IDENTIFICATION OF POTENTIAL VERTICAL SHELTERS IN GALVESTON, TEXAS

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ABSTRACT

Buildings that may be available for use as potential vertical shelters in Galveston, Texas are estimated and their physical characteristics summarized. Information is collected on the building ownership (public/private), its footprint area (i.e the area enclosed by the first floor), the number of floors in the building, the governing building code, the estimated age of the building, the structural materials, and the framing concept used. Classificatory criteria for the potential vertical shelters and placement of structures into an appropriate category are also developed.

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Introduction

In the event of a hurricane, shelters are made available to desiring residents. Traditionally, the capacity of these shelters, i.e. the number of people that can be sheltered, is based on the space requirement per person. Shelter capacity is estimated by dividing the total space available in a building by the space requirement per person. Therefore, the shelter capacity is a function of the total space available and the space requirement per person.

In an earlier part of this study, we have argued that the expected number of fatalities in a given structure subjected to a given hurricane depends on the number of occupants in the structure, as well as the characteristics of the structure and the hurricane. Since the traditional method of determining shelter capacity ignores any consideration of risk, the method fails to provide a rational basis for selection of vertical shelters.

As an alternative to the traditional method of estimating shelter capacity, the following methodology is proposed. First, potential shelters are identified. Second, relevant statistical characteristics of the shelter and the hurricane are determined. Third, the risk (expressed in terms of expected fatalities) associated with using the shelter is estimated. Finally, the number of occupants in the shelter is based on some acceptable level of risk. In this portion of the study, we attempt to complete the first and second steps. The third and fourth steps are presented elsewhere.

Objective of the Study

The first objective of this study is to estimate the number, and summarize the physical characteristics of, buildings that may be available for use as potential vertical shelters in Galveston, Texas. In the survey, information is to be collected on the building ownership (public/private), its footprint area (i.e the area enclosed by the first floor), the number of floors in the building, the governing building code, the estimated age of the building, the structural materials, and the framing concept used. The second objective of the study is to develop classificatory criteria for the potential vertical shelters and place each structure into an appropriate category. This categorization will simplify future risk computations for the vertical evacuation option for the city as a whole.

Methodology

The following methodology was developed to estimate the number of potential vertical shelters. First, criteria were established to identify potential structures and to collect the appropriate building data needed for further analysis. Areas of the city containing these buildings were then identified. Next, these areas were physically surveyed, the potential buildings were identified, and the buildings were classified by structural type and ownership. Finally, a standard building was defined for each structural type and the number of these buildings within the city was estimated.

Criteria for Selecting Potential Shelters

Criteria were established to identify potential shelters and to collect the data required to categorize those structures. The criteria used here to identify potential shelters are as follows:

1. The building must provide dry space in the event that the region is flooded;
2. The building must not be located in the high velocity zone;
3. Single family residences (including duplexes) are excluded as potential shelters;
4. Buildings which show signs of neglect or disrepair (in the opinion of the inspecting engineer) are to be excluded as potential shelters; and
5. Buildings which appear not to have received attention from professional architects and engineers are to be excluded as potential shelters.

The height requirement for potential shelters (criterion 1) can be determined from storm surge data. Figures 1 to 4 show the potential storm surge penetration for Galveston Island for hurricanes of intensities 74 mph to over 155 mph (2). Note that, except for the northeastern portion of the island protected by the seawall, the remainder of the island will be flooded in the event that a category 2 storm occurs. The maximum estimated surge height within the non-high velocity zone is 2.0 feet. For a hurricane of category 4 or greater, the entire island will be flooded. The maximum estimated surge height, which occurs during a category 4 storm twenty miles left of Galveston, is 10.8 feet above ground level (3). Therefore, to provide dry space, the structure must be at least two stories high.

Figure 5 shows the limits of the V-zone for the Island (1). As shown in the figure, the V-zone penetrates all of the island west of the airport and Galveston Bay. Therefore, only structures within the area east of the airport and north of Seawall Boulevard need be considered.

After applying the remaining criteria to the entire city, four areas were delineated which contained potential shelters. These areas included the Central Business District (CBD), the Seawall/beachfront area, the University of Texas Medical Branch, and a collection of schools. Each of these areas was then field surveyed to identify potential shelters and collect the needed data.

The Building Survey

In addition to identifying potential shelters, data were also needed to summarize the physical characteristics of the buildings. For each building, the following data were collected in a field survey:

1. The building address,
2. The building ownership (public/private),
3. The building footprint,
4. Number of stories in the building,
5. The governing building code,
6. The estimated age of the building,
7. The structural framing system used for the building, and
8. The major structural materials used for the building.

How this information was gathered for each of the four city areas is described below.

The Public Schools

The schools within the city were the first group of buildings to be surveyed for potential shelters. Due to the relatively small number of schools, which were located in the residential portion of the city, all schools were surveyed. A total of twenty buildings were identified, but only six met the criteria for potential shelters. The latter buildings were all of reinforced concrete/masonry construction and were two stories high. Footprints of these buildings ranged from approximately 12,000 square feet to 126,000 square feet. All six buildings were either recently constructed (within the last decade) or renovated. This information is presented in Table 1.

