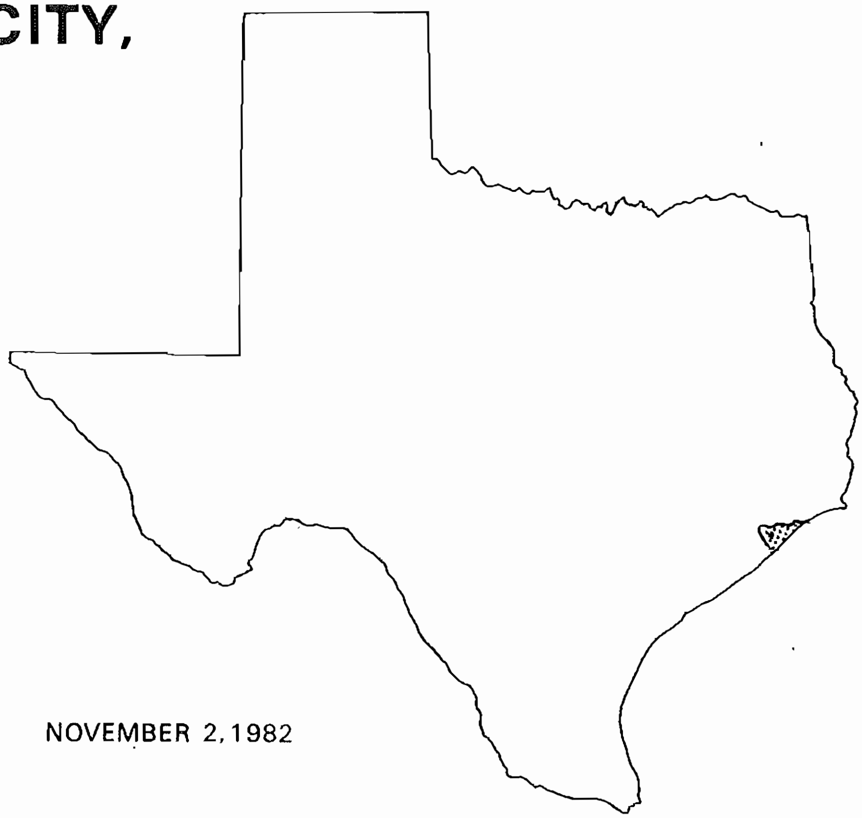
FLOOD INSURANCE STUDY

WAVE HEIGHT ANALYSIS

CITY OF LEAGUE CITY, TEXAS

GALVESTON COUNTY



NOVEMBER 2, 1982

Federal Emergency Management Agency

COMMUNITY NUMBER - 485488

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PUBLISHED SEPARATELY:

1.0 INTRODUCTION

1.1 Purpose of Study

The purpose of this Flood Insurance Study investigates the existence and severity of flood hazards in the City of League City, Galveston County, Texas, and aids in the administration of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973. Initial use of the information will be to maintain League City in the regular program of flood insurance by the Federal Emergency Management Agency (FEMA). The City of League City had been converted to the regular program on June 5, 1970. Further use of the information will be made by local and regional planners in their efforts to promore sound land use and flood plain development.

In some states or communities, flood plain management criteria or regulations may exist that are more restrictive or comprehensive than those on which these Federally-supported studies are based. These criteria take precedence over the minimum Federal criteria for purposes of regulating development in the flood plain, as set forth in the Code of Federal Regulations at 44 CFR, 60.3 (d & e). In such cases, however, it shall be understood that the state (or other jurisdictional agency) shall be able to explain these requirements and criteria.

1.2 Authority and Acknowledgments

The source of authority for this Flood Insurance Study is the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973.

The hydrologic and hydraulic analyses for this study were performed by Tetra Tech, Inc., for the Federal Emergency Management Agency, under Contract No. H-4788. This study was completed in July 1981.

1.3 Coordination

The following organizations were contacted for coordination in the development of this study; City of League City, County of Galveston, Clear Lake Area Chamber of Commerce, Houston-Galveston Area Council, National Oceanic and Atmospheric Administration (NOAA), Texas Highway Department, Texas State Department of Water Resources, U.S. Army Corps of Engineers, Galveston District (COE), U.S. Geological Survey (USGS), and U.S. Soil Conservation Service (SCS).

The State Coordinator was involved with this study through the officer of the Federal Emergency Management Agency.

On June 3, 1982, the results of this study were reviewed at a final coordination meeting attended by representatives of Tetra Tech, Inc., the City of League City and FEMA. The study was acceptable to the community.

2.0 AREA STUDIED

2.1 Scope of Study

This Flood Insurance Study covers the incorporated arec of the City of League City, Galveston County, Texas. The area of study is shown on the Vicinity Map (Figure 1). The study analysis includes coastline flooding due to hurricane-induced storm surge. Both the open coastal surge and its inland propagation were studied; in addition, the added effects of wave heights were also considered. The following sources of flooding in the city were studied in detail: Benson Bayou, Galveston Bay/Clear Lake, Clear Creek, Magnolia Creek and Unnamed Tributary of Clear Creek.

Also included is detailed study of Magnolia Bay and Bordens Gully which were taken from the previous Flood Insurance Study.

The areas studied by detailed methods were selected with priority given to all known flood hazard areas, and areas of projected development or proposed construction for the next five years, through July 1986. Approximate analyses were used to study those areas having a low development potential or minimal flood hazards. The scope and methods of study were determined by FEMA, with the community and study contractors in consultation at the meeting in May 1978.

2.2 Community Description

The City of League City occupies an area of approximately 44.3 square miles in the southeastern portion of Texas, in the northeastern region of Galveston County (Reference 1). It is situated approximately 30 miles southeast of Houston and 40 miles northwest of Galveston. The study are is bounded on the north by Clear Creek and Harris County, on the east by the cities of Clear Lake Shores and Kemah, and unincorporated areas of Galveston County, on the south by uunincorporated areas of the county, and on the west by the City of Friendswood and Brazoria County.

League City was incorporated in 1962. The U.S. Bureau of the Census recorded the 1970 population of League City at 10,818 (Reference 2), which represented a 412 percent increase over the 1960 census of 2,622 (Reference

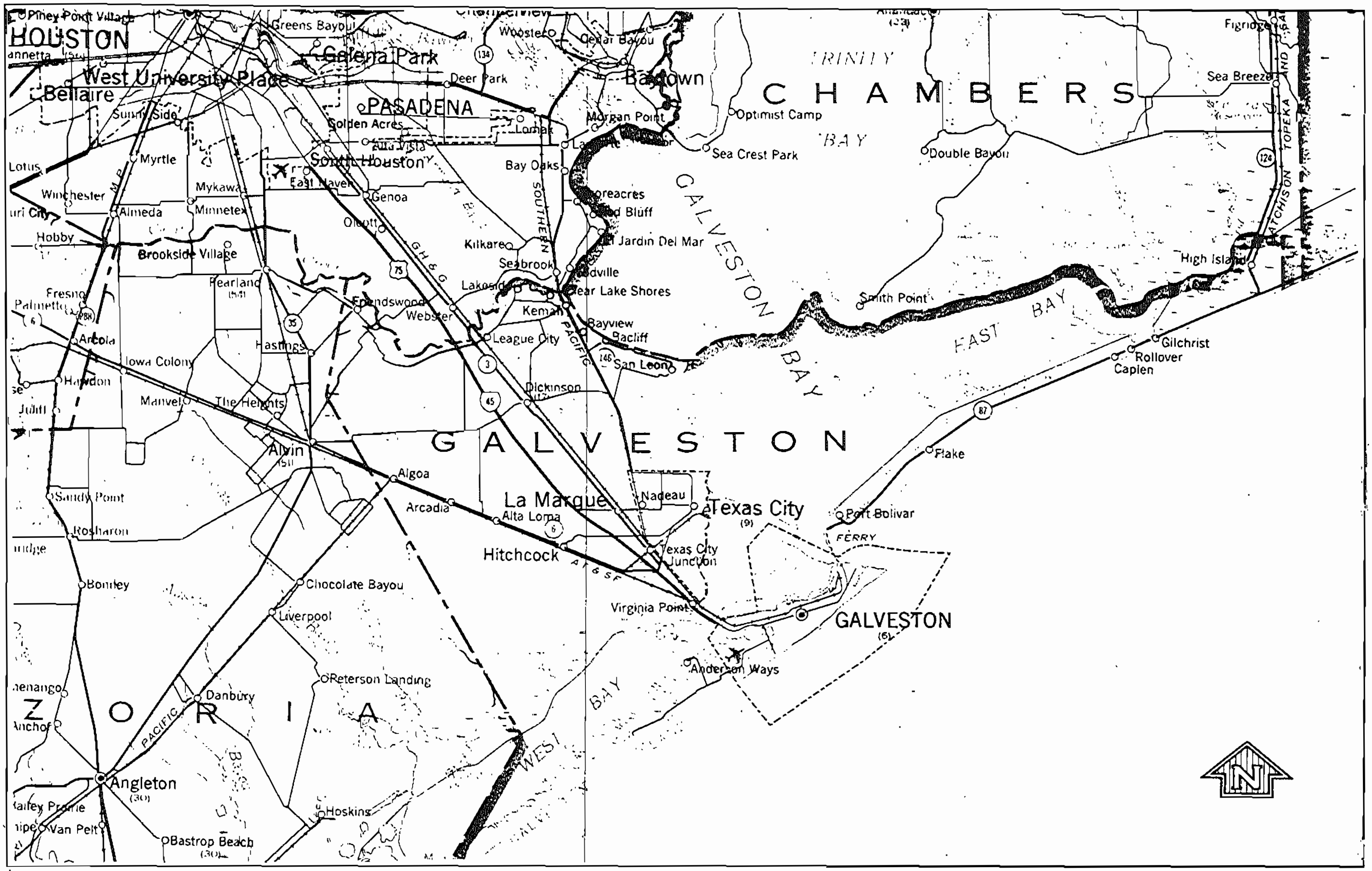

FIGURE 1

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

APPROXIMATE SCALE

8 0 8 16 24 MILES

VICINITY MAP

3). The 1979 population was estimated to be about 20,000, which represents an increase of approximately 91 percent over the 1970 level. It is estimated that the population of League City will increase to 50,000 by the year 1985 (Reference 4). This growth is associated with the growth of the Houston metropolitan area.

