D.2.7 Overland Wave Propagation

This subsection provides guidance for estimating wave heights and wave crest elevations on flooded land areas. FEMA's WHAFIS model is described.

D.2.7.1 Overview

The fundamental analysis of overland wave effects for an FIS is provided by the WHAFIS 3.0 program, a DOS-based program that uses representative transects to compute wave crest elevations in a given study area. Transects must be specified by the Mapping Partner, who must also identify topographic, vegetative, and cultural features along each transect landward of the shoreline. WHAFIS uses this and other input information to calculate wave heights, wave crest elevations, flood insurance risk zone designations, and flood zone boundaries along the transects (FEMA, 1988). The Mapping Partner can specify an incident wave height, or WHAFIS can compute an incident wave height at the seaward end of each transect. Please note that the WHAFIS-calculated incident wave height is based on the fetch provided by the Mapping Partner and does not take into account refraction, diffraction, or bottom dissipation effects. The Mapping Partner should perform separate wave transformation calculations if these effects will cause the incident wave height to depart markedly from the value generated by WHAFIS. The Mapping Partner should consult FEMA's approved wave model list at http://www.fema.gov/plan/prevent/fhm/en_coast.shtm if additional wave studies are required.

The original basis for the WHAFIS model was the 1977 NAS report *Methodology for Calculating Wave Action Effects Associated with Storm Surges*. The NAS methodology accounted for varying fetch lengths, barriers to wave transmission, and the regeneration of waves over flooded land areas. Because the incorporation of the NAS methodology into the initial version of WHAFIS, periodic upgrades have been made to WHAFIS to incorporate improved or additional wave considerations. Figure D.2.7-1 illustrates the basic factors that WHAFIS considers in its overland wave height and wave crest elevation calculations.

The current WHAFIS model is fully documented (*Technical Documentation for WHAFIS Program Version 3.0*, FEMA, September 1988). Briefly, the wave action conservation equation governs wave regeneration caused by wind and wave dissipation by marsh plants in the model. This equation is supplemented by the conservation of waves equation, which expresses the spatial variation of the wave period at the peak of the wave spectrum. The wave energy (equivalently, wave height) and wave period respond to changes in wind conditions, water depths, and obstructions as a wave propagates. These equations are solved as a function of distance along the wave analysis transect.

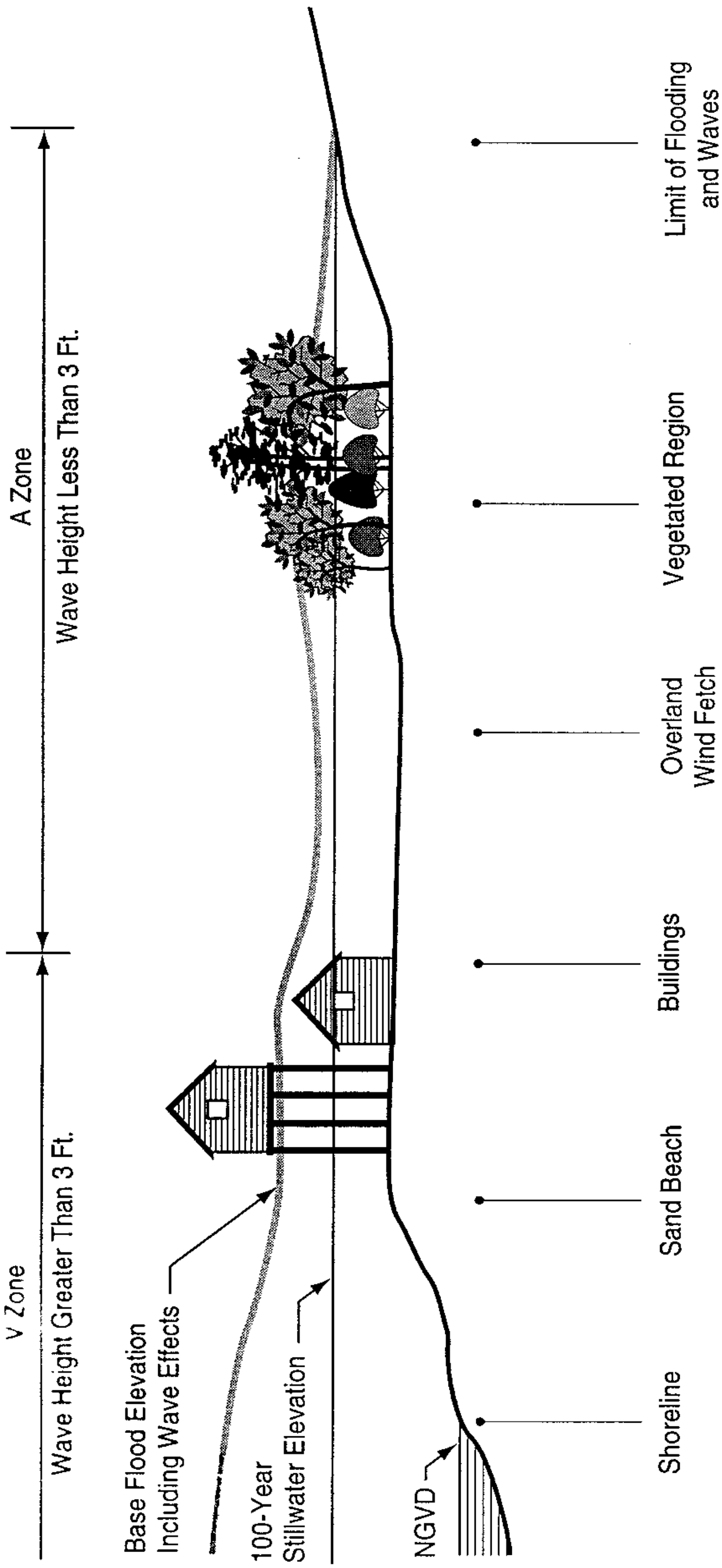

Figure D.2.7-1. Wave Height and Wave Crest Variations Along a WHAFIS Transect

A fundamental element in this wave treatment remains unchanged from the NAS methodology: the controlling wave height[5] (approximately, the average height of the highest 1 percent of waves during storm conditions) is limited to 78 percent of the local stillwater level depth. Also, the model assumes that 70 percent of the controlling wave height lies above the SWEL, resulting in the wave crest elevation being 0.55 times the local stillwater depth above the SWEL, or 1.55 times the local stillwater depth above the ground elevation (see Figure D.2.7-2).

The WHAFIS program is available as a stand-alone program, or as a part of FEMA's Coastal Hazard Analysis Modeling Program (CHAMP). CHAMP is a Windows-interfaced Visual Basic program that allows the user to enter data, perform coastal engineering analyses, view and tabulate results, and chart summary information for each representative transect along a coastline, within a user-friendly graphical interface. With CHAMP, the user can import digital elevation data; perform storm-induced erosion treatments, wave height analyses, and wave runup analyses; plot summary graphics of the results; and create summary tables and reports in a single environment.

