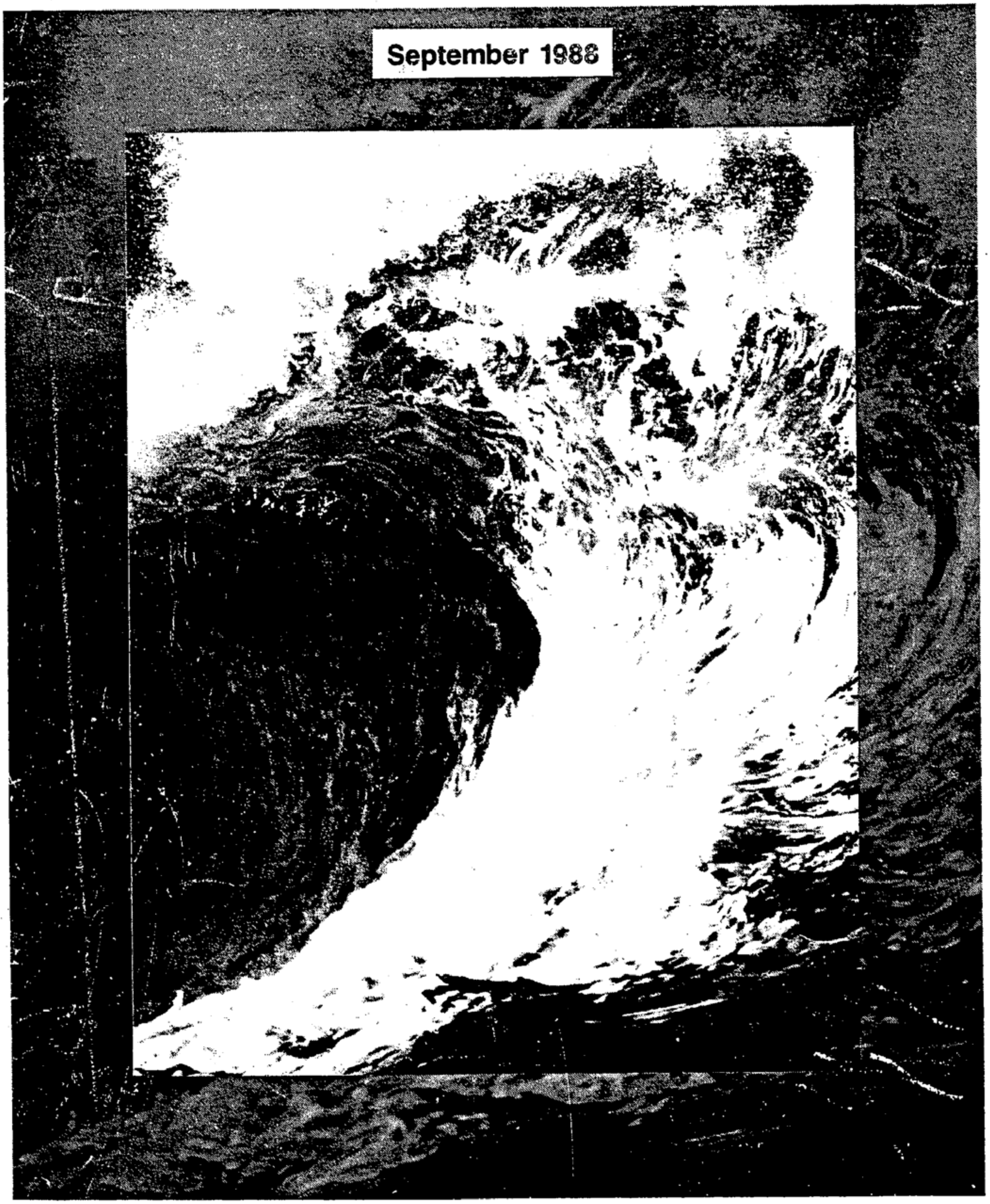
WAVE HEIGHT ANALYSIS FOR FLOOD INSURANCE STUDIES

(TECHNICAL DOCUMENTATION FOR WHAFIS PROGRAM VERSION 3.0)



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1. INTRODUCTION

1.1 BACKGROUND

Under the National Flood Insurance Act of 1968 (as amended), the Federal Emergency Management Agency (FEMA) is responsible for promoting the public welfare by ensuring the availability of insurance protection against the risk of flood and mudslide losses and by encouraging sound floodplain management by communities as a condition for the insurance protection. In the context of those responsibilities, FEMA has considerable opportunity to develop programs that will reduce annual property losses resulting from floods and mudslides.

In the delineation of coastal high hazard zones, the Wave Height Analysis for Flood Insurance Studies (WHAFIS) model was developed to predict wave heights associated with hurricane coastal storm surge. The model was based on the methodology developed by the National Academy of Sciences (NAS) in 1977 (Reference 1). Since its completion in 1980, several revisions have been made to the model. The first version used approximate inland and overwater fetch growth curves, as recommended by the NAS, to evaluate wave heights over flooded land or open water without the presence of obstructions. In 1984, a procedure to compute wave height decay or growth in marsh grass areas was incorporated into the model. That procedure used the conservation of wave energy equation (Version 2.1, Reference 2). In 1987, during the preparation of the report entitled Guidelines and Specifications for

Wave Elevation Determination and V Zone Mapping (Reference 3), the model was updated to incorporate methodologies describe in the U.S. Army Corps of Engineers' 1984 Shore Protection Manual (SPM) (Reference 4). This report describes the methodologies incorporated in the latest revision (Version 3.0) of the WHAFIS model.

1.2 SCOPE OF REPORT

The major revisions of the WHAFIS model (Version 3.0, dated September 1988) reflect the inclusion of an approximate form of the conservation of wave action equation and the conservation of waves equation to calculate wave height and wave period change over shallow water areas (IF, OF, and VH Cards), and the application of an interpolation procedure for the input stillwater elevations.

The overwater and inland fetch growth fetch (F and G) curves for shallow water wave height calculation used in the previous model (Version 2.1) were based on the wave growth curves in the 1975 SPM (Reference 5). Those curves were revised significantly in the latest (1984) version of the SPM (Reference 4). The wave growth predicted using the latest SPM curves can be approximately reproduced using the conservation of wave action equation and conservation of waves equation. The wave energy equation used in the previous model (Version 2.1) to calculate wave-height modifications in wave transect segments containing marsh vegetation (VH Cards, Version 2.1) was also replaced by a modified form of those two equations. However, for the transect segments containing buildings, dunes, and trees (BU, DU, and VE Cards), the computational procedure remains unchanged from the previous version of the model.

Very often, the 100-year stillwater elevations in backbay or inland areas differ from those along the open coast. In the previous model (Version 2.1), when a new stillwater elevation was given at a location along the transect, the model used an abrupt water-surface change at that location instead of a gradual decrease (or increase) between two given stillwater change locations. That method of interpolation between stillwater elevation changes resulted in a discontinuity of wave dynamics. The procedure of stillwater interpolation implemented in the current model (Version 3.0, dated September 1988) results in a gradual decrease (or increase) of the stillwater surface profile.

Chapter 2 describes the approximate conservation of wave action equation and conservation of waves equation for the computation of wave heights in inland and overwater fetch areas and marsh grass areas.

The conservation of wave action equation computes the wave action variations resulting from the wind energy input, wave energy redistribution, and dissipation. Wave action, short for wave action density, is a generalization of wave energy and is given by the wave energy density divided by the intrinsic (circular) frequency. When time-mean currents are negligible, this frequency is given by $2\pi/T$ where T is the spectral peak wave period. Wave shoaling, but not wave refraction, is accounted for in the conservation of wave action equation. The conservation of wave action equation is more fundamental than the conservation of wave energy equation, because it applies to moving as well as stationary systems and to systems with a variable spectral peak wave period.

The conservation of waves equation states that under the slowly varying assumptions of wave ray theory, and in the absence of source terms, waves are neither destroyed or created. When source terms are present, the conservation of waves equation allows waves to, in effect, be created and destroyed through the action of the wind and various dissipation mechanisms. This equation is used in the present WHAFIS model (Version 3.0, dated September 1988) to calculate the change of peak spectral peak wave period in fetch and marsh grass areas.

A combined analytic finite difference numerical technique is used to solve the governing equations. The solution scheme is explained in detail, followed by the stillwater interpolation procedure used in obtaining the stillwater profile along the transect.

Chapter 3 summarizes the methodology used in the revision. Appendix A presents the derivation of the source term of the conservation of waves equation. Appendix B presents the derivation of the finite difference form of the conservation of waves equation. The source program listing is presented in Appendix C. Finally, an example calculation including the input data and the model output data is covered in Appendix D to assist the user in using the model. To prepare the data and apply it to the model, the user should refer to the Guidelines and Specifications for Wave Elevation Determination and V Zone Mapping (Reference 3) for detailed information.

2. WAVE HEIGHT ANALYSIS FOR FETCHES AND MARSHES

The waves propagating inland from the coast receive wind energy input and/or dissipate wave energy due to overland obstructions. Waves also have their energy modified by the wave shoaling and refraction processes. Wave shoaling refers to variations of wave group velocity due to variations in the stillwater depth and spectral peak wave period. Wave refraction refers to changes in the direction of the waves. In the latest version of WHAFIS (Version 3.0, dated September 1988), wave shoaling, but not wave refraction effects, are accounted for. Wave refraction effects can be roughly parameterized by allowing a wave transect to change direction at a point (usually the National Geodetic Vertical Datum of 1929 (NGVD) shoreline) near where significant refraction effects occur. Such a direction change is not normally needed at the open coast since waves are assumed to travel perpendicularly to the open-coast NGVD shoreline at the shoreline.

The calculation of wave growth or decay along a wave ray (assumed to approximately coincide with a wave transect) requires the evaluation of wave dynamics pertinent to wave propagation. The conservation of wave action and conservation of waves equations have been developed and used to compute the wave characteristics for shallow water areas in the past (References 6 and 7). The equations approximately reproduce the wave-growth curves described in the current SPM for shallow-water waves and appropriately describe the one-dimensional, general Stokes wave propagation associated with overland storm surge flooding. Section 2.1 explains the formulas in detail. The numerical technique used to solve the governing equations is described in Section 2.2. Section 2.3 briefly describes the procedures for stillwater interpolation implemented in the revision.

2.1 CONSERVATION OF WAVE ACTION AND CONSERVATION OF WAVES

Wave action, short for wave action density, is a generalization of wave energy and is given by E/Ω. Here E is the wave energy density and Ω is the intrinsic (circular) frequency. In general, Ω is a function of the spectral peak wave period T and the (time) mean current. In the present WHAFIS model, the mean current is assumed negligible compared to the wave-induced fluctuating current. Therefore Ω is assumed to be given by $2\pi/T$ which is the appropriate expression when the average current is negligible (Reference 7).

Wave energy propagates at the wave group velocity when the intrinsic frequency Ω is constant. When the spectral peak wave period T, and hence Ω, is not constant, wave action propagates at the wave group velocity (References 6 and 7). The intrinsic frequency Ω and spectral peak wave period T undergo significant changes when the net wind energy input to waves is significant, as in hurricanes.

When T and Ω are approximately constant, the conservation of wave energy equation can be used to model wave growth and decay. In hurricanes, T and Ω are usually not constant. Therefore, the conservation of wave energy equation cannot be used in general to model hurricane wave propagation. Rather, the conservation of wave action equation and conservation of waves equation must be used to model the propagation of these waves.

The conservation of wave action equation is the generalized version of the conservation of wave energy equation (References 2 and 6). Wave action variation can be expressed as a function of wind energy input (source), wave-wave interaction redistribution (source), and wave energy dissipation (sink) due to whitecapping, obstructions, and bottom friction. The conservation of wave action equation, taking into account the change in spectral peak wave period, is used to calculate the wave height of steady, slowly varying (in space) water waves.

The conservation of waves equation determines the change of wave spectral peak frequency as a function of the "source" term which, in turn, is a function of wave height, stillwater depth, and spectral peak wave period.

2.1.1 Governing Equations

2.1.1.A. Conservation of Wave Action Equation

The approximate conservation of wave action equation governing wave height variation along a wave transect (References 7 and 8), neglecting the mean current veloctity and refraction effect is:

$$\frac{\partial}{\partial x}\left(\frac{C_g E}{\Omega}\right) = \frac{W_{net} - E_p}{\Omega} \qquad (1)$$

where

E = time averaged total wave energy per unit area (wave energy density)

C_g = wave group velocity

Ω = intrinsic angular frequency = $2\pi/T$

T = spectral peak wave period, i.e., period of waves at the peak of the wave spectrum

W_{net} = time-averaged rate of net wind energy input per unit area

E_p = time-averaged rate of energy dissipation per unit area due to plants

x = distance along the transect (waves are assumed to propagate in the direction of increasing x

The factors E, W_{net}, and E_p are averaged over a wave period. W_{net} includes the effects of wind energy input, wave "whitecapping," wave-wave interaction, and bottom friction.

Equation 1 has been simplified by omitting the term involving the partial time derivative of action density, (E/Ω). This omission is justified because FEMA is primarily concerned with maximum wave heights at a given shallow location for the storm or storms that produce the 100-year stillwater flood level (SWFL) at that location. Maximum wave heights occur at a shallow water location when the time derivative of the wave height and wave period is approximately zero there. Hence the time derivative of E is approximately zero there (since E is proportional to the wave height squared) and the time derivative of Ω is approximately zero there, too. (Because T is inversely proportional to Ω.) Because the time derivative of both E and Ω is zero, the time derivative of the action density will be zero at the location. The time derivative of the wave period is approximately zero at a shallow-water location when maximum wave heights occur because maximum wave heights and wave periods usually occur at nearly the same time. This near simultaneity arises from the shape-preserving nature of the wave spectrum (Reference 10) which directly couples the wave periods and wave heights together. The near simultaneity can also be justified a postiori using equation A13 in Appendix A.

Expanding the derivative on the left side of Equation 1 and using $\Omega = 2\pi/T$, this equation can be expressed as:

$$\left(C_g T\right)\frac{\partial E}{\partial x} + E\,\frac{\partial\left(C_g T\right)}{\partial x} = TW_{net} - TE_p \qquad (2)$$

This is the governing equation used for solving the wave heights along a wave transect. Equation 2 can also be derived from the spectral wave action equation by taking the zeroth moment in wave vector space and imposing the narrow spectrum approximation. The source term W_{net} is determined by using approximate differential forms of the "shallow water" wave height and wave period growth equations in the 1984 SPM (Reference 4).

2.1.1.B. Conservation of Waves Equation

In the conservation of wave action equation (Equation 2), the spectral peak wave period and its spatial variation need to be determined in order to evaluate the wave height changes. In this report, a differential equation that is equivalent to the conservation of waves (or crests) equation (References 6 and 9), with a source term, is used to calculate the spectral peak wave period.

The conservation of waves equation states that, if no new waves are being generated by a local disturbance, the time rate of change of wave number is balanced by the spatial rate of change of the angular frequency, that is

$$\frac{\partial k}{\partial t} + \frac{\partial \Omega}{\partial x} = 0 \qquad (3)$$

where k is the wave number and $\Omega = 2\pi/T$ is as previously defined.

Omitting the time variation of the wave number, and considering the generation of near waves by the local wind, Equation 3 can be modified as

$$\frac{\partial\Omega}{\partial x} = S \qquad (4)$$

where S is the source term as a function of water depth, wave height, windspeed, and the spectral peak wave period T itself. The source term is derived in a manner analogous to the W_{nat} term in the conservation of wave action equation. Equation 4 can also be derived from the spectral wave action equation by taking the first moment in wave vector space and imposing the narrow spectrum approximation.

Equation 4 is further expanded in connection with the evaluation of the term $\frac{\partial(C_g T)}{\partial x}$ described in Section 2.1.2.B.

2.1.2 Wave Energy Density and Wave Group Velocity

The left hand side of Equation 2 involves the wave energy density E, the product of the wave group velocity C_g, and the spectral peak wave period T. It is preferable to express the wave energy and the wave group velocity as a function of wave height, wave period, and water depth.

2.1.2.A. Wave Energy Density (E)

If hurricane waves were monochromatic, the wave energy density E would be related to the wave height by

$$E = (1/8)\ (\rho)\ (g)\ (H^2) \tag{5}$$

where

ρ = water mass density = 1.99 slugs/ft^3

g = gravitational acceleration = 32.2 ft/sec

H = the wave height.