The city is primarily residential. Most tourist areas are located in the northeastern, western, and central parts of the city, and most recreational areas are located in the northeastern portion of the city. Commercial development is located throughout the city; there is no zoning in the area. Current industrial development consists of a proposed industrial park that is being negotiated for the airport area. The leading employer in the area, the National Aeronautics and Space Administration, is located to the north of the city. A garment factory and terminal base for export and import contribute to the city's economy.

League City is located in the humid subtropical climatic zone which is characterized by mild winters and warm summers. Rainfall is abundant and quite evenly distributed throughout the year. The heaviest rains usually occur during the hurricane season, which extends from about June through October. Average annual precipitation in the region is approximately 44 inches, and the average annual temperature is approximately 68 degrees F. (Reference 5).

The most common vegetation in the area is sage grass; tidal marsh along the bayous supports a growth of salt-loving weeds and grasses. Cropland and woodland are abundant in the area.

Soils in League City are clayey and loamy, and are categorized in the Lake Charles-Bernard and the Beaumont-Morey-Lake Charles soil associations which have low infiltration rates and high runoff potential. The soils are classified in SCS Group D for hydrologic purposes (References 6 and 7).

League City lies within the Gulf Coastal Plain and is characterized by relatively flat, featureless terrain. The elevation in the study area ranges from sea level to about 35 feet above National Geodetic Vertical Datum of (NGVD) in the western part of the community.

The land in League City is subject to subsidence, primarily due to high volume well water withdrawal in the surrounding area. Between 1943 and 1978, the approximate loss of ground elevation was between 4 and 5 feet. In the recent years between 1973 and 1978, the land has subsided approximately 0.5 to 0.75 feet (References 8 and 9).

The major stream within the city is Clear Creek, which flows generally eastward through the northern part of League City from the vicinity of northeastern Fort Bend County into Clear Lake/Galveston Bay. Its watershed, an area of about 260 square miles, is about 45 miles long (Reference 10). Benson Bayou, Magnolia Bayou and Bordens Gully are tributaries of Dickinson Bayou; they flow through the southeastern portion of the city. Robinson Bayou, Magnolia Creek, and an unnamed tributary flow north into Clear Creek through the central part of the city.

2.3 Principal Flood Problems

Flooding in League City results primarily from overflow of the streams (caused by rainfall runoff), ponding, and sheet flow, and from tidal surge and associated wave action (caused by hurricanes and tropical storms). Not all storm that pass close to the study area produce extremely high tides. Similarly, storms that produce extreme conditions in one area may not necessarily produce critical conditions in other parts of the study area. Under certain conditions, tides generated at the mouth of Clear Creek in Clear Lake/ Galveston Bay can intrude far upstream. Rainfall which usually accompanies hurricanes can aggravate the tidal flood situation. Because of the flatness of the terrain, many inland areas are characterized by shallow flooding during heavy rainfalls.

Land-surface subsidence in the area of League City is also a principal problem because it is making previously non-flood prone areas subject to inundation by high tides (Reference 9).

Storms passing Texas in the vicinity of League City have produced severe floods as well as structural damage. Brief descriptions of several significant tropical storms provide historical information to which flood hazards and the projected flood depths can be compared (References 11, 12, 13, 14, 15, 16, and 17).

September 4 to 14, 1961 (Hurricane Carla)

This hurricane, considered one of the major Gulf hurricanes of the century, crossed the Texas shoreline near Port O'Connor. Minimum barometric pressure at Texas City was 29.26 inches. Carla caused maximum tide levels of 9.3 feet above MSL in the Gulf at Galveston, and water-surface elevations along the westerly shore of Galveston Bay reached approximately 14 feet above MSL. During the four-day period from September 9 through 12, recorded rainfall at Galveston was 15.32 inches, and at Crabb, 9.26. Water levels in homes in the League City area reached 2 to 3 feet.

July 24 to 27, 1979 (Tropical Storm Claudette)

"Claudette," an upper air low pressure cell, originated in the Atlantic near Puerto Rico and moved westward into the Gulf of Mexico. It brought gale-force winds and heavy rainfall to many parts of southeastern Texas, causing severe flooding along streams and coastal areas. Within a 48-hour period, League City received 24.9 inches of rainfall. Estimated tide were between 4 and 5 feet in Galveston Bay and its upper reaches. League City was hit hard by this storm, and about 2,000 residents in the low-lying areas between the Gulf Freeway (Interstate Highway 45) and Galveston Bay were evacuated. Clear Creek, normally 100 to 150 feet wide where it flows under the Gulf Freeway, was more than a mile wide on July 26. The creek topped the Freeway with water two feet deep.

League City sustained over $6 million in damages to approximately 200 structures. Almost all areas of the city, and all new subdivisions, were flooded, as was the main sewer plant. On July 28, president Carter declared six counties, including Galveston, to be major disaster areas.

<u>September 19, 1979</u>

Heavy rain from this storm caused Clear Creek to overflow its banks. many subdivisions in League City were evacuated. In areas such as Bayridge and Glen Cove, many streets became impassable.

<u>June 4 and 5, 1981</u>

Late on the 4th of June, a tropical depression formed over the western Gulf of Mexico. Thunderstorms spawned by the depression brought heavy rains over Southeast Texas on the 5th, then moved eastward into the Gulf of Mexico and Louisiana.

The ground throughout Southeast Texas had already been saturated by recent rains thereby increasing the flooding from this storm. Many communities suffered extensive flood damage.

The heaviest rainfall and most of the flooding was reported in communities near the coast: Galveston, Texas City, Baytown, Pasadena, Bay City, Wharton, Liberty, and Pearland.

The western end of Galveston Island recorded 9 inches of rainfall; Dickinson recorded 7 inches; Alvin recorded 3.92; Alta Loma recorded 5.65 inches; and Hitchcock recorded 7.38 inches. In Baytown, where 9 inches of rainfall was reported, most arterial roads were under water on the 5th. Minor flooding was reported in League City.

2.4 Flood Protection Measures

To alleviate the flooding along Clear Creek, plans are being considered for both enlargement and rectification of the existing channel, and for the opening of a diversion channel at the mouth of Clear Lake. Since these flood protection measures are still in the planning stages, they have not been considered in this study.

Nonstructural flood protection measures in League City consist of a flood ordinance which places controls on the types of development and activities permissible in the city.

3.0 ENGINEERING METHODS

For the flooding sources studied in detail in the community, standard hydrologic and hydraulic study methods were used to determine the flood hazard data required for this study. Flood events of a magnitude which are expected to be equalled or exceeded once on the average during any 10-, 50-, 100-, and 500-year period (recurrence intervals), have been selected as having special significance for flood plain management and for flood insurance premium rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10, 2, 1, and 0.2 percent chance, respectively, of being equalled or exceeded during any year. Although the recurrence interval represents the long term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than one year are considered. For example, the risk of having a flood which equals or exceeds the 100-year flood (one percent chance of annual occurrence) in any 50 year period is about 40 percent (four in 10), and for any 90 year period, the risk increases to about 60 percent (six in 10). The analyses reported here reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish peak discharge-frequency relationships for floods of the selected recurrence intervals for each flooding source studied in detail in the community.

The determination of inundation caused by passage of a hurricane storm surge was approached by the Joint Probability Method (Reference 18). The storm populations were described by probability distributions of five parameters that influence surge heights. These were central pressure depression (which measures the intensity of the storm), radius to maximum winds, forward speed of the storm, shoreline crossing point, and crossing angle. These characteristice were described statistically based on an analysis of observed storms in the vicinity of Galveston County. Primary sources of data for this were the National Weather Service (References 19, 20, and 21), the National Hurricane Research Project (Reference 22), and the Mariners Weather Log (Reference 23). A summary of the parameters used for the Galveston County area is presented in Table 1.

CENTRAL PRESSURE DEPRESSION (Millibars)	5	15	25	35	45	55	65	75	85	95	105
PROBABILITY: ENTERING EXITING PARALLEL	0.16	0.16	0.17	0.10	0.14	0.07	0.08	0.07	0.02	0.02	0.01
STORM RADIUS (Nautical Miles)			20					35			
PROBABILITY			0.8					0.2			
FORWARD SPEED (Knots)			8		14			20			
PROBABILITY: ENTERING EXITING PARALLEL			0.63		0.28			0.09			
CROSSING ANGLE (Degrees)			21		-24			-69			
PROBABILITY			0.29		0.28			0.43			
FREQUENCY OF OCCURRENCE	1.99×10^{-3} storms/nautical miles/years										

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CITY OF LEAGUE CITY, TX

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PARAMETER VALUES FOR SURGE ELEVATION COMPUTATIONS

TABLE 1

The determination of maximum wave crest elevations associated with the 10- and 100-year events was approached by the method recommened by the National Academy of Sciences (Reference 24).

Flood magnitude and frequency values for areas subject flooding from Clear Creek were available from the COE, Galveston District (Reference 10). The peak discharge-frequency and drainage areas of each stream studied in League City are shown in Table 2, "Summary of Discharges".

TABLE 2 - SUMMARY OF DISCHARGES

FLOODING SOURCE AND LOCATION	DRAINAGE AREA (sq. miles)	PEAK DISCHARGES (cfs) 10-YEAR	50-YEAR	100-YEAR	500-YEAR
CLEAR CREEK					
At mouth	260.8	24,562	33,224	37,144	53,000
At junction of Magnolia Bayou	174.6	14,140	19,285	21,910	31,100
BENSON BAYOU					
At city boundary	3.2	1,215	1,550	1,670	2,000
MAGNOLIA CREEK					
At mouth	4.1	1,060	1,450	1,660	2,650
UNNAMED TRIBUTARY OF CLEAR CREEK					
At mouth	3.1	890	1,220	1,390	2,150

3.2 Hydraulic Analyses

Analyses of the hydraulic characteristics of the flooding sources studied in detail in the community were carried out to provide estimates of the elevations of floods of the selected recurrence intervals along each of the flood sources.