- WHAFIS 3.0 is available at http://www.fema.gov/plan/prevent/fhm/dl_wfis3.shtm.
- CHAMP 1.2 is available at http://www.fema.gov/plan/prevent/fhm/dl_champ.shtm.

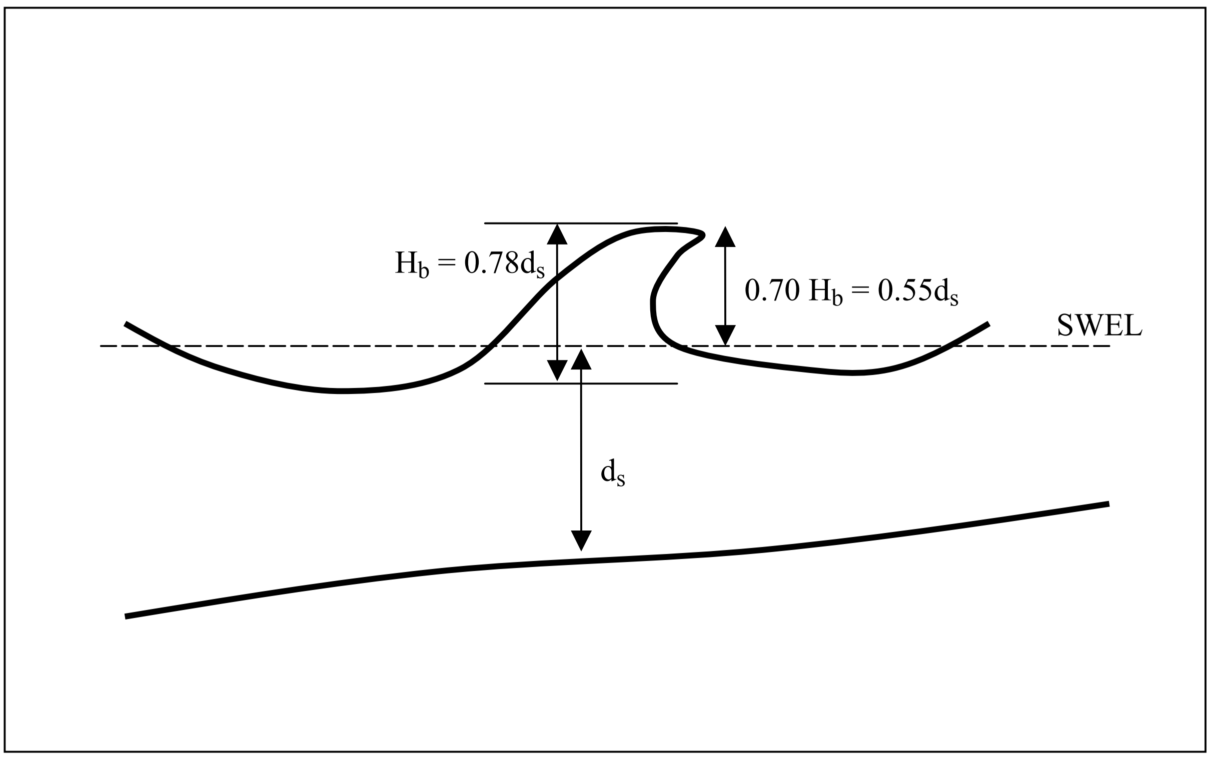

Figure D.2.7-2 WHAFIS relationships between local stillwater depth, d_s, maximum breaking wave height, H_b, and wave crest elevation.

[5] For NFIP purposes, the controlling wave height is taken to be 1.6 times the significant wave height.

D.2.7.2 WHAFIS Transect Considerations

The WHAFIS model considers the study area by representative transects. For accurate WHAFIS results, transects must be representative of major topographic, vegetative, and cultural features. Highly variable upland areas will require more closely spaced transects than areas where features are uniform. Closer spacing of transects may be also desirable along uniform upland areas, to reduce potential problems associated with the interpolation of flood insurance risk zones and BFEs between transects. However, Mapping Partners should be advised that spacing transects too closely may result in irregular gutters and an increased workload, without a significant increase in map quality. There are no set rules for transect spacing, but transects will usually be spaced from a few hundred feet apart (where upland characteristics are highly variable) to a few thousand feet apart (where uplands are uniform and development is sparse).

Transects should be located along any shoreline across which damaging waves may propagate during the base flood. This certainly includes all open-coast shorelines and other shorelines along large sheltered bodies of water subject to storm surge flooding (bays, sounds, and estuaries). However, damaging waves are not likely to accompany storm surge flooding along portions of small tributaries leading into large coastal bodies of water, particularly where those tributaries are narrow and winding and fetches are short. WHAFIS transects will not be required in these instances.

Transects should be oriented in the direction that waves propagate across the 0.0-ft NGVD29 or NAVD88 shoreline (from water to land) during the base flood. In most instances, this results in transects approximately perpendicular to the shoreline. However, in cases where the shoreline curves or has a highly variable shape (near tidal inlets or bay mouths, or on islands, or at the ends of peninsulas and spits), waves may approach at angles that deviate significantly from the perpendicular, and some transects may be required that are not shore-perpendicular. Another consequence of curved or irregular shorelines can be crossing transects. In general, specification of crossing transects should be minimized, but some crossings may be necessary to preserve the range of possible wave approach directions in the study area.

Some situations may arise where barrier islands are flooded during a severe storm, and transects can be drawn from the island's open-coast shoreline across a bay or sound and onto the mainland. If there is a large and/or unusually shaped embayment behind the island, it may be necessary to place additional transects just along the mainland shore. These transects may not be parallel to the transects originating at the island's open coast, and they may cross the longer, open-coast transects. The Mapping Partner may consider using multiple sets of transects (one set limited to the island, and one crossing the mainland shoreline) before the final transect selection is made.

The Mapping Partner shall also consider multiple flooding sources when specifying transects. For example, different transects may be required along different sides of a barrier island, if both the open coast and the back side of the island are subject to waves during a severe storm (high winds and waves may approach the island from different directions). This situation may require multiple specifications for water level and wave height, and multiple overland wave height analyses, with the flood map based on the more severe water level and wave conditions on land. Ultimately, transect specification requires a balance between representing coastal flood and severe wave conditions in developed upland areas (or other upland areas of interest) and study resources. In some cases, multiple analyses may be required and conducted; in other cases, a single analysis based on the dominant flood source and associated wave conditions may be performed.

