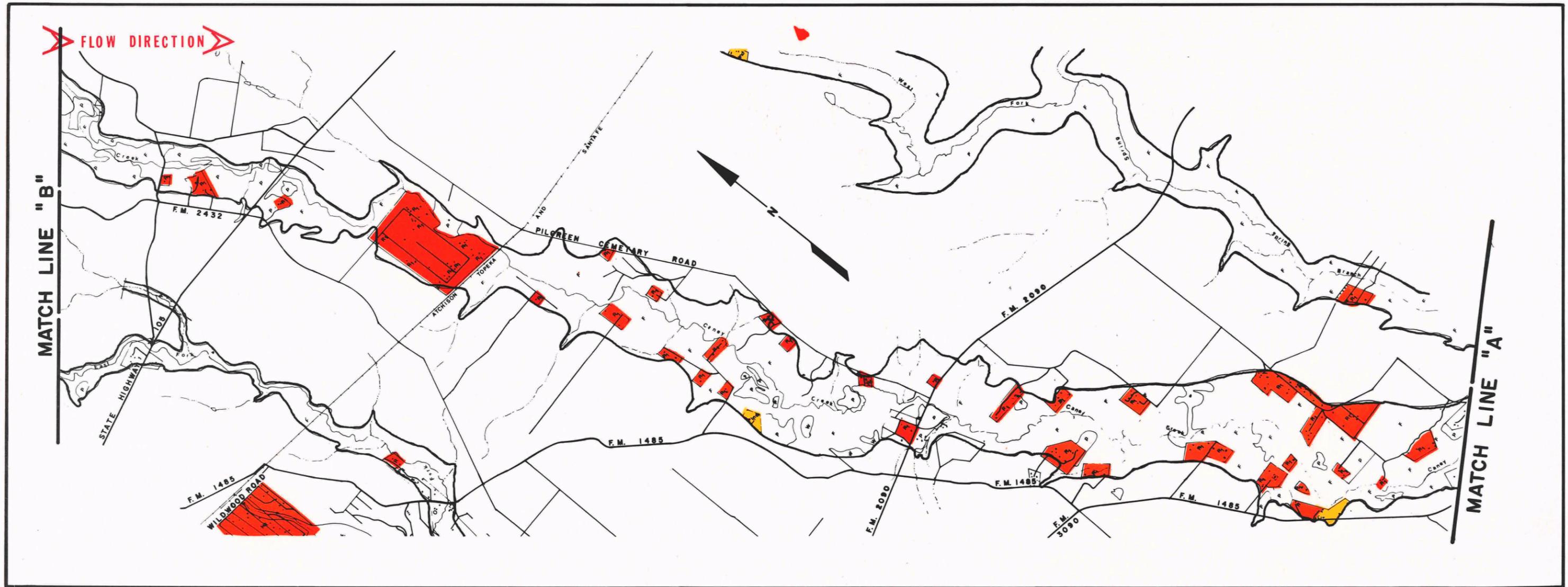
1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982



**CANEY CREEK
STREAM SEGMENT 1
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-1A



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1		Gas Well
	School		Improved Land For Development Imp/R2		Recreational
			Wetland		Flood Plain Reclamation

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

1. Base Map - USGS 1:24000 - 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 - 1982

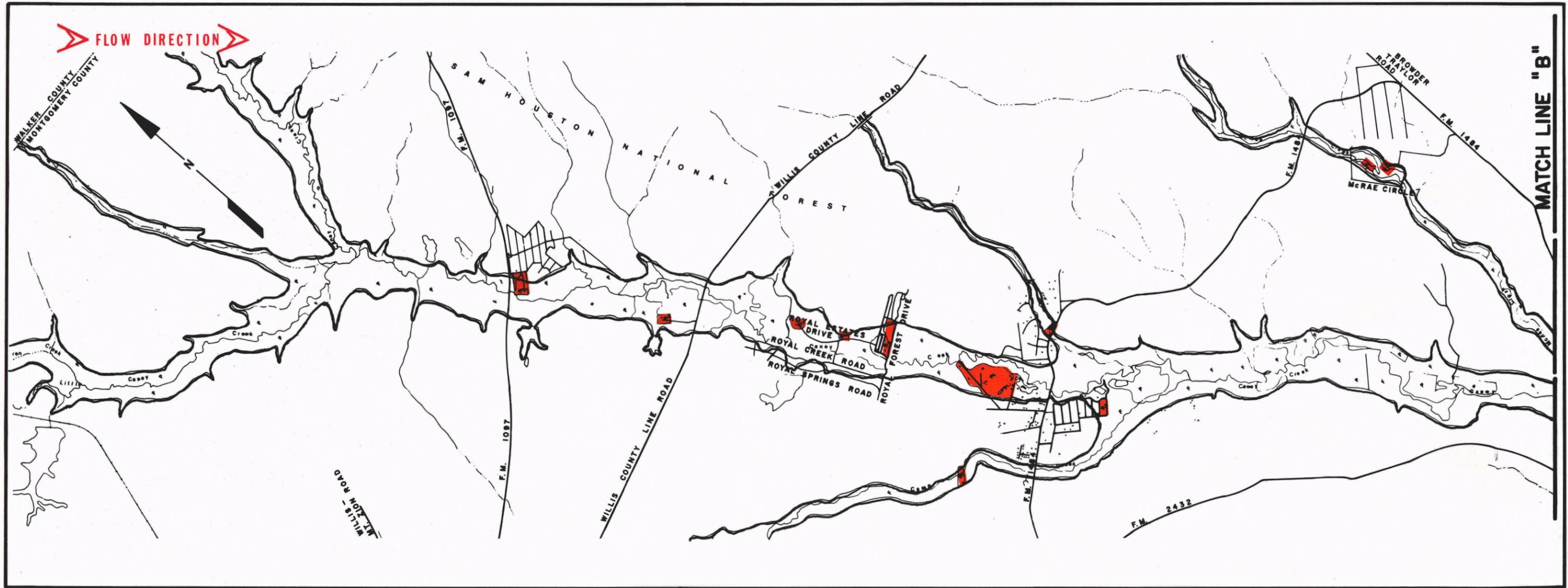


**CANEY CREEK
STREAM SEGMENT 2
EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-2A



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R ₁ /R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