For areas subject to flooding directly from the Gulf of Mexico/Galveston Bay/Trinity Bay, FEMA's standard coastal surge model was used to simulate the coastal surge generated by any chosen storm (that is, any combination of the five storm parameters defined previously). Performing such simulations for a large number of storms, each of known total probability, permits one to establish the frequency distribution of surge height as a function of coastal location. These distributions incorporate the large scale surge behavior but do not include an analysis of the added effects associated with much finer scale wave phenomena such as wave heights, setup, or runup. The astronomic tide for the region is then statistically combined with the computed storm surge to yield recurrence intervals of total water level (Reference 25).

This model uses a grid pattern approximating the geographic features of the study area and the adjoining areas. Subsidence prior to 1975 was considered in this study (Reference 26). Surges were computed using grids of 5 nautical miles for the open coast computations and 1.5 miles for the Galveston Bay computations.

For areas subject to riverine flooding water-surface elevations for floods of the selected recurrrence intervals were developed using the U.S. Army COE HEC-2 water-surface profile computer model (References 27 and 28). Starting water-surface elevations for Benson Bayou, Magnolia Creek, and the Unnamed Tributary of Clear Creek were set equal to normal depth. Cross sectional data for Magnolia Creek and the Unnamed Tributary were obtained from the COE, Galveston District. Cross sectional data for Benson Bayou was obtained from field surveys and from USGS topographic maps (Reference 29).

Channel roughness factors (Manning's "n") used in the hydraulic computations were chosen by engineering judegement based on field observations, aerial photos of the strems and flood plain areas, and on USGS Water Supply Paper 1849 (Reference 30). Roughness values used for the main channels and their tributaries ranged from 0.03 to 0.04, with flood plain roughness values ranging from 0.08 to 0.15 for all floods.

Flood profiles were drawn showing computed water-surface elevation to an accuracy of 0.5 foot for floods of the selected recurrence intervals. Locations of selected cross sections used in the hydraulic analyses are shown on the Flood Profiles (Exhibit 1). Flood profiles for Clear Creek were available from the COE, Galveston District (Reference 10). For stream segments for which a floodway was computed, selected cross section locations are also shown on the Flood Boundary and Floodway Map (Exhibit 3).

The hydraulic analyses for this study were based on unobstructed flow. The flood elevations shown on the profiles are thus considered valid only if hydraulic structures remain unobstructed, operate properly, and do not fail.

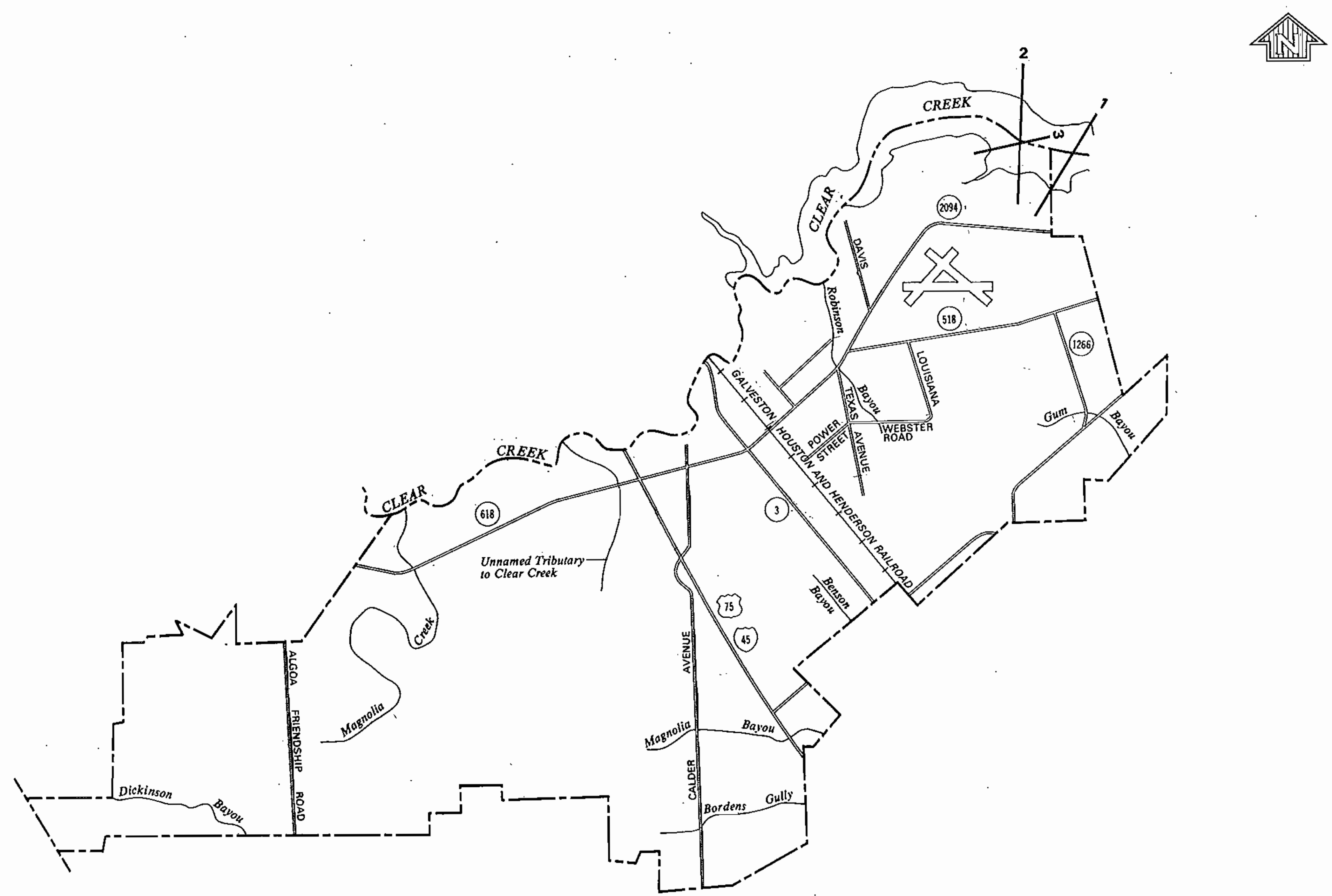
3.3 Wave Height Analysis

The methodology for analyzing the effects of wave heights associated with coastal storm surge flooding is described in the National Academy of Sciences report (Reference 24). This method is based on the following major concepts. First, depth-limited waves in shallow water reach a maximum breaking height that is equal to 0.78 times the stillwater depth. The wave crest is 70 percent of the total wave height plus the stillwater elevation. The second major concept is that wave height may be diminished due to the presence of obstructions such as sand dunes, dikes and seawalls, buildings, and vegetation. The amount of energy dissipation is a function of the physical characteristics of the obstruction and is determined by procedures prescribed in Reference 31. The third major concept is that wave height can be regenerated in open fetch areas due to the transfer of wind energy to the water. This added energy is related to fetch length and depth.

Wave heights were computed along transects (cross section lines) that were located along the coastal areas, as illustrated in Figure 2, in accordance with the Users Manual for Wave Height Analysis (Reference 31). The transects were located with consideration given to the physical and cultural characteristics of the land so that they would closely represent conditions in their locality. Transects were spaced close together in areas of complex topography and dense development. In areas having more uniform characteristics, they were spaced at larger intervals. It was also necessary to locate transects in areas where unique flooding existed and in areas where computed wave heights varied significantly between adjacent transects.

The transects were continued inland until the wave was dissipated or until flooding from another source with equal or greater elevation was reached. Along each transect, wave heights and elevations were computed considering the combined effects of changes in ground elevation, vegetation, and physical features. The stillwater elevations for the 100-year flood were used as the starting elevations for these computations. Wave heights were calculated to the nearest 0.1 foot, and wave elevations were determined at whole-foot increments along the transects. Areas with a wave component 3-feet or greater were designated as velocity zones. Other areas subject to wave action were designated as A Zones with base flood elevations adjusted to include wave crest elevations.

Figure 3 is a profile for a hypothetical transect illustrating the effects of energy dissipation and regeneration on a wave as it moves inland. This figure shows the wave elevations being diminished by obstructions, such as buildings, vegetation, and rising ground elevations, and being increased by open, unobstructed wind fetches. Actual wave conditions in the City of League City may not necessarily include all the situations illustrated in Figure 3.