D.2.7.3 WHAFIS Input Considerations

Another important consideration is the specification of input water level and wave conditions for each transect. On open coast Atlantic and Gulf shorelines, the typical procedure is to specify the peak (1-percent-annual-chance) SWEL (including wave setup) and the peak significant wave height (or the initial period of dominant waves) at the transect start. WHAFIS then computes an appropriate depth-limited wave height at the transect start. The only check necessary is to confirm that incident waves are likely to exceed that height and that a wave condition limited by water depth occurs.

On sheltered shorelines, the procedure is not as simple. The peak water level and peak wave conditions may not occur at the same time. For example, winds blowing across the longest fetch, which generate the highest wave heights at a particular shoreline, may also act to empty a water body or set down the water level. In such cases, the Mapping Partner may have to conduct several analyses, using different combinations of water levels and associated wave conditions, to determine the most severe upland flood conditions to be mapped. The Mapping Partner should keep in mind that on some sheltered shorelines the peak wave height may be smaller than the depth-limited height at the shoreline.

The Mapping Partner should also be aware that mapping flood hazards on an island or an upland area with multiple shorelines and flood sources may actually involve the mapping of a statistical flood surface, not a hydraulic surface representing a single flood event. This scenario is most likely where a barrier island is separated from the mainland by a bay or sound large enough to generate large waves against the back side of the island, and where flooding and waves can strike the island from two directions. A complete analysis of this scenario require the specification of transects, water levels and wave conditions at both shorelines, and multiple WHAFIS analyses. At any point on the island, the highest water surface and wave heights from the analyses would control the flood mapping.

Past practice in such cases has sometimes involved running a single set of transects across the island, starting at the side with the highest SWEL and most severe waves. The user then identified an area of transition between the different SWELs, with the higher SWEL extending inland to the highest point of the ground profile, after erosion considerations have been addressed. WHAFIS performed a linear interpolation within a transect segment where SWELs differed at the end stations. The interpolated elevations were compared to the ground elevations and adjusted, if necessary, to be above the ground elevations. Using this method, the Mapping Partner may have to input the SWEL a second time to identify areas of constant elevation and elevation transition.

Mapping Partners should note that the increasing use of modern hydrodynamic, storm surge, and wave models to provide input water level and wave conditions may complicate the specification of WHAFIS incident conditions at the shoreline and base flood SWELs along transects. Mapping partners shall consult with the FEMA Study Representative before using outputs from these models to specify WHAFIS inputs.

Once water level and wave conditions are determined and ground elevations along transects are input, natural and cultural features along the transects shall be specified.

- Vegetation: WHAFIS has two separate routines for vegetation: one for rigid vegetation that can be represented by an equivalent “stand” of equally spaced circular cylinders (NAS, 1977), and one for marsh vegetation that is flexible and oscillates with wave action (FEMA, 1984). For either type, the Mapping Partner shall exercise considerable care in selecting representative parameters and in ruling out the possibility that the vegetation will be intentionally removed or that effects would be markedly reduced during a storm through erosion, uprooting, or breakage. Details on coding vegetation are contained in Subsection D.2.7.3.2.

- Coastal Structures: The location, height, and extent of elongated manmade structures (seawalls, revetments, dikes, and levees, for instance) should be identified and shown as part of the ground profile, after each structure’s stability under forces of the base flood is confirmed as discussed in Subsection D.2.10.

- Buildings: Buildings shall be specified on the transect as rows perpendicular to the transect. Because buildings are not always situated in perfect rows, the Mapping Partner shall exercise judgment to determine which buildings can be represented by a single row. The required input value for each row of buildings is the ratio of open space to total space. This is simply the sum of distances between buildings in a row, divided by the total length of that row. The Mapping Partner shall examine the first several rows of buildings along the shoreline to determine whether they will be obstructions during the base flood – only large, fully-engineered buildings with solid, nonbreakaway shearwalls, deep beams, or other horizontal structural elements extending below the BFE should be considered as obstructions. It is useful to contact local officials to obtain construction information and the lowest floor elevations of structures before coding buildings as obstructions. If buildings are elevated above the base flood wave crest on pilings, columns, or other open foundations, waves will propagate under the structures with minimal reduction in height. The mapping partner should code these buildings using the BU card (see Subsection D.2.7.3.1) and indicate 100-percent open space. This procedure acknowledges the presence of the pile-elevated buildings and allows others to see that the buildings were considered in the analysis, but recognizes that the presence of the open-foundation buildings will not lead to wave height reductions or flood insurance risk zone changes.

- Post-Storm Situations: Mapping Partners may encounter situations where many or all of the buildings and development in a study area have been destroyed during a storm. Mapping Partners must decide whether to run WHAFIS using existing (close to bare earth) conditions or with the assumption that most of the buildings and development will be replaced in a short period of time. Unless directed otherwise by the FEMA Study Representative, Mapping Partners shall code WHAFIS transects to the conditions that exist at the time of the study, and not in anticipation of future buildings and development in the study area. The Mapping Partner has no assurance of the exact nature or location of future buildings and development, so including them in WHAFIS is not appropriate.

WHAFIS allows the user to account for wave regeneration over flooded areas, using either the overwater fetch (OF) or inland fetch (IF) transect codes. WHAFIS uses an 80-mph sustained windspeed for OF calculations during the base flood, and a 60-mph sustained windspeed for IF calculations.

D.2.7.3.1 Input Coding for WHAFIS

After all the necessary input data have been identified on the transect, the Mapping Partner performing the study shall divide the transect into contiguous segments, each representing a continuous open fetch or a single obstruction. Fetches are flooded areas with no obstruction, while obstructions include dunes, manmade barriers, buildings, and vegetation. The Mapping Partner shall subdivide the fetches at points where the ground elevation changes abruptly and in the transition area of changing SWELs. The Mapping Partner shall subdivide obstructions into smaller segments at the transect's seaward edge to model the wave dissipation more accurately. Rigid vegetation shall have two to three seaward segments, extending 10 to 50 feet, and the first two or three rows of buildings shall have a segment for each row. Marsh vegetation will be subdivided within WHAFIS, so segmented input from the Mapping Partner is not necessary.

The Mapping Partner shall enter the necessary data using 11 line types, including the title line. The 10 remaining lines, each describing a certain type of fetch or obstruction, are listed as follows:

- The Initial Elevation (IE) line describes the initial overwater fetch and the initial SWELs.
- The IF and OF lines define the endpoint stationing and the elevation of inland and overwater fetches, respectively.
- Obstructions are categorized either as buildings (BU line), rigid vegetation (VE line), marsh vegetation (VH and MG lines), dunes or other natural or manmade elongated barriers (DU line), or areas where the ground elevation is greater than the base SWEL (AS line).
- The End of Transect (ET) line requires no data but indicates the end of the input data.

Each line has an alphanumeric field describing the type of input for that line, followed by 10 numeric fields describing the parameters.