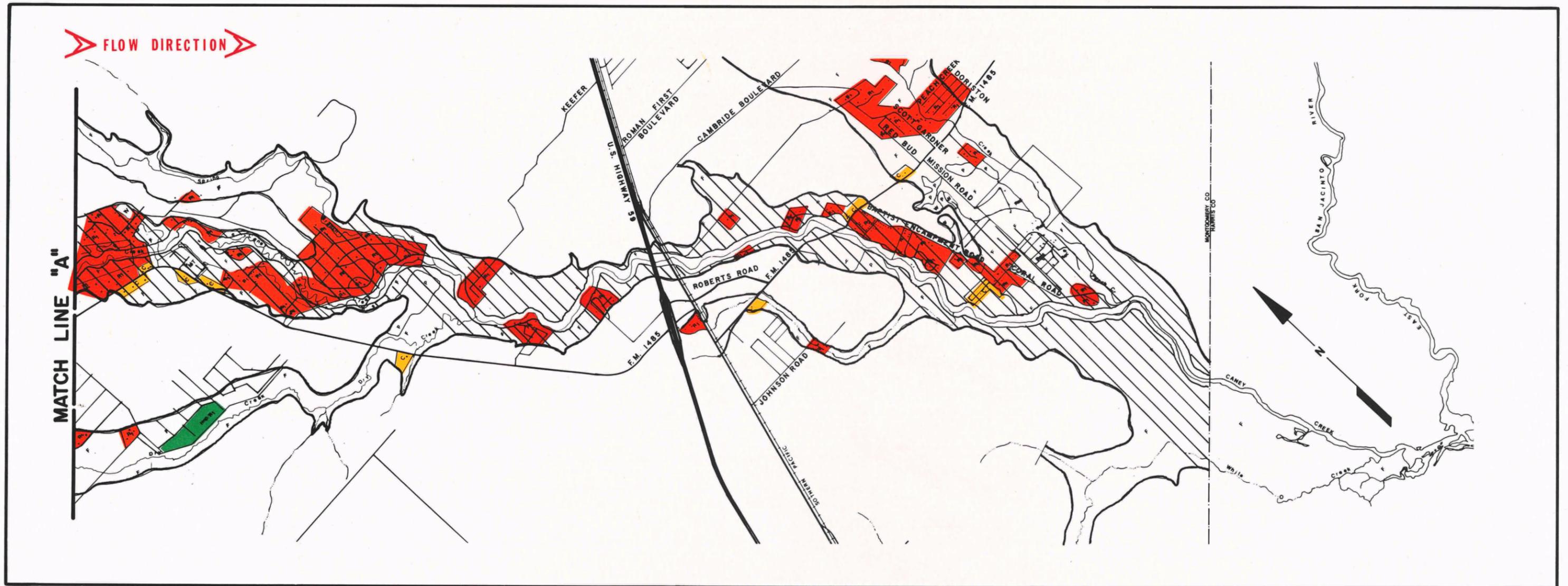
Sources
 1. Base Map - USGS 1:24000 - 1959 - 1979.
 2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 - 1982



**CANEY CREEK
STREAM SEGMENT 3
EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-3A



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

Sources

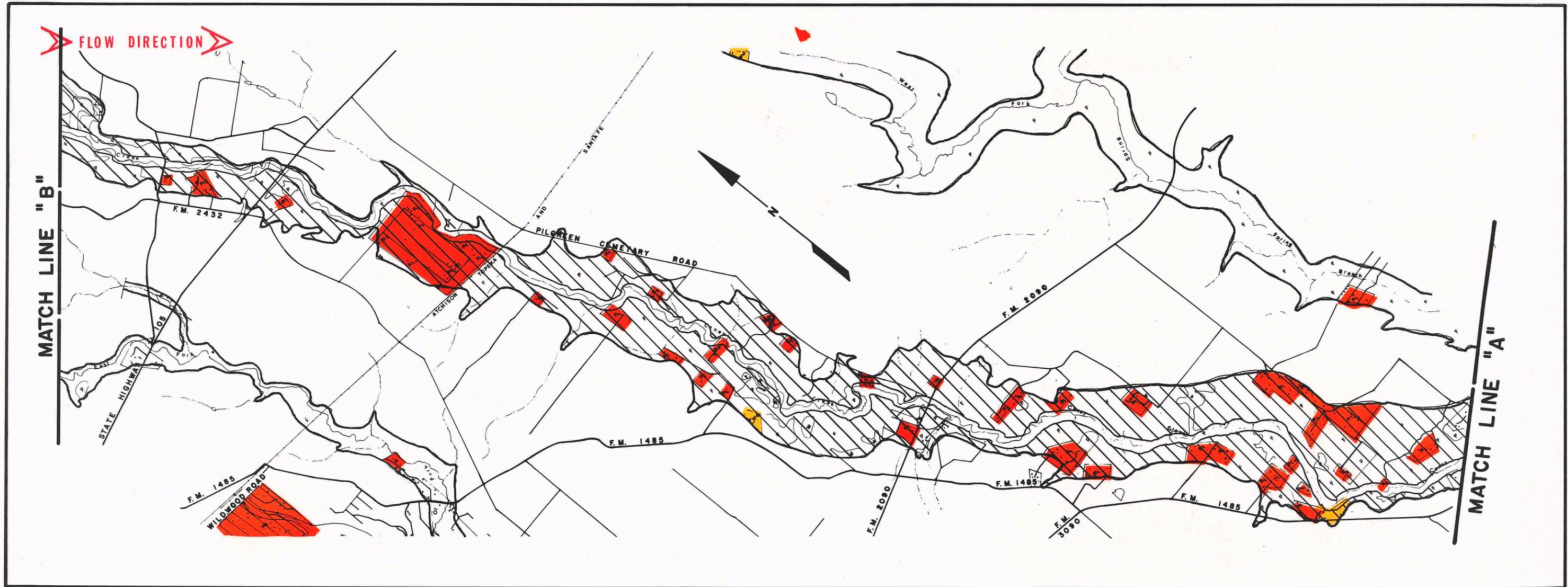
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



CANEY CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-1B



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

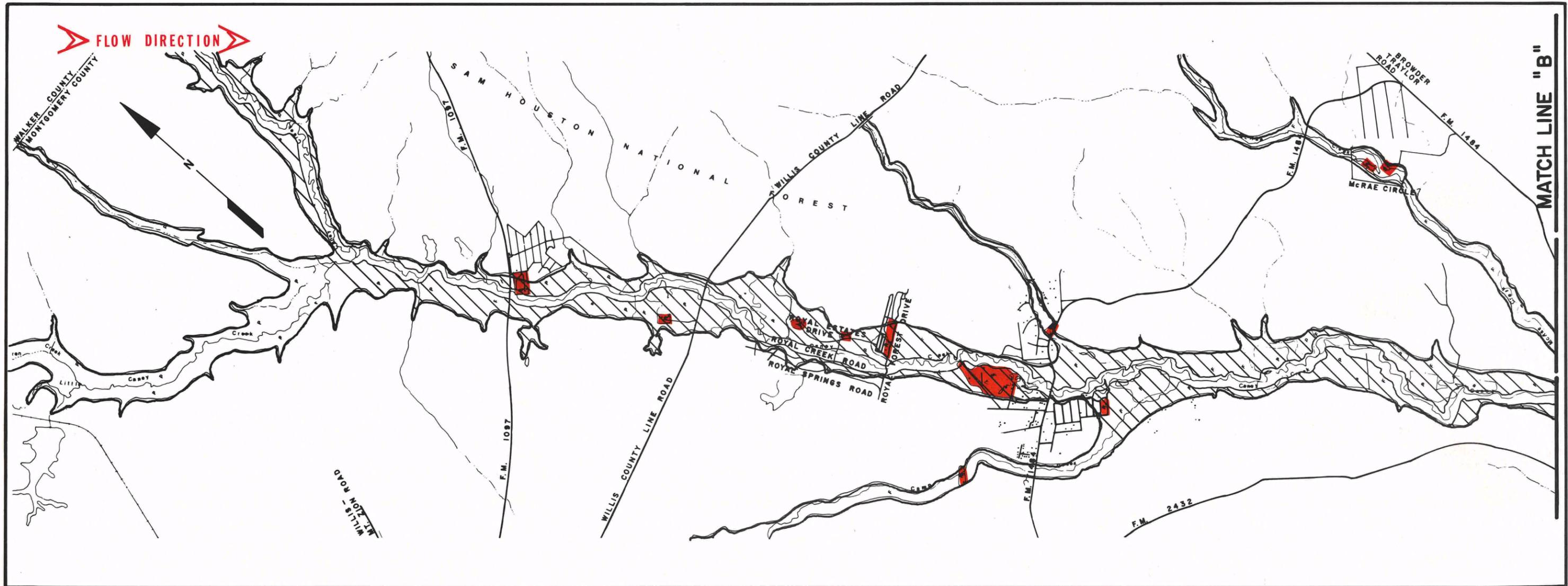
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**CANEY CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-2B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp _{R1} R ₂		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