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CITY OF LEAGUE CITY, TEXAS
GALVESTON COUNTY, TEXAS

TRANSECT LOCATION MAP

FIGURE 2

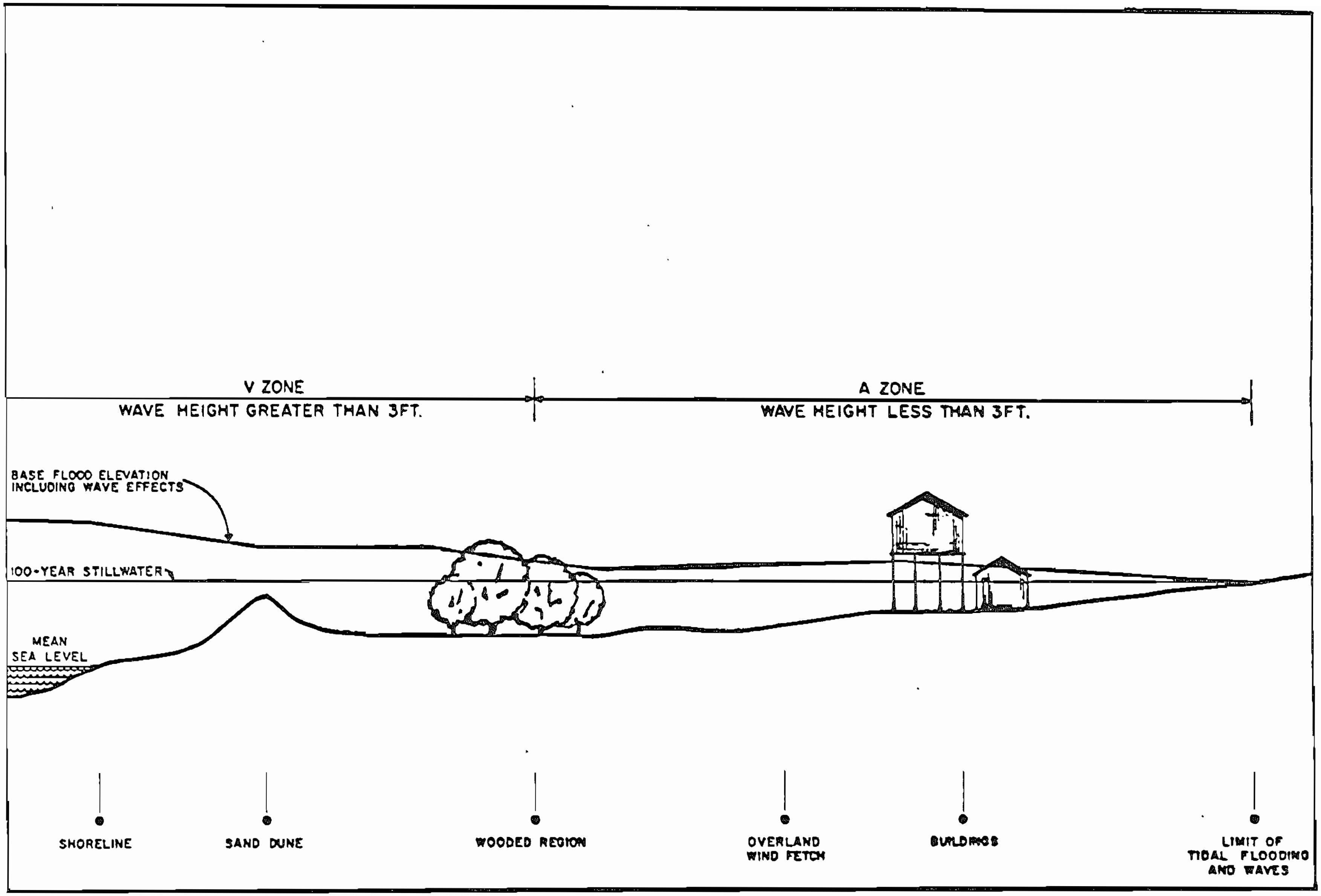


FIGURE 3

HYPOTHETICAL TRANSECT SCHEMATIC

Data for the model grid systems and for the wave height calculations were obtained from USGS quadrangle sheets (Reference 29), a topographic map of the Clear Lake area (Reference 32), NOAA nautical charts (References 33, 34, 35, 36, and 37), and from aerial photographs (Reference 38). The results of this study are considered accurate until local topography, vegetation, or cultural development undergo any major changes.

All elevations are referenced to NGVD. Elevation reference marks used in this study are shown and described on the maps.

4.0 FLOOD PLAIN MANAGEMENT APPLICATIONS

The National Flood Insurance Program encourages state and local governments to adopt sound flood plain management programs. Therefore, each Flood Insurance Study includes a flood boundary map designed to assist communities in developing sound flood plain management measures.

4.1 Flood Boundaries

In order to provide a national standard without regional discrimination, the 100-year flood has been adopted by FEMA as the base flood for purposes of flood plain management measures. The 500-year flood is employed to indicate additional areas of flood risk in the community. For each stream studied in detail, the boundaries of the 100- and the 500-year floods have been delineated using the flood elevations determined at each cross section; between cross sections, the boundaries were interpolated using topographic maps at scales of 1:24,000 and 1:12,000 with contour intervals of 5 feet and 1 and 2 feet, respectively (References 29 and 32); and aerial photographs at a scale of 1:9,600 (Reference 38). Additional maps were consulted to cross-check boundaries (Reference 39, 40 and 41).

Flood boundaries are indicated on the Flood Insurance Rate Map. On this map, the 100-year flood boundary corresponds to the boundary of the area of special flood hazard (Zones A2 A3, A5, A6, A8, A10, A13, A14 and V20), and the 500-year flood boundary corresponds to the boundary of the area of moderate flood hazard (Zone B). In cases where the 100- and the 500-year flood boundaries are close together, only the 100-year boundary has been shown.

4.2 Floodways

Encroachment on flood plains, such as artificial fill, reduces the flood-carrying capacity, increases the flood heights of streams, and increases flood hazards in areas beyond the encroachment itself. One aspect of flood plain management involves balancing the economic gain from flood plain development against the resulting increase in flood hazard. For purposes of the National Flood Insurance Program, the concept of a floodway is used as a tool to assist local communities in this aspect of flood plain management. Under this concept, the area of the 100-year flood is divided into a floodway and a floodway fringe. The floodway is the channel of a stream plus any adjacent flood plain areas that must be kept free of encroachment in order that the 100-year flood may be carried without substantial increases in flood heights. Minimum standards of FEMA limit such increases in flood heights to 1.0 foot, provided that hazardous velocities are not produced.

Floodways are not delineated in coastal high hazard areas. The floodways proposed in this study for riverine areas were computed on the basis of equal conveyance reduction from each side of the flood plain. Floodway analyses were based on increasing the computed 100-year rainfall flooding level. The results of these computations are tabulated at selected cross sections for each stream studied in detail (Table 3).

As shown on the Flood Boundary and Floodway Map (Exhibit 3), the floodway boundaries were determined at cross sections; between cross sections, the boundaries were interpolated.

The area between the floodway and the boundary of the 100-year flood is termed the floodway fringe. The floodway fringe thus encompasses the portion of the flood plain that could be completely obstructed without increasing the water-surface elevation of the 100-year flood more than 1.0 foot at any point. Typical relationships between the floodway and the floodway fringe and their significance to flood plain development are shown in Figure 4.

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)[2]	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY[3]	WITHOUT FLOODWAY (FEET NGVD)	WITH FLOODWAY (FEET NGVD)	INCREASE
Clear Creek								
A	4.61	2,436	15,886	1.4	11.3	6.1	6.9	0.8
B	5.23	2,090	24,158	0.9	11.3	6.2	7.0	0.8
C	5.83	727	5,040	4.3	11.3	6.6	7.4	0.8
D	6.03	1,523	11,113	2.0	11.3	7.2	8.2	1.0
E	6.24	1,594	8,233	2.7	11.3	7.3	8.3	1.0
F	6.78	1,063	8,118	2.7	11.4	7.8	8.7	0.9
G	7.10	913	13,323	1.6	11.4	8.4	9.3	0.9
H	7.41	925	10,640	2.0	11.4	8.5	9.4	0.9
I	7.68	1,337	11,230	1.9	11.4	8.6	9.5	0.9
J	7.86	1,125	13,241	1.6	11.4	8.7	9.6	0.9
K	8.39	1,990	3,921	5.4	11.4	9.0	9.9	0.9
L	8.65	1,016	11,069	1.9	12.1	9.8	10.6	0.8
M	8.77	930	10,828	2.0	12.1	9.9	10.7	0.8
N	8.97	1,250	13,287	1.6	12.1	10.0	10.8	0.8
O	9.38	575	6,436	3.2	12.1	10.3	11.1	0.8
P	9.59	905	9,878	2.1	12.1	10.4	11.2	0.8
Q	9.90	1,315	13,890	1.5	12.1	10.6	11.4	0.8
R	10.12	865	9,845	2.1	12.1	10.7	11.5	0.8
S	10.26	440	4,720	4.4	12.2	10.8	11.7	0.9
T	10.61	988	10,935	1.9	12.5	11.7	12.5	0.8
U	10.99	999	11,388	1.8	13.0	12.2	13.1	0.9
V	11.39	860	11,869	1.7	13.2	12.4	13.3	0.9
W	11.68	689	9,327	2.2	13.4	12.7	13.6	0.9
X	11.91	722	9,181	2.2	13.5	12.9	13.8	0.9
Y	12.26	931	11,654	1.8	13.7	13.3	14.2	0.9

[1]Miles above mouth
[2]Floodway width extends beyond corporate limits
[3]Combined flooding effects from Galveston Bay and Clear Creek

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX
(GALVESTON CO.)

FLOODWAY DATA

CLEAR CREEK

TABLE 3

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY (FEET NGVD)	WITH FLOODWAY (FEET NGVD)	INCREASE
Unnamed Tributary of Clear Creek								
A	0	80	623	2.2	13.2[2]	4.8	5.8	1.0
B	900	80	597	2.3	13.2[2]	5.1	6.0	0.9
C	1,340	44	241	5.8	13.2[2]	5.1	6.0	0.9
D	1,990	41	214	6.5	13.2[2]	7.3	7.5	0.2
E	2,430	44	193	7.2	13.2[2]	8.7	8.8	0.1
F	3,370	40	228	6.1	13.2[2]	12.1	12.2	0.1
G	4,470	40	276	5.0	14.0	14.0	14.4	0.4
H	5,870	39	174	8.0	18.6	18.6	18.8	0.2
I	6,310	40	219	6.3	21.4	21.4	21.5	0.1
J	8,160	136	556	2.9	23.7	23.7	24.6	0.9

[1]Feet above mouth.
[2]Combined flooding effects from Galveston Bay and Clear Creek.

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX
(GALVESTON CO.)