To ensure proper modeling, the Mapping Partner shall enter all segments of each transect either as fetches or obstructions, with one input line used for each fetch or obstruction segment. The first two columns of each line identify the type of fetch or obstruction. The remaining 78 columns consist of one field of six columns followed by nine fields of eight columns. The Mapping Partner shall right-justify the numbers in any data field only if no decimal point is used. Decimal points are permitted but not required. The endpoint of one fetch or obstruction is the beginning of the next. The first two numeric fields of each line are used to read in the stationing (measured in feet from the beginning of transect) and elevation (in feet) of the endpoint. The last two fields used on each line are for entering new SWELs. An interpolation is performed within a transect segment starting at the closest station with an input SWEL. This interpolation uses the new SWEL input at the endpoint of the segment, and the SWEL input at a previous segment. If these fields are blank or zero, the SWELs remain unchanged.

The input data requirements are summarized below for each line type. The Title line must be the first line, followed by the IE line, followed by any combination of the various fetch and obstruction lines. The ET line must be the last card entered for the transect. A blank line must follow to signify the end of the run. If multiple transects are being run, the Title line for the next transect will follow the blank line. All units are in feet unless otherwise specified.

TITLE Line (Title)
This line is required and must be the first input line.

Data Field	Columns	Contents of Data Fields
0	1-2	Blank
1-10	3-80	Title information centered about column 40

<u>IE Line (Initial Elevations)</u>

This line is required and must be the second line. It is used to begin a transect at the shoreline and to compute the wave height arising through the overwater fetch.

Data Field	Columns	Contents of Data Fields
0	1-2	IE
1	3-8	Stationing of endpoint of initial overwater fetch, in feet (zero at beginning of transect)
2	9-16	Ground elevation at endpoint in feet (usually zero at beginning of transect)
3	17-24	Overwater fetch length (miles), if wave condition is to be calculated. Values of 24 miles or greater yield identical results.
4	25-32	10-percent-annual-chance SWEL in feet
5	33-40	1-percent-annual-chance SWEL in feet
6	41-48	Initial wave height in feet; a blank or zero causes a default to a calculated wave height
7	49-56	Initial wave period (seconds); a blank or zero causes a default to a calculated wave period. The period is usually the most convenient wave specification for open coasts.
8-10	57-80	Not used

AS Line (Above Surge)

This line is used to identify the endpoint of an area with a ground elevation greater than the 1-percent-annual-chance SWEL (such as a high dune or other land mass). It is used when the ground surface temporarily rises above the 1-percent-annual-chance SWEL. The line immediately preceding the AS line must enter the stationing and elevation of the point at which the ground elevation first equals the 1-percent-annual-chance SWEL. The SWEL on the inland side may differ from the SWEL on the seaward side. The ground elevation entered on the AS line must equal the SWEL that applies to the inland side of the land mass. Computer calculations will be terminated if a ground elevation greater than the 1-percent-annual-chance SWEL is encountered.

Data Field	Columns	Contents of Data Fields
0	1-2	AS
1	3-8	Stationing at endpoint, in feet, of area above 1-percent-annual-chance SWEL
2	9-16	Ground elevation in feet at endpoint
3	17-24	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to the 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

BU Line (Buildings)

This line enters information needed to compute wave dissipation at each group of buildings.

Data Field	Columns	Contents of Data Fields
0	1-2	BU
1	3-8	Stationing of endpoint, in feet, of group of buildings
2	9-16	Ground elevation at endpoint, in feet
3	17-24	Ratio of open space between buildings to total transverse width of developed area
4	25-32	Number of rows of buildings
5	33-40	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
6	41-48	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
7-10	49-80	Not used

DU Line (Dune)

This line enters information necessary to compute wave dissipation over flooded sand dunes and other natural or manmade elongated barriers (such as levees and seawalls).

Data Field	Columns	Contents of Data Fields
0	1-2	DU
1	3-8	Stationing at top of dune or barrier, in feet
2	9-16	Elevation at top of dune or barrier, in feet
3	17-24	A blank or zero indicates a dune or other natural barrier; any other number indicates a seawall or other manmade barrier
4	25-32	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
5	33-40	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
6-10	41-80	Not used

IF Line (Inland Fetch)

This line enters the parameters necessary to compute wave regeneration through somewhat sheltered fetches and over shallow inland water bodies. The IF regeneration is computed using a sustained windspeed of 60 mph.

Data Field	Columns	Contents of Data Fields
0	1-2	IF
1	3-8	Stationing at endpoint of fetch, in feet
2	9-16	Ground elevation at endpoint, in feet
3	17-24	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

OF Line (Overwater Fetch)

This line enters the parameters necessary to compute wave regeneration over large bodies of water (such as large lakes or bays) using a sustained windspeed of 80 mph. If an inland body of water is sheltered and has a depth of 10 feet or less, the IF line calling for reduced windspeed should be used.

Data Field	Columns	Contents of Data Fields
0	1-2	OF
1	3-8	Stationing at endpoint of fetch, in feet
2	9-16	Ground elevation at endpoint, in feet
3	17-24	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
4	25-32	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
5-10	33-80	Not used

VE Line (Vegetation)

This line enters parameters necessary to compute wave dissipation due to rigid vegetation stands. See Subsection 2.7.3.2 for additional information on coding with the VE card.

Data Field	Columns	Contents of Data Fields
0	1-2	VE
1	3-8	Stationing at endpoint of vegetation, in feet
2	9-16	Ground elevation at endpoint, in feet
3	17-24	Mean effective diameter of equivalent circular cylinder, in feet
4	25-32	Average actual height of vegetation, in feet
5	33-40	Average horizontal spacing between plants, in feet
6	41-48	Drag coefficient; a blank or zero, causes a default to 1.0
7	49-56	A blank or zero indicates no change to 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
8	57-64	A blank or zero indicates no change to 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
9-10	65-80	Not used

VH Line (Vegetation Header for Marsh Grass)

Marsh grass is often part of a plant community that may consist of several types. The VH line is used to enter data that apply to all plant types modeled in the transect segment. To enter data for each plant type, MG lines for each plant type must follow the VH line. See Subsection 2.7.3.2 for additional information on coding with the VH card.