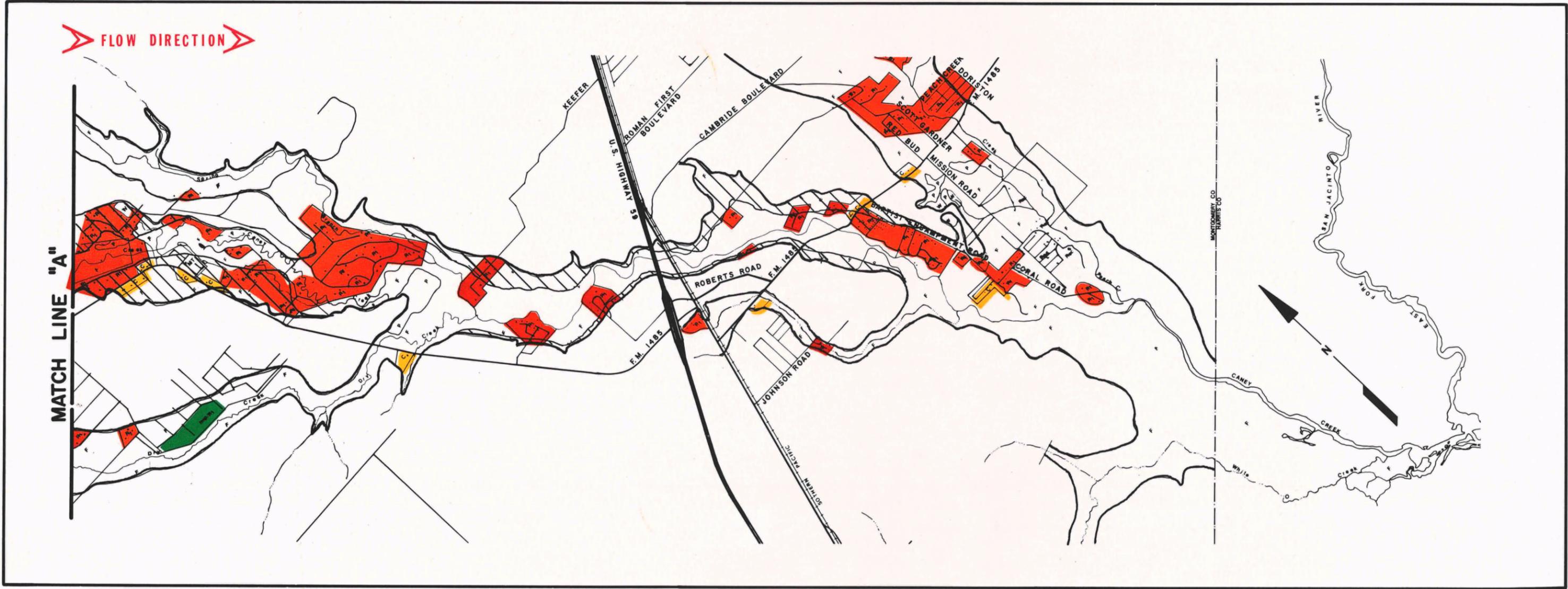
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**CANEY CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
TOTAL CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-3B



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1/R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY

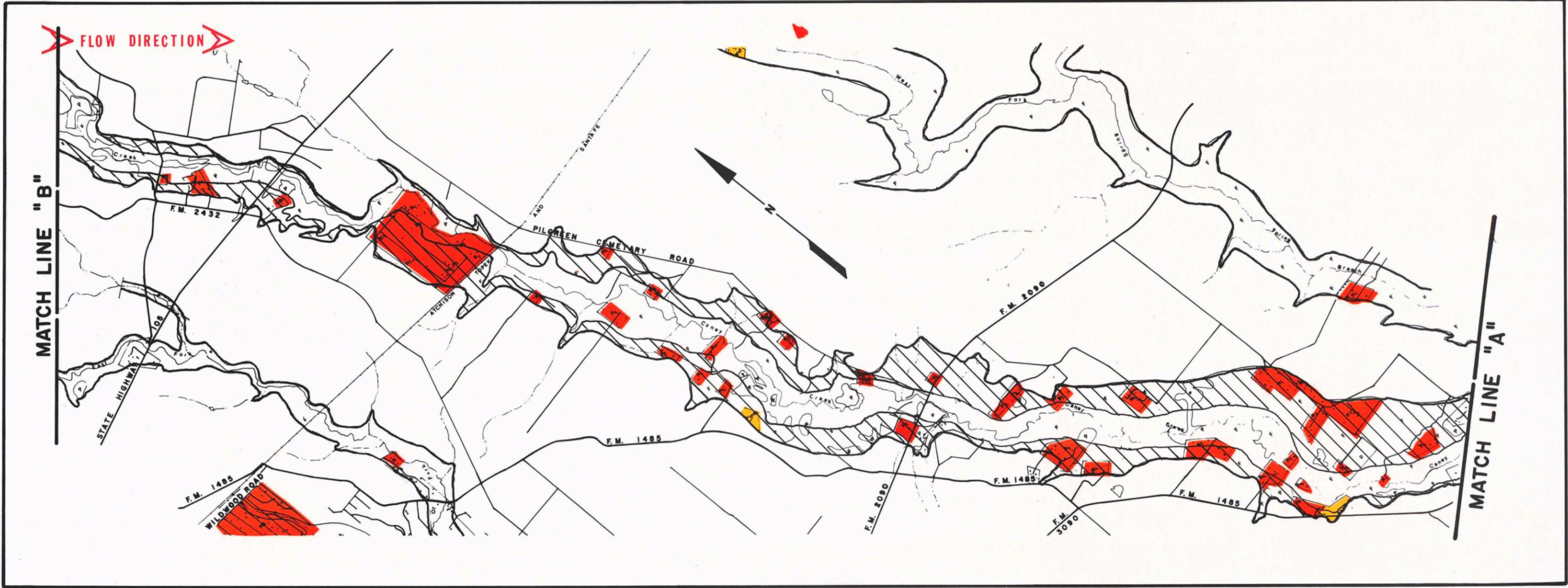
Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