The University of Texas Medical Branch

The University of Texas Medical Branch was the second group of buildings in Galveston to be surveyed. Using existing maps of the campus, a list of buildings was first compiled. Next, a field survey was performed to see which of the buildings could possibly function as shelters. If a building was deemed suitable as a shelter, then the appropriate building data were collected.

The data for buildings on the University of Texas Medical Branch campus are summarized in Table 2. Of the 56 buildings on the campus, 34 met the criteria as potential shelters. All structures appeared to be reinforced concrete/masonry construction. The majority of these buildings were new, with a few older renovated structures. Heights of these buildings ranged from two to ten stories. Their functions included administration, academic, hospital/medical care and residential. Footprint areas also ranged from a low of 4,500 square feet to a maximum of 41,000 square feet.

The Central Business District

The buildings in the Central Business District were the third group to be surveyed. Since so many buildings were present in the region, the building characteristics for the area were estimated from a sample population. According to the Comprehensive Plan Report for the City of Galveston (4) the CBD is defined as the area bounded by the wharves, Avenue K, 19th Street, and 26th Street (Figure 5). This area encompasses a total of 69 blocks. To construct the sample, each block was assigned a number between 1 and 69. A random number table was used to produce a random ordering of the blocks. Each block, in the order selected, was then surveyed. The potential shelters in that block were identified and the needed data collected. The sampling was halted when the average footprint/building and average number of floors/building converged. Of the 69 blocks in the CBD, 24 were surveyed.

The CBD yielded a more varied assortment of building types and functions. As is typical for a business district the majority of the structures functioned as retail or commercial establishments; however, some residential buildings (i.e., apartments and hotels) were present. While a sizeable number of the buildings surveyed in the

CBD were built at the turn of the century, they appeared to be in good structural condition as a result of renovations. The sample of the CBD produced buildings as high as 11 stories, and footprints ranging from less than 3,000 square feet to slightly over 27,000 square feet. Also, a combination of steel framed and reinforced concrete/masonry structures were identified. The data for this category are summarized in Table 3.

The Seawall Area

Finally, the Seawall/beachfront area was surveyed for potential shelters. This area included those blocks along Seawall Boulevard beginning at 1st Street and continuing to 103rd Street. While not all numbered streets physically extend to Seawall Boulevard, their intersection with Seawall Boulevard was estimated. Initially, the Seawall area was inspected for city blocks which did not contain suitable structures. These blocks were eliminated from the survey. The remaining blocks were numbered consecutively, then randomly ordered for the field survey. The Seawall area was then surveyed for potential buildings in a manner similar to that used for the CBD. The sampling was stopped when the average footprint/building and number of floors/building converged. Seventy-five blocks along the Seawall contained potential shelters, and of these, a total of 40 were sampled.

Buildings in this area were built primarily for recreational or residential use (i.e., hotels or condominiums) and ranged in heights from two to 12 stories. Footprints of these structures ranged from

3,000 to 53,000 square feet. Along the seawall, framing systems used were found to be either rigid steel frame or concrete frame, with the exception of some low level condominiums which were wooden frame structures. Those buildings constructed of steel and pre-cast, post-tensioned concrete were counted as steel framed structures. Data for the sample of buildings on the seawall is summarized in Table 4.

Classification of Potential Shelters by Structural Type

Within each of these four geographical areas, the buildings were classified according to the structural framing and number of stories. From the data collected, six structural types were identified. The six structural types are defined in Table 5.

Recall that Tables 3 and 4 contained information only on the sample used for the CBD or the Seawall. For these two cases, the total number of buildings, in terms of the structural type defined in Table 5, were estimated using the equation:

$$B_{ti} = (N_b/n)B_i \qquad (1)$$

where: N_b = the number of blocks in the total population area; n = the number of blocks in the sample; B_i = the number of buildings in the sample for structural type i; and B_{ti} = the estimated number of buildings in the population for structural type i. The estimated number of buildings in the CBD and the Seawall/beachfront areas are summarized in Table 6. The distribution of buildings, by structural type and location, is summarized in Table 7.

Further details on each structural type is provided in Tables 8 and 9. Note that, although the average heights of the buildings belonging to one structural type varies little from area to area, the corresponding variation in the footprint of the same type is quite large. For example, the average footprint for a Type A school is more than eight times the area of an average Type A structure on the seawall.

Classification of Potential Shelters By Ownership

The potential shelters identified were next classified by ownership; that is public or private. Fortunately, all of the structures in any of the areas conveniently fell into one of the above categories. The majority of the schools and the buildings of the University of Texas Medical Branch were public property. The potential shelters within the CBD, with the exception of a few governmental buildings, were found to be privately owned. The buildings in the Seawall/beachfront area were also privately owned. The potential shelter areas for private and public structures is summarized in Table 10 as a function of the structural type.

Definition of Standard Buildings

A standard building may be defined as a building which belongs to one of the six structural types and whose height and footprint are related to the average values of the buildings in that category. For example, the standard Type A building will contain the weighted average of the footprint (12,250 sq. ft.) and the average number of stories (2) for all to the Type A buildings in the sample. The properties of the six standard buildings are summarized in Table 11. Note that the last columns in Tables 10 and 11 are identical.