However, monochromatic waves exist only in the laboratory. Real waves have a range of heights and periods, referred to as a "wave spectrum."

The spectrum can be modeled as if it were monochromatic if a properly defined "effective wave height" for the spectrum is used. If there were no interaction between waves of different periods and heights, then the higher waves in the spectrum would be attenuated more than the lower ones, effectively reshaping the spectrum. It has been observed (Reference 10) that real wave spectra tend to preserve their shapes when undergoing change. To account for this shape-preserving characteristic of real spectra, the effective wave height for the spectra must be chosen as the root mean square (rms) wave height (H_{rms}). However, H_{rms} is related to the wave energy density E in the same manner as in Equation 5 but with H replaced by H_{rms}; i.e., by

$$E = (1/8)\ (\rho)\ (g)\ (H_{rms})^2 \tag{6}$$

Physically, $(H_{rms})2$ at a given location is eight times the variance of a wave record at that location. Rather than directly expressing E in terms of H_{rms}, it is more convenient to express it in terms of an energy-related wave height, the so-called "zero moment wave height" (H_{m0}). By definition, H_{m0} is proportional to the square root of the "zero frequency moment" of the wave energy spectral density, hence its name. H_{rms} is given in terms of H_{m0} by the approximate expression

$$H_{rms} = H_{m0}/\sqrt{2} \tag{7}$$

Equation 7 essentially defines H_{m0} and its relationship to H_{rms}. H_{m0} is convenient to use since it can be related directly (Reference 11) to the "significant wave height" (H_s), and H_s in turn can be related directly to FEMA's "controlling wave height" (H_c). H_s is the average height of the highest (1/3) waves, and H_c is 1.6 times H_s (Reference 1). In deep water, H_{m0} and H_s are approximately equal. In shallow water, H_s can be up to 70 percent greater than H_{m0}. For Flood Insurance Studies, H_c is of primary interest.

By substituting Equation 7 for H_{rms} into Equation 6 for E, the following expression is obtained:

$$E = (1/16)\ (\rho)\ (g)\ (H_{mo})^2 \tag{8}$$

Equation 8 is used in the present study to calculate the wave energy density (E) and Equation 7 is used to calculate the effective wave height (H_{rms}).

Substituting Equation 8 into Equation 2 and rearranging, the wave action equation becomes

$$(C_gT)\frac{\partial(H_{m0})^2}{\partial x} + (H_{m0})^2\,\frac{\partial(C_gT)}{\partial x} = \left(\frac{16}{\rho g}\right)(W_{net}T - TE_p) \tag{9}$$

2.1.2.B. Wave Group Velocity (C_g)

The expression used for the wave group velocity (C_g) also depends upon whether monochromatic waves or a spectrum of waves is being modeled. Because the present model is meant to represent a relatively narrow spectrum of waves, C_g is approximately equal to the average group velocity of waves near the spectral peak, which in turn is approximately equal to the group velocity at the spectral peak. (As noted at the beginning of Section 2.1, the wave action E/Ω, not the wave energy E, propagates at this group velococity). The approximate expression used to calculate C_g is therefore given as

$$C_g = \frac{L}{T}\left(\frac{1}{2} + \frac{kd}{\sinh(2kd)}\right) \qquad (10)$$

where

k = wave number = $2\pi/L$

π = 3.14159

d = stillwater depth (including wave setup)

L = local wavelength of waves at spectral peak

$$= \left(\tanh\frac{2\pi d}{L_o}\right)^{1/2} \qquad (11)$$

L_o = equivalent deep water wavelength of waves at spectral peak

$$= \frac{g}{2\pi}T^2 \qquad (12)$$

The expression for the local 'peak wave length' (L) is given by Eckart (Reference 15) and is correct to within about 5 percent. The maximum error of 5 percent occurs when $2\pi d/L$ is approximately equal to 1 (Reference 4, p 2-9). Equation 10 for C_g is the same as that for a monochromatic wave, except that the monochromatic wave period has been replaced by the spectral peak wave period (T).

To use Equation 10 for C_g, it must be assumed that the wave spectrum being modeled fulfills the "dominant peak" assumption, i.e., the frequency spectrum has one dominant, relatively sharp peak (and possibly several considerably smaller secondary peaks). Shallow areas with water depths of less than 30 feet are of primary interest to FEMA for calculations of wave-height variation. Hurricane spectra for those areas appear to fulfill the "dominant peak" assumption because the shallow water tends to amplify the spectral peak associated with the longest period wavetrain at the expense of the peak(s) associated with the shorter period wavetrain(s).

If Equation 10 is rearranged, the equation becomes

$$C_g T = \frac{L}{2} \left(1 + \frac{2kd}{\sinh(2kd)} \right) \tag{13}$$

Taking the partial derivative of Equation 13 with respect to x, we can evaluate the expression of $\frac{\partial(C_g T)}{\partial x}$ for Equation 9.

Let $\lambda = 2kd$ from Equation 12, and we have

$$\frac{\partial(C_g T)}{\partial x} = \frac{L}{2}\,\frac{\partial}{\partial x}\left(1 + \frac{\lambda}{\sinh\lambda}\right) + \frac{1}{2}\left(1 + \frac{\lambda}{\sinh\lambda}\right)\frac{\partial L}{\partial x} \tag{14}$$

Expanding the derivatives on the right hand side and using Equation 11, we have

$$\frac{\partial(C_g T)}{\partial x} = 2\pi\left(\frac{1-\lambda\coth\lambda}{\sinh\lambda}\right)\frac{\partial d}{\partial x} + \left(\frac{\pi}{2}\right)\frac{T_2}{d^{1/2}}\left[1 + \left(\frac{\lambda}{\sinh\lambda}\right)^2\cosh\lambda\right]\frac{\partial d}{\partial x}$$

$$+ \frac{T_3}{2}\left[1 + \left(\frac{\lambda}{\sinh\lambda}\right)^2\cosh\lambda\right]\frac{\partial L_o}{\partial x} \tag{15}$$

where

$$T_2 = \left(\frac{L_o}{2\pi}\right)^{1/2}\left[\frac{2\pi D}{(\sinh(2\pi D))(\cosh^3(2\pi D))}\right]^{1/2} \tag{16}$$

$$T_3 = (\tanh 2\pi D)^{1/2}\left(1 - \frac{2\pi D}{\sinh 4\pi D}\right) \tag{17}$$

$$D = \frac{d}{L_o} \tag{18}$$

Taking the partial derivative of Equation 12 with respect to x and introducing a parameter,

$$\tau = T^3 \tag{19a}$$

the $\frac{\partial L_o}{\partial x}$ in Equation 15 can be expressed as

$$\frac{\partial L_o}{\partial x} = \left(\frac{g}{3\pi T}\right) \frac{\partial \tau}{\partial x}$$

or

$$\frac{\partial L_o}{\partial x} = \left(\frac{g}{3\pi T}\right) S_{in} \tag{19b}$$

where $S_{in} = \frac{\partial \tau}{\partial x}$, involves the peak spectral period (T) and the water depth (d). From Equations 4 and 19b we have

$$S_{in} = - \frac{3T^4}{2\pi} S$$

where S and $\frac{\partial \Omega}{\partial x}$ are related by the conservation of waves equation, Equation 4.

$$S = \frac{\partial \Omega}{\partial x}$$

The equation for S_{in} is derived in Appendix A. Substituting Equations 15 and 19b into Equation 9, we have

$$(C_g T)\frac{\partial (H_{m0})^2}{\partial x} + (H_{m0})^2 \left(T_4 \frac{\partial d}{\partial x} + \frac{T_5}{d^{1/2}} \frac{\partial d}{\partial x} + T_6 S_{in} \right) = \left(\frac{16}{\rho g} \right) \left(W_{net} T - T E_p \right) \qquad (20)$$

where

$$T_4 = 2\pi \left(\frac{1 - \lambda \coth\lambda}{\sinh\lambda} \right),$$

$$T_5 = \frac{\pi}{2} \left[1 + \left(\frac{\lambda}{\sinh\lambda} \right)^2 \cosh\lambda \right] T_2, \text{ and;}$$

$$T_6 = \frac{g}{6\pi T} \left[1 + \left(\frac{\lambda}{\sinh\lambda} \right)^2 \cosh\lambda \right] T_3$$

where T_2 and T_3 are described as Equations 16 and 17.

2.1.3 Net Wind Energy Input (W_{net})

The "wind input function" (W_{net}) accounts for the energy input from the wind to the waves, wave energy losses from whitecapping and bottom friction, and wave energy redistribution from wave-wave interaction. There is apparently no expression in the current literature that can be used to specify W_{net} for waves traveling in shallow and intermediate water-depth areas. Several expressions do exist in the literature for the spectral W_{net} function associated with the full spectral wave action equation. One of these spectral W_{net} expressions must be integrated over wave vector space to arrive at an expression for the W_{net} function that can be used in the present model. Such an integration is quite complex and does not appear to have been done yet for waves in water of shallow and intermediate depth, an indirect approach must be used to determine the expression for W_{net} in the present model.

The expression for W_{net} was derived by requiring the solution of the conservation of wave action equation to approximately reproduce the wave-height spatial growth expressions in the current SPM when the conditions arise for which the SPM expressions are valid. These conditions are:

a. Time dependence is absent.

b. The plant dissipation function E_p is zero.

c. The stillwater depth d and adjusted windspeed U_A are independent of space and time.

d. H_{m0} and T are zero at the initial point of the fetch.

The requirement used to determine W_{net} is reasonable since the SPM expressions are widely recognized as good first approximations in situations where conditions a through d hold.

It is possible to derive an expression for W_{net} so that the current SPM wave height growth expressions and curves are reproduced exactly when conditions a through d hold. However, the resulting expression for W_{net} causes numerical problems when substituted into the wave action equation and the latter is numerically solved for H_{m0}. In particular, the expression for W_{net} becomes imaginary when H_{m0} is greater than $H_{m0,\infty}$. Here $H_{m0,\infty}$ is the infinite fetch value of the H_{m0} associated with the value of d and U_A. Since H_{m0} is larger than $H_{m0,\infty}$ in breaking and near-breaking areas, it was not possible to use the model in many areas with significant flooding potential. In addition, W_{net} becomes nearly singular for sufficiently small d and H_{m0}. This near singularity produces very erratic computed values of H_{m0} and T. To eliminate these numerical problems, a new parameterized form of the current SPM wave-height growth expression was devised and used to derive an expression for W_{net}.

In the current SPM, the expression for H_{m0} is given by

$$H_{m0} = \alpha_h \left(\frac{U_A^2}{g} \right) \beta_h \tanh q^{m_h} \tag{21}$$

where

$\alpha_h = 0.283$

$$\beta_h = \tanh\left\{\gamma_h\left(\frac{gd}{U_A^2}\right)^{0.75}\right\} \qquad (22)$$

$\gamma_h = 0.53$

$m_h = 0.5$

$$q = \left(\frac{\sigma_h}{\beta_h}\right)^{\frac{1}{m_h}}\left(\frac{gx}{U_A^2}\right) \qquad (23)$$

x = fetch

$\sigma_h = 0.00565$

$U_A = 0.589U^{1.23}$ = "adjusted" windspeed

U = wind speed (statute miles per hour)

The factor 0.589 relating U_A to $U^{1.23}$ accounts for the variation of the windstress coefficient with windspeed. U includes the effects of air-sea temperature difference. If U is derived from an observed windspeed, U also includes corrections to account for the location of the observation point compared to the overwater location where the wave calculation is being done.

An alternative, approximate form of Equation 21 can be derived by approximating tanh q^{m_h} by $(1-e^{-q})^{m_h}$, i.e., by replacing Equation 21 with

$$H_{m0} = \alpha_h \left(\frac{U_A^2}{g} \right) \beta_h (1-e^{-q})^{m_h} \qquad (24)$$

It can be shown that $(1-e^{-q})^{m_h}$ differs from $\tanh q^{m_h}$ by no more than 4.8 percent for $m_h = 0.5$. Because this difference appears to be less than the scatter in the data used to construct Equation 21, Equation 24 is an equally valid and convenient alternative to the wave growth equation (Equation 21).

In order to obtain the expression for W_{nat}, we need to first evaluate the term $\frac{\partial (H_{m0})^2}{\partial x}$ under conditions for which the SPM expression for H_{m0} holds. Assuming for the moment that d and U_A are constant, and that H_{m0} is zero when x is zero, from Equation 24,

$$\frac{\partial (H_{m0})^2}{\partial x} = \left(\frac{U_A}{g} \right)^2 (\alpha_h \beta_h)^2 e^{-q} \frac{\partial q}{\partial x} \qquad (25)$$

e^{-q} can be expressed as, from Equation 24,

$$e^{-q} = 1 - \left[\frac{H_{m0}}{\left(\frac{U_A^2}{g}\right)\alpha_h\beta_h} \right]^{\frac{1}{m_h}} \tag{26}$$

and from Equation 21

$$\frac{\partial q}{\partial x} = \left(\frac{\sigma_h}{\beta_h}\right)^{\frac{1}{m_h}} \left(\frac{g}{U_A^2}\right) \tag{27}$$

From Equation 24, as x approaches infinity,

$$H_{m0} = H_{m0,\infty}$$

where

$$H_{m0,\infty} = \left(\alpha_h\beta_h\right)\frac{U_A^2}{g} \tag{28}$$

Substituting Equations 26, 27, and 28 into Equation 25, and rearranging, the following expression is obtained:

$$\left.\frac{\partial(H_{m0})^2}{\partial x}\right|_{SPM} = (\sigma_h\alpha_h)^2 \frac{U_A^2}{g} \left\{ 1 - \left(\frac{(H_{m0})_{SPM}}{H_{m0,\infty}} \right)^2 \right\} \tag{29}$$

where the subscript "SPM" means evaluated using the reparameterized SPM formula, Equation 24.

Defining $\left(\frac{16}{\rho g}\right) W_{net}T$ as I_{net} Equation 20, the input factor I_{net} is given by

$$I_{net} = \left(C_g T\right)\left(\sigma_h \alpha_h\right)^2 \frac{U_A^2}{g} \left\{ 1 - \frac{\left(H_{m0}\right)_{SPM}^2}{\left(H_{m0,\infty}\right)^2} \right\} + \left(H_{m0}\right)_{SPM}^2 T_6 S_{in} \qquad (30a)$$

with

$$W_{net} = \frac{\rho g I_{net}}{16\ T} \qquad (30b)$$

Equations 30a and 30b give the expression for the wind input function (W_{net}) when marsh grass is absent and the 100-year stillwater depth (d) and adjusted windspeed (U_A) are constant and H_{m0} is zero at the beginning of the fetch. Since these equations do not involve the fetch distance (x) explicitly, they are also valid for situations where H_{m0} is nonzero at the beginning of the fetch.

When d and U_A are "slowly varying" with x, and H_{m0} is not zero at the beginning of the fetch, it is expected that Equations 30a and 30b, as a function of d, U, and H_{m0}, should still be a good approximate expression for W_{net}. It is also expected that these equations should be satisfactory when the energy dissipation due to marsh grass is modest, i.e., E_p is not very large. However, when the dissipation due to marsh grass is strong, i.e., E_p is large, it is expected that Equations 30a and 30b may not be a good approximation for W_{net} under some circumstances. Nevertheless, because a better representation of W_{net} does not exist for shallow as well as deep areas, Equations 30a and 30b are assumed to be a valid approximate representation (as a function of U, d, and W_{net}) under all circumstances. Therefore Equations 30a and 30b with $H_{m0|SPM}$ replaced by H_{m0} is used in the present model to calculate W_{net} for all H_{m0}.

2.1.4 Plant-Induced Wave Energy Dissipation (E_p)

The wave energy dissipation through marshes is mainly the result of the drag force generated between the marsh plant and the wave current. The total energy dissipation through a predetermined marsh grass transect segment is also a function of the plant density within the segment and the individual plant geometry. In this section, the formulation of the wave energy dissipation E_p is summarized in terms of individual components that contribute to the total energy dissipation. For a detailed derivation and description of this concept, refer to References 2 and 12.

2.1.4.A. Density and Geometry of Marsh Plants

A transect segment containing marsh plants can be considered as a rectangular "swath" of ground. Within a swath, marsh grass usually grows in individual "patches" or "zones" (see Figure 1). Each patch may contain one or more plant types. To represent the relative areal extent of each plant type in a marsh grass transect swath, the parameter F_{cov} is used. For each species, F_{cov} is defined as the ratio of total patch area for that species to the total swath area for the transect segment (References 2 and 12).