CANEY CREEK
STREAM SEGMENT 1
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS



Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential — R1 | | Forest | | Sewage Disposal |
| | Residential — R2 | | Pasture | | River Bottom |
| | Residential — M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp/R1/R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

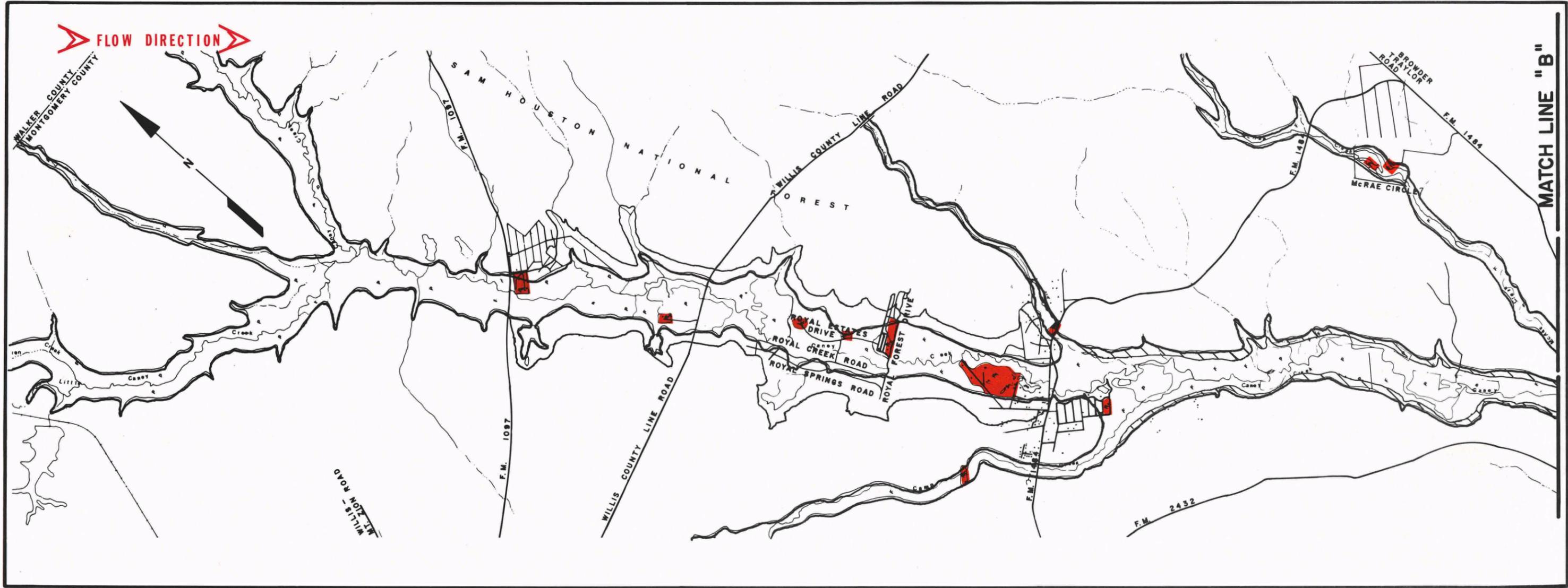
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**CANEY CREEK
STREAM SEGMENT 2
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-2G



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forest		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp/R1, R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

Sources

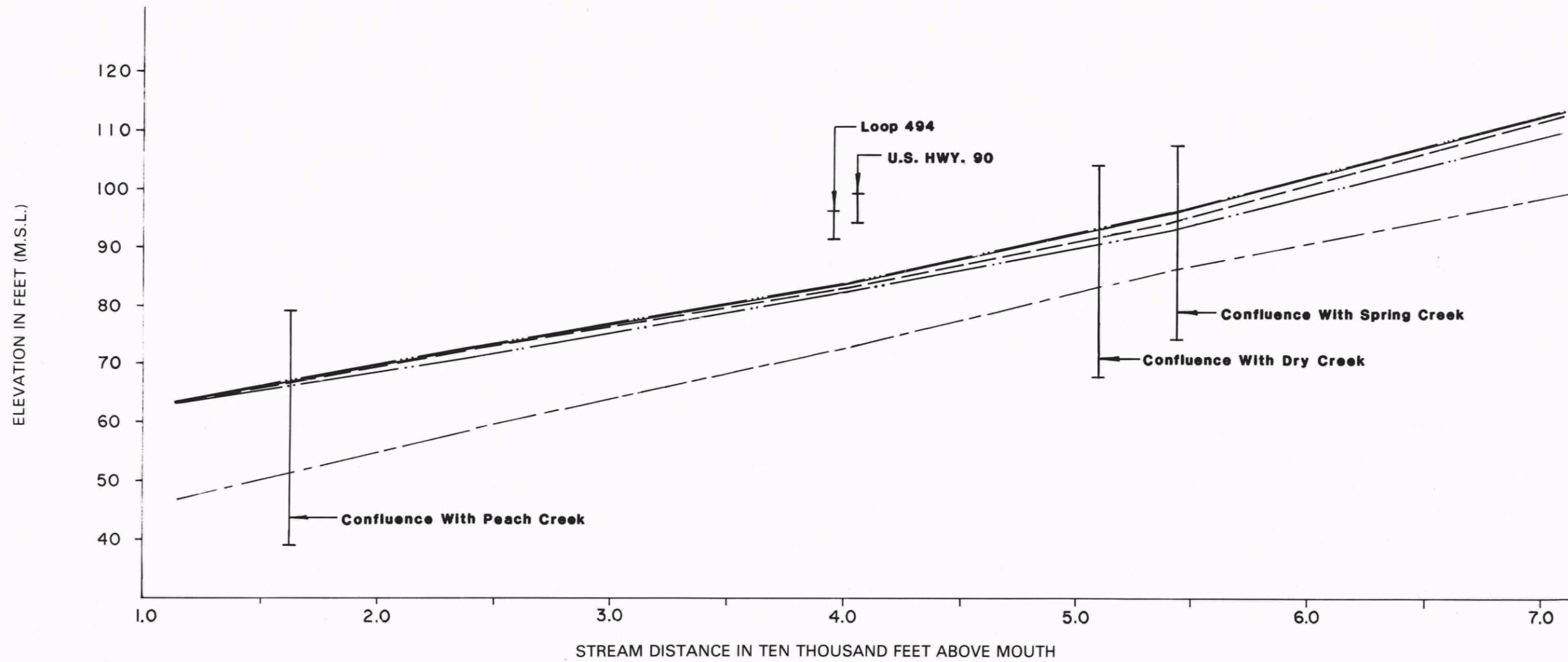
1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**CANEY CREEK
STREAM SEGMENT 3
FLOOD PLAIN RECLAMATION PRODUCED BY
RESERVOIR**

WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-3G



LEGEND

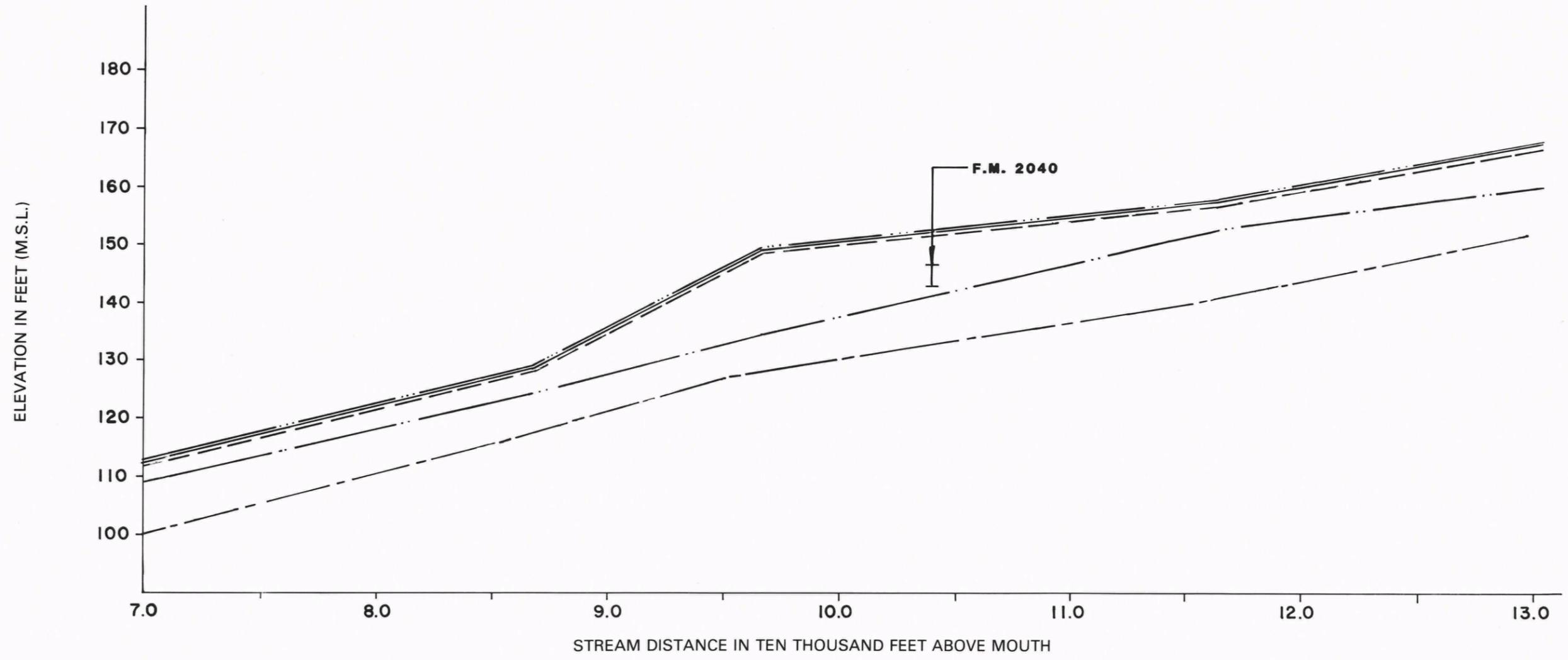
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- - - - - SELECTIVE CHANNELIZATION
- . - . - DESNAGGING
- RESERVOIR
- BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**CANEY CREEK
STREAM SEGMENT 1
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT CC-1H



LEGEND

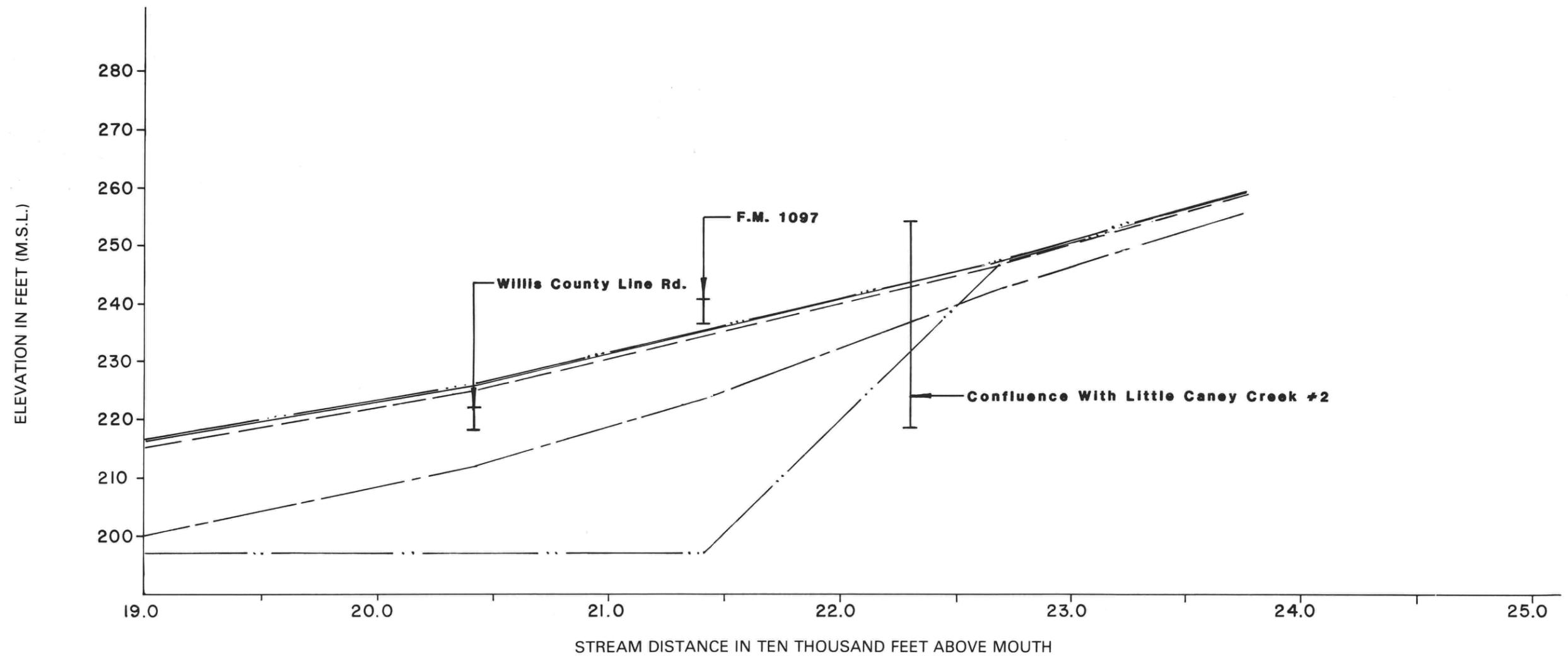
- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- SELECTIVE CHANNELIZATION
- DESNAGGING
- · · — RESERVOIR
- · · — BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**CANEY CREEK
STREAM SEGMENT 2
PROFILE**

 **WAYNE SMITH & ASSOCIATES, INC.**
HOUSTON, TEXAS

EXHIBIT CC-2H



LEGEND

- 100 YR. FLOOD
- - - - - TOTAL CHANNELIZATION
- · - · - SELECTIVE CHANNELIZATION
- · · · · DESNAGGING
- - - - - RESERVOIR
- · · · - BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
IMPROVEMENT AND FLOOD CONTROL
PLANNING STUDY**

**CANEY CREEK
STREAM SEGMENT 4
PROFILE**

 WAYNE SMITH & ASSOCIATES, INC.
HOUSTON, TEXAS

EXHIBIT CC-4H



NOTE:
100 YR. FLOOD PLAIN BOUNDARY
SHOWN ON THIS MAP SHOULD BE
CONSIDERED APPROXIMATE AND
DOES NOT REFLECT FLOOD PLAIN
BEING DETERMINED BY FEDERAL
EMERGENCY MANAGEMENT AGENCY.