Summary

The first objective of this study was to estimate the number and summarize the physical characteristics of buildings that may be available for use as potential vertical shelters in Galveston, Texas. Using the procedure outlined in this report we have found that:

1. Approximately 256 buildings, ranging from 2 to 12 stories in height are potential vertical shelters;
2. Approximately 12,000,000 square feet of floor space is available in thes structures;
3. Of the floor space available, 30 percent is located in public buildings; and
4. Seventy-seven (77) percent of the structures are reinforced concrete frames, sixteen (16) percent are wooden framed structures, and seven (7) percent are steel framed structures.

The second objective of this study was to develop classificatory criteria for potential structures then categorize each structure. The following six categories were identified: 1) Reinforced concrete frames, two stories high; 2) Reinforced concrete frames, three to five stories high; 3) Reinforced concrete frames, more than five stories high; 4) Steel frames, two stories high; 5) Steel frames, three or more stories high; and 6) Wooden frames, two to four stories high. In addition, the average characteristics of a building in each category was determined based on the properties of the structures in the survey population.

REFERENCES

1. Federal Emergency Management Agency, "Flood Insurance Rate Maps, City of Galveston, Texas, Galveston County", *National Flood Insurance Program*, October 16, 1984.

2. Ruch, Carlton, *Hurricane Relocation Planning for Brazoria, Galveston, Harris and Chambers Counties*, Center for Strategic Technology, Texas Engineering Experiment Station, Sea Grant College Program, TAMU-SG-81-604, Texas A&M University, College Station, Texas, June 1981.

3. Ruch, Carlton, *Hurricane Vulnerability Analysis for Brazoria, Galveston, Harris and Chambers Counties*, Research Division College of Architecture and Environmental Design, Texas A&M University, College Station, Texas, August 1983.

4. Springer, Marvin and Associates, *Comprehensive Plan Report City of Galveston, Texas*, Prepared for The Planning and Zoning Commission, December 1973.

Table 1. Galveston Schools That Are Potential Vertical Shelters

Bldg. No.	Footprint Area (SF)	No. of Stories	Ownership	Structural Frame Material
1	126,000	2	Public	RC[1]/masonry
2	69,300	2	Public	RC/masonry
3	60,800	2	Public	RC/masonry
4	41,000	2	Private	RC/masonry
5	12,600	2	Private	RC/masonry
6	38,000	2	Public	RC/masonry

[1]RC = Reinforced Concrete.

Table 2. University of Texas Buildings That Are Potential Shelters

Bldg. No.	Footprint Area (SF)	No. of Stories	Use
1	4,500	2	Office
2	15,000	5	Office
3	11,200	5	Academic
4	41,100	4	Academic
5	27,200	7	Hospital
6	37,400	2	Hospital
7	13,500	4	Academic
8	6,400	2	Academic
9	6,400	2	Academic
10	34,900	6	Hospital
11	6,400	2	Academic
12	23,400	6	Academic
13	12,200	4	Academic
14	22,400	5	Hospital
15	38,400	9	Hospital
16	30,900	10	Hospital
17	21,200	4	Hospital
18	31,500	6	Hospital
19	19,500	3	Academic
20	10,000	4	Academic
21	19,200	6	Academic
22	13,500	4	Academic
23	8,500	5	Academic
24	21,300	3	Library
25	6,400	2	Dorm
26	5,600	2	Dorm
27	5,600	9	Hospital
28	12,500	3	Academic
29	10,000	5	Hospital
30	20,600	5	Office
31	15,600	3	Hospital
32	13,100	2	Academic
33	6,400	2	Dorm
34	6,400	2	Dorm

1. All buildings are of reinforced concrete/masonry .
2. All buildings are publicly owned.

Table 3. Potential Vertical Shelters in the Central Business District

Bldg. No.	Footprint Area (SF)	No. of Stories	Ownership	Structural Frame Material	Use
1	4,300	2	Private	RC[1]/CMU[2]	Retail
2	8,400	2	Private	RC/CMU	Commercial
3	2,800	2	Private	CMU	Apartment
4	10,300	8	Private	RC	Commercial
5	9,800	3	Private	RC	Retail
6	9,800	2	Private	RC/CMU	Retail
7	7,800	3	Private	RC	Retail
8	20,000	4	Public	RC	Library
9	7,500	2	Private	RC	Commercial
10	13,100	5	Public	Steel	Office
11	9,400	2	Public	RC	Office
12	3,200	2	Private	CMU	Retail
13	2,800	2	Public	CMU	Commercial
14	4,700	4	Private	RC	Commercial
15	25,000	2	Private	RC	Commercial
16	5,000	2	Private	RC	Commercial
17	25,000	3	Private	Steel	Commercial
18	3,700	2	Private	CMU	Apartment
19	15,600	3	Private	RC	Commercial
20	9,000	10	Private	RC	Residential
21	18,200	6	Private	RC	Commercial
22	7,500	3	Private	RC	Office
23	8,500	2	Private	Steel	Office

Table 3. (Continued)

Bldg. No.	Footprint Area (SF)	No. of Stories	Ownership	Structural Frame Material	Use
24	5,300	2	Private	Steel	Office
25	12,700	2	Private	RC	Retail
26	23,900	2	Private	RC	Retail
27	7,000	3	Private	RC	Retail
28	3,500	3	Private	RC	Office
29	4,100	3	Private	RC	Office
30	9,400	2	Private	Steel	Commercial
31	8,400	3	Private	RC	Retail
32	22,500	2	Private	RC	Retail
33	24,100	4	Private	RC	Commercial
34	27,500	3	Private	RC	Retail
35	4,300	4	Private	RC	Retail
36	4,300	3	Private	RC	Retail
37	16,200	3	Private	RC	Commercial
38	11,300	3	Private	RC	Commercial
39	4,200	11	Private	RC	Commercial
40	4,200	5	Private	RC	Commercial
41	10,000	2	Private	RC	Office
42	4,200	2	Private	RC	Office
43	5,000	2	Private	RC	Commercial
44	5,000	2	Private	RC	Commercial
45	5,000	2	Private	RC	Commercial

[1]RC = Reinforced Concrete.
[2]CMU = Concrete Masonry Unit.