Another parameter, N, is used for each plant type in a given transect segment to represent the average number of plants per square foot in a typical patch. F_{cov} and N for each plant type are related as shown below:

$$\text{Number of plants in segment} = (F_{cov})(N)(\text{area of segment swath}) \tag{31}$$

To produce realistic wave-marsh grass interactions, a detailed schematization must be developed for the marsh plant geometry. Each plant is assumed to consist of an "inflorescence," the flowering head; a "mainstem," the stem below the inflorescence; an "inflorescence stem," the part of the stem at the center of the inflorescence; and the leaves (see Figure 2). The leaves consist of cylindrical and flat parts. The cylindrical parts of all leaves essentially lie on the same plane, the unflexed "leaf plane," when the plants are erect. The

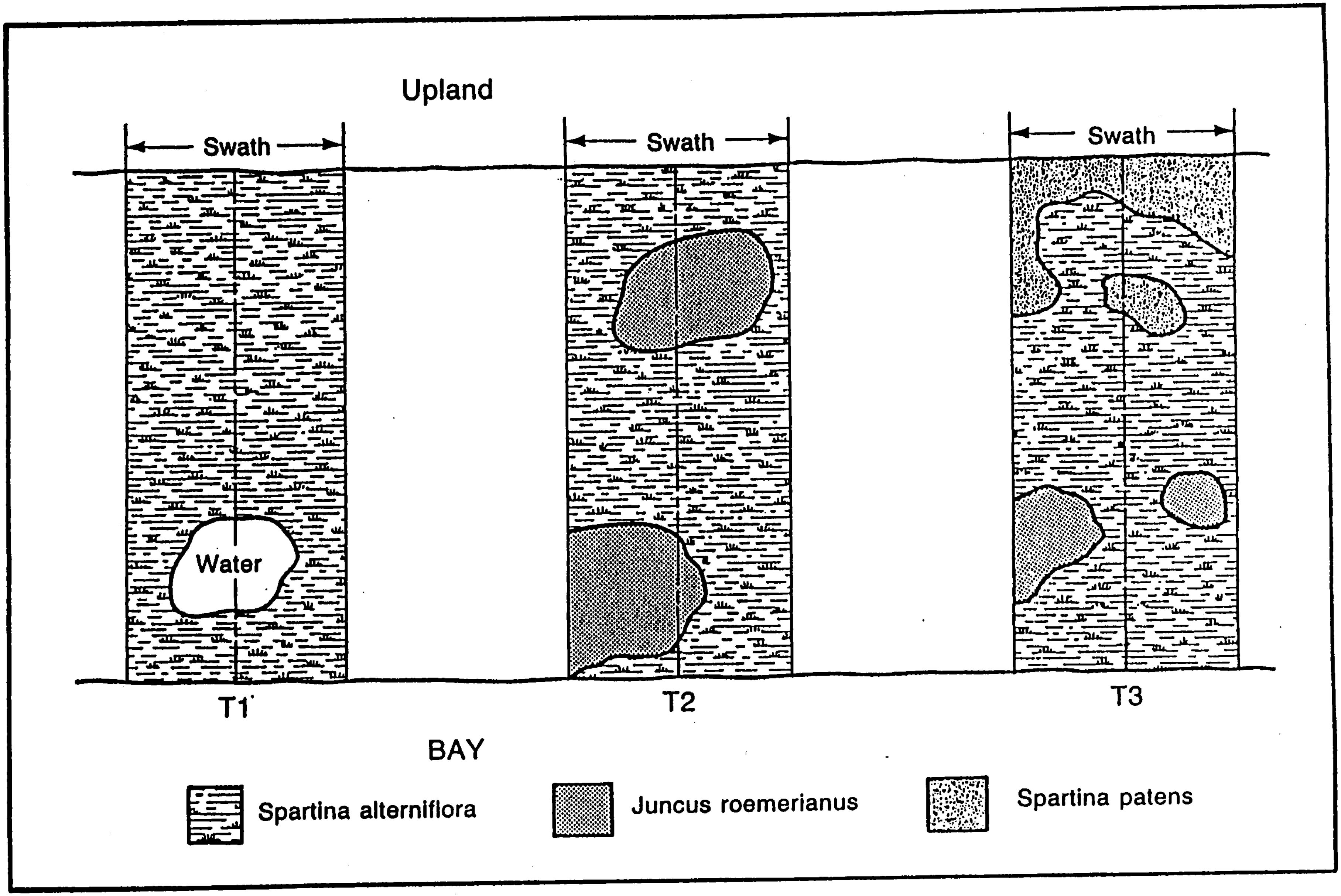

FIGURE 1. Three Examples of Ground Cover Variation Within Transect Swaths.

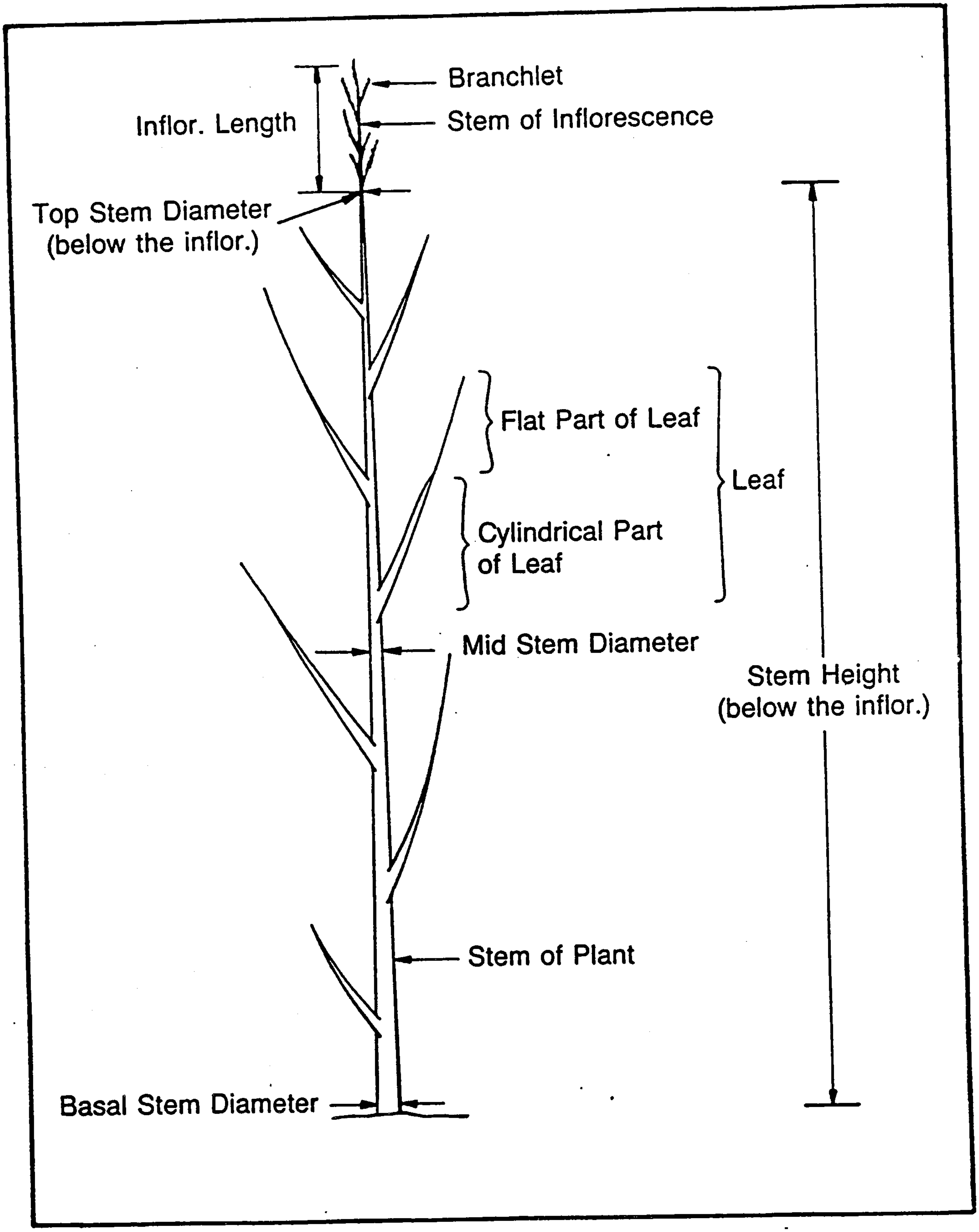

FIGURE 2. Schematic Diagram of Marsh Grass Plant Geometry.

inflorescence consists of discrete "branchlets" growing symmetrically from the stem. Field observation indicates that there is no preferred horizontal orientation for the leaf plane or the inflorescence branchlets.

2.1.4.B. Formulation of E_p

The plant energy dissipation E_p is the energy dissipated by marsh plants per second/square foot of ground area at a given point on a transect segment, which is averaged in time over a local spectral peak wave period T and in space over a rectangular ground area a_g surrounding the point. The ground area a_g, assumed to contain A_g square feet with $A_g > 1$, is referred to as the "averaging ground area" or just "averaging area." The averaging area is assumed to be large enough to contain many marsh plants of the various types found in the transect segment swath but small enough that the zero moment wave height (H_{m0}) does not change significantly within the area.

To calculate E_p, it is necessary to use a "plant statistical mechanics approach." This approach consists of summing and averaging the contributions to E_p from individual plants in the averaging ground area surrounding the arbitrary point on the transect segment. Use of a "plant statistical mechanics approach" is necessary because the contributions to E_p from an individual plant is a strong function of "leaf plane" orientation and inflorescence branchlet orientation of the plant, and those change randomly from plant to plant. Since so few plants have an inflorescence, the effect of the inflorescence on wave energy dissipation is disregarded.

Let the value of E_p for the j^{th} member of the i^{th} plant type in the averaging ground area a_g be designated $E_{i,j}$. The range of a subscript j varies from plant type to plant type (i.e. depends on i) and is given by $1<j<n_i$ where n_i is the number of "type i plants" in the averaging ground area a_g and the "plant type index" fulfills $1<i<N_{pl}$. Here N_{pl} is the number of plant types in the transect segment assumed to be the same as the number of plant types in the averaging area A_g. The factor n_i is given in terms of averaging area size A_g and numerical density of type i plants N_i by

$$n_i = (N_i)\ (A_g) \tag{32}$$

Summing the energy dissipation per plant $E_{i,j}$ over the N_{pl} plant types and the individual plants in the averaging ground area, dividing the result sum by A_g, and simplifying, the plant dissipation function (E_p) is expressible as

$$E_p = \sum_{i=1}^{N_{pl}} (F_{cov,i})(N_i)E_i \tag{33}$$

where the following average has been introduced

$$E_i = \left(\frac{1}{n_i}\right) \sum_{j=1}^{n_i} E_{i,j} \tag{34}$$

and Equation 32 has been used to eliminate n_i in Equation 33 in favor of the number density N_i.

By definition, the time-average energy dissipation per plant ($E_{i,j}$) is given by the following double integral:

$$E_{i,j} = \left(\frac{1}{T}\right) \int_0^T \int_0^{h_i^*} \left| (F_{i,j})(u) \right| \, dz \, dt \tag{35}$$

where

z = elevation of some arbitrary point on a marsh plant, reference local ground elevation z_b (positive values refer to values above ground)

F = instantaneous horizontal drag force (at elevation z), per unit of water depth, acting on a marsh plant in the averaging ground area A_g

$F_{i,j}$ = value of F for the j^{th} member of the i^{th} plant type in the averaging ground area A_g

h_i^* = h_i; if $h_i \le (d + \eta)$ i.e. plants submerged
= $(d + \eta)$; if $h_i > (d + \eta)$ i.e. plants exposed

$(d + \eta)$ = time-varying water depth
η = Wave crest elevation references to the stillwater floodlevel (including wave setup)

h_i = time varying stem top elevation of type "i" plants in the averaging ground area A_g

u = horizontal current velocity produced by the waves at a given point in space and time above the averaging ground area A_g

The storm surge induced current is assumed to be negligible compared to the maximum value of wave induced current U at a given location.

2.1.4.C. Specification of Drag Forces

The product of drag force ($F_{i,j}$) and current velocity (u) in Equation 35 for ($E_{i,j}$) represents the instantaneous energy dissipated per second per unit depth of water by a marsh plant. The drag force per plant ($F_{i,j}$) is assumed to be caused by "profile drag" and can therefore be expressed as

$$F_{i,j} = 0.5 \rho C_D D'_{i,j} |u| u \qquad (36)$$

where ρ is the water mass density, C_D is the "local drag coefficient," assumed to be 1.0, D' is the "local effective diameter" at elevation z of a marsh plant in the averaging ground area, and $D'_{i,j}$ is the value of D' for the j^{th} member of the i^{th} plant type in the averaging ground area. The contribution to the drag force

$$\mathrm{Rcosh}_i = \cosh[(k)(h_i^*)] / \cosh[\ kd\ ] \quad ; \text{ if } d \geq h_i^*$$

$$= 1.0 \quad ; \text{ if } d < h_i^* \qquad (41)$$

$$\chi = (\ k\ x\ ) - (\ \Omega\ t\ ) = \text{wave phase} \qquad (42)$$

$$k = (\ 2\ \pi\ )/L = \text{wave number of waves at spectral peak} \qquad (43)$$

$$\Omega = (2\ \pi\ )/T = \text{circular frequency of waves at spectral peak} \qquad (44)$$

Substituting the equations for drag force per plant ($F_{i,j}$), rearranging and simplifying, it is seen that $E_{i,j}$ can be expressed as

$$E_{i,j} = (f_{i,j})\ (H_{m0})^3 \qquad (45)$$

where

$$f_{i,j} = \frac{1}{2\sqrt{2}} \frac{\rho}{12\pi} g^3 \left(\frac{T}{L}\right)^3 \left(\frac{C_D}{4}\right) G_{i,j} \qquad (46)$$

$$G_{i,j} = \left(\frac{6\pi}{T}\right) \int_0^{T/2} (\mathrm{Rcosh}_i)^3 \left(\int_0^{h_i^*} D'_{i,j} \left(\frac{z}{h_i^*}\right)^3 dz \right) \cos^3 \chi\ dt \qquad (47)$$

Substituting the expressions for $E_{i,j}$, $f_{i,j}$, and $G_{i,j}$ into Equation 34 for E_i, the resulting equation for E_i into Equation 33 for E_p, rearranging and simplifying, it is found that the expression for the plant dissipation function E_p can be written as

$$E_p = (f_p)\ (H_{m0})^3 \tag{48}$$

where

$$f_p = \frac{1}{2\sqrt{2}}(\rho g)\left(\frac{\Omega}{12\pi}\right) \tag{49}$$

$$\Gamma = \sum_{i=1}^{N_{pl}}\left(F_{cov,i}\right)\left(C_{D,i}\right)(AW)_i\left(N_i\right)\left(F_{3,i}\right) \tag{50}$$

$$F_{3,i} = g^2\ (T/L)^3(\mathrm{rcosh}_i)^3 \tag{51}$$

$$\begin{aligned}\mathrm{rcosh}_i &= [\cosh(\ 0.5\ k\ h_i)]\ /\cosh(\ k\ d\ );\ d > (0.5h_i)\\ &= 1.0 \qquad\qquad ;\ d \le (0.5h_i)\end{aligned} \tag{52}$$

$(Aw)_i$ = average 'wetted' frontal area per unflexed plant for the i^{th} plant type in the marsh grass segment

$$(AW)_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \left(\int_0^{h_i^*} \left(D'_{i,j} \right) dz \right)_{\text{plant unflexed}} \qquad (53)$$

and N_{pl} is the number of plant types in a marsh grass segment, $F_{cov,i}$ is the coverage parameter for the i^{th} plant type in the marsh grass segment (i.e. the fraction of the segment covered by the i^{th} plant type), $C_{D,i}$ is the effective drag coefficient for the i^{th} plant type in the segment, N_i is the "number density" for the i^{th} plant type in the segment (i.e. the number of plants per square foot), and h_i is the stem height (i.e. "main stem height") of an unflexed type "i" plant in the averaging ground area. The equation for effective drag coefficient $C_{D,i}$ is extremely complex and is given in Procedures for Determining Wave Heights in Flood Marshes (Reference 12).