Data Field	Columns	Contents of Data Fields
0	1-2	VH
1	3-8	Stationing at endpoint of marsh vegetation segment, in feet
2	9-16	Ground elevation at endpoint, in feet
3	17-24	Reg_p, number of the primary seacoast region for default plant parameters. See Figure D.2.7-3.
4	25-32	Wt_p, weighting factor for the primary seacoast region
5	33-40	Reg_s, number of secondary seacoast region. See Figure D.2.7-3
6	41-48	N_{p1}, number of plant types; range is 1 to 10, inclusive. One MG line is required for each plant type.
7	49-56	A blank or zero indicates no change to the 10-percent-annual-chance SWEL; otherwise new 10-percent-annual-chance SWEL
8	57-64	A blank or zero indicates no change to the 1-percent-annual-chance SWEL; otherwise new 1-percent-annual-chance SWEL
9	65-72	Not used
10	73-80	This field is for overriding the default method of averaging flood hazard factors in A Zones; if 1 in column 80, averaging process begins or ends at end of vegetation segment; otherwise, default averaging method is used

MG Line (Marsh Grass)

This line is used to enter data for a particular plant type. The first MG line must be preceded by a VH line. For the common seacoast marsh grasses listed in Table D.2.7-2, some potentially useful default values are supplied in Table D.2.7-4, and the program can provide additional default values (FEMA, October 1984). If a plant type not listed in the table is used, then appropriate data must be developed for Fields 2 through 9. See Subsection 2.7.3.2 for additional information on coding with the MG card.

Data Field	Columns	Contents of Data Fields
0	1-2	MG
1	5-8	Marsh plant type abbreviation (see Table D.2.7-2)
2	9-16	C_D, effective drag Coefficient; default value is 0.1
3	17-24	F_{cov}, decimal fraction of vegetated area to be covered by this plant type; a blank or zero causes a default to be calculated so that each plant type is represented equally
4	25-32	h, mean unflexed height of stem (feet); for marsh plants, the inflorescence is not included
5	33-40	N, number of plants per square foot
6	41-48	D_1, base stem diameter (inches)
7	49-56	D_2, midstem diameter (inches)
8	57-64	D_3, top stem diameter (inches)
9	65-72	CA_b, ratio of the total frontal area of cylindrical part of leaves to frontal area of main stem
10	73-80	Not used

ET Line (End of Transect)

This line is required and must be the last card, because it identifies the end of input for the transect.

Data Field	Columns	Contents of Data Fields
0	1-2	ET
3-10	3-80	Not used

D.2.7.3.2 Treatment of Vegetation by WHAFIS

For the areas of rigid vegetation located on the transect, the required input values are the drag coefficient, CD; mean wetted height, h; mean effective diameter, D; and mean horizontal spacing, b. The value of CD should vary between 0.35 and 1.0, with 1.0 being used in most cases of wide vegetated areas. When the vegetation is in a single stand, the Mapping Partner shall use a value of 0.35. The Mapping Partner shall obtain representative values for h, D, and b from field surveys.

For marsh vegetation, a more complicated specification is required for completeness. The eight parameters used to describe the dissipational properties of a specific type are explained in Table D.2.7-1. However, WHAFIS incorporates considerable basic information on the eight common types of seacoast marsh plants listed in Table D.2.7.2 (FEMA, 1984). That information can be used by specifying either the Table D.2.7.2 abbreviation or a geographical region, as indicated in Figure D.2.7-3. Figure D.2.7-3 shows the coastal wetland regions of the Atlantic and Gulf coasts, along with the identifying numbers used in WHAFIS. If the site is near a regional border, the likely plant parameters can be interpolated using an input weighting factor. Although the South Texas region has insignificant amounts of marsh grass, it is included for use in spatial interpolation. Figures D.2.7-4 and D.2.7-5 provide information on the typical salt tolerance and vertical distribution of plants across the profile.

Climate affects the geographic range of each marsh plant type, so that some plant types are not found in all regions. Table D.2.7-3 lists the dominant plant type in each region, where the term “dominant” refers to the plant types that cover the largest amount of area in the marshes. Table D.2.7-4 shows the significant plant types in each region, where the term “significant” refers to the plant types that occur in large enough patches (at least 10,000 square feet) to significantly affect waves. For marsh plants, simply the coastal wetland region, plant type, and area or percentage of coverage may be specified. Given this information, WHAFIS will supply default values for the other marsh plant parameters appropriate to the site (FEMA, 1984).

Following the identification of the marsh plant types present, the area and fraction of coverage, F_{cov}, for each plant type must be calculated. The total area of marsh vegetation coverage is determined for each transect. The different types of vegetation within this area usually occur in patches. F_{cov} is defined for each plant type as the ratio of the patch area for that type to the total marsh area. Using the above data, a fairly good determination can be made of the plant types present, but an attempt should be made to confirm these plant types. Local, county, or State officials may provide some assistance, and a site visit can be very useful.

Table D.2.7-1. Marsh Plant Parameters

Parameter	Explanation
C_D	Effective drag coefficient. Includes effects of plant flexure and modification of the flow velocity distribution. Default value is 0.1, usually appropriate for marsh plants without strong evidence to the contrary.
F_{cov}	Fraction of coverage. A default value is calculated by the program so that each plant type in the transect is represented equally, and the sum of the coverage for the plant types is equal to 1.0.
h	Unflexed stem height (feet). The stem height does not include the flowering head of the plant, the inflorescence.
N	Number density. Expressed as plants per square foot. The relationship to the average spacing between plants, b, can be expressed as $N = 1/b^2$.
D_1	Base stem diameter (inches). Default value may be determined from stem height and regression equations built into the program.
D_2	Midstem diameter (inches). Default value may be determined from plant type and base stem diameter.
D_3	Top stem diameter (inches), at the base of the inflorescence. Default value may be determined from plant type and base stem diameter.
CA_b	Ratio of the total frontal area of the cylindrical portion of the leaves to the frontal area of the stem below the inflorescence. Default value may be determined from the plant type.

Table D.2.7-2. Abbreviations of Marsh Plant Types used in WHAFIS

Species or Subspecies	Abbreviation
Cladium jamaicense (saw grass)	CLAD
Distichlis spicata (salt grass)	DIST
Juncus gerardi (black grass)	JUNM
Juncus roemerianus (black needlerush)	JUNR
Spartina alterniflora (medium saltmeadow cordgrass)	SALM
Spartina alterniflora (tall saltmeadow cordgrass)	SALT
Spartina cynosuroides (big cordgrass)	SCYN
Spartina patens (saltmeadow grass)	SPAT