FLOODWAY DATA

UNNAMED TRIBUTARY OF CLEAR CREEK

TABLE 3

FLOODING SOURCE		FLOODWAY			BASE FLOOD WATER SURFACE ELEVATION			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY (FEET NGVD)	WITH FLOODWAY (FEET NGVD)	INCREASE
Clear Creek (cont.)								
Z	12.52	804[2]	9,729	2.1	13.9[3]	13.5	14.4	0.9
AA	12.92	1,200[2]	12,904	1.6	14.2[3]	13.8	14.8	1.0
AB	13.43	670[2]	8,805	2.3	14.5[3]	14.3	15.2	0.9
Benson Bayou								
A	9,800	73	492	3.4	15.4	15.4	16.1	0.7
B	14,150	420	1,417	1.2	17.8	17.8	18.4	0.6
Magnolia Creek								
A	150	45	299	5.5	14.5[3]	7.4	8.4	1.0
B	2,550	83	443	3.7	14.5[3]	11.9	12.6	0.7
C	3,600	50	318	5.2	14.5[3]	13.8	14.2	0.4
D	4,000	50	355	4.7	14.5[3]	14.5	14.9	0.4
E	6,400	43	267	6.2	19.5	19.5	20.2	0.7
F	7,730	50	300	4.6	22.9	22.9	23.4	0.5
G	9,301	560	960	1.4	26.7	26.7	27.5	0.8

[1]Feet above mouth
[2]Floodway width extends beyond corporate limits
[3]Combined flooding effects from Galveston Bay and Clear Creek

FEDERAL EMERGENCY MANAGEMENT AGENCY

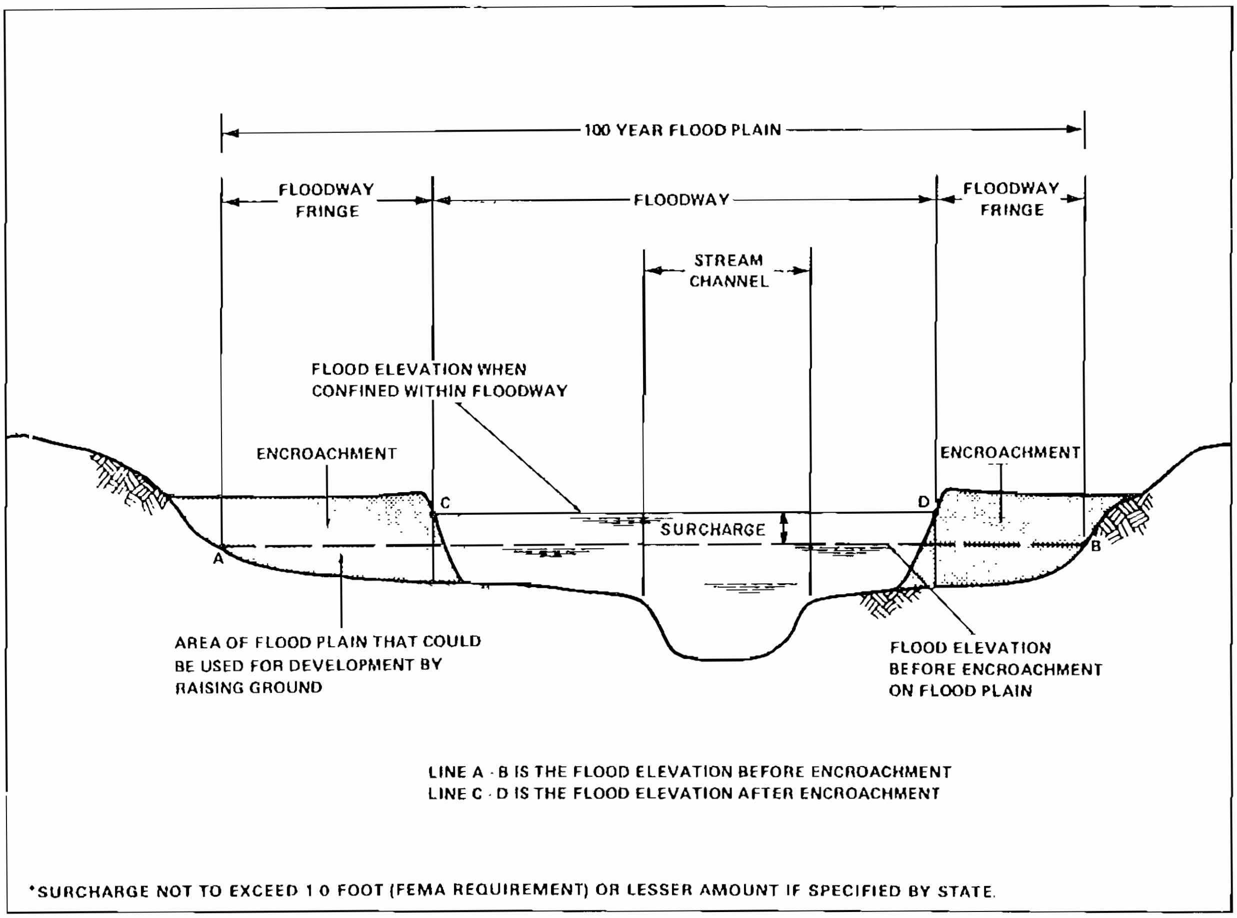
CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

FLOODWAY DATA

CLEAR CREEK-BENSON BAYOU-MAGNOLIA CREEK

TABLE 3



FLOODWAY SCHEMATIC — Figure 4

4.3 Base Flood Elevations

Areas within the communities studied by detailed engineering methods have base flood elevations established in A and V Zones. These are the elevations of the base (100-year) flood relative to the National Geodetic Vertical Datum (Mean Sea Level of 1929). In coastal areas affected by wave action, base flood elevations are generally maximum at the normal open shoreline. These elevations generally decrease in a landward direction at a rate dependent on the presence of obstructions capable of dissipating the wave energy. Where possible, changes in base flood elevations have been shown in 1-foot increments on the FIRMs. However, where the scale did not permit, 2- or 3-foot increments were sometimes used. Base flood elevations shown in the wave action areas represent the average elevation within the zone. These elevations vary from 11 to 14 feet NGVD in the incorporated area of League City and are shown on the Flood Insurance Rate Map. Current program regulations generally require that all new construction be elevated such that the first floor, including basement, is above the base flood elevation in A and V Zones.

4.4 Velocity Zones

The U.S. Army Corps of Engineers (Reference 42) has established the 3-foot breaking wave as the criterion for identifying coastal high hazard zones. This was based on a study of wave action effects on structures. This criterion has been adopted by the Federal Emergency Management Agency for the determination of V Zones. Because of the additional hazards associated with high-energy waves, the National Flood Insurance Program regulations require much more stringent flood plain management measures in these areas, such as elevating structures on piles or piers. In addition, insurance rates in V Zones are higher than those in A Zones with similar numerical designations.

The location of the V Zone is determined by the 3-foot breaking wave as discussed previously. The detailed analysis of wave heights performed in this study allowed a much more accurate location of the V Zone to be established. The V Zone generally extends inland to the point where the 100-year flood depth is insufficient to support a 3-foot breaking wave.

5.0 INSURANCE APPLICATION

In order to establish actuarial insurance rates, FEMA has developed a process to transform the data from the engineering study into flood insurance criteria. This process includes the determination of reaches, Flood Hazard Factors (FHFs), and flood insurance zone designations for each significant flooding source affecting the City of League City.

5.1 Reach Determinations

Reaches are defined as lengths of watercourses having relatively the same flood hazard, based on the average weighted difference in water-surface elevations between the 10- and 100-year floods. This difference does not have a variation greater than that indicated in the following table for more than 20 percent of the reach.

Average Difference Between 10- and 100-Year Floods	Variation
Less than 2 feet	0.5 foot
2 to 7 feet	1.0 foot
7.1 to 12 feet	2.0 feet
More than 12 feet	3.0 feet

The location of reaches determined for the riverine flooding sources of League City are shown on the Flood Profiles (Exhibit 1), and summarized in the Flood Insurance Zone Data Table (See Section 5.3).

Coastal flood plains are divided into areas having relatively the same flood hazard based upon the 100-year wave height and the average weighted difference inter water-surface elevations between the 10-year and 100-year floods. These flood hazard areas are shown on the Flood Insurance Rate Map.

5.2 Flood Hazard Factors (FHFs)

The Flood Hazard Factor is used to correlate flood information with insurance rate tables. Correlations between property damages from floods and their assigned FHFs are used to set actuarial insurance premium rate tables based on FHFs from 005 to 200.

The FHF for a reach is the average weighted difference between the 10- and 100-year flood water-surface elevations expressed to the nearest one-half foot, and shown as a three-digit code. For example, if the difference between the water-surface elevations of the 10- and 100-year floods is 0.7 foot, the FHF is 005; if the difference is 1.4 feet, the FHF is 015; if the difference is 5.0 feet, the FHF is 050. When the difference between the 10- and 100-year flood water-surface elevations is greater than 10.0 feet, the accuracy for the FHF is to the nearest foot.

In coastal areas where wave action (wave heights greater than 3 feet), affects flood hazards, the FHF of the V Zone is determined using the differences between the 10-year wave crest elevation and the 100-year wave crest elevation. This difference is estimated as the difference between the stillwater elevations multiplied by 1.55. For areas where wave heights are less than three feet, the FHF is determined using the difference between the 10-year stillwater elevation and the 100-year wave crest elevation. For areas not subject to wave action the FHF is determined using the difference between the 10-year and 100-year stillwater elevations.

5.3 Flood Insurance Zones

After the determination the number of reaches and their respective FHFs, the entire incorporated area of the City of League City was divided into zones, each having a specific flood potential or hazard. The zone numbers are determined by multiplying the FHF by 2.0. Each zone was assigned one of the following flood insurance zone designations.