Table 4. Potential Vertical Shelters on the Seawall/Beachfront

Bldg. No.	Footprint Area (SF)	No. of Stories	Ownership	Structural Frame Material	Use
1	10,200	3	Private	CMU[1]	Residential
2	3,400	3	Private	CMU	Residential
3	6,600	4	Private	RC[2]	Commercial
4	24,400	5	Private	RC	Commercial
5	15,600	3	Private	Steel	Residential
6	12,600	11	Private	RC	Residential
7	12,500	5	Private	RC	Commercial
8	2,800	2	Private	RC	Commercial
9	8,400	2	Private	Wood	Commercial
10	11,300	2	Private	CMU	Residential
11	14,100	4	Private	RC	Residential
12	6,600	2	Private	CMU	Residential
13	6,600	2	Private	CMU	Residential
14	6,600	2	Private	CMU	Residential
15	6,750	2	Private	RC	Residential
16	53,100	2	Private	Wood	Residential
17	5,000	3	Private	CMU	Residential
18	5,000	3	Private	CMU	Residential
19	5,000	3	Private	CMU	Residential
20	5,000	3	Private	CMU	Residential
21	5,000	3	Private	CMU	Residential
22	5,000	3	Private	CMU	Residential
23	5,000	3	Private	CMU	Residential
24	9,000	8	Private	Steel	Residential

Table 4. (Continued)

Bldg. No.	Footprint Area (SF)	No. of Stories	Ownership	Structural Frame Material	Use
25	23,400	4	Private	Wood	Residential
26	23,400	4	Private	Wood	Residential
27	23,400	4	Private	Wood	Residential
28	23,400	4	Private	Wood	Residential
29	15,600	2	Private	Wood	Residential
30	10,000	12	Private	RC	Residential
31	34,000	3	Private	CMU	Residential
32	34,000	3	Private	CMU	Residential
33	28,100	4	Private	Wood	Residential
34	28,100	4	Private	Wood	Residential
35	9,400	2	Private	Wood	Residential
36	9,400	2	Private	Wood	Residential
37	9,400	2	Private	Wood	Residential
38	9,400	2	Private	Wood	Residential
39	9,300	6	Private	RC	Residential
40	22,500	4	Private	Wood	Residential
41	22,500	4	Private	Wood	Residential
42	22,500	4	Private	Wood	Residential
43	22,500	4	Private	Wood	Residential
44	22,500	4	Private	Wood	Residential
45	22,500	4	Private	Wood	Residential
46	22,500	4	Private	Wood	Residential
47	22,500	4	Private	Wood	Residential

[1]CMU = Concrete Masonry Unit.
[2]RC = Reinforced Concrete.

Table 5. Structural Categories for Potential Vertical Shelters

Structural Type	Description of Framing
A	Reinforced Concrete Frame, 2 stories
B	Reinforced Concrete Frame, 3-5 stories
C	Reinforced Concrete Frame, greater than 5 stories
D	Steel Frame, 2 stories
E	Steel Frame, greater than 2 stories
F	Wooden Frame, 2-4 stories

Table 6. Estimate of the Number of Potential Shelters in the CBD and Seawall

STRUCTURAL TYPE	CBD*		Seawall**	
	No. of Bldg. Sampled	Est. No. of Bldg.	No. of Bldg. Sampled	Est. No. of Bldg.
A	19	55	6	11
B	17	49	13	24
C	4	12	3	6
D	3	9	0	0
E	2	6	2	4
F	0	0	21	39

*$N_b/n = 2.9$
**$N_b/n = 1.9$

Table 7. Estimate of the Number of Potential Shelters By Location and Structural Type

STRUCTURAL TYPE	Building Estimate				TOTAL
	CBD	Seawall	UT[1]	Schools	
A	55	11	10	6	82
B	49	24	16	-	89
C	12	6	8	-	26
D	9	-	-	-	9
E	6	4	-	-	10
F	-	39	-	-	39

[1]University of Texas Medical Branch.

Table 8. Average Footprint per Building By Structural Type

STRUCTURAL TYPE	Average Footprint per Building (SF)				POPULATION AVERAGE*
	CBD	Seawall	UT[1]	Schools	
A	9,000	7,000	9,900	57,900	12,400
B	10,600	8,200	16,500	-	11,000
C	9,900	10,600	25,800	-	15,000
D	7,700	-	-	-	7,700
E	19,000	12,300	-	-	16,300
F	-	21,200	-	-	21,200

[1]University of Texas Medical Branch.
*Weighted Average.