2.1.4.E. Evaluation of Wetted Frontal Area per Unflexed Plant ($(Aw)_i$)

Before the above expression for $(Aw)_i$ can be evaluated, the local effective plant diameter ($D'_{i,j}$) must be specified for a plant in the unflexed state. Since the geometry of marsh grass is relatively sophisticated, the expression for $D'_{i,j}$ is relatively complicated and the evaluation of $(Aw)_i$ is quite tedious. The derivation of expressions for $D'_{i,j}$ and $(Aw)_i$ is found in <u>Procedures for Determining Wave Heights in Flood Marshes</u> (Reference 12). The final expression for $(Aw)_i$ is shown in that report to be

$$(Aw)_i = (Aw_s)_i + (2/\pi)\ (Aw_1)_i \tag{54}$$

where

$$\begin{aligned}(Aw_s)_i &= \Big[(D_1)_i + \big[(D_2)_i - (D_1)_i \big] \Big] (d);\ d \le (h_i/2) \\ &= (1/4)\ [(D_1)_i + (D_2)_i]\ (h_i) + (D_2)_i (h_i) [(d/h_i) - 0.5] \\ &\quad + \big[(D_3)_i - (D_2)_i \big]\ \big[(d/h_i) - 0.5) \big] z; \quad (h_i/2) < d \le h_i \\ &= (A_s)_i \qquad ;\ h_i < d\end{aligned} \tag{55}$$

$$(A_s)_i = (1/4)\ \big[(D_1)_i + (2)(D_2)_i (D_3)_i \big] (h_i) \tag{56}$$

$$(Aw_1)_i = (A_1)_i\ (d/h_i);\ d \le h_i = (A_1)_i \qquad ;\ d > h_i \tag{57}$$

$$(A_1)_i = (CA_b)_i\ (A_s)_i \tag{58}$$

and $(D_1)_i$ is the base stem diameter for plant type "i" in the averaging ground area, $(D_2)_i$ is the analogous diameter at the midpoint of the "main stem" (the stem below the inflorescence), $(D_3)_i$ is the analogous diameter at the top of the main stem just below the inflorescence, and $(CA_b)_i$ is the value of the constant CA_b for plant type i. Equation 58 defines CA_b for the i^{th} plant type. Values of the three stem diameters and the CA_b parameter have been determined for the most common marsh grass species found along the Atlantic and Gulf coasts and are given in Procedures for Applying Marsh Grass Methodology (Reference 2) and Procedures for Determining Wave Heights in Flood Marshes (Reference 12).

2.1.4.F. Effective Drag Coefficient ($C_{D,i}$)

It is shown in an appendix to Reference 12 that $C_{D,i}$ ranges between approximately 0.069 and 0.25 for marsh grass plant types of interest to FEMA under various conditions of flexure. Focusing attention on only those situations where the flexing is near a maximum and ignoring "outlier" values of $C_{D,i}$, it is also shown in that appendix that $C_{D,i}$ ranges between approximately 0.069 and 0.121 for these same plant types. FEMA is primarily interested in the maximum flexure and near-maximum flexure situations associated with hurricane waves. Therefore, the expected range of $C_{D,i}$ for these situations, excluding "outlier" values, is 0.069 to 0.121. At present, our knowledge of plant flexure physics does not appear to warrant using anything other than a constant $C_{D,i}$. Consequently, the value of $C_{D,i}$ adopted by FEMA for all marsh grasses is the mean value of this range after rounding, namely,

$$C_{D,i} = 0.1 \tag{59}$$

This value is also supported by estimates of $C_{D,i}$ from equivalent Manning's "n" values for steady uniform flow through marsh grass (Reference 12).

2.2 NUMERICAL SOLUTION SCHEME

A. Finite Difference Equation

Inserting Equation 30d (for the wind energy input) and Equation 48 (for the wave energy dissipation due to vegetation) into Equation 20 (the approximate conservation of wave action equation) and rearranging, we have

$$\left(C_g T\right) \frac{\partial \left(H_{m0}\right)^2}{\partial x} + \left(H_{m0}\right)^2 \left(T_4 \frac{\partial d}{\partial x} + T_5 d^{-1/2} \frac{\partial d}{\partial x} + \left(C_g T\right)\left(\sigma_h \alpha_h\right)^2 \frac{\left(U_A\right)^2}{g\left(H_{m0,\infty}\right)^2} \right)$$

$$= \left(C_g T\right) \left(\sigma_h \alpha_h\right)^2 \frac{\left(U_A\right)^2}{g} - \left(\frac{16}{\rho g}\right)\left(f_p\right) T \left(H_{m0}\right)^3 \tag{60}$$

Note that the term $(H_{m0})^2$ T_6 S_{in} has cancelled out. Letting $R = (H_{m0})^2$ and rearranging Equation 60, we have

$$\frac{\partial R}{\partial x} + R\left(T_7 \frac{\partial(d^{1/2})}{\partial x} + T_8 \frac{\partial(\ln d)}{\partial x} + b + cH_{m0}\right) = a \qquad (61)$$

where

$$a = (\sigma_h \alpha_h)^2 \frac{(U_A)^2}{g} \qquad (62)$$

$$b = \left(\frac{\sigma_h}{\beta_h}\right)^2 \frac{g}{(U_A)^2} \qquad (63)$$

$$c = \left(\frac{16}{\rho g}\right) \frac{f_p}{C_g} \qquad (64)$$

$$T_7 = \frac{2T_4 d^{1/2}}{C_g T} \qquad (65)$$

$$T_8 = \frac{T_5 d^{1/2}}{C_g T} \qquad (66)$$

This is the first-order differential equation to be solved for H_{m0}. All symbols in Equations 62 to 66 have been previously defined. The factors a, b, c, T_7, and T_8 are functions of stillwater depth d, spectral peak wave period T, adjusted wind speed U_A wave group velocity Cg, and the plant characteristics. In Equation 61, a accounts for wind energy input to the waves and wave-

wave interactions, b for wave energy dissipation due to whitecapping and bottom friction, c for wave energy dissipation due to marsh plants, and T_7 and T_8 for wave energy changes due to "shoaling" (i.e. due to spatial changes in the group velocity).

Equation 61 is solved using a combined analytic-finite difference numerical method. A transect segment for an inland or overwater fetch (IF or OF Cards) or containing marsh grasses (VH Card) is divided into one-dimensional grid cells of variable length. A grid point is at the boundary of each cell. The WHAFIS program solves Equation 61 for H_{m0} at the j^{th} grid point based on the value of H_{m0} at the $(j-1)^{th}$ grid point as shown in Figure 3. This computation is done for all grid points in the segment. Grid point $j=1$ corresponds to the beginning of the segment. The grid cell lengths are automatically set by WHAFIS in a manner explained in Section 2.2E.

The adjusted windspeed U_A is assumed to be a constant in an IF, OF, or VH transect segment. In the present WHAFIS program, the windspeed U is either 60 statute miles/hour (IF fetch segments and VH segments) or 80 statute miles/hour (OF fetch segments). U_A is related to U by $U_A = 0.589\ U^{1.23}$ where U is in statute miles/hour. Therefore U_A takes on the value appropirate to the U_V value in a particular IF, OF, or VH segment.

Equation 61 may be rewritten as

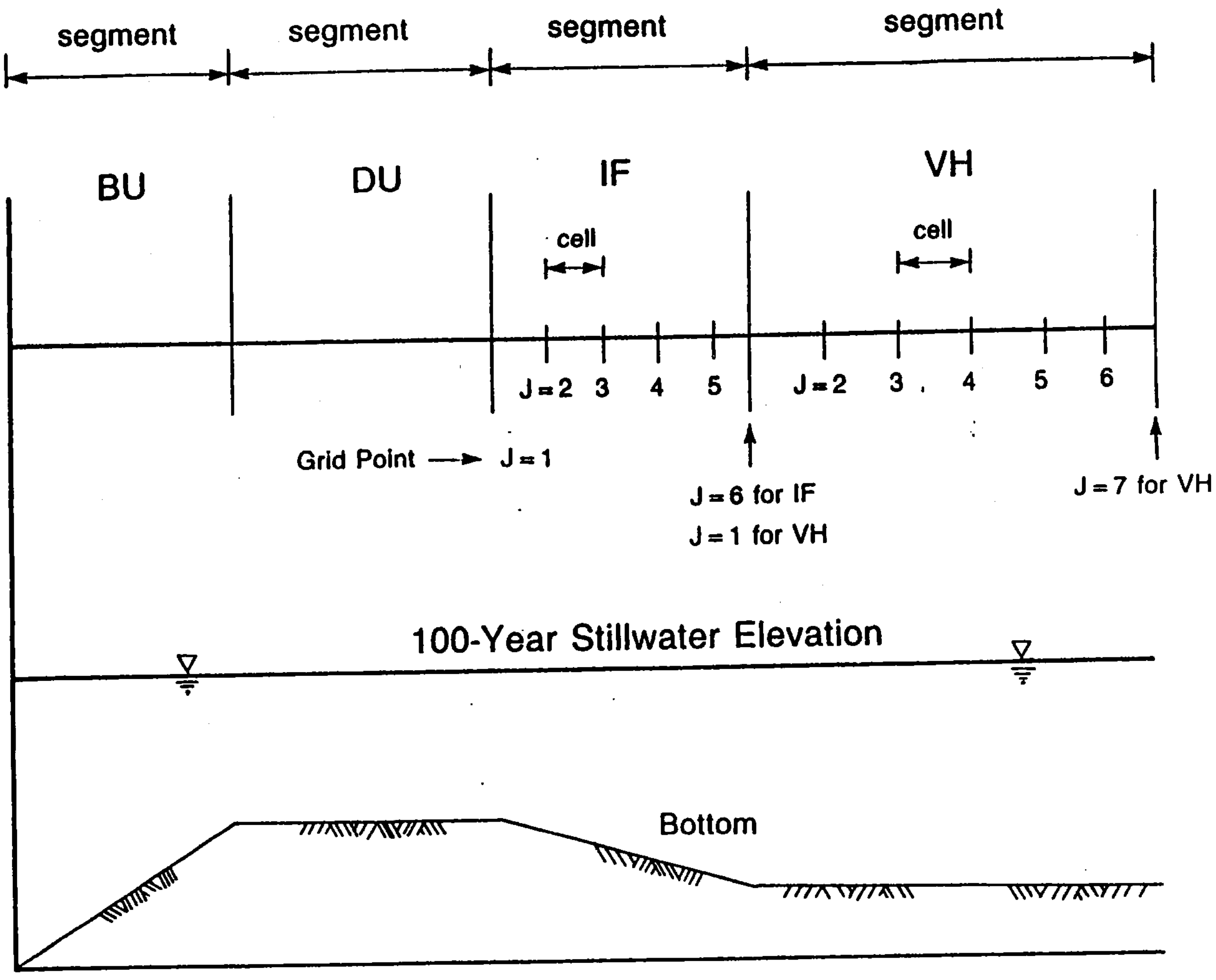

FIGURE 3. Finite Difference Grid for WHAFIS.

$$\frac{\partial R}{\partial x} + YR = a \tag{67}$$

where

$$Y = T_7 \frac{\partial\left(d^{1/2}\right)}{\partial x} + T_8 \frac{\partial(\ln d)}{\partial x} + b + cH_{m0} \tag{68}$$

Equation 67 is a first-order differential equation which can be solved analytically between grid points x_{j-1} and x_j by using the integrating factor.

$$\exp\left\{\int_{x_{j-1}}^{x} Ydx\right\} \tag{69a}$$

Multiplying Equation 67 by Equation 69a and rearranging, it is found that Equation 67 can be rewritten as

$$\frac{\partial}{\partial x}\left(R \exp\left[\int_{x_{j-1}}^{x} Ydx\right]\right) = a \exp\left[\int_{x_{j-1}}^{x} Ydx\right] \tag{69b}$$

Integrating 69b from x_{j-1} to x_j within a grid cell of length (Δx)

$$R_j \exp\left[\int_{x_{j-1}}^{x_j} Y dx \right] - R_{j-1} = a \int_{x_{j-1}}^{x_j} \exp\left[\int_{x_{j-1}}^{x'} Y dx'' \right] dx'$$

or

$$R_j = R_{j-1} \exp\left[-\int_{x_{j-1}}^{x_j} Y dx \right] + a \exp\left[-\int_{x_{j-1}}^{x_j} Y dx \right] \int_{x_{j-1}}^{x_j} \exp\left[\int_{x_{j-1}}^{x'} Y dx'' \right] dx \quad (70)$$

Evaluating the integration factor on the right side of Equation 70 and assuming slowly varying wave motion within the grid cell, we have

$$R_j = R_{j-1} \left(\frac{d_{j-1}}{d_j} \right)^{T_8|_{j-1/2}} \exp\left[-T_7|_{j-1/2}\left(d_j^{1/2} - d^{1/2}{}_{j-1} \right) - b'_{j-1/2} \Delta x \right]$$

$$+ \ a(\Delta x) \left(\frac{d_{j-1/2}}{d_j} \right)^{T_8|_{j-1/2}} \exp\left[-T_7|_{j-1/2} \left(d^{1/2}j - d_{j-1/2}^{1/2} \right) \right] \left(\frac{1-\exp\left[-b'_{j-1/2}\Delta x \right]}{b'_{j-1/2}\Delta x} \right) \tag{71}$$

and

$$(H_{m0})_j = (R_j)^{1/2} \tag{72a}$$

This is the finite difference form of $H_{m0}|_j$ where

$$\Delta x = x_j - x_{j-1} \tag{72b}$$

$$b'_{j-1/2} = b_{j-1/2} + c_{j-1/2} \ H_{m0}|_{j-1} \tag{73}$$

$$b_{j-1/2} = \left(\frac{\sigma_h}{\beta_h|_{j-1/2}} \right)^2 \frac{g}{(U_A)^2} \tag{74}$$

$$c_{j-1/2} = \left(\frac{16}{\rho g} \right) \frac{f_p}{C_g} = \frac{\Gamma_{j-1/2}(\tau_j + \tau_{j-1})}{3\sqrt{2}\pi \ (C_g T)_{j-1/2}} \tag{75}$$

and

$$\tau = T^3$$

In Equations 71 through 75, the subscripts j, j-1, and j-1/2, respectively, denote the value to be determined at grid point j, the value at grid point j-1 (known), and the halfway value between j and j-1. The variables appear in Equations 71 through 75 and were explained previously. In solving for R_j, these variables were defined previously, based either on values calculated at previous grid point j-1 or on the predetermined stillwater elevation and bottom profile. The spectral peak wave period T_j, however, has to be solved using the conservation of waves equation described in Sections 2.1 and 2.1.3. The explicit form of the source term for this equation is derived in Appendix A. The finite difference form of the equation is derived in Appendix B.

B. FEMA's Controlling Wave Height

The zero moment wave height (H_{m0}) is not of direct interest in Flood Insurance Studies. For those studies, the controlling wave height (H_c) is used. H_c is approximately equal to the 1-percent waveheight, i.e., the average height of the highest 1-percent waves. As suggested by the NAS (1977), H_c is related to the significant wave height H_s by

$$H_c = 1.6\ H_s \tag{76}$$

H_s, by definition, is the average height of the highest one-third of all waves. In relatively deep water, H_s is approximately equal to H_{m0}. In general, H_s is greater than H_{m0}. The two wave heights can be related (References 2, 11, and 12) to each other. The functional form of the relationship, when the wave is not breaking or just barely breaking, is:

$$H_s = [(R')_{av}]\ H_{m0} \quad ; \quad H_s \leq H_{sb} \tag{77}$$

where

$$H_{sb} = H_{cb}/1.6 \tag{78}$$

$$H_{cb} = S_b d \tag{79}$$

$$(R')_{av} = \text{smaller value of } R_{av} \text{ and } 1.7 \tag{80}$$

$$R_{av} = 1.477 + (0.477)\left[(d_0/d)^{0.8557} - 1.0\right] \tag{81}$$

and $d = d/(g\ T^2)$, $d_0 = 1.357\text{x}10^{-3}$, and S_b, the breaking index for the controlling wave height, is approximately 0.78. Note that H_{sb} and H_{cb} are the breaking wave depth limited values of H_s and H_c respectively.