Legend

	Flood Plain		Industry		Oil Well
	Residential - R1		Forcst		Sewage Disposal
	Residential - R2		Pasture		River Bottom
	Residential - M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
3. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 1
 EXISTING 100yr. FLOOD PLAIN**

WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-1A

▶ FLOW DIRECTION ▶



NOTE:
 100 YR. FLOOD PLAIN BOUNDARY
 SHOWN ON THIS MAP SHOULD BE
 CONSIDERED APPROXIMATE AND
 DOES NOT REFLECT FLOOD PLAIN
 BEING DETERMINED BY FEDERAL
 EMERGENCY MANAGEMENT AGENCY.

Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forest		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 2
 EXISTING 100yr. FLOOD PLAIN**



WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-2A



NOTE:
100 YR. FLOOD PLAIN BOUNDARY
SHOWN ON THIS MAP SHOULD BE
CONSIDERED APPROXIMATE AND
DOES NOT REFLECT FLOOD PLAIN
BEING DETERMINED BY FEDERAL
EMERGENCY MANAGEMENT AGENCY.



Legend

	Flood Plain		Industry		Oil Well
	Residential — R1		Forcst		Sewage Disposal
	Residential — R2		Pasture		River Bottom
	Residential — M.F.		Cropland		Microwave Tower
	Commercial		Improved Land For Development Imp R1 R2		Gas Well
	School		Wetland		Recreational
			Flood Plain Reclamation		

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information
 Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp.
 1:2000 ft. 1976 — 1982



**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 1
 FLOOD PLAIN RECLAMATION PRODUCED BY
 TOTAL CHANNELIZATION**

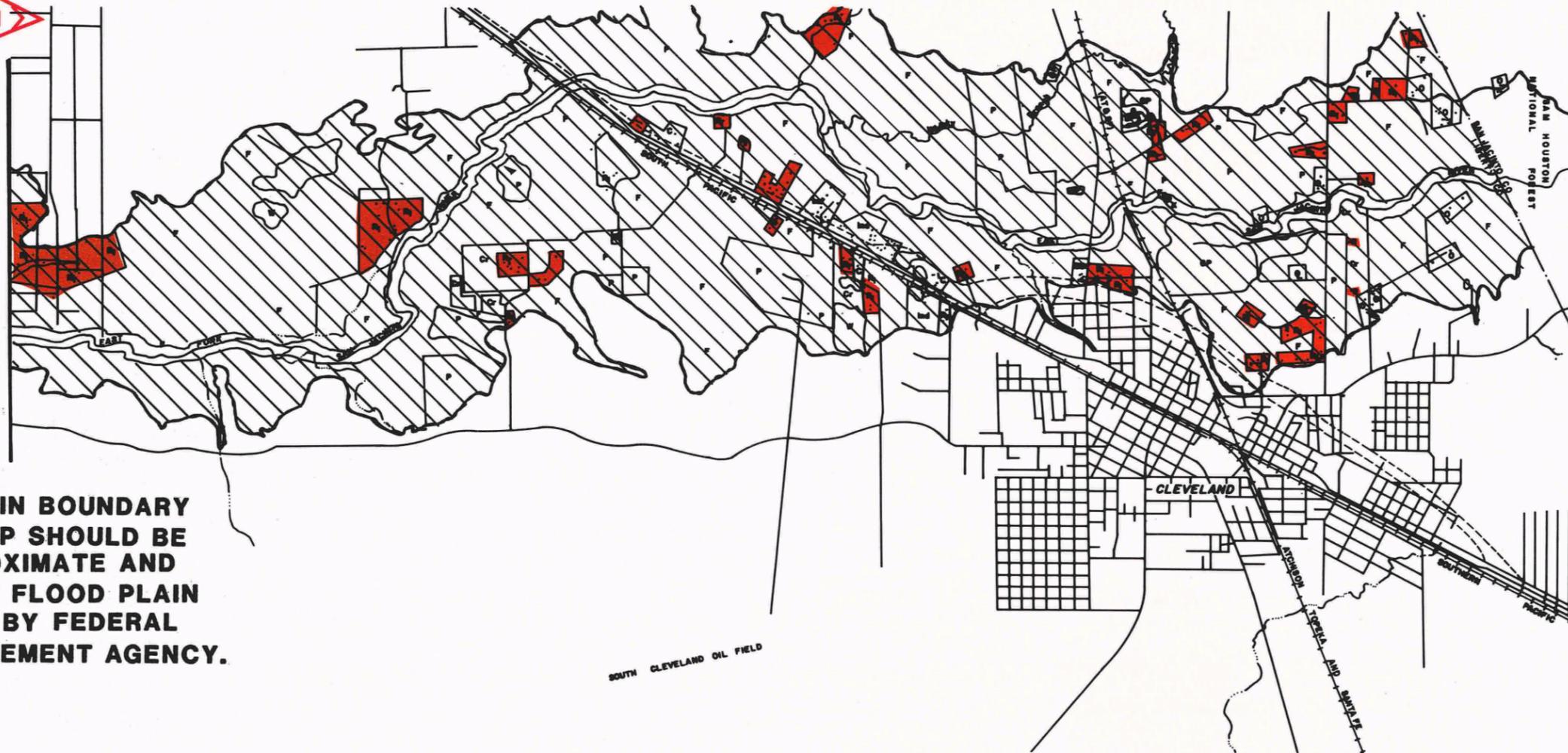


WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-1B

▶ FLOW DIRECTION ▶

MATCH LINE "A"



NOTE:
 100 YR. FLOOD PLAIN BOUNDARY
 SHOWN ON THIS MAP SHOULD BE
 CONSIDERED APPROXIMATE AND
 DOES NOT REFLECT FLOOD PLAIN
 BEING DETERMINED BY FEDERAL
 EMERGENCY MANAGEMENT AGENCY.

Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential — R1 | | Forest | | Sewage Disposal |
| | Residential — R2 | | Pasture | | River Bottom |
| | Residential — M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development Imp R1 R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

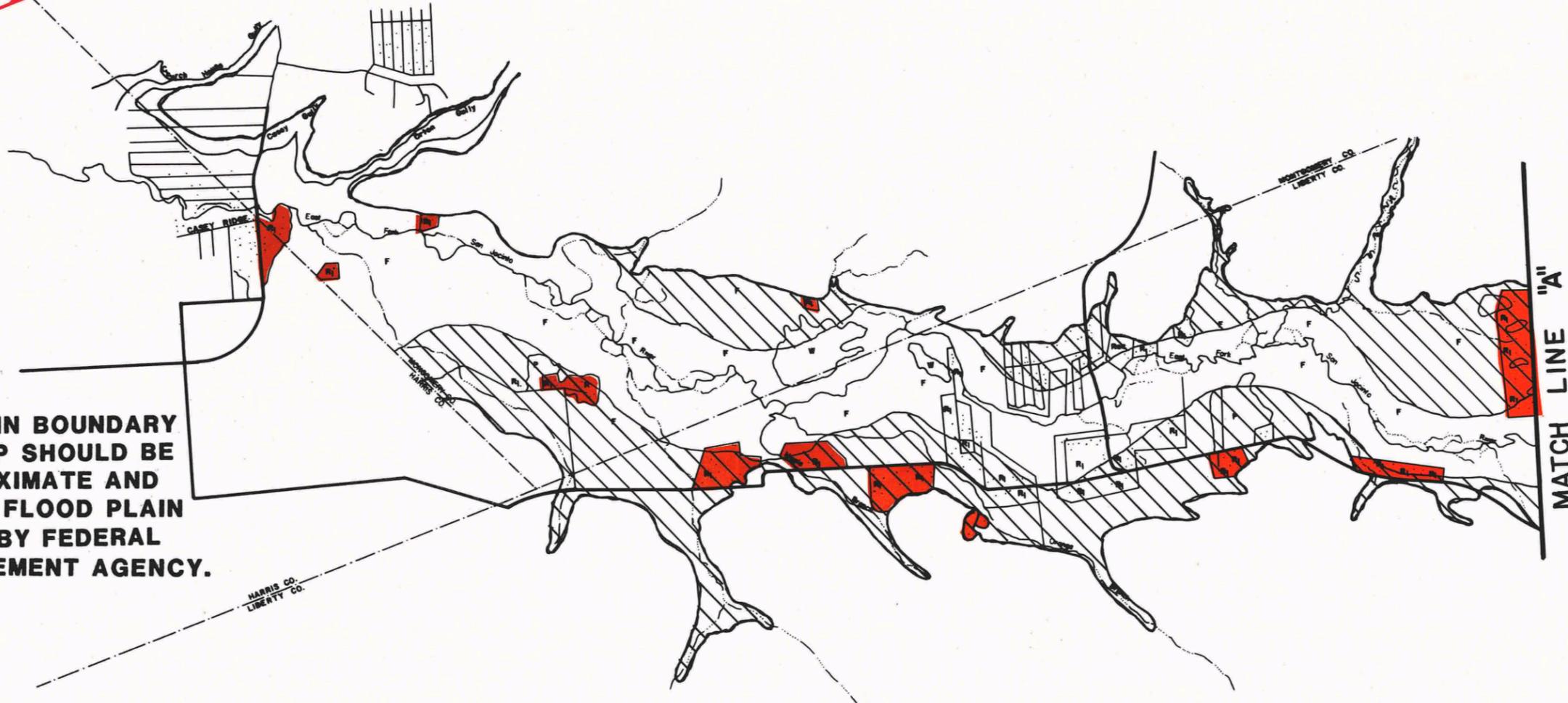
- Sources
1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 3. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 2
 FLOOD PLAIN RECLAMATION PRODUCED BY
 CHANNELIZATION**

WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

▶ FLOW DIRECTION ▶



NOTE:
 100 YR. FLOOD PLAIN BOUNDARY
 SHOWN ON THIS MAP SHOULD BE
 CONSIDERED APPROXIMATE AND
 DOES NOT REFLECT FLOOD PLAIN
 BEING DETERMINED BY FEDERAL
 EMERGENCY MANAGEMENT AGENCY.

Legend

- | | | | | | |
|--|--------------------|--|---|--|-----------------|
| | Flood Plain | | Industry | | Oil Well |
| | Residential — R1 | | Forcst | | Sewage Disposal |
| | Residential — R2 | | Pasture | | River Bottom |
| | Residential — M.F. | | Cropland | | Microwave Tower |
| | Commercial | | Improved Land For Development imp R1 R2 | | Gas Well |
| | School | | Wetland | | Recreational |
| | | | Flood Plain Reclamation | | |

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

Sources

1. Base Map — USGS 1:24000 — 1959 - 1979.
2. Existing Flood Plain Information Flood Ins. Study, 1982.
2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982