Zone V20:	Special Flood hazard Areas along coasts inundated by the 100-year flood as determined by detailed methods, and that have additional hazards due to velocity (3 feet or more of wave action); base flood elevations shown, and zones subdivided according to FHF.
Zones A2,A3,A5,A6,A8, A10, A13 and A14:	Special Flood Hazard Areas inundated by the 100-year flood, determined by detailed methods; base flood elevations shown, and zones subdivided according to FHFs.
Zone A:	Special Flood Hazard Areas inundated by the 100-year flood, determined by approximate methods; no base flood elevation shown or zones subdivided according to FHFs.
Zone B:	Areas between the Special Flood Hazard Area and the limits of the 500-year flood, including areas of the 500-year flood plain that are protected from the 100-year flood by dike, levee, or other water control structure; areas subject to certain types of 100-year shallow flooding where depths are less than 1.0 foot; or areas subject to 100-year flooding from sources with drainage areas less than 1 square mile. Zone B is not subdivided.

Zone C: Areas of minimal flooding.

Table 4, "Flood Insurance Zone Data," and Table 5 "Coastal Flood Insurance Zone Data", summarize the flood elevation differences, FHFs, flood insurance zones, and base flood elevations for each flooding source studied in detail in the community.

5.4 Flood Insurance Rate Map Description

The Flood Insurance Rate Map for the City of League City is, for insurance purposes, the principal result of the Flood Insurance Study. This map (published separately) contains the official delineation of flood insurance zones and base flood elevation lines. Base flood elevation lines show the locations of the expected whole-foot water-surface elevations of the base (100-year) flood. This map is developed in accordance with the latest flood insurance map preparation guidelines published by FEMA.

6.0 OTHER STUDIES

Flood Insurance Rate Maps were prepared for the City of League City in 1970 and revised in 1977 (Reference 39). Other studies that concentrate on portions of the study area include Flood Insurance Rate Maps and Flood Hazard Boundary Maps published in 1971 for unincorporated areas of Galveston County (Reference 43); the Flood Insurance Study for the area from Sabine Lake to Matagorda Bay (Reference 44), and Flood plain and Flood Hazard Information Reports that cover Clear Creek and nearby Dickinson Bayou (References 45 and 46).

The previous studies indicate that the 100-year stillwater surge level is 15.5 feet above NGVD in League City. The findings of this study denote a 100-year stillwater surge level of 11.5 feet above NGVD with the maximum wave crest elevation of 14.3 feet above NGVD. The differences reflect the fact that the present study adopted more detailed techniques for the treatment of both the statistical and the hydraulic aspects of the analysis than had been used previously.

Flood Insurance Studies are currently being conducted for the cities of Friendswood, Kemah, Clear Lake Shores and Galveston County (Reference 47, 48, 49, and 50). This Galveston County Flood Insurance Study (FIS) will supersede the previous FIS for Galveston County. A Flood Insurance Study is also being prepared by the U.S. Army COE, Galveston District for Harris County (Reference 51). These studies will be in agreement with the League City study.

Other related studies include: land-surface subsidence investigation (References 8,9, and 52); and the U.S. Army COE, Galveston District's National Shoreline study (Reference 53).

FLOODING SOURCE	PANEL[1]	ELEVATION DIFFERENCE[2] BETWEEN 1% (100-YEAR) FLOOD AND			FLOOD HAZARD FACTOR	ZONE	BASE FLOOD ELEVATION[3] (FEET NGVD)
		10% (10-YEAR)	2% (50-YEAR)	0.2% (500-YEAR)			
Clear Creek							
Reach 1[4]	0010	-5.1	-1.6	+3.2	050	A10	11
Reach 2[4]	0010	-3.8	-1.5	+2.7	040	A8	12
Reach 3[4]	0005,0010, 0025,0030	-3.1	-1.0	+3.5	030	A6	Varies
Benson Bayou Reach 1	0030	-1.3	-0.3	_0.5	015	A3	Varies
Magnolia Creek Reach 1	0025	-1.3	-0.4	+1.4	015	A3	Varies
Unnamed Tributary of Clear Creek Reach 1	0025,0030	-1.5	-0.5	+1.4	015	A3	Varies
Dickinson Bayou Reach 1	0025	-1.1	-0.3	+0.6	010	A2	Varies
Magnolia Bayou Reach 1	0030	*	*	*	025	A5	Varies
Bordens Gully Reach 1	0030	*	*	*	015	A3	Varies

[1] Flood Insurance Rate Map Panel [2] Weighted Average [3] Rounded to Nearest Foot

[4] Combined flooding effects from Galveston Bay and Clear Creek.

*Information not available, zones obtained from previous FIRM (6/17/77)

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(GALVESTON CO.)

FLOOD INSURANCE ZONE DATA

CLEAR CREEK-BENSON BAYOU-MAGNOLIA CREEK-UNNAMED TRIBUTARY OF CLEAR CREEK-DICKINSON BAYOU-MAGNOLIA BAYOU-BORDENS GULLY

TABLE 4

FLOODING SOURCE	TRANSECTS	PANELS	STILLWATER ELEVATIONS				FLOOD HAZARD FACTOR[1]	ZONE[1]	BASE FLOOD ELEVATION[2] (FEET NGVD)
			10-YR	50-YR	100-YR	500-YR			
Galveston Bay/ Clear Lake	1-3	0011	4.8	9.6	11.3	14.7	100	V20	14
		0011	4.8	9.6	11.3	14.7	070	A14[3]	11-13
	N/A	0010,0011,0013	4.8	9.6	11.3	14.7	065	A13	11

1-Includes the effects of Wave Action, where applicable.

2-Due to map scale limitations, Base Flood Elevations (BFEs) shown on the Flood Insurance Rate Map may represent average elevation for the zone depicted.

3-Weighted Average

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

COASTAL FLOOD INSURANCE ZONE DATA

GALVESTON BAY/CLEAR CREEK

TABLE 5

Previous 100-year hurricane surge elevations for the Gulf Coastal Engineering Research Center, in 1969 (Reference 54), and by the Galveston District in 1979 (Reference 55).

This study is authoritative for the purposes of the National Flood Insurance Program, and data presented in this report either supersede, or are compatible with all previous determinations.

7.0 LOCATION OF DATA

Information concerning the pertinent data used in preparation of this study can be obtained by contacting the Natural and Technological Hazards Division, Federal Emergency Management Agency, Federal Center, Denton, Texas 76201.

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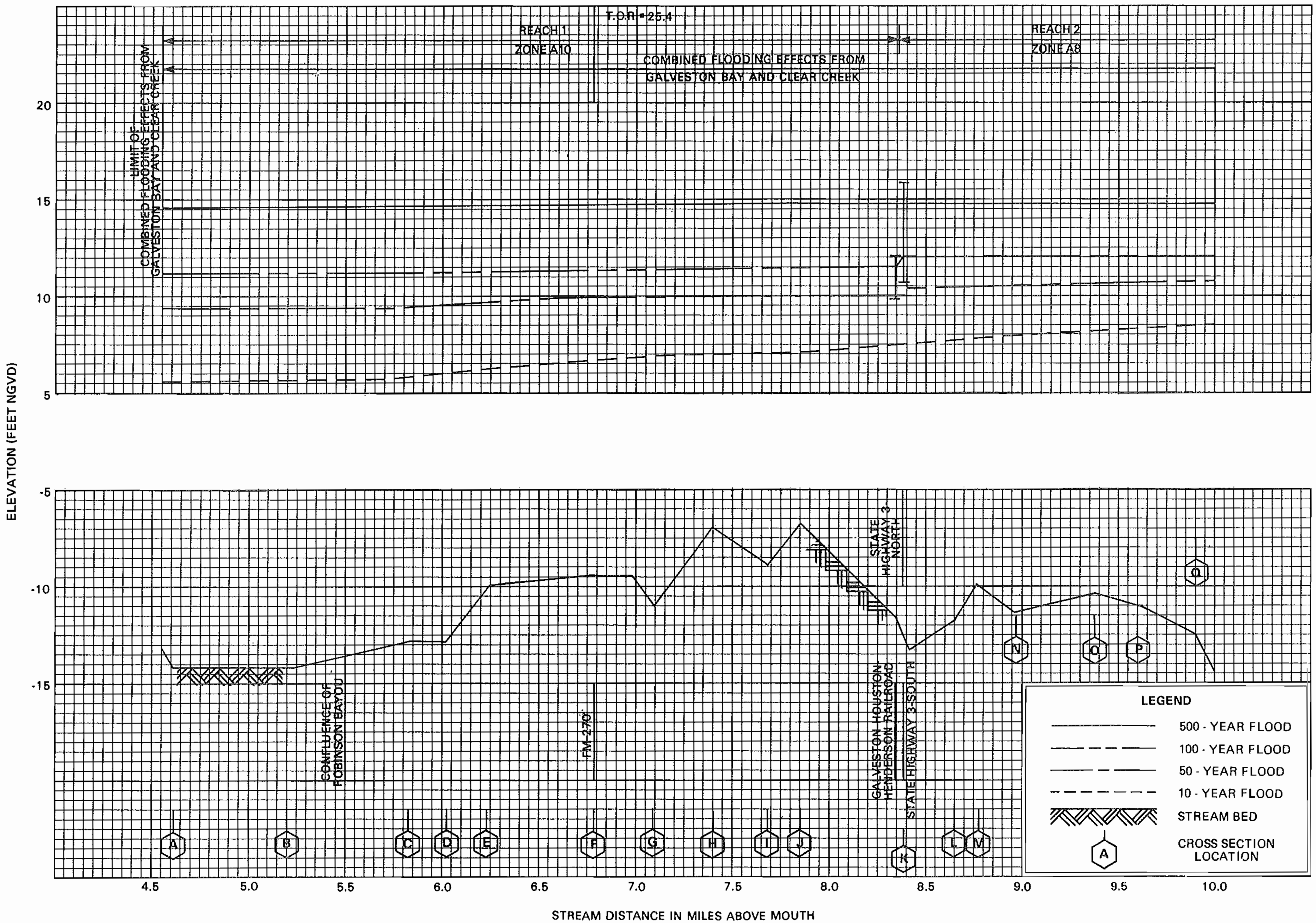