Table 9. Average Number of Floors per Building By Structural Type

STRUCTURAL TYPE	Average Number of Floors				POPULATION AVERAGE*
	CBD	Seawall	UT[1]	Schools	
A	2.0	2.0	2.0	2.0	2.0
B	3.4	3.5	4.1	-	3.6
C	8.8	4.8	7.9	-	7.6
D	2.0	-	-	-	2.0
E	4.0	5.0	-	-	4.4
F	-	3.0	-	-	3.0

[1]University of Texas Medical Branch.
*Weighted Average.

Table 10. Total Area as a Function of Ownership

STRUCTURAL TYPE	Total Area (SF)		TOTAL AREA (SF)
	Public	Private	
A	893,000	1,144,000	2,037,000
B	1,015,000	2,455,000	3,470,000
C	1,983,000	1,351,000	3,334,000
D	-	108,000	108,000
E	-	678,000	678,000
F	-	2,480,000	2,480,000
Totals	3,891,000	8,216,000	12,107,000

Table 11. Properties of the Six Standard Buildings

STRUCTURAL TYPE	NO. OF BLDG.	Weighted Average		TOTAL AREA (SF)
		Footprint Area (SF)	No. of Floors	
A	85	12,000	2.0	2,040,000
B	79	11,000	4.0	3,476,000
C	32	15,000	7.0	3,360,000
D	7	8,000	2.0	112,000
E	9	16,000	5.0	720,000
F	39	21,000	3.0	2,457,000

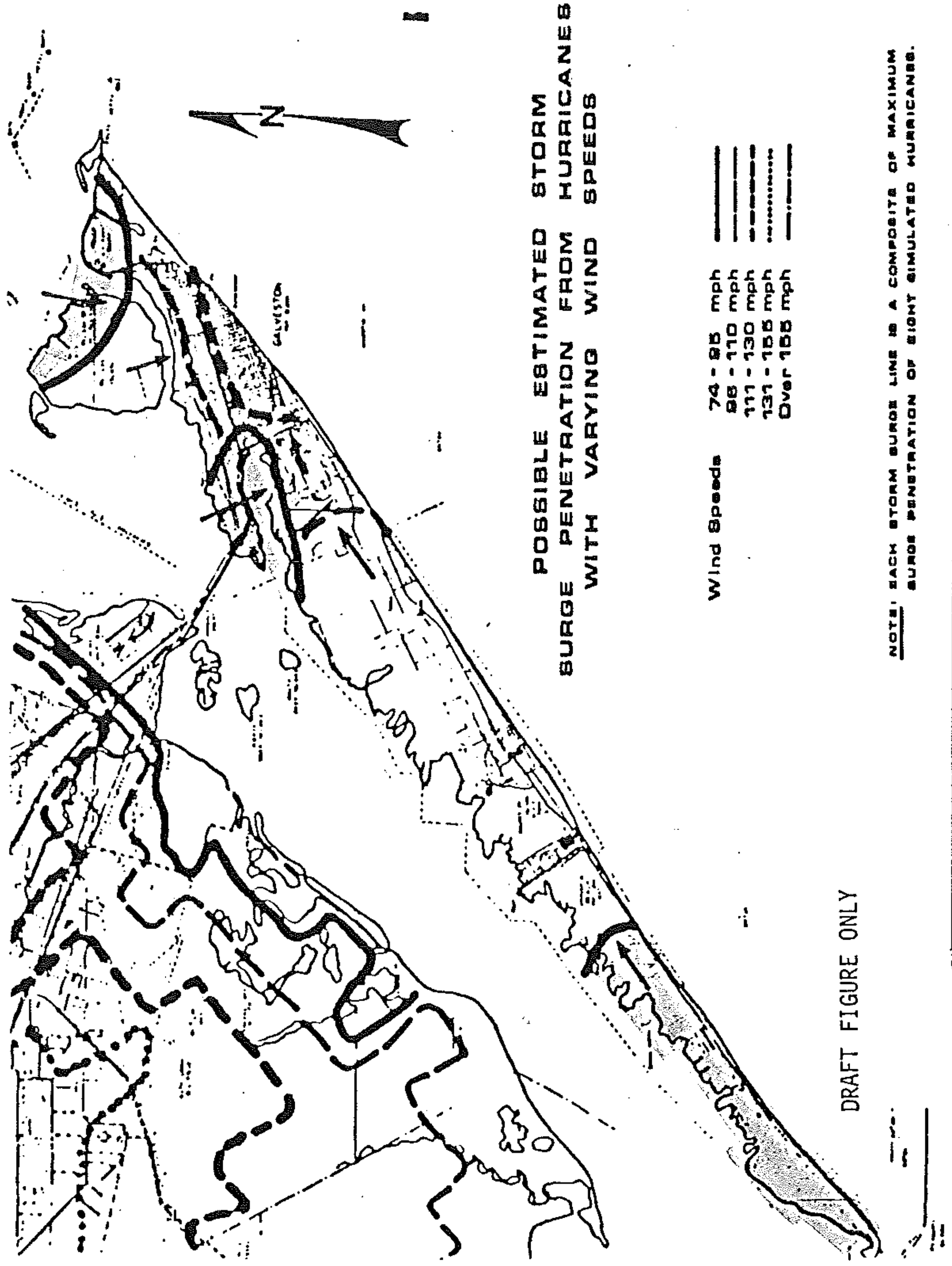

Figure 1. Potential Surge Penetration for a Category 1 Hurricane (Reference 2.)