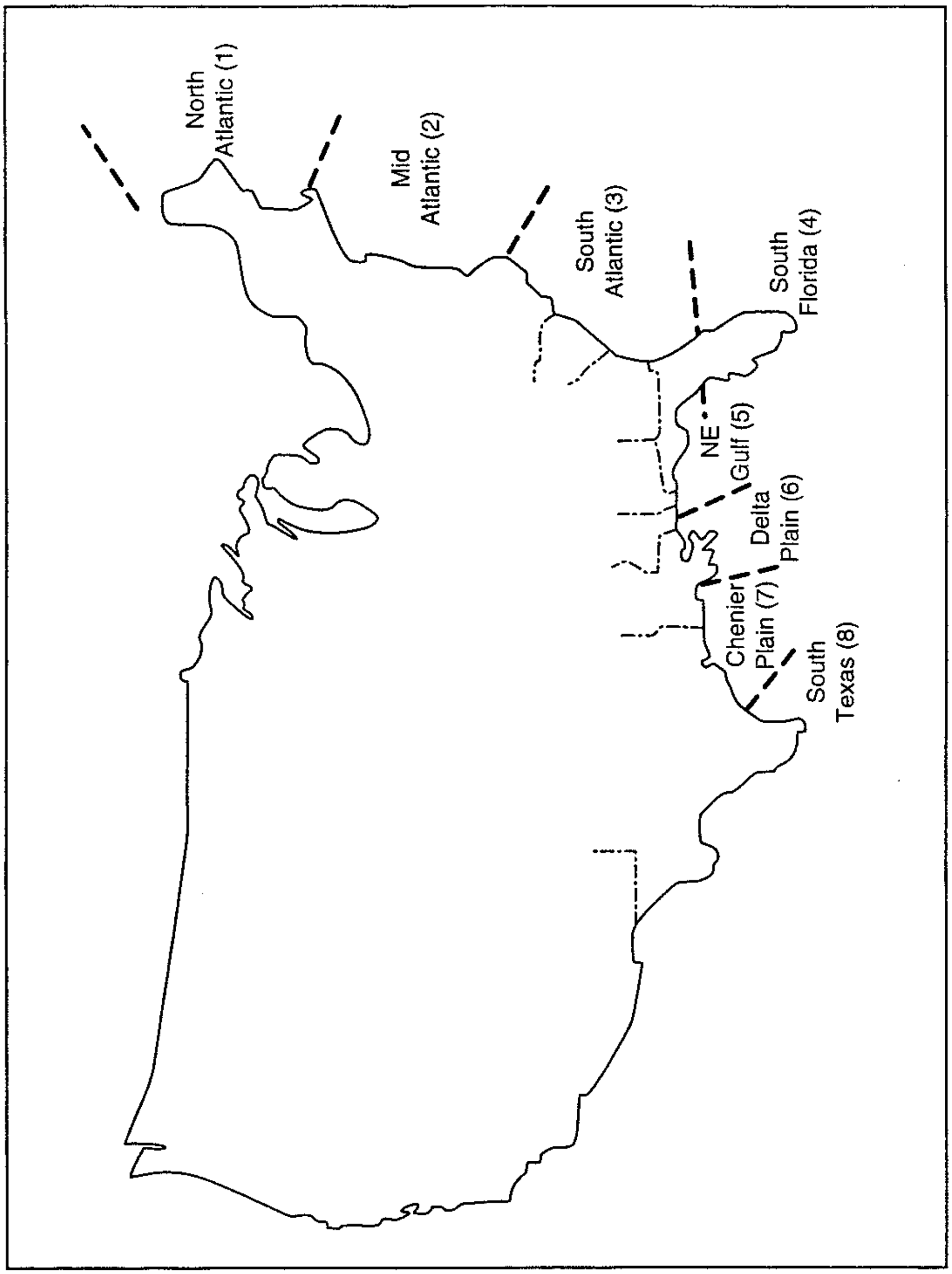

Figure D.2.7-3. Coastal wetland regions of Atlantic and Gulf coasts having enough marsh grass to significantly affect wave heights.

Table D.2.7-3. Dominant Marsh Plant Types by Region and Habitat

Region Number	Region Name	Habitat	Dominant Species
1	North Atlantic	salt[1] brackish[2]	**S. alterniflora* (medium, tall) *Spartina patens*
2	Mid-Atlantic	salt brackish	*S. alterniflora* (medium, tall) **Juncus roemerianus/S. patens*
3	South Atlantic	salt brackish	**S. alterniflora* (medium, tall) *J. roemerianus*
4	South Florida	salt brackish	*S. alterniflora* (medium, tall) **C. jamaicense*
5	Northeastern Gulf	salt brackish	--- **J. roemerianus*
6	Delta Plain	salt brackish	**S. Alterniflora* (medium, tall) *S. patens*
7	Chenier Plain	salt brackish	*S. alterniflora* (medium, tall) **S. patens*
8	South Texas	salt brackish	--- ---

Salt concentration is greater than 20 parts per thousand (ppt)
[2]Salt concentration is between 5 and 20 ppt
*When more than one dominant plant type occurs within the region, the indicated type covers the largest geographic area (acreage)
--- Insignificant amounts of marsh plants within the given habitat in the region

Table D.2.7-4. Significant Marsh Plant Types in Each Seacoast Region and WHAFIS Default Regional Plant Parameter Data

	1	2	3	4	5	6	7	8
	NORTH ATLANTIC	**MID-ATLANTIC**	**SOUTH ATLANTIC**	**SOUTH FLORIDA**	**NORTHEASTERN GULF**	**DELTA PLAIN**	**CHENIER PLAIN**	**SOUTH TEXAS**
CLAD	---	---	---	7.50(+) 0.0656 6	6.00(2) 0.0260 6	---	---	---
DIST	---	0.78(1) 0.0039 211	1.00(1) 0.038 243	1.00(+) 0.0038 248	--- ---	1.08(4) 0.0035 102	1.08(+) 0.0035 102	---
JUNM	1.23(1) 0.0042 300	1.23(+) 0.0042 300	---	---	---	---	---	---
JUNR	---	2.95(+) 0.0095 147	2.95(+) 0.0095 147	---	2.95(3) 0.0095 147	3.00(4) 0.0106 83	2.95(+) 0.0095 147	---
SALM	1.39(1) 0.0184 45	1.06(1) 0.0103 36	1.63(1) 0.0141 12	1.63(+) 0.0141 12	---	1.67(4) 0.0141 21	2.62(5) 0.0211 16	---
SALT	1.86(1) 0.0175 37	2.21(1) 0.0169 18	3.20(1) 0.0183 10	3.20(+) 0.0183 10	---	3.20(4) 0.0183 10	3.20(+) 0.0183 10	---
SCYN	---	---	8.29(+) 0.0492 6	---	---	4.00(4) 0.0267 7	---	---
SPAT	1.03(1) 0.0025 409	0.85(1) 0.0019 327	1.65(1) 0.0019 236	---	2.58(2) 0.0026 236	1.88(4) 0.0016 333	1.88(+) 0.0019 333	---

Data arranged in vertical triplets:
h, stem height below inflorescence, in feet
D, base diameter, in feet
N, number density, in inverse square feet

Parenthetical references indicate data source:
1 = Hardisky and Reimold, 1977
2 = Monte, August 1983
3 = Kruczynski, Subrahmanyam, Drake, 1978
4 = Hopkinson, Gosselink, Parrondo, 1980, Diameters extrapolated
5 = Turner and Gosselink, 1975, Diameters extrapolated
+ = Extrapolated Data
--- = Insignificant amounts of this plant type in the region