The value of H_{m0} calculated by equation 72 and H_s by equation 77 are accepted as long as the wave is not breaking, that is, H_s is less than or equal to H_{sb}. When H_s, calculated by equation 77, is greater than H_{sb}, H_s is reset to H_{sb} and H_{m0} a value H_{m0b} consistent with H_{sb}. H_{m0b} and H_{sb} are related to each other by:

$$H_{sb} = (S') H_{m0b} \tag{82}$$

where S' is a multiplicative factor that is a function of stillwater depth and H_{m0b}. S' takes on values ranging from 1.0 to 1.7. The approximate expression for S' is

$$\begin{aligned} S' &= (S')_{ac} && ;1 \leq (S')_{ac} \leq (R')_{av} \\ &= 1.0 && ;(S')_{ac} < 1.0 \\ &= (R')_{av} && ;(S')_{ac} > (R')_{av} \end{aligned} \tag{83}$$

where

$$\begin{aligned} (S')_{ac} &= (S')_a && ;\ \epsilon' \leq 2.0 \\ &= (S')_c && ;\ \epsilon' > 2.0 \end{aligned} \tag{84}$$

$$(S')_a = (S')_{com} - (1.411) \log_{10}(\epsilon') \tag{85}$$

$$(S')c = (S')_{com} - (.1188) - (1.017)\log10(\epsilon') \tag{86}$$

$$(S')_{com} = 0.9 + (0.4271)\log_{10}(\partial/\partial_{ref}) \qquad (87)$$

and $\bar{\partial}_{ref}$ is 5.5722×10^{-5}, ϵ is $H_{m0} / 4\ L$, and ϵ' is $\epsilon/0.002$. Equation 82 must be solved for H_{m0b} as a function of H_{sb} and spectral peak wavelength (L). The resulting expression for H_{m0b} is in the form of

$$H_{m0b} = (.008)\ (L)\ \epsilon^{*} \qquad (88)$$

where ϵ^{*} fulfills the transcendental equation

$$(\epsilon')_{s} = (\epsilon^{*})\ [S'\ (\epsilon^{*}, \partial)] \qquad (89)$$

where $(\epsilon')_{sb}$ is given in terms of breaking significant wave height (H_{sb}) and L by $(\epsilon')_{sb} = H_{s}/(.008\ \ L\ \ )$, and S' (ϵ^{*},∂) is the S' function defined by Equations 83 through 87 with ϵ' replaced by ϵ^{*}. Symbolically, S' is written in the transcendental equation as a function of the two arguments ϵ^{*} and ∂ to emphasize its dependence on these two parameters. The transcendental equation for ϵ^{*} is solved by an iterative procedure that is explained in detail in Procedures for Determining Wave Heights in Flood Marshes (Reference 12).

C. Initial Value of H_{m0}

An initial value of H_{m0} at the beginning of the IF, OF, or marsh grass segment is needed for the numerical scheme to solve Equations 71 and 72. However, such a value is not immediately available from the computations done before the segment. Instead, an initial value of controlling wave height (H_c) is available at the beginning of the segment. To generate an initial value of H_{m0}, Equations 76 through 89 are used. First, Equation 76 is solved for H_s in terms of the available value of H_c at the beginning of the segment. Then that value of H_s and Equations 77 through 81 are used to evaluate the initial value of H_{m0} if the wave is not breaking. The resulting expression for H_{m0} is :

$$H_{m0} = H_s / [(R')_{av}] \qquad (90)$$

If the wave is breaking, that is, if the H_s value computed from Equation 76 is greater than H_{sb}, then H_s is reset to H_{sb}, H_c to H_{cb}, and H_{m0} is set equal to H_{m0b}. H_{m0b} is determined by solving Equation 89 and evaluating Equation 88.

D. Wave Crest Elevation η

The National Academy of Science (NAS 1977) recommends approximating η for FISs in terms of controlling wave height H_c by the expression

$$\eta = \mu H_c \tag{91}$$

where $\mu = 0.7$ and η is measured relative to the stillwater elevation. In general, $\overset{\mu}{\cancel{U}}$ is a function of local wave period, stillwater depth, wave height, and bottom slope. It ranges from $\mu = 0.5$ for deepwater waves to almost 1.0 for breaking and near-breaking solitary and coincidental waves. The NAS recommends $\mu = 0.7$ as an average covering the range of conditions of primary interest to FEMA.

The present version of the WHAFIS program uses Equation 91 to calculate η. However, η is measured relative to the effective stillwater elevation, that is, the stillwater elevation which includes the effects of wave setup. WHAFIS does not calculate the wave setup. Rather, it assumes that the wave setup has been externally calculated and included in the stillwater elevation values input to the program.

E. Algorithm to Determine the Grid Cell Length Δx

The grid cell length Δx is automatically set by WHAFIS to efficiently resolve the non-linear wave height variations within an IF or OF fetch segment or a VH segment.

At the beginning of the segment (see Figure 3), an initial value of Δx is calculated as the smaller of 50 feet or 1/10 the segment length (in feet). This Δx value is designated as Δx_2 since it is associated with calculations for j=2, the first grid point inside the segment. The full wave period, wave height, wave crest elevation calculation is then completed for j=2.

The value of Δx associated with grid point j=3, designated as Δx_3 is then calculated based on the absolute difference between the zero moment wave height values at the beginning and end of the previous grid cell, i.e. on the absolute difference between H_{m0} values at grid point j=2 and grid point j=1. Let us designate this absolute difference in H_{m0} values as diffH (2,1). If this absolute difference is between 0.05 feet inclusive and 0.1 feet exclusive, then Δx_3 is unchanged from Δx_2. If diffH (2,1) is less than 0.05 feet Δx_3 is increased to twice that of Δx_2. If diffH (2,1) is greater than or equal to 0.1 foot, Δx_3 is reduced to half that of Δx_2. The location (x coordinate) of grid point j=3, designated as x_3 is calculated from the value of Δx_3 using $x_3 = x_2 + \Delta x_3$, where x_2 is the location of grid point j=2.

The value of Δx for the j^{th} grid point, j greater than 3, is determined in a manner similar to that for j=3. More explicitly, let Δx_{j-1} and Δx_j designate the Δx value for grid points j-1 and j respectively, and let diffH(j-1, j-2) designate the absolute difference between the zero moment wave heights at grid points j-1 and j-2. The value of Δx_j is determined using the following expression:

$$\begin{aligned} \Delta x_j &= 0.5 \left(\Delta x_{j-1} \right) && \text{if diffH(j-1,j-2)} < 0.05 \text{ feet} \\ &= \Delta x_{j-1} && \text{if } 0.05 \text{ feet} \le \text{diffH(j-1,j-2)} < 0.1 \text{ feet)} \\ &= 2.0 \left(\Delta x_{j-1} \right) && \text{if } 0.1 \text{ feet} \le \text{diffH(j-1,j-1)} \end{aligned} \quad (92)$$

The location (x coordinate) of grid point j, designated as j, is calculated from the value of Δx_j using $x_j = x_{j-1} + \Delta x_j$ where x_{j-1} is the location of grid point j-1.

If the location of grid point j, j $\geq$ 3, based on the expression above is beyond the end of the segment, Δx_j is reduced to a value that will bring grid point j exactly to the end of the segment.

2.3 STILLWATER INTERPOLATION

In general, the 100-year stillwater flooding levels change inland from the open coast due to elevated ground, complicated geographic features, and different flooding sources or processes. The stillwaters taken from storm surge joint-probability modeling are the values at the center of a modeled grid cell. A wave height analysis transect commonly extends through more than one grid cell. However, the stillwater surface along a transect must have a gentle slope instead of an abrupt change experienced in the previous versions of the WHAFIS program, unless the new stillwater elevation exists behind high ground. In order to ensure a smooth water-surface profile, an interpolation scheme has been incorporated in the latest version (Version 3.0, dated September 1988) to perform the stillwater elevation interpolation along a transect if the stillwater input changes.

The linear interpolation is performed within a transect segment where the stillwater elevations at each end station differ. This linear interpolation scheme yields new stillwater elevations for stations within the segment. The interpolated stillwater elevation at each station within the segment is then compared with the corresponding ground elevation. If the interpolated stillwater elevation is above the corresponding ground elevation, i.e., without ground cut off, the interpolated stillwater values are used as the stillwater elevations for the computation of wave heights (Figure 4(a)). Otherwise, the

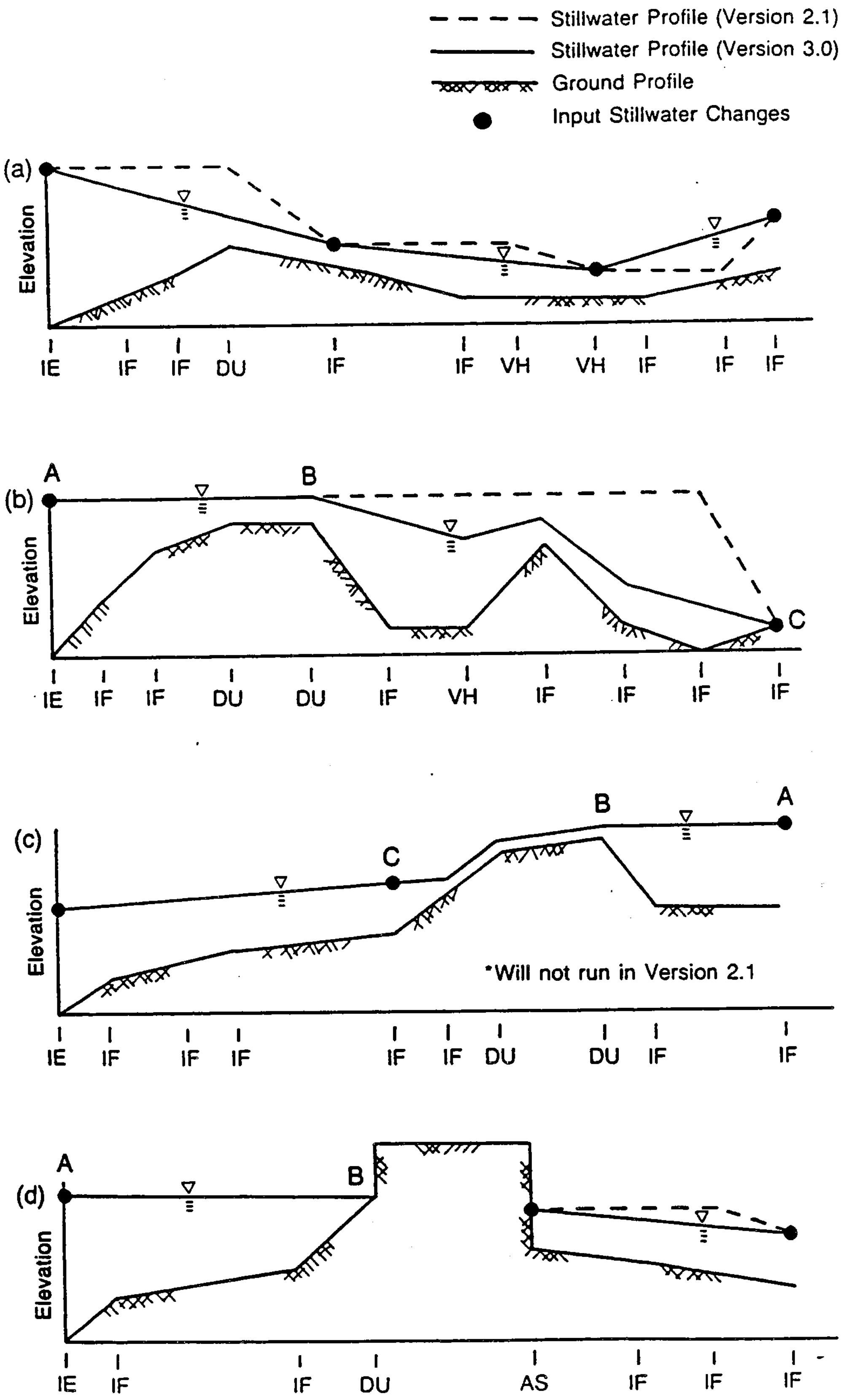

FIGURE 4. Stillwater Interpolation Examples

stillwater elevations will be determined by a method similar to the algorithm used in the FEMA SURGE Model (Reference 16) to determine flow over a barrier. In this method (Figures 4(b) and (c)), the higher stillwater elevation is held equal between the highest ground station (Station B) within the segment and the segment end station with the higher stillwater elevation (Station A). A linear interpolation is then performed within the subsegment between the highest ground station (Station B) and the segment end station with the lower stillwater elevation (Station C), using the given stillwater values at Stations B and C. If the interpolated stillwater elevation at any station in this subsegment is lower than the corresponding ground elevation, the new stillwater elevation at the station is set equal to the greatest of:

a. The ground elevation plus the water depth at the highest ground station,

b. The second interpolated value, or

c. The stillwater elevation at the lower stillwater station in the segment.

This approach not only accounts for the surge flooding hydrodynamics but also resolves, to some extent, the stillwater distribution ambiguity inherent in the geographic discretization of the FEMA SURGE Model. However, note that the linear interpolation does not apply to the situation involving an above surge (AS) card. For that case (Figure 4(d)), the stillwater elevation remains unchanged between the last stillwater elevation input station (Station A) before the AS station and the beginning of the AS segment (Station B).

3. SUMMARY

The methodology revisions implemented in the WHAFIS Model (Version 3.0, dated September 1988) for inland fetch, overwater fetch, and marsh grass segments described in the previous sections are based on the conservation of wave action equation and the conservation of waves equation. These equations approximately reproduce the wave growth curves in the current SPM when the conditions arise for which the curves are valid. The revisions to WHAFIS make it a significantly improved wave model. The conservation of wave action equation and conservation of waves equation describe the wave propagation dynamics of slowly-varying wave motion. The waves associated with overland storm surge flooding fall into this category. The solution scheme involves analytical and finite difference techniques to obtain the wave heights and peak spectral wave period at any location. The scheme is stable and efficient. Finally, the new linear stillwater interpolation routine provides a procedure for obtaining a water-surface profile without abrupt changes for the calculation of wave heights along transects.

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APPENDIX A

DERIVATION OF THE SOURCE TERM IN THE CONSERVATION OF WAVES EQUATION

A.1 INTRODUCTION

The conservation of waves equation is given by Equation 4 in the main body of this report. This equation states that

$$\frac{\partial \Omega}{\partial x} = S \qquad \text{(A1)}$$

where $\Omega = 2\pi/T$, T is the spectral peak wave period, x is the distance along the transect, and S is the source term.

S is determined in a manner similar to the net wind energy input per unit area W_{net} in the conservation of wave action equation. Below is a summary of the derivation.

A.2 REPARAMETERIZED SPM EXPRESSION FOR T

In order to minimize numerical problems and increase numerical efficiency, a reparameterized form of the SPM expression for T was devised and used to derive and expression for source term S.

The requirement was imposed that any reasonable expression for S produce values of T that differ little from those computed using wave period growth expressions in the current SPM when the following circumstances hold:

a. The plant dissipation function (E_p), defined in Equation 48 of the main text, is zero.

b. The stillwater depth d and adjusted windspeed U_A (see right below Equation 23 in main text) are independent of space and time, i.e. are constant.

c. T and the zero moment wave height H_{m0} are zero at the beginning of the fetch.

In the current SPM, the expression for T is given by

$$T = \alpha_t \left\{ \frac{U_A}{g} \right\} \beta_t \tanh\left(q_t \right)^{m_t} \qquad \text{(A2)}$$

where

$$\alpha_t = 7.54$$

$$\beta_t = \tanh\left\{ \gamma_t \left\{ \frac{gd}{U_A^2} \right\}^{3/8} \right\} \qquad \text{(A3)}$$

$$\gamma_t = .833$$

$$m_t = 1./3.$$

g = gravitational acceleration

$$q_t = \left\{\frac{\sigma_t}{\beta_t}\right\}^{1/m_t} \left\{\frac{gx}{U_A^2}\right\} \tag{A4}$$

σ_t = .0379

U_A = 0.589 $U^{1.23}$ = adjusted windspeed

U = windspeed (statute miles per hour)

An alternative approximate form of Equation A2 can be derived by approximating $\tanh(q_t)^{m_t}$ by $\left(1-e^{-q_t}\right)^{m_t}$, i.e. by replacing Equation A2 with

$$T = \alpha_t\left(\frac{U_A}{g}\right) \beta_t \left(1 - e^{-q_t}\right)^{m_t} \tag{A5}$$

Equation A5 is analogous to Equation 24 for H_{m0} in the main text. It can be shown that $\left(1-e^{-q_t}\right)^{m_t}$ differs from $\tanh\left(q_t\right)^{mt}$ by no more than 5.8% when m_t=1/3. This reparameterized form of the SPM expression for T is inconvenient to use in practice since it does not explicitly display the coupling of H_{m0} and T. Such a coupling occurs in the situations encountered in practice (d not constant, plant dissipation function E_p not zero) in FEMA FISs.