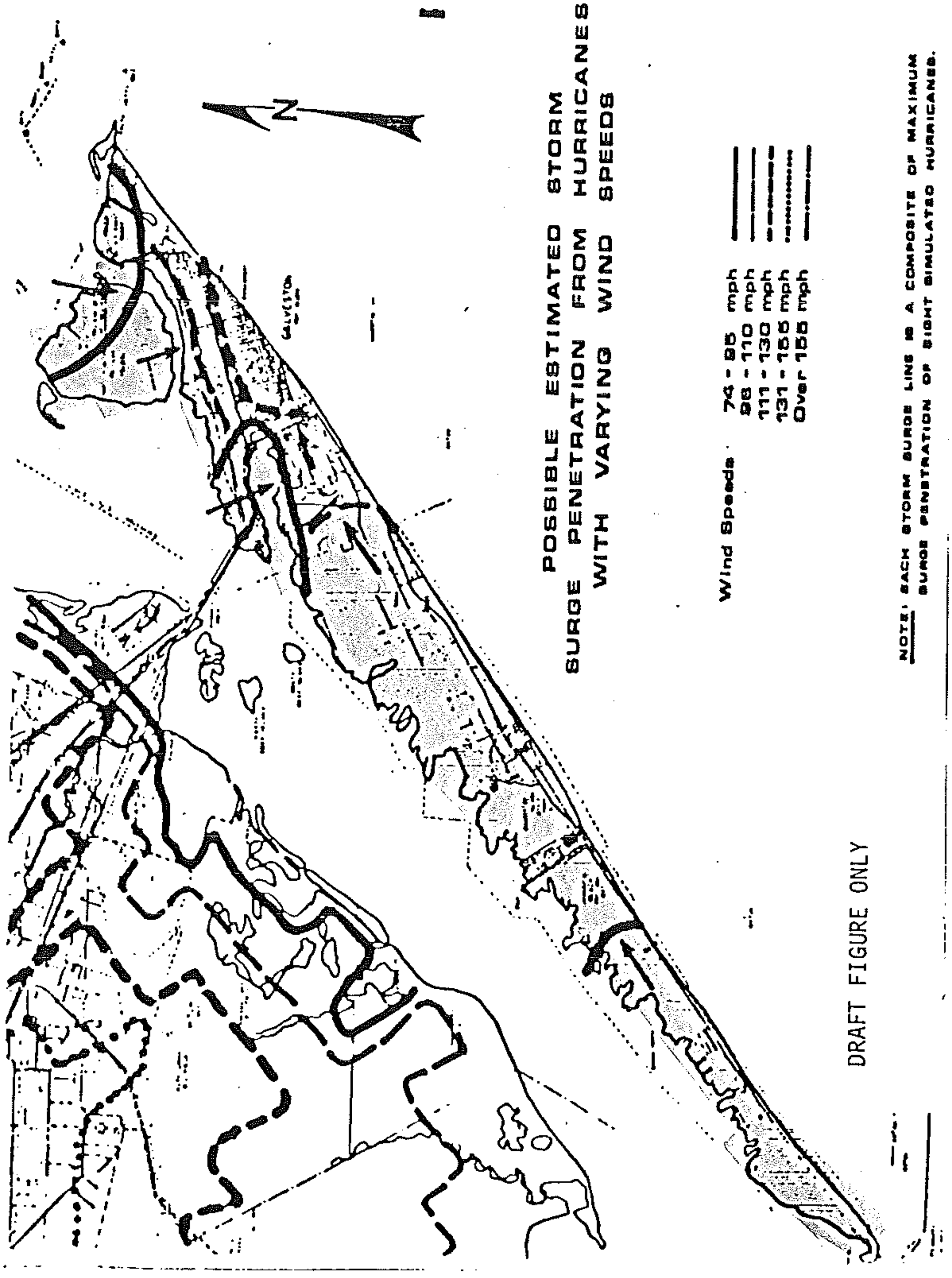

Figure 2. Potential Surge Penetration for a Category 2 Hurricane (Reference 2.)