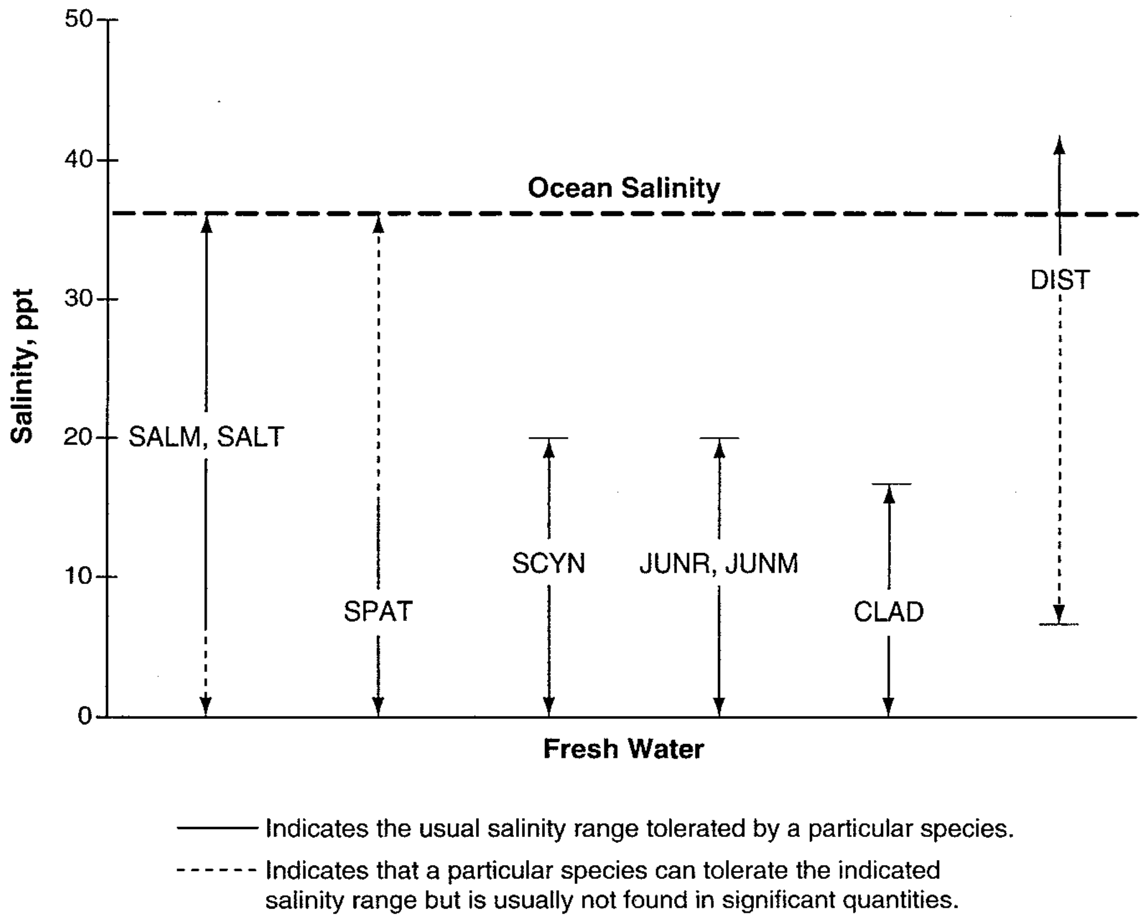

Figure D.2.7-4. Salinity Tolerance of Marsh Plants, from Knutson and Woodhouse, 1983

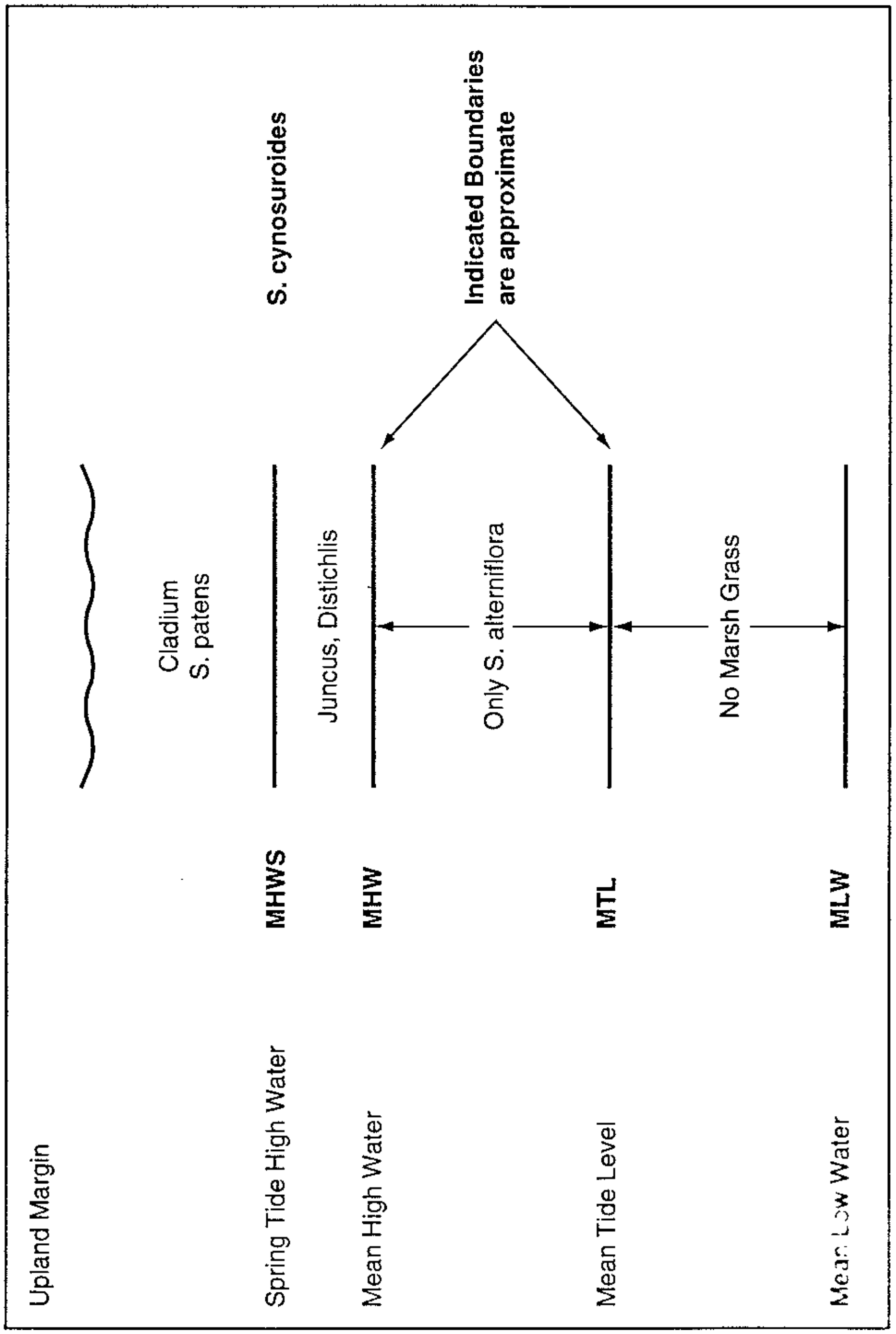

Figure D.2.7-5. Tidal Control on Salt Marsh Plant Viability

D.2.7.4 WHAFIS Output Description

The output of the program provides all the data necessary for plotting the BFEs and flood insurance risk zones along the transect. The output is in six parts, as discussed below.