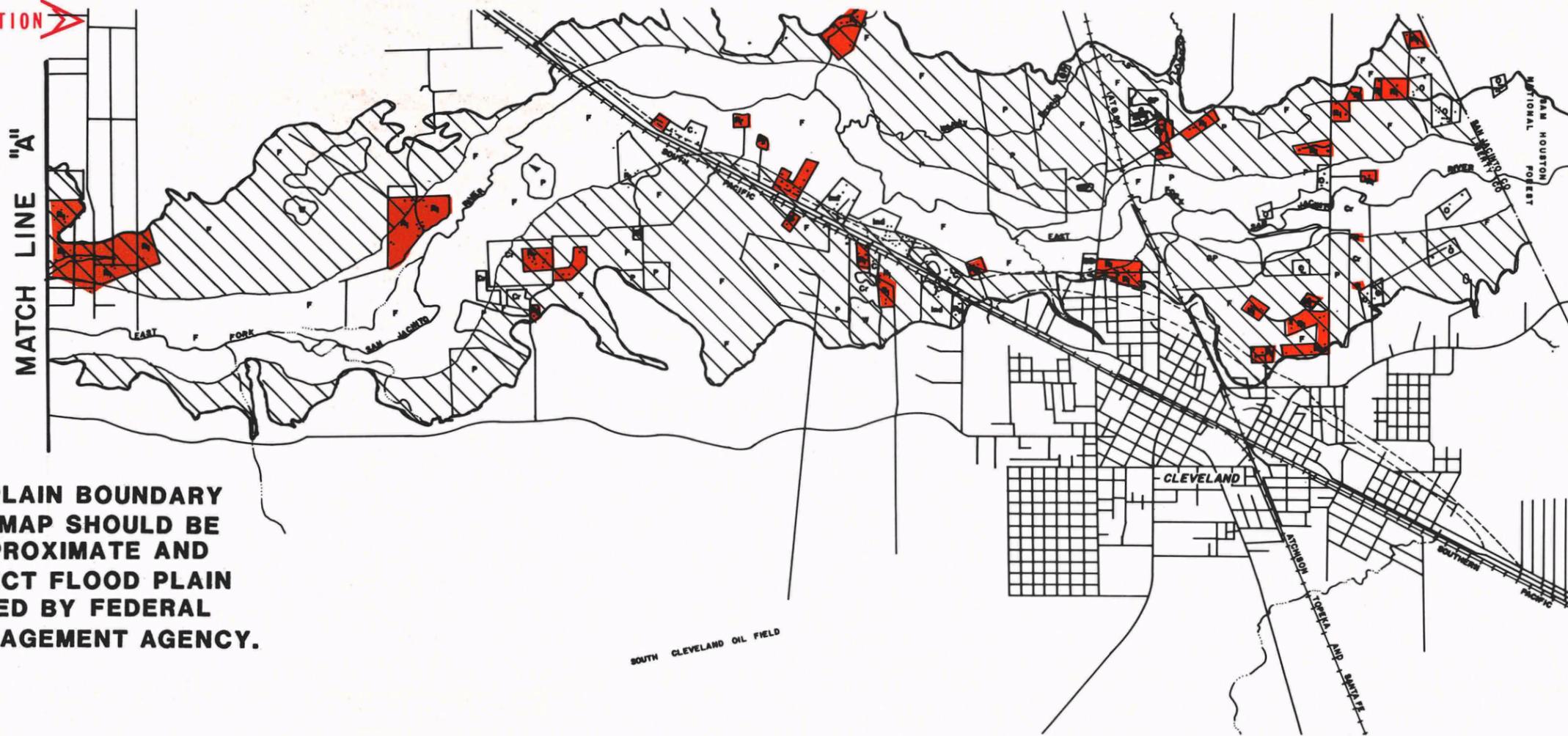


**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 1
 FLOOD PLAIN RECLAMATION PRODUCED BY
 RESERVOIR**



WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-1G



NOTE:
 100 YR. FLOOD PLAIN BOUNDARY
 SHOWN ON THIS MAP SHOULD BE
 CONSIDERED APPROXIMATE AND
 DOES NOT REFLECT FLOOD PLAIN
 BEING DETERMINED BY FEDERAL
 EMERGENCY MANAGEMENT AGENCY.

Legend

- | | | |
|--------------------|---|-------------------------|
| Flood Plain | Industry | Oil Well |
| Residential — R1 | Forest | Sewage Disposal |
| Residential — R2 | Pasture | River Bottom |
| Residential — M.F. | Cropland | Microwave Tower |
| Commercial | Improved Land For Development Imp R1 R2 | Gas Well |
| School | Wetland | Recreational |
| | | Flood Plain Reclamation |

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

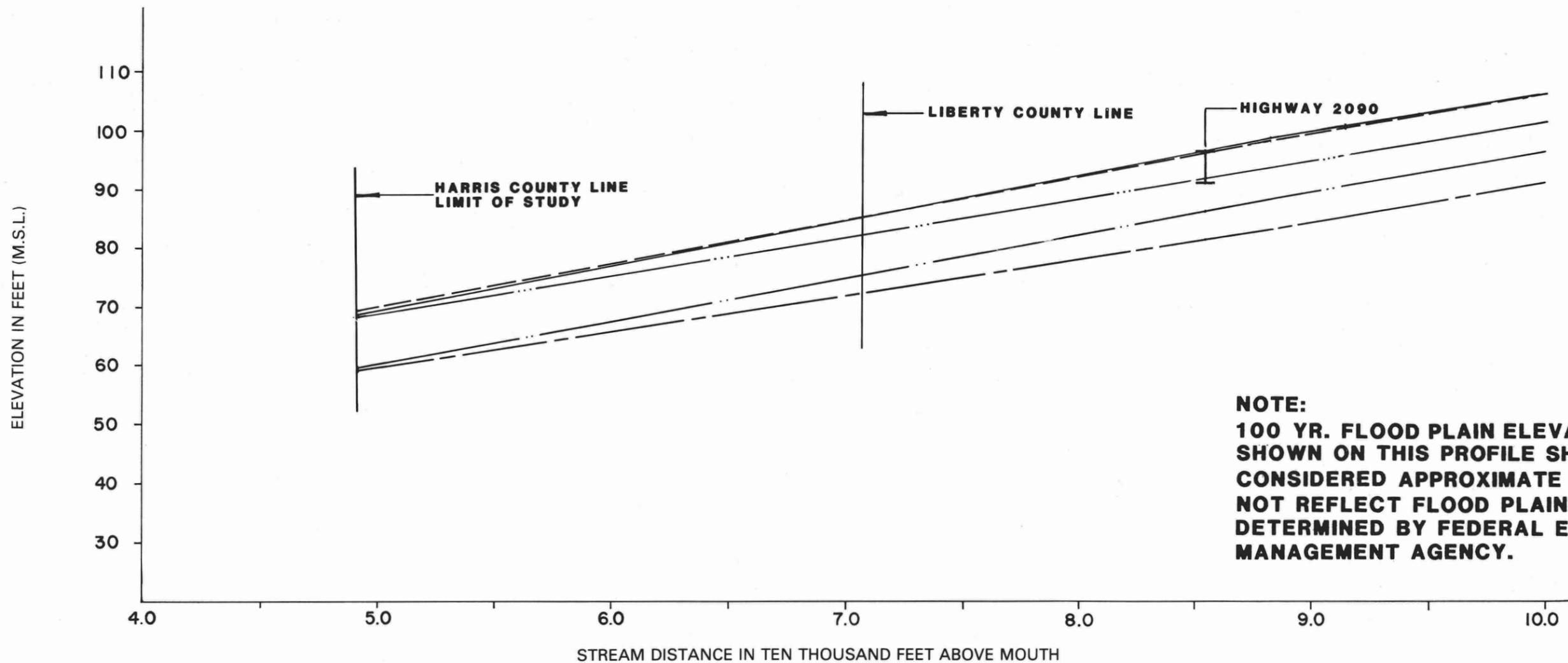
- Sources**
1. Base Map — USGS 1:24000 — 1959 - 1979.
 2. Existing Flood Plain Information Flood Ins. Study, 1982.
 2. Land Use, Aerial Photog. Interp. 1:2000 ft. 1976 — 1982



**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 2
 FLOOD PLAIN RECLAMATION PRODUCED BY
 RESERVOIR**

WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-2G



NOTE:
 100 YR. FLOOD PLAIN ELEVATIONS SHOWN ON THIS PROFILE SHOULD BE CONSIDERED APPROXIMATE AND DO NOT REFLECT FLOOD PLAIN BEING DETERMINED BY FEDERAL EMERGENCY MANAGEMENT AGENCY.

LEGEND

- 100 YR. FLOOD
- TOTAL CHANNELIZATION
- . - . - . SELECTIVE CHANNELIZATION
- DESNAGGING
- · — · — · RESERVOIR
- · · — · · BRIDGE MODIFICATIONS

**SAN JACINTO UPPER WATERSHED DRAINAGE
 IMPROVEMENT AND FLOOD CONTROL
 PLANNING STUDY**

**EAST FORK OF SAN JACINTO
 STREAM SEGMENT 1
 PROFILE**



WAYNE SMITH & ASSOCIATES, INC.
 HOUSTON, TEXAS

EXHIBIT EF-1H