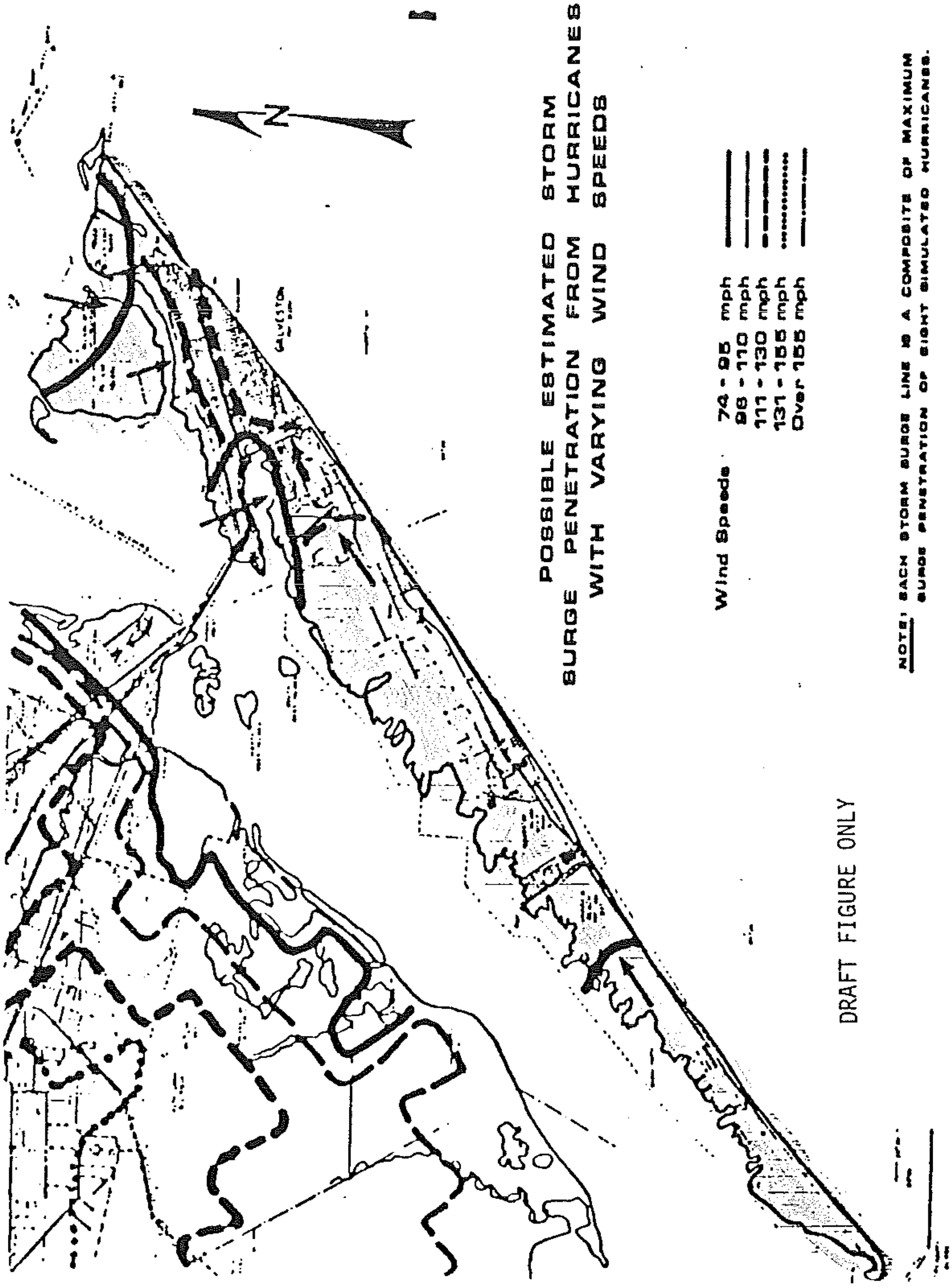

Figure 3. Potential Surge Penetration for a Category 3 Hurricane (Reference 2.)