FLOOD PROFILES

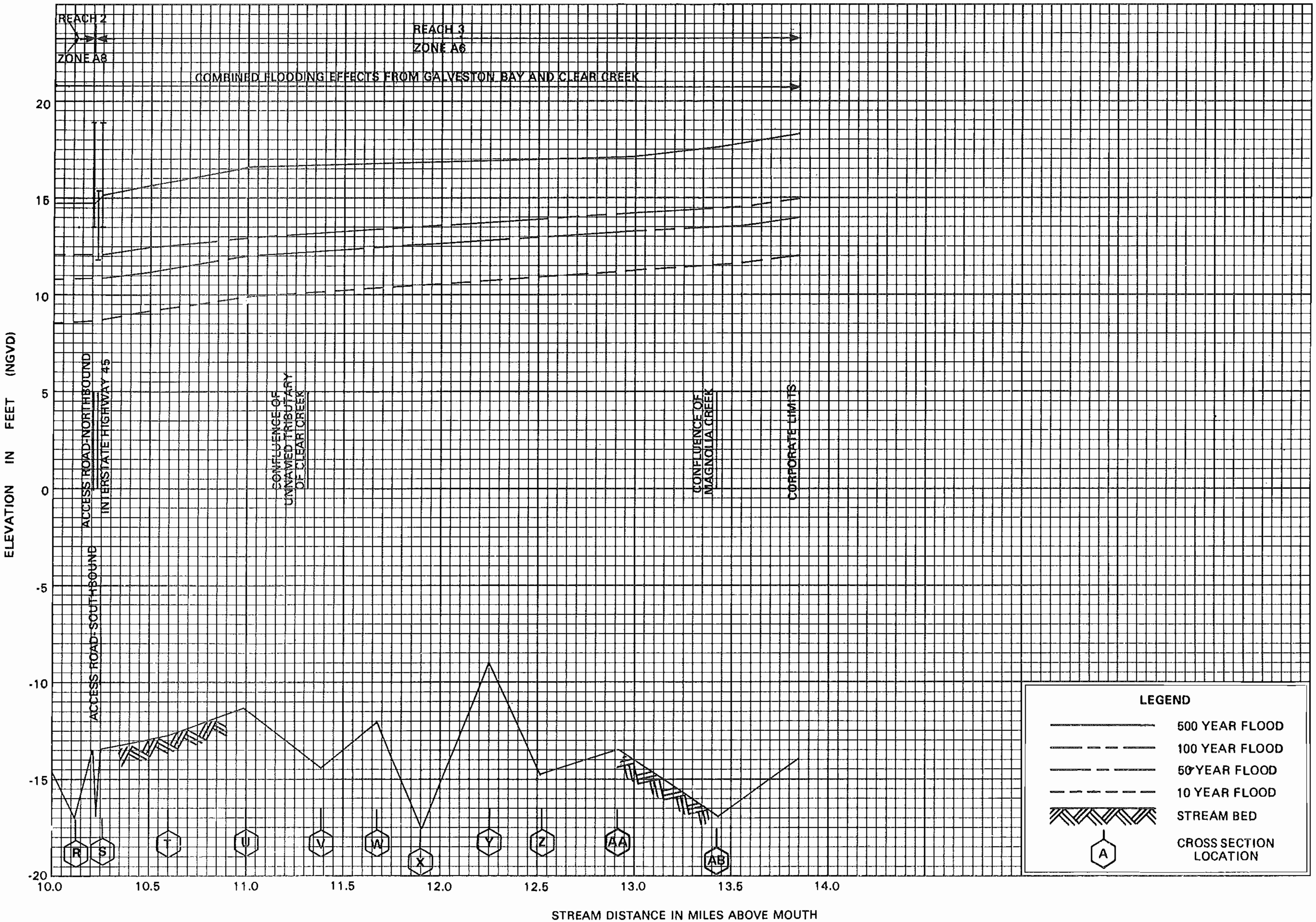
CLEAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO)

01P



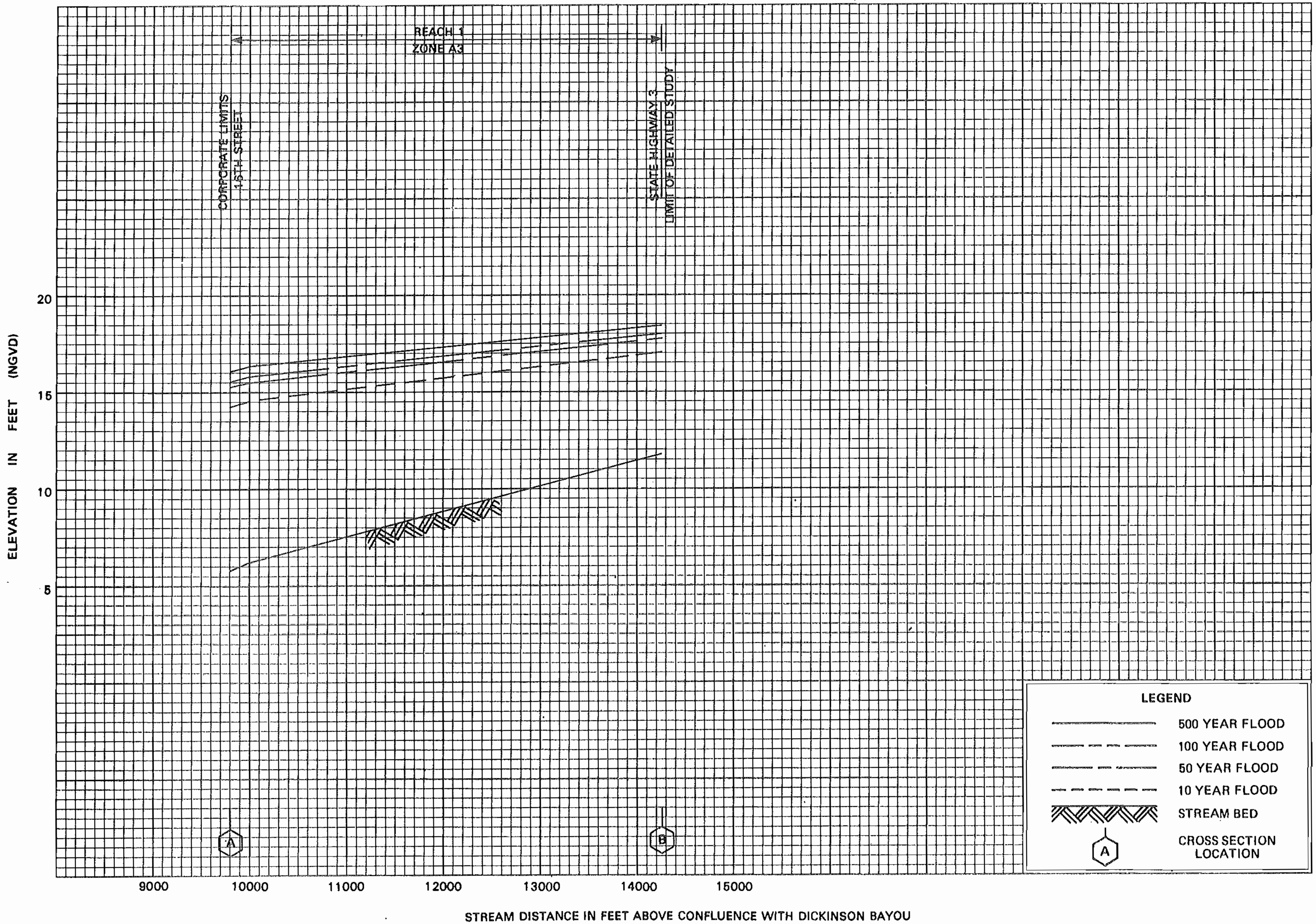
FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX (GALVESTON CO)