Part 1 - Input

This is a printout showing all input data lines and the parameters assigned to each line, both manually and by default. This is followed by a more detailed printout with column headings for each input data line. When VH and MG Lines are used, a separate insert will be printed directly beneath the MG Line to show any default values supplied by the computer.

Part 2 - Controlling Wave Heights, Spectral Peak Wave Period, and Wave Crest Elevations

This is a list of the calculated controlling wave heights, spectral wave peak periods, and wave crest elevations at the endpoint of each fetch and obstruction of the input, and at calculation points generated between the input stations.

Part 3 - Location of Areas Above 1-Percent-Annual-Chance Surge

This is a list of the locations where the ground elevation is greater than the 1-percent-annual-chance stillwater (surge) elevation. Only areas identified by AS lines are listed.

Part 4 - Location of Surge Elevations

This is a list of the 10- and 1-percent-annual-chance stillwater (surge) elevations and the stationing of the points where each set of SWELs first becomes fully effective.

Part 5 - Location of V Zones

This is a list of the locations of the V/A Zone boundaries and the locations of the V-zone areas relative to these boundaries. The stationing is given for each V/A Zone boundary. The locations of the V-zone areas in relation to these boundaries are given as windward or leeward of the boundary.

Part 6 - Numbered A Zones and V Zones

This is a list of the zone data needed to delineate the flood hazard boundaries on the FIRM. The location of a flood zone boundary and the wave crest elevation at that boundary are on the left. Between the boundary listings are the zone designations and FHFs. Under FEMA's Map Initiatives Procedure guidelines, all numbered V and A Zones should be changed to VE and AE Zones, respectively (elevations will not change), and the FHFs can be ignored (FEMA, 1991). When the same zone and elevation are repeated in a list, they should be treated as a single zone.

D.2.7.5 WHAFIS Error Messages

The error messages that may appear when running the model are described below.

- "AS card ground elevation less than SWEL, should use other type card, job dumped." Only use the AS (above surge) line when the ground elevation is above the SWEL. Otherwise use IF, OF, BU, DU, VE, or VH.

- "Ground elevation greater than surge elevation encountered, job dumped." If ground elevation is above surge elevation, the AS card should be used.

- "Average depth less than or equal to zero, job dumped." The water depth must be greater than zero, or a wave height cannot be computed. Check the SWEL and the ground elevation if the point of job dump is not the last point along the transect profile.

- "The above card contains illegal data in the first 2 columns." Check input data for incorrect values, or input in the wrong columns. Aside from the title line, the first two columns in each line should contain the card identifiers.

- "Transmitted wave height at last fetch or obstruction = ______ which exceeds 0.5." Code the transect profile up to the inland limit where ground elevation intersects the SWEL so that wave height should decrease to zero. If the scope of work ends at the corporate limits before the ground elevation meets the SWEL, this message can be ignored.

- "Array dimensions exceeded. Job dumped." The size of the array is limited, and the number of input parameters has exceeded the array. Check the number of input parameters at the location where the job dumped.

- "Invalid data in field 1 of IF card, a" etc. Check input data to make sure that data are in the correct columns.

- "Wave period less than or equal to zero in subroutine fetch. Abort run." Either a fetch length or a wave period must be input for the program to run properly. Check input data.

- "Invalid data in field 3 or field 5 of VH card." Check input data.

- "Invalid data in field 4 of VH card." Check input data.

- "Invalid data in field 3 of MG card." Check input data. The fraction of vegetated area covered by the stated plant type should be a decimal number between 0.0 and 1.0.

- "Missing MG card or incorrect data in field 6 of VH card." The MG card must always follow the VH card. Field 6 of the VH card pertains to the number of plant types, and one MG card is required for each plant type.

- "Invalid input data." Check input data for invalid characters, such as an O instead of a zero. Check to be sure that all data are in their correct columns.

- "Fcov was found to be negative for plant type = _______." Check input data to be sure that the decimal fraction of the vegetated area covered by the plant type is not negative.

- "Ncov is .LE. zero in Sub.Lookup when it should be .GT. zero. Abort run." Check input for number of plants covering the area.

- "The first card is not an IE card, this transect is aborted. Continued to next transect." The first card after the title line must always be an IE card. Check input data.

- "**** The surge elevation at this station (stationing ____), which is ____ card, is less than the ground elevation. The interpolation process is continued. *** Please double check the surge and ground elevations in the vicinity of this station" The surge elevation should not be below the ground elevation. If the interpolated surge elevation is below the ground elevation, insert additional cards to specify surge and ground elevations and use an AS card if necessary.

- "Interpolation line cuts off more than two portions of high ground ridge. This transect is aborted, re-assign 1-percent-annual-chance elevations at high ground stations." When the interpolated value falls below the ground elevation, insert additional cards to better model the area and set the SWEL equal to the ground elevation where appropriate. Insert AS cards as necessary.

- "**** Unreasonable high ground elevation at station ____ which is ____ card. This transect is aborted, continued to next transect. **** Double check the surge and ground elevations in the vicinity of this station. If the ground elevations are correct, either assign a higher surge elevation or use AS cards." Add additional input data as necessary to better define the ground elevation and surge elevation in this area.

D.2.7.6 WHAFIS Documentation for the FIS

The Mapping Partner shall document all assumptions used to define input waves for WHAFIS analyses, including a brief description of offshore wave conditions, and a description of wave transformation, attenuation or dissipation between the wave source area and the shoreline. In sheltered waters, this shall include a summary of fetch determination, winds (speeds, directions, and duration), and bathymetry used in hindcasts. The documentation shall include the approximations or assumptions used in the analysis. When observational data, such as wave buoy data, are available, the wave height, period, and spectral parameters should be compared to the predicted waves.

The Mapping Partner shall document the WHAFIS analysis assumptions, methods, input data, and results. This shall include documentation of any field observations or measurements, as well as available historical or anecdotal information regarding overland wave propagation during flooding events.

See Subsection D.2.12 for additional documentation considerations.