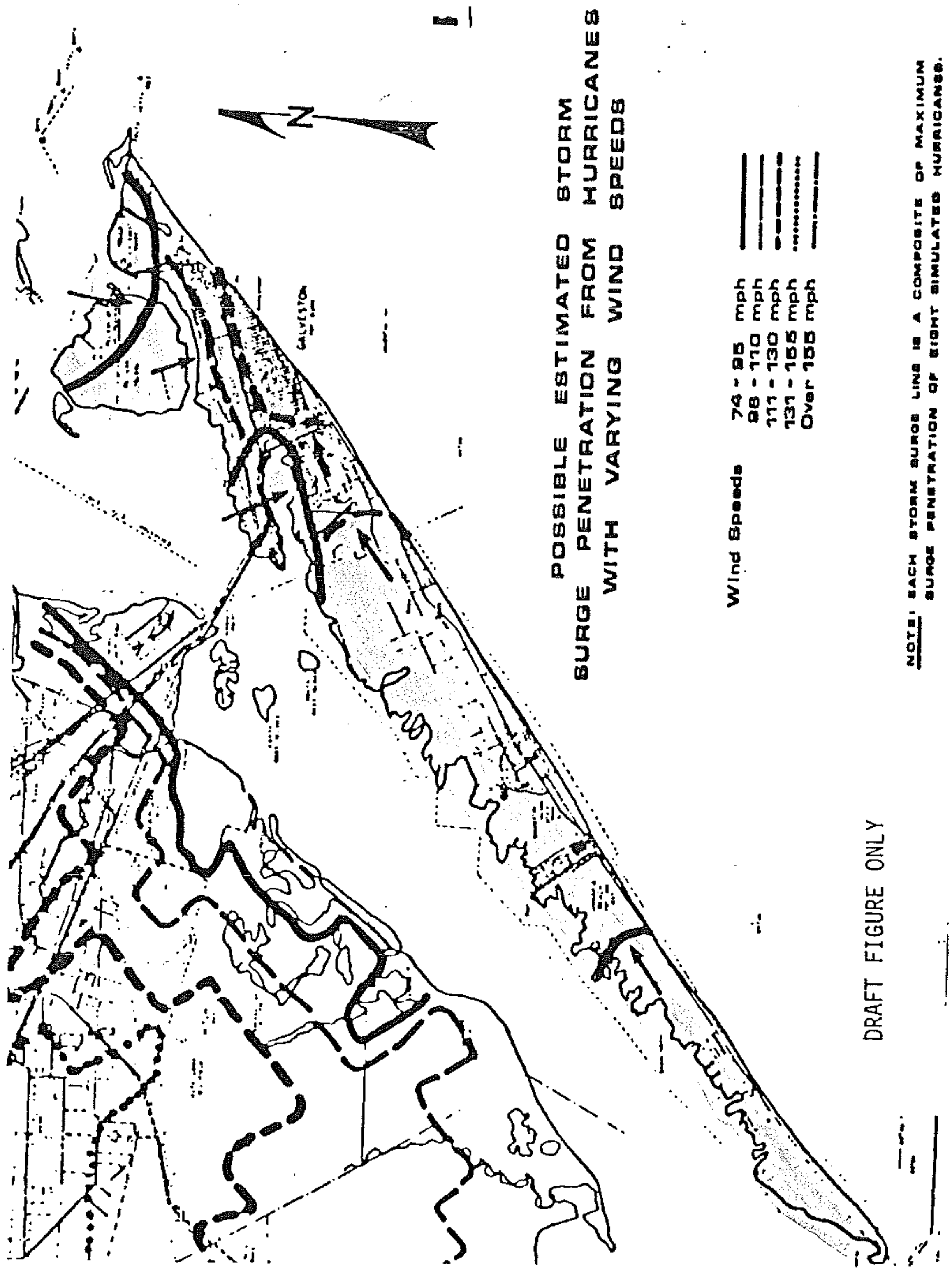

Figure 4. Potential Surge Penetration for Category 4 and 5 Hurricanes (Reference 2.)

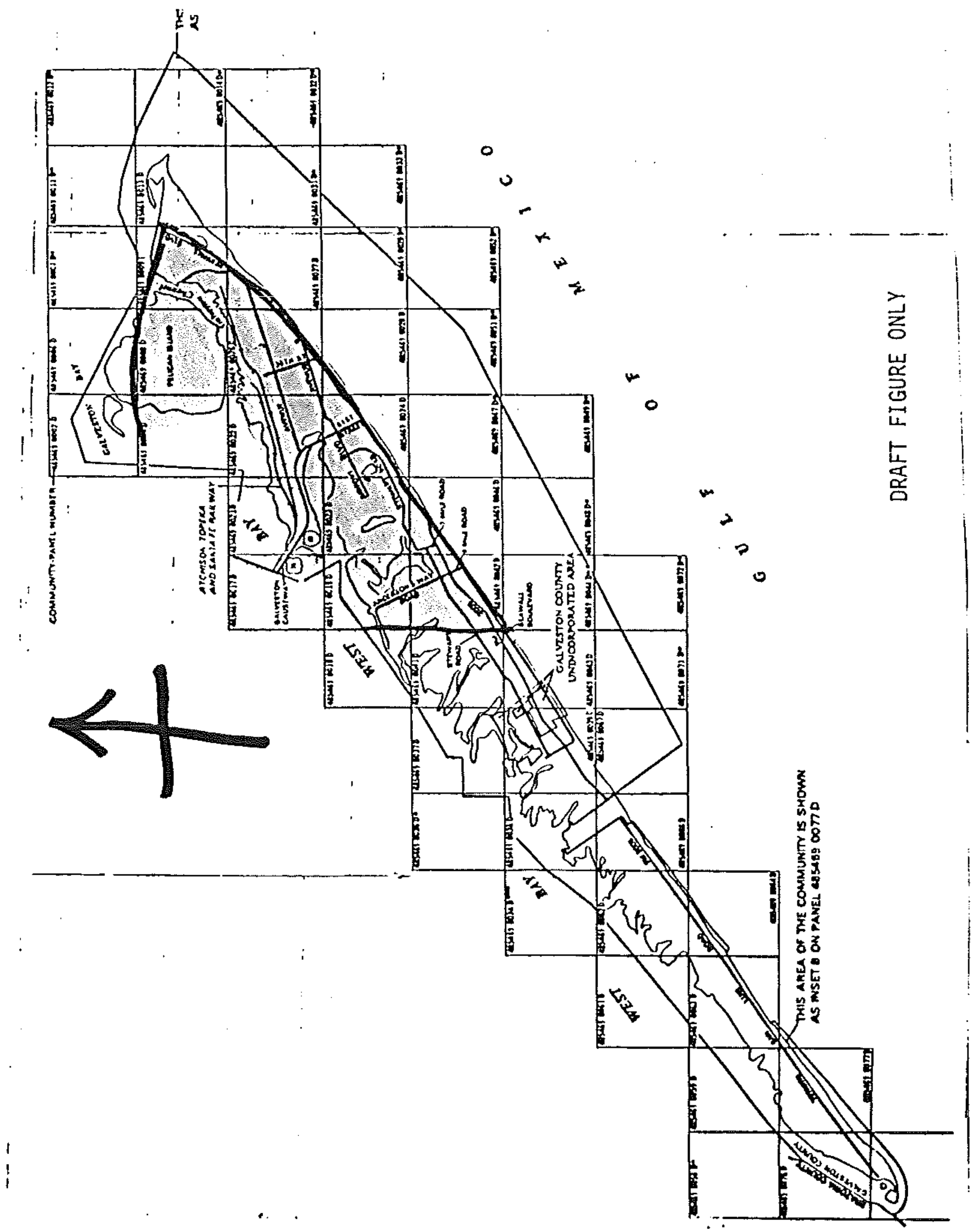

Figure 5. Limits of V-Zone for Galveston (Reference 1.)