To derive this second alternative "coupled" form of Equation A2, we proceed as follows. Eliminating gx/U_A^2 between Equation 23 of the main text and Equation A4, it is for that q and q_t in these two equations are related by

$$q_t = (\nu_t)q \tag{A6}$$

where

$$\nu_t = \left(\frac{\beta_h}{\sigma_h}\right)^{1/m_h}\left(\frac{\sigma_t}{\beta_t}\right)^{1/m_t} \tag{A7}$$

where σ_t, β_t, and m_t have already been defined in this appendix and

$$m_h = 0.5$$

$$\sigma_h = 0.00565$$

$$\beta_h = \tanh\left\{\gamma_h\left\{\frac{gd}{U_A^2}\right\}^{0.75}\right\} \tag{A8}$$

$$\gamma_h = 0.53$$

Solving Equation 24 in the main text for e^{-q} in terms of zero moment wave height H_{m0}, we find that

$$e^{-q} = 1 - \left[\frac{H_{m0}}{H_{m0,\infty}} \right]^{1/m_h} \tag{A9}$$

where $H_{m0,\infty}$ is given by Equation 28 in the main text, namely

$$H_{m0,\infty} = \left[\alpha_h \beta_h \right] \frac{U_A^2}{g} \tag{A10}$$

with

$\alpha_h = 0.283$,

and all other symbols have been previously defined in this Appendix. Substituting Equation A9 into Equation A6, the following equation for e^{-q_t} results:

$$e^{-q_t} = e^{-\nu_t q} \tag{A11}$$

Substituting Equation A9 into Equation A11, it is found that

$$e^{-q_t} = \left\{ 1 - \left[\frac{H_{m0}}{H_{m0,\infty}} \right]^{1/m_h} \right\}^{\nu_t} \tag{A12}$$

Finally substituting Equation A12 into Equation A5, the following equation for T results:

$$T = T_\infty \left[1 - \left\{ 1 - \left[\frac{H_{m0}}{H_{m0,\infty}} \right]^{1/m_h} \right\}^{\nu_t} \right]^{m_t} \qquad \text{(A13)}$$

where

$$T_\infty \equiv \alpha_t \left[\frac{U_A}{g} \right] \beta_t \qquad \text{(A14)}$$

Equation A13 is the sought for "coupled" form of the SPM expression for spectral peak wave period T. It along with Equation A5 will be used to determine the source term S in Equation A1.

A.3 CONSTRUCTION OF SOURCE TERMS S_{in} and S

The term $\frac{\partial \Omega}{\partial x}$ in Equation A1 can be rewritten in terms of T as

$$\frac{\partial \Omega}{\partial x} = - \frac{2\pi}{T^2} \frac{\partial T}{\partial x} \qquad \text{(A15)}$$

where the definition of Ω in terms of T, namely $\Omega = 2\pi/T$ has been used. Substituting Equation A15 into Equation A1, multiplying through by $(1/m_t)T^{(1/m_t)-1}$ and introducing τ where

$$\tau = T^{1/m_t} \tag{A16}$$

Equation A1 becomes

$$\frac{\partial \tau}{\partial x} = S_{in} \tag{A17}$$

where

$$S_{in} \equiv - \frac{\left[T^{(1/m_t)+1}\right]S}{2\pi m_t} \tag{A18}$$

defines S_{in} in terms of T and S. Equation A17 is convenient for determining the source term S_{in}. S is then calculated by solving Equation A18 for S in terms of S_{in} giving

$$S = - \frac{(2\pi m_t)S_{in}}{T^{(1/m_t)+1}} \tag{A19}$$

In order to obtain an expression for the source term S_{in} in equation A17, we need to first determine the term $\frac{\partial \tau}{\partial x}$ under conditions for which the expressions for T and H_{m0} hold. Assume for the moment that stillwater depth d and adjusted windspeed

U_A are constant, and that T and hence τ are zero when x is zero. Therefore, from equation A5 and A14

$$\frac{\partial \tau}{\partial x} = (T_\infty)^{1/m_t} e^{-q_t} \frac{\partial q_t}{\partial x} \tag{A20}$$

From Equation A4,

$$\frac{\partial q_t}{\partial x} = \frac{g}{U_A^2} \left[\frac{\sigma_t}{\beta_t} \right]^{1/m_t} \tag{A21}$$

Substituting Equations A12 and A21 into Equation A20 and rearranging, the following expression is obtained:

$$\left.\frac{\partial \tau}{\partial x}\right|_{SPM} = \frac{g}{U_A^2} \left[\frac{T_\infty \sigma_t}{\beta_t} \right]^{1/m_t} \left\{ 1 - \left[\frac{H_{m0}|_{SPM}}{H_{m0,\infty}} \right]^{1/m_h} \right\}^{\nu_t} \tag{A22}$$

where the subscript "SPM" means using the reparameterized SPM formula. Using equation A14, the product of the first two terms in Equation A22 becomes

$$\frac{g}{U_A^2}\left[\frac{T_\infty \sigma_t}{\beta_t}\right]^{1/m_t} = \frac{1}{g\left(\frac{U_A}{g}\right)^2}\left[\alpha_t \sigma_t \frac{U_A}{g}\right]^{1/m_t}$$

$$= \frac{(\alpha_t \sigma_t)^{1/m_t}}{g}\left(\frac{U_A}{g}\right)^{(1/m_t)-2} \qquad \text{(A23)}$$

Substituting Equation A23 into Equation A22, the latter becomes

$$\frac{\partial \tau}{\partial x}\bigg|_{SPM} = S_{in}^*\big|_{SPM} \qquad \text{(A24)}$$

where

$$S_{in}^*\big|_{SPM} \equiv \frac{(\alpha_t \sigma_t)^{1/m_t}}{g}\left(\frac{U_A}{g}\right)^{(1/m_t)-2}\left\{1 - \left[\frac{H_{m0}|_{SPM}}{H_{m0,\infty}}\right]^{1/m_h}\right\}^{\nu_t} \qquad \text{(A25)}$$

Observe that Equation A25 is only valid as long as $H_{m0}|_{SPM}$ is $\leq H_{m0,\infty}$ and τ is $\leq \tau_\infty$ where

$$\tau_\infty = (T_\infty)^{1/m_t} \qquad \text{(A26)}$$

Thus, it is convenient to define a new function $S_{in}^{**}|_{SPM}$ in terms of $S_{in}^{*}|_{SPM}$, $H_{m0,\infty}$, and τ_∞ as follows:

$$\begin{aligned} S_{in}^{**}|_{SPM} &= S_{in}^{*}|_{SPM} \quad \text{if } H_{m0}|_{SPM} \le H_{m0,\infty} \text{ and } \tau \le \tau_\infty \\ &= 0 \qquad\qquad \text{if } H_{m0}|_{SPM} > H_{m0,\infty} \text{ or } \tau > \tau_\infty \end{aligned} \tag{A27}$$

In terms of $S_{in}^{**}|_{SPM}$, the expression for $\frac{\partial\tau}{\partial x}|_{SPM}$ becomes

$$\frac{\partial\tau}{\partial x}|_{SPM} = S_{in}^{**}|_{SPM} \tag{A28}$$

Comparing Equation A28 with Equation A17, it is seen that $S_{in}^{**}|_{SPM}$ is the expression for the source function S_{in} when marsh grass is absent, the stillwater depth d and windspeed U are constant, and spectral peak wave period T (and hence $\tau = T^{1/m_t}$)

is zero at the beginning of the fetch. Since Equation A27 after substituting (Equations A10, A14, A25, and A26) does not involve the fetch distance (x) explicitly, it is valid for situations where T (and hence τ) is non-zero at the beginning of the fetch.

When d and U are "slowly varying" with x, T (hence τ) is not zero at the beginning of the fetch, and energy dissipation due to marsh grass is modest, i.e. E_p is not very large, it is expected that Equation A27 after substituting (Equations A10, A14, A25, and A26) should still be a good approximation for S_{in}. However, when dissipation due to marsh grass is strong, i.e. E_p is large, it is expected that Equation A27 may not be a good approximation for S_{in}. Nevertheless, because a better representation of S_{in} does not exist for shallow as well as deepwater areas, Equation A27 is assumed to be a valid approximate representation (as a function of U, d, H_{m0}) under all circumstances. Therefore Equation A27 (after substituting Equations A10, A14, A25 and A26) with $H_{m0}|_{SPM}$ replaced by H_{m0} is used in the present model to calculate the source function S_{in} for all H_{m0}. Equation A19 is then used to calculate S.

APPENDIX B

NUMERICAL SOLUTION OF CONSERVATION OF WAVES EQUATION

B.1 FORM OF CONSERVATION OF WAVES EQUATION TO BE SOLVED NUMERICALLY

Equation A1 of Appendix A (hereafter, all equations beginning with an A are from Appendix A), with $\frac{\partial \Omega}{\partial x}$ given by Equation A15 and S given in terms of S_{in} by Equation A19, governs the spectral peak wave period T. However, this equation produces numerical problems when discretized and then solved for small T since $\frac{\partial T}{\partial x}$ becomes unbounded as T approaches zero.

To overcome this numerical problem, it has been found that use of Equation A17 in discretized form leads to a numerically stable, well-behaved calculation of T for the full range of T. Thus the present model solves the following equations numerically for T:

$$\frac{\partial \tau}{\partial x} = S_{in} \qquad \text{(B1)}$$

where T is determined from τ using

$$T = \tau^{m_\tau} \qquad \text{(B2)}$$

with $m_t = 1/3$, and the source term S_{in} in Equation B1 is given by

$$
\begin{aligned}
S_{in} &= S^*_{in} && \text{if } H_{m0} \le H_{m0,\infty} \text{ and } \tau \le \tau_\infty \\
&= 0 && \text{if } H_{m0} > H_{m0,\infty} \text{ or } \tau > \tau_\infty
\end{aligned}
\tag{B3}
$$

where

$$S^*_{in} \equiv \frac{(\alpha_t \sigma_t)^{1/m_t}}{g} \left(\frac{U_A}{g}\right)^{(1/m_t)^{-2}} \left\{1 - \left[\frac{H_{m0}}{H_{m0,\infty}}\right]^{1/m_h}\right\}^{\nu_t} \tag{B4}$$

α_t = 7.54

σ_t = .0379

g = gravitational acceleration

U_A = $0.589\ U^{1.23}$ = adjusted windspeed

U = windspeed (statute miles per hour)

$$H_{m0,\infty} = [\alpha_h \beta_h] \frac{U_A^2}{g} \tag{B5}$$

α_h = 0.283

$$\beta_h = \tanh\left\{\gamma_h \left[\frac{gd}{U_A^2}\right]^{0.75}\right\} \qquad \text{(B6)}$$

$\gamma_h = 0.53$

d = stillwater depth

$m_h = 0.5$

$$\nu_t = \left(\frac{\beta_h}{\sigma_h}\right)^{1/m_h} \left(\frac{\sigma_t}{\beta_t}\right)^{1/m_t} \qquad \text{(B7)}$$

$\sigma_h = 0.00565$

$$\beta_t = \tanh\left\{\gamma_t \left[\frac{gd}{U_A^2}\right]^{3/8}\right\} \qquad \text{(B8)}$$

$\gamma_t = .833$

$$\tau_\infty = T_\infty^{1/m_t} \qquad \text{(B9)}$$

$$T_\infty = \alpha_t \left(\frac{U_A}{g}\right) \beta_t \qquad \text{(B10)}$$

Note that S_{in} is just $S_{in}^{**}|_{SPM}$ in Equation A27, generalized to hold for all H_{m0}, not just the SPM expression for H_{m0}. Similarly, S_{in}^{*} is just $S^*_{in}|_{SPM}$ in equation A25 generalized to hold for all H_{m0}.

B.2 NUMERICAL SCHEME

A. Finite Difference Equation

Equation B1 is solved numerically in each IF and OF fetch segment and VH segment using the same grid introduced to solve the conservation of wave action equation. This grid is discussed in the main body of this report (hereafter referred to as the main report) and illustrated schematically in Figure 3 of the report.

The WHAFIS program solves Equations B1 and B2 at the j^{th} grid point in a given transect segment based on the value of H_{m0} and T at the $(j-1)^{th}$ grid point, and the value of stillwater depth d halfway between the j^{th} and $(j-1)^{th}$ grid point. The adjusted windspeed U_A is constant in the segment, as discussed in the main report. The grid cell lengths, i.e. the distance between grid points j and j-1, are set in the manner described in the main report.

Integrating Equation B1 from x_{j-1} to x_j within grid cell Δx where

$$\Delta x = x_j - x_{j-1} \tag{B11}$$

$$\tau_j = \tau_{j-1} + \Delta x \, S'_{in}|_{j-1/2} \tag{B12}$$

and from Equation B2,

$$T_j = (\tau_j)^{m_t} \tag{B13}$$

This is the finite difference form of T_j where

$$\begin{aligned} S'_{in}|_{j-1/2} &= S^{+}_{in}|_{j-1/2} \quad \text{if } (H_{m0})_{j-1} \le H_{m0,\infty}|_{j-1/2} \text{ and } \tau_{j-1} \le \tau_{\infty}|_{j-1} \\ &= 0 \qquad\qquad \text{otherwise} \end{aligned} \tag{B14}$$

$$S^{+}_{in}|_{j-1/2} = \frac{(\alpha_t \sigma_t)^{1/m_t}}{g} \left(\frac{U_A}{g}\right)^{(1/m_t)-2} \left\{ 1 - \frac{R_{j-1}}{R_{\infty}|_{j-1/2}} \right\}^{\nu_t|_{j-1/2}} \tag{B15}$$

$$R_{j-1} \equiv \left[(H_{m0})_{j-1} \right]^{1/m_h} \tag{B16}$$

$$R_{\infty}|_{j-1/2} \equiv \left[H_{m0,\infty}|_{j-1/2} \right]^{1/m_h} \tag{B17}$$

In Equations B12 through B17, the subscripts j, j-1, and j-1/2, respectively, denote the value to be determined at grid point j, the known value at grid point j-1, and the value halfway between j and j-1.

B. Computation Order

Assume that all variables have been calculated for grid point j-1 in an IF (inland), or OF (overwater), fetch segment or a VH (marsh grass) segment. To determine variable values at grid point j, the following computation sequence occurs:

1. The grid spacing Δx between grid points j-1 and j is determined. This Δx value is then used to determine location x_j of grid point j.

2. τ_j and spectral peak wave period $T_j = (\tau_j)^{m_t}$ are determined using the equations in this appendix.

3. R_j, zero moment wave height $(H_{m0})_j = (R_j)^{m_h}$, controlling wave height

and wave crest elevation $(\eta_c)_j$ are determined using the equations in the main report.

The WHAFIS program executes this sequence for all grid points in the segment. Grid point j=1 corresponds to the beginning of the segment.