FLOOD PROFILES

CLEAR CREEK

02P



FLOOD PROFILES

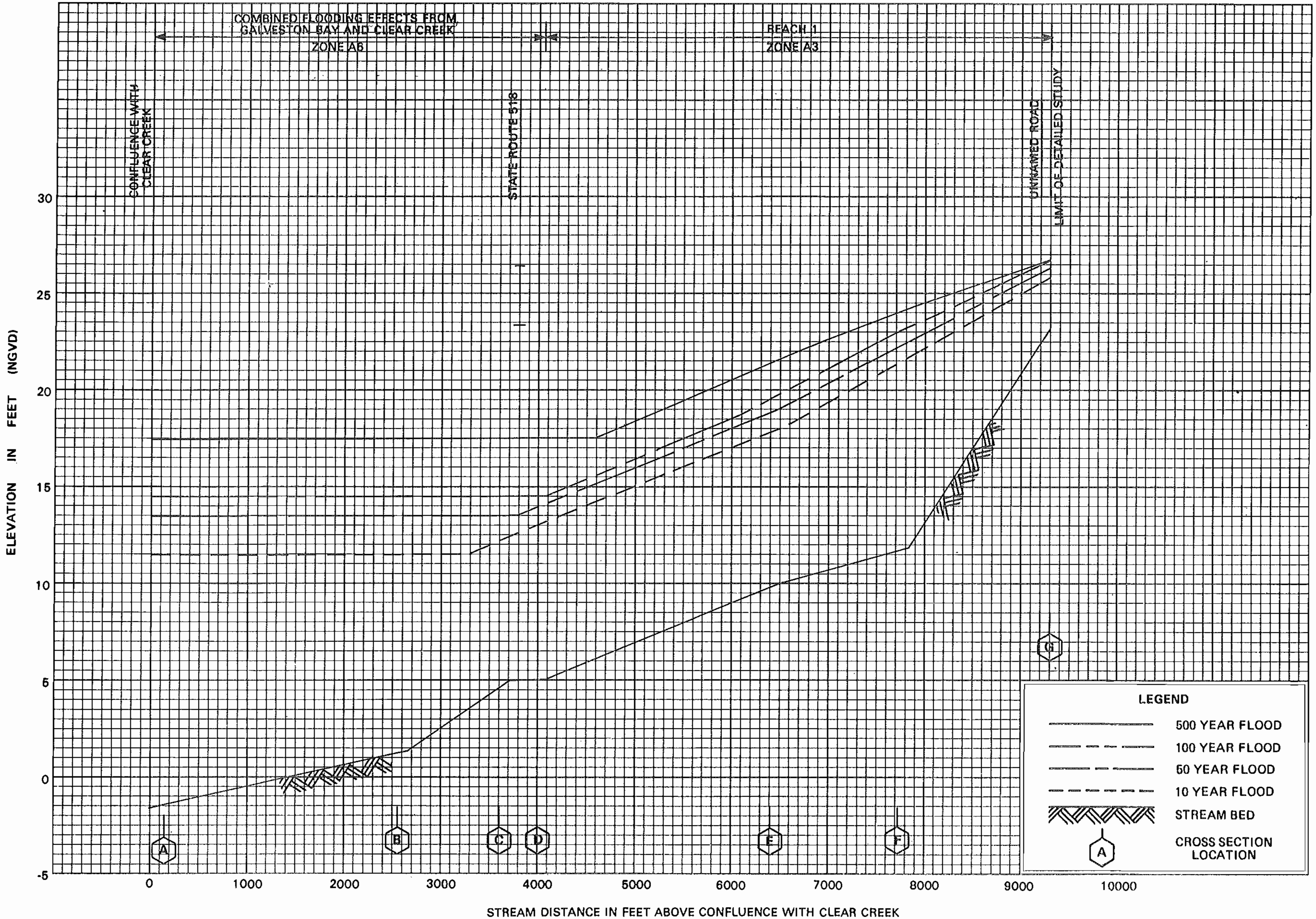
BENSON BAYOU

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

03P



FLOOD PROFILES

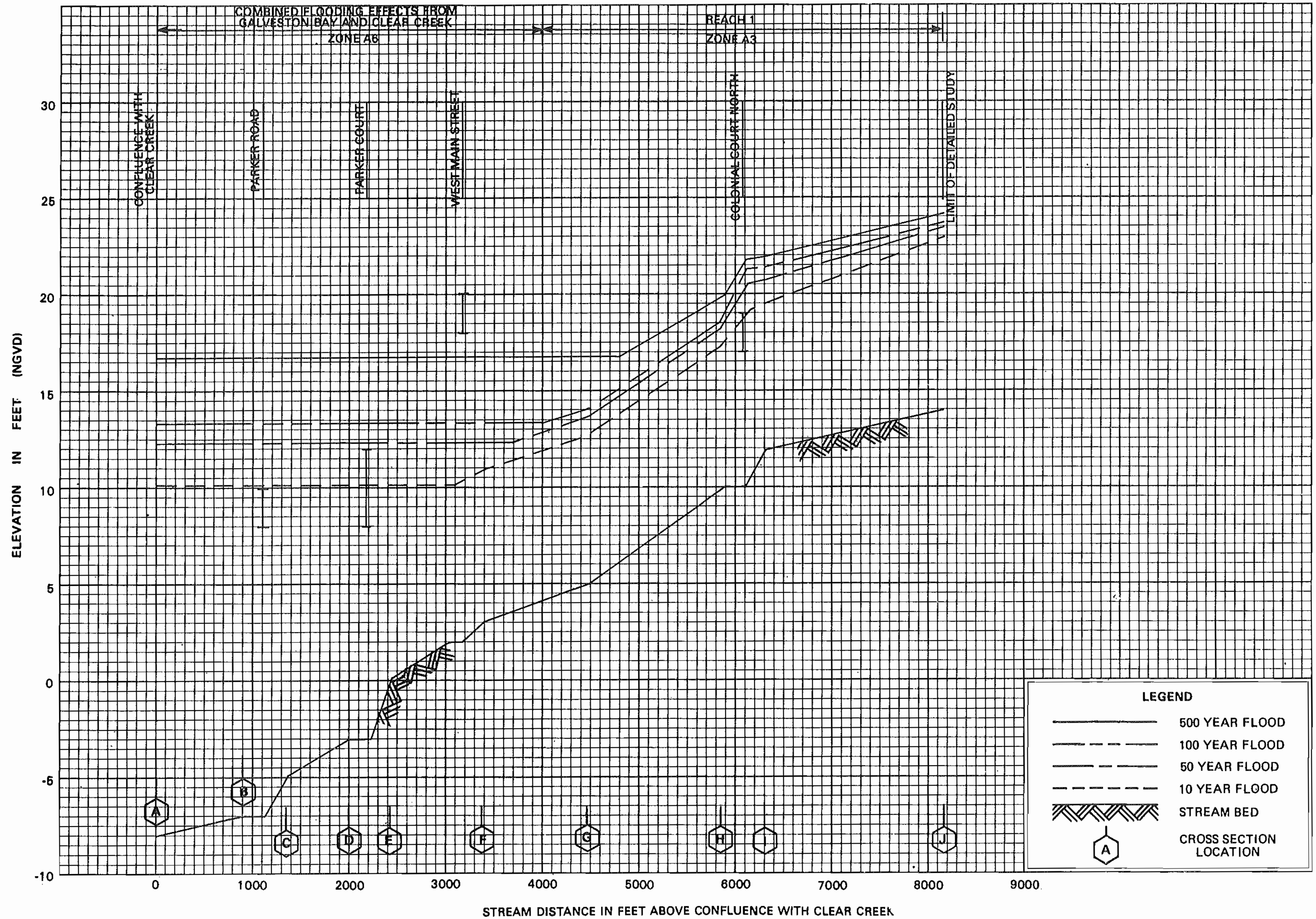
MAGNOLIA CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

04P



FLOOD PROFILES

UNNAMED TRIBUTARY OF CLEAR CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)

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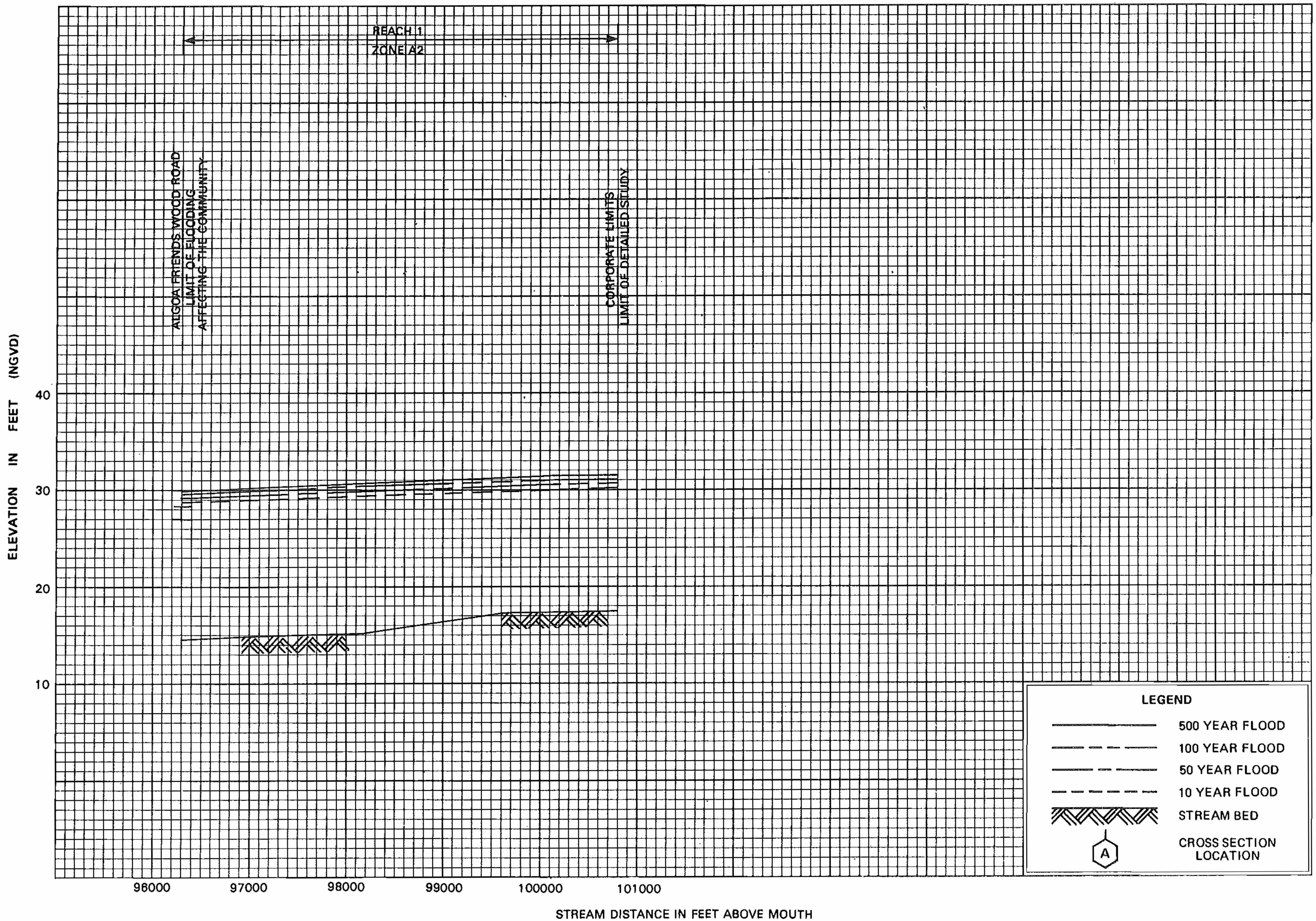

FLOOD PROFILES

DICKINSON BAYOU

FEDERAL EMERGENCY MANAGEMENT AGENCY

CITY OF LEAGUE CITY, TX

(GALVESTON CO.)