APPENDIX C PROGRAM LISTING

```
C     PROGRAM WHAFIS   BY  DAVID HARTY,DAMES AND MOORE, OCT. 20, 1980
C
*********************************************************************
C
C        FEMA WHAFIS MODEL, VERSION 3.0, SEPTEMBER 1988
C
C********************************************************************
C
C     REVISED AUGUST 14, 1984
C
C
C        REVISED AND CORRECTED ON 13 MARCH 1985 AND 22 MAY 1985
C        BY DR. BARRY E. HERCHENRODER OF GREENHORNE AND O'MARA,
C        INC., GRRENBELT MD., 301-220-1868. THE RESULTING WHAFIS
C        IS REFERRED TO AS WHAFIS2.1
C
C     REVISED AND CORRECTED FEBRUARY 1987 BY DR. BARRY E. HERCHENRODER
C     (SAME # AS ABOVE) OF GREENHORNE AND O'MARA, GREENBELT, MARYLAND.
C     (301-220-1868) OF GREENHORNE AND O'MARA.
C     REVISED AND CORRECTED FURTHER IN MAY AND JUNE 1987 BY
C     DR. BARRY E. HERCHENRODER (SAME # AS ABOVE), OF
C     GREENHORNE AND O'MARA.
C     THE RESULTING WHAFIS IS REFERRED TO AS WHAFIS3, JUNE 1987.
C
C     REVISED AND CORRECTED IN SEPTEMBER 1988 BY DR. BARRY E.
C     HERCHENRODER (SAME # AS ABOVE), OF GREENHORNE & O'MARA. THE
C     RESULTING WHAFIS IS REFERRED TO AS FEMA WHAFIS MODEL, VERSION 3.0,
C     SEPTEMBER 1988.
C
C///////////////////////////////////////////////////////////////////////
C
C     WAVE HEIGHT ANALYSIS FOR FLOOD INSURANCE STUDIES (WHAFIS) IS
C     A PROGRAM WRITTEN TO ANALYZE THE DISSIPATION AND REGENERATION
C     OF WIND WAVES ASSOCIATED WITH THE 100-YEAR STORM IN COASTAL AREAS.
C     THE METHODOLGY USED CONFORMS TO PROCEDURES REQUIRED BY THE FEDERAL
C     INSURANCE ADMINISTRATION.
C     THIS PROGRAM DETERMINES WAVE HEIGHTS AND ELEVATIONS, FLOOD HAZARD
C     FACTORS, ZONE DESIGNATIONS, AND THE LOCATION OF  ZONE  BOUNDARIES
C     FOR FLOOD INSURANCE STUDIES.
C
C
C
      PROGRAM WHAFIS3
C
      LOGICAL TEST,AZONE,VZONE
C
      DIMENSION FFL(10),FFF(10),GFL(10),GFF(10),PARAM(10),
     1HBW(500),EW(500),TITLE(80),
     1STVG(500),VZNE(500),STEG(500),ELZ(500),GS(500),
```

```
     1NSE(500),SELZ(500),SAVE(500),
     1SA(500,5),AP(500),SBP(500),SEP(500)
      DIMENSION HDN(8,8,7),PPSD(8,3),PLTYP(8)
C
C G&O SEPT 88
C
      DIMENSION SPWP(500)
C
      COMMON/ARRAY1/ SPWP
C
C END G&O SEPT 88
C
      COMMON /PPT/HDN,PPSD,PLTYP
      COMMON /FONLY/FFL,FFF,GFL,GFF
      COMMON /AONLY/NFOM1
      COMMON /AFGV/TOF,PARAM,BSFO,BEFO,WHI,WHT,NFO,
     1HBW,AP,SET,SE,STEG,ELZ,GS,EW,SA,M,NAP
CG&O 2/87
      COMMON /BTSLOP/GSLB,GSLE
CG&O 2/87
      DATA EI,DU,BU,VE,FI,FO,ET/2HIE,2HDU,2HBU,2HVE,2HIF,2HOF,2HET/
      DATA WIND,WARD,BLEE,AS/4HWIND,4HWARD,4H LEE,2HAS/
      DATA PI,BLANK/3.14159,1H /
      DATA VH/2HVH/
C
C
C         UNIT 5 IS THE INPUT FILE
C         UNIT 6 IS THE OUTPUT FILE
C         UNIT 7 IS THE MARSH GRASS DATA FILE
C         UNIT 8 IS THE SCRATCH FILE FOR ECHOING THE INPUT
C                IN TABULAR FORM
C         UNIT 9 IS THE SCRATCH FILE USED TO WRITE MARSH
C                GRASS DEFAULT PARAMETERS WHEN THE LATTER
C                ARE OBTAINED BY REGRESSION AND INTERPOLATION.
C         UNIT 10 IS THE SCRATCH FILE USED TO STORE THE
C                 RESULTED TRANSECT INFORMATION AFTER THE
C                 STILLWATER SURGE ELEVATIONS BEEN INTERPOLATED
C                 BY THE SUBROUTINE SCANE.
C
C         OPEN THE VARIOUS FILES
C
      OPEN(5,FILE='@DATA',PAD='YES')
C
C G&O SEPT 88
C
      OPEN(6,FILE='WHAFIS3.SEPT88.RESULTS',STATUS='FRESH'
     1 , CARRIAGECONTROL='FORTRAN')
C
C END G&O SEPT 88
C
      OPEN(7,FILE='MG.DF',STATUS='OLD',IOINTENT='INPUT')
      OPEN(8,STATUS='SCRATCH',PAD='YES')
```

```
      CLOSE (9,ERR=9)
 9    OPEN(9,STATUS='SCRATCH',PAD='YES')
      CLOSE (10,ERR=1099)
  1099  OPEN(10,STATUS='SCRATCH',PAD='YES')
C
C     READ IN TABULAR DATA FOR MARSH GRASS
      CALL READIN
C
C            CALL SCANE TO INTERPOLATE 100-YR STILLWATER ELEVATIONS
C
      CALL SCANE
C
C     READ THE TITLE CARD
      READ(10,805)(TITLE(I),I=1,80)
C     PRINT HEADING AND TITLE
C     INITIALIZE VARIABLES FOR CURRENT TRANSECT
C
 4    BSFO=0
      N=0
      M=0
      NFO=0
      NAP=0
      WRITE(6,830)
      WRITE(6,835)(TITLE(I),I=1,80)
      WRITE(6,840)
C
C     READ DATA CARD DESCRIBING FETCH OR OBSTRUCTION
    5 READ(10,810)TOF,(PARAM(I),I=1,10)
C     ECHO INPUT
      WRITE(6,815)TOF,(PARAM(I),I=1,10)
C
C     WRITE INPUT TO SCRATCH FILE
      WRITE(8,815)TOF,(PARAM(I),I=1,10)
C
C
C     BRANCH TO THE APPROPRIATE SEGMENT OF THE PROGRAM DEPENDING ON THE
C     TYPE OF FETCH OR OBSTRUCTION (TOF)
      IF(TOF.EQ.DU)GO TO 50
      IF(TOF.EQ.BU)GO TO 100
      IF(TOF.EQ.VE)GO TO 125
      IF(TOF.EQ.FI)GO TO 150
      IF(TOF.EQ.FO)GO TO 200
      IF(TOF.EQ.AS)GO TO 230
      IF(TOF.EQ.VH)GO TO 240
      IF(TOF.EQ.ET)GO TO 300
C
C     IF TOF IS ILLEGAL PRINT MESSAGE AND STOP
      IF(TOF.NE.EI)WRITE(6,820)
      IF(TOF.NE.EI)GO TO 1000
C
C
C     INITIAL ELEVATIONS PROGRAM SEGMENT
```

```
      ESFO=PARAM(1)
      EEFO=PARAM(2)
      FL=PARAM(3)
      SET=PARAM(4)
      SE=PARAM(5)
      WHT=PARAM(6)
      WPT=PARAM(7)
CG&O 2/87
      WPI=WPT
      WHI=WHT
      GSLB=PARAM(9)
      GSLE=GSLB
CG&O 2/87
      ASE=SE
C
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE)WRITE(6,780)
      IF(EEFO.GT.SE)GO TO 1000
C
C IF INITIAL WAVE HEIGHT IS KNOWN BRANCH TO ARRAY LOADING PROGRAM SEGMENT
CG&O 2/87  **  COMMENTED OUT  ***
C     IF(WHT.NE.0)GO TO 250
C
C     IN CASE FETCH LENGTH IS NOT ON CURVE
C     IF(FL.GE.24.0)FF=1.0
C     IF(FL.LT..1) FF=(FL/0.1)*FFF(1)
C     IF(FL.LT..1.OR.FL.GE.24)GO TO 25
C
C     FIND FETCH LENGTH ON F CURVE
C     DO 20 I1=1,9
C     IF(FL.GE.FFL(I1).AND.FL.LT.FFL(I1+1))NF=I1
C  20 CONTINUE
C
C     INTERPOLATE BETWEEN POINTS ON F CURVE
C     DIFF1=FFF(NF+1)-FFF(NF)
C     DIFF2=ALOG10(FFL(NF+1))-ALOG10(FFL(NF))
C     DIFF3=ALOG10(FL)-ALOG10(FFL(NF))
C     FF=(DIFF1/DIFF2)*DIFF3+FFF(NF)
C
C     COMPUTE TRANSMITTED WAVE HEIGHT
C  25 WHT=.78*FF*SE
C     IF(EEFO.EQ.SE)WHT=0
CG&O 2/87  **  END OF COMMENTTED OUT  ***
C     COMPUTE WAVE PERIOD
      IF(WPT.GT.0)GO TO 20
      AFL=5280*FL
      IF( AFL .EQ. 0.0 ) AFL=5280.*24.
      WPT=T(0,AFL,117.0,26.0)
C
CG&O 2/87
C
   20 CONTINUE
```

```
C
C   CALCULATE INITIAL TRANSMITTED CONTROLLING WAVE HEIGHT IF IT IS
C   NOT KNOWN
C
      IF(WHT. EQ. 0.0) THEN
      AFL=5280.*FL
      IF( AFL .EQ. 0.0 ) AFL=5280.*24.
      WHT=HIN(0.0,AFL,117.0,26.0,WPT)
      ENDIF
C
C   CALCULATE BREAKING WAVE HEIGHT AND RESET WHT IF IT IS TOO LARGE
C
      SDEB=AMAX1(0.0,SE-EEFO)
      HB=SHBM(WPT,GSLE,SDEB)
      WHT=AMIN1(WHT,HB)
CG&O 2/87 END
C
C     BRANCH TO ARRAY LOADING PROGRAM SEGMENT
      GO TO 250
C
C
C     DUNE PROGRAM SEGMENT
   50 ESFO=PARAM(1)
      EEFO=PARAM(2)
      AMMB=PARAM(3)
      SETN=PARAM(4)
      SEN=PARAM(5)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
C
CG&O 2/87
C     UPDATE SURGE ELEVATIONS
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE.AND.AMMB.EQ.0)WRITE(6,780)
      IF(EEFO.GT.SE.AND.AMMB.EQ.0)GO TO 1000
      ASE=(SA(NFO,4)+SE)/2.0
      EEB=EEFO
      SDEB=SE-EEB
C     COMPUTE TRANSMISSION COEFFICIENT B
CG&O 2/87
      HBM=SHBM(WPI,GSLE,SDEB)
C     IF(WHI.LT.SDEB*.78)B=1.0
      IF(WHI.LT.HBM)B=1.0
CG&O 2/87 END
      IF(WHI.EQ.0)GO TO 80
C     CHECK FOR ARTIFICIAL OR MAN MADE BARRIERS
      IF(AMMB.NE.0)GO TO 75
```

```
CG&O 2/87
C     IF(WHI.GE..78*SDEB)B=(.78*SDEB)/WHI
      IF(WHI.GE.HBM)B=HBM/WHI
CG&O 2/87
      GO TO 80
C     COMPUTE B FOR ARTIFICIAL BARRIERS
   75 IF(EEB.GE.SE+.5*WHI)B=0
      IF(EEB.GE.SE+.5*WHI)GO TO 80
CG&O 2/87
C     IF(WHI.GE.SDEB*.78)B=(1/(2*WHI))*(.78*SDEB+WHI)
      IF(WHI.GE.HBM)B=(1/(2*WHI))*(HBM+WHI)
CG&O 2/87
      IF(EEB.GT.SE)B=.5-((EEB-SE)/WHI)
C     COMPUTE TRANSMITTED WAVE HEIGHT
   80 WHT=B*WHI
C     COMPUTE WAVE PERIOD AT END OF SEGMENT
      WPT=WPI
C     BRANCH TO ARRAY LOADING PROGRAM SEGMENT
C
      GO TO 250
C
C     BUILDING PROGRAM SEGMENT
  100 ESFO=PARAM(1)
      EEFO=PARAM(2)
      R=PARAM(3)
      RB=PARAM(4)
      SETN=PARAM(5)
      SEN=PARAM(6)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
CG&O 2/87
C     UPDATE SURGE ELEVATIONS
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
      ASE=(SA(NFO,4)+SE)/2.0
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE)WRITE(6,780)
      IF(EEFO.GT.SE)GO TO 1000
C
C  B IS A FUNCTION OF THE RATIO OF OPEN SPACE TO TOTAL TRANSVERSE WIDTH
C  (R), AND THE NUMBER OF ROWS OF BUILDINGS (RB).
      B=R**(RB/2.0)
      WHT=WHI*B
      IF(EEFO.EQ.SE)WHT=0
C     COMPUTE WAVE PERIOD AT END OF SEGMENT
      WPT=WPI
C     BRANCH TO ARRAY LOADING PROGRAM SEGMENT
      GO TO 250
C
```

```
C
C     VEGETATION PROGRAM SEGMENT
  125 ESFO=PARAM(1)
      EEFO=PARAM(2)
      D=PARAM(3)
      AH=PARAM(4)
      AHS=PARAM(5)
      DC=PARAM(6)
      SETN=PARAM(7)
      SEN=PARAM(8)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
C
CG&O 2/87
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
      ASE=(SA(NFO,4)+SE)/2.0
      IF(DC.EQ.0)DC=1.0
      W=ESFO-BSFO
C
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE)WRITE(6,780)
      IF(EEFO.GT.SE)GO TO 1000
C
C     COMPUTE AVERAGE WETTED HEIGHT OF VEGETATION
      AEG=(BEFO+EEFO)/2.0
      ADV=ASE-AEG
C     CHECK FOR NEGATIVE DEPTHS
      IF(ADV.LE.0)WRITE(6,790)
                IF(ADV.LE.0.) THEN
                WRITE(6,791) TOF,PARAM(1)
                ENDIF
  791           FORMAT(/2X,'TOF= ',A2,2X,'STATION= ',F8.2/)
      IF(ADV.LE.0)GO TO 1000
      AWH=AMIN1(AH,ADV)
C
C
C     COMPUTE TRANSMISSION COEFFICIENT, TRANSMITTED WAVE HEIGHT AND
C     BRANCH TO ARRAY LOADING PROGRAM SEGMENT
      PART1=DC*WHI*AWH*D*W
      PART2=3*PI*(AHS**2)*(ADV**2)
      B=1/(1+(PART1/PART2))
      WHT=WHI*B
      IF(EEFO.EQ.SE)WHT=0
C     COMPUTE WAVE PERIOD AT END OF SEGMENT
      WPT=WPI
C
      GO TO 250
C
```

```
C
C     INLAND FETCH PROGRAM SEGMENT
  150 ESFO=PARAM(1)
      EEFO=PARAM(2)
      SETN=PARAM(3)
      SEN=PARAM(4)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
CG&O 2/87
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
CG&O 2/87
C
C   CHECK FOR MIISSING AS CARD
C
      IF(EEFO. GT. SE) THEN
      WRITE(6,780)
      GO TO 1000
      ENDIF
CG&O 2/87
C
      ASE=(SA(NFO,4)+SE)/2.0
C
C         THE SECTION THAT IGNORES REGENERATION FOR FETCHES
C         SHORTER THAN 0.1 MILESIS DISABLED BELOW. INSTEAD,
C         AN ESTIMATE OF THE G OR F FACTOR FOR FETCHES SHORTER
C         THAN 0.1 MILES IS MAKE USING LINEAR INTERPOLATION
C         BETWEEN THE G OR F VALUE FOR 0.1 MILES AND F=0 OR
C         G=0 FOR 0.0 MILES
C
C     NO REGENERATION FOR FETCHES SHORTER THAN .1 MILE
CG&O 2/87  **  COMMENTTED OUT  ***
C     AFL=ESFO-BSFO
C     AFLHOLD= AFL
C     IF(AFL.LT.528)WHT=WHI
C     IF(AFL.LT.528)GO TO 250
C
C     CHECK FOR MISSING AS CARD
C
C     IF(EEFO.GT.SE)WRITE(6,780)
C     IF(EEFO.GT.SE)GO TO 1000
CG&O 2/87  **  END OF COMMENTTED OUT   ***
C
C     COMPUTE FETCH FACTOR
      AEG=(EEFO+BEFO)/2.0
      ADF=ASE-AEG
      ADFHOLD= ADF
C     CHECK FOR NEGATIVE DEPTHS
      IF(ADF.LE.0)WRITE(6,790)
```

```
                IF(ADF.LE.0.) THEN
                WRITE(6,791) TOF,PARAM(1)
                ENDIF
      IF(ADF.LE.0)GO TO 1000
CG&O 2/87
C
C   INITIALIZE ERROR FLAG
C
      TEST=.FALSE.
C
C   SET WINDSPEED W IN STATUTE MILES PER HOUR
C
      W=60.0
C
C   NOTE THAT WHI AND WHT COMMUNICATE WITH MAIN PROGRAM THROUGH THE
C   AFGV COMMON BLOCK AND THAT WHT AND WPT ARE SET IN SUBROUTINE FETCH.
C
      CALL FETCH(WPI,TEST,WPT,W)
C
CG&O 2/87 END
C
C     COMPUTE WAVE PERIOD
C
CG&O 2/87  **  COMMENTTED OUT AND INSERTED ***
C
C     AFL= AFLHOLD
C     ADF= ADFHOLD
C     WPI=T(WPI,AFL,88.0,ADF)
C     IF(HBW(NFO).LT..1)WPI=.1
C
C   SKIP TO NEXT TRANSECT IF ERROR FLAG IS SET
C
      IF(TEST) GO TO 1000
C
CG&OO 2/87   **  END OF COMMENTTED OUT AND INSERTED  ***
C
      GO TO 5
C
C     OVER-WATER FETCH PROGRAM SEGMENT
C     SAME PROCEDURE AS INLAND FETCH EXCEPT FETCH FACTOR IS DEFINED
C     DIFFERENTLY AND F CURVES ARE USED INSTEAD OF G CURVES
  200 ESFO=PARAM(1)
      EEFO=PARAM(2)
      SETN=PARAM(3)
      SEN=PARAM(4)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
CG&O 2/87
      IF(SETN.NE.0)SET=SETN
```

```
      IF(SEN.NE.0)SE=SEN
      ASE=(SA(NFO,4)+SE)/2.0
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE)WRITE(6,780)
      IF(EEFO.GT.SE)GO TO 1000
C
CG&O 2/87  **  COMMENTTED OUT AND INSERTED  ***
C
C     AFL=ESFO-BSFO
C     AFLHOLD= AFL
      AEG=(EEFO+BEFO)/2.0
      ADF=ASE-AEG
C     ADFHOLD= ADF
      IF(ADF.LE.0)WRITE(6,790)
                IF(ADF.LE.0.) THEN
                WRITE(6,791) TOF,PARAM(1)
                ENDIF
      IF(ADF.LE.0)GO TO 1000
C
C   INITIALIZE ERROR FLAG
C
      TEST=.FALSE.
C
C   SET WINDSPEED W IN STATUTE MILES PER HOUR
C
      W=80.0
C
C   NOTE THAT WHT AND WHI COMMUNICATED WITH MAIN PROGRAM THROUGH THE
C   AFGV COMMON BLOCK AND THAT WHT AND WPT ARE SET IN SUBROUTINE FETCH.
C
      CALL FETCH(WPI,TEST,WPT,W)
C
C     COMPUTE WAVE PERIOD
C
C     AFL= AFLHOLD
C     ADF= ADFHOLD
C     WPI=T(WPI,AFL,117.0,ADF)
C     IF(HBW(NFO).LT..1)WPI=.1
C
C   SKIP TO NEXT TRANSECT IF ERROR FLAG IS SET
C
      IF(TEST) GO TO 1000
C
CG&O 2/87  **  END OF COMMENTTED OUT AND INSERT  ***
C
      GO TO 5
C
C
C     ABOVE SURGE PROGRAM SEGMENT FOR B AND C ZONES
C     ESTABLISH GUTTERS AT BEGIN STATION AND END STATION
  230 ESFO=PARAM(1)
      EEFO=PARAM(2)
```

```
      SETN=PARAM(3)
      SEN=PARAM(4)
CG&O 2/87
C
      GSLB=GSLE
      WPI=WPT
      WHI=0.0
      GSLE=PARAM(9)
CG&O 2/87
C     UPDATE SURGE ELEVATIONS
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
      IF(EEFO. LT. SE) THEN
        WRITE(6,785) TOF,PARAM(1),PARAM(2),SE
  785     FORMAT(/1X,'*** AS CARD GROUND ELEVATION LESS THAN',
     A    ' STILLWATER ELEVATION, SHOULD USE OTHER TYPE CARD, JOB',
     B    ' DUMPED  ***'/,
     C           'TOF= ',A2,' STATION= ',F9.2,' GROUND ELEVATION= ',
     D           F8.2,' STILLWATER ELEVATION= ',F8.2)
        GO TO 1000
      ENDIF
      M=M+1
      STEG(M)=BSFO
      ELZ(M)=EW(NFO)
      M=M+1
      STEG(M)=ESFO
      ELZ(M)=SE
      WHT=0
      WPT=0.1
      GO TO 250
C
C
C     PROGRAM SEGMENT FOR MARSH GRASS OR OTHER COMPLEX PLANT COMMUNITY
  240 ESFO=PARAM(1)
      EEFO=PARAM(2)
      SETN=PARAM(7)
      SEN=PARAM(8)
CG&O 2/87
      GSLB=GSLE
      WPI=WPT
      WHI=WHT
      GSLE=PARAM(9)
CG&O 2/87
C     CHECK FOR SURGE CHANGE
      IF(SETN.NE.0)SET=SETN
      IF(SEN.NE.0)SE=SEN
C     CHECK FOR MISSING AS CARD
      IF(EEFO.GT.SE)WRITE(6,780)
      IF(EEFO.GT.SE)GO TO 1000
C     CHECK FOR NEGATIVE DEPTH
      ASE=(SA(NFO,4)+SE)/2.0
      AEG=(BEFO+EEFO)/2.0
```

```
      ADF=ASE-AEG
      IF(ADF.LE.0)WRITE(6,790)
              IF(ADF.LE.0.) THEN
              WRITE(6,791) TOF,PARAM(1)
              ENDIF
      IF(ADF.LE.0)GO TO 1000
C     INITIALIZE ERROR FLAG
      TEST=.FALSE.
CG&O 2/87
C
C   SET WINDSPEED W IN STATUTE MILES PER HOUR
C
      W=60.0
C
C   NOTE THAT WHI AND WHT COMMUNICATE WITH MAIN PROGRAM THROUGH THE
C   AFGV COMMON BLOCK AND THAT WHT AND WPT ARE SET IN SUBROUTINE VEG.
C
C     CALL SUBROUTINE
      CALL VEG(WPI,TEST,WPT,W)
C
CG&O 2/87  END
C
C     SKIP TO NEXT TRANSECT IF ERROR FLAG IS SET
      IF(TEST)GO TO 1000
      GO TO 5
C
C
C     ARRAY LOADING PROGRAM SEGMENT
  250 NFO=NFO+1
      IF(NFO.GT.500)WRITE(6,995)
      IF(NFO.GT.500)STOP
      GS(NFO)=ESFO
C
C
CG&O 2/87
      SDEB=AMAX1(0.0,SE-EEFO)
C
C     COMPUTE MAXIMUM WAVE HEIGHT
C     WHM=.78*(SE-EEFO)
      WHM=SHBM(WPT,GSLE,SDEB)
C
CG&O 2/87
      IF(TOF.EQ.DU.AND.AMMB.NE.0)WHM=WHT
C
C     COMPUTE WAVE HEIGHTS AND ELEVATIONS
      HBW(NFO)=AMIN1(WHT,WHM)
CG&O 2/87
      STMP = EEFO + SDEB
C     EW(NFO)=.7*HBW(NFO)+ASE
      EW(NFO)=.7*HBW(NFO)+STMP
CG&O 2/87
      IF(TOF.EQ.AS)EW(NFO)=EEFO
```

```
C
C G&O SEPT 88
C
C                   STORE SPECTRAL PEAK WAVE PERIOD IN THE
C                   WPWP ARRAY
C
      SPWP(NFO)= WPT
C
C END G&O SEPT 88
C
C     STORE INFORMATION NEEDED LATER FOR FLOOD INSURANCE ZONE DATA
      SA(NFO,1)=BSFO
      SA(NFO,2)=ESFO
      SA(NFO,3)=SET
      SA(NFO,4)=SE
      SA(NFO,5)=TOF
      IF(PARAM(10).NE.1)GO TO 275
      NAP=NAP+1
      AP(NAP)=ESFO
      M=M+1
      STEG(M)=GS(NFO)
      ELZ(M)=EW(NFO)
C
C     INCIDENT WAVE HEIGHT AND PERIOD FOR NEXT OBSTRUCTION
C     EQUALS TRANSMITTED WAVE HEIGHT AND PERIOD OF CURRENT
C     OBSTRUCTION
  275 WHT=HBW(NFO)
C     IF(HBW(NFO).LT..1)WPT=.1
CG&O 2/87 ** COMMENTTED OUT  ***
C     IF(HBW(NFO).LT..1)WPT=.1
C     WPI=WPT
CG&O 2/87 **  END OF COMMENTTED OUT  ***
C
C     BEGINNING POINT OF NEXT OBSTRUCTION IS END POINT OF CURRENT
C     OBSTRUCTION
      BSFO=ESFO
      BEFO=EEFO
C
C     BRANCH BACK TO READ STATEMENT AND READ ANOTHER CARD
C
      GO TO 5
C
C
C     THIS POINT WILL BE REACHED IF THE LAST CARD WAS AN ET CARD
C     SIGNALING THE END OF THE TRANSECT.
C     CALL SUBROUTINE TO PRODUCE AN ANOTATED INPUT LISTING
  300 CALL ECHO
C
C G&O SEPT 88
C
C     PRINT HEADINGS AND OUTPUT FOR PART2 (LOCATION, CONTROLLING
C     WAVE HEIGHT, SPECTRAL PEAK WAVE PERIOD, AND WAVE CREST
```

```
C     ELEVATION)
C
C     WRITE(6,870)
C     WRITE(6,880)
C
      WRITE( 6,875 )
  875 FORMAT(///, 48X, ' PART2: CONTROLLING WAVE HEIGHTS, SPECTRAL '
     1 , / 55X, 'PEAK WAVE PERIOD, AND WAVE CREST ELEVATIONS' )
C
      WRITE( 6,882 )
  882 FORMAT( /, 42X, 10HLOCATION  , 6X, 11HCONTROLLING, 2X
     1   , 14HSPECTRAL PEAK , 2X, 10HWAVE CREST, / 58X, 11HWAVE HEIGHT
     2  , 2X, 14HWAVE PERIOD   , 2X, 10HELEVATION  )
C
C END G&O SEPT 88
C
      DO 310 I=1,NFO
C
C G&O 3/87
C
      TEMP = SA(I,5)
C
C     IF(SA(I,5).EQ.1.0.OR.SA(I,5).EQ.2.0) GO TO 310
      IF(SA(I,5).EQ.1.0.OR.SA(I,5).EQ.2.0) TEMP = 2H
C
C     WRITE(6,890) SA(I,5),GS(I),HBW(I),EW(I)
C
C G&O SEPT 88
C
C     WRITE(6,890) TEMP   ,GS(I),HBW(I),EW(I)
C
C                 ZERO OUT SPECTRAL PEAK WAVE PERIOD
C                 APWP(I) IF CONTROLLING WAVE HEIGHT HBW(I)
C                 IS ZERO. THIS IS TO PREVENT WAVES WITH A
C                 NON-ZERO WAVE PERIOD FROM OCCURING WHEN THE
C                 WAVE HEIGHT IS ZERO.
C
      IF( HBW(I) .EQ. 0.0 ) SPWP(I) = 0.0
C
      WRITE( 6,892 ) TEMP, GS(I), HBW(I), SPWP(I), EW(I)
  892 FORMAT( /, 40X, A2, F11.2, 3F13.2 )
C
C END G&O SEPT 88
C
C G&O 3/87 END
C
  310 CONTINUE
C
C
C     CHECK THAT WAVE IS NEARLY DAMPED OUT AT END OF TRANSECT
      IF(HBW(NFO).GT..5)WRITE(6,860)HBW(NFO)
      WRITE(6,895)
```

```
C
C
C    LIST LOCATION OF AREAS ABOVE SURGE
      MM1=M-1
      IF(M.EQ.0)GO TO 316
      DO 315 I=1,NFO
      IF(SA(I,5).EQ.AS)WRITE(6,950)SA(I,1),SA(I,2)
  315 CONTINUE
  316 IF(M.EQ.0)WRITE(6,970)
C
C
C     LIST LOCATION OF SURGE CHANGES AND ESTABLISH GUTTERS AT THESE LOCATIONS
      WRITE(6,885)
      WRITE(6,985)
      NFOM1=NFO-1
      DO 318 I=1,NFOM1
      IF(SA(I,3).EQ.SA(I+1,3).AND.SA(I,4).EQ.SA(I+1,4))GO TO 318
      IF(SA(I,5).EQ.1.0.OR.SA(I,5).EQ.2.0)GO TO 317
      M=M+1
      STEG(M)=GS(I)
      ELZ(M)=EW(I)
  317 IF(SA(I+1,5).EQ.1.0.OR.SA(I+1,5).EQ.2.0)GO TO 318
      M=M+1
      STEG(M)=GS(I+1)
      ELZ(M)=EW(I+1)
      WRITE(6,960)STEG(M),SA(I+1,3),SA(I+1,4)
  318 CONTINUE
      IF(M-1.EQ.MM1)WRITE(6,975)
C
C
C     FIND LOCATIONS WHERE THE HEIGHT OF THE BREAKING WAVE IS 3.0 FEET
C     AND ESTABLISH GUTTERS AT THESE LOCATIONS
      DO 330 I=1,NFOM1
      TEST=.FALSE.
      SLOPE=(HBW(I+1)-HBW(I))/(GS(I+1)-GS(I))
      IF(I.EQ.1.AND.HBW(1).NE.3)GO TO 319
      IF(I.NE.1)GO TO 319
      N=N+1
      M=M+1
      STVG(N)=GS(1)
      STEG(M)=GS(1)
      ELZ(M)=EW(1)
      TEST=.TRUE.
  319 IF(SLOPE.EQ.0)GO TO 320
      IF(HBW(1).EQ.3)GO TO 325
      X=(3-HBW(I))/SLOPE+GS(I)
      IF(X.LE.GS(I).OR.X.GT.GS(I+1))GO TO 330
      N=N+1
      M=M+1
      STVG(N)=X
      STEG(M)=X
      ELZ(M)=2.1+((SA(I,4)+SA(I+1,4))/2.0)
```

```
      TEST=.TRUE.
  320 IF(HBW(I).NE.3.AND.HBW(I+1).NE.3)GO TO 325
      N=N+1
      STVG(N)=GS(I+1)
      TEST=.TRUE.
  325 IF(TEST.AND.SLOPE.GT.0)VZNE(N)=BLEE
      IF(TEST.AND.SLOPE.LE.0)VZNE(N)=WIND
  330 CONTINUE
      IF(N.EQ.0)GO TO 336
C
C
C     LIST LOCATIONS OF V ZONE GUTTERS AND V ZONES
      WRITE(6,900)
      WRITE(6,940)
      DO 335 I=1,N
      WRITE(6,905)STVG(I),VZNE(I),WARD
  335 CONTINUE
C
C
C     FIND ELEVATION GUTTERS AT PLACES WHERE WAVE ELEVATION IS AN ODD MULTIPLE
C     OF .5 FEET
  336 DO 370 I=1,NFOM1
      BIG=AMAX1(EW(I),EW(I+1))
      SMALL=AMIN1(EW(I),EW(I+1))
      ITRNK=INT(SMALL)
      TST=SMALL-ITRNK
      IF(TST.LT..5)GTST=FLOAT(ITRNK)+.5
      IF(TST.GT..5)GTST=FLOAT(ITRNK)+1.5
      IF(TST.EQ..5)GTST=SMALL
  340 IF(GTST.GT.BIG)GO TO 370
      TEST=.FALSE.
      SLOPE=(EW(I+1)-EW(I))/(GS(I+1)-GS(I))
      IF(SLOPE.EQ.0)GO TO 370
      M=M+1
      STEG(M)=(GTST-EW(I))/SLOPE+GS(I)
      ELZ(M)=GTST
      GTST=GTST+1.0
      GO TO 340
  370 CONTINUE
C
C      AT LEAST TWO GUTTERS ARE NEEDED
      M=M+1
      STEG(M)=GS(1)
      ELZ(M)=EW(1)
      M=M+1
      STEG(M)=GS(NFO)
      ELZ(M)=EW(NFO)
C
C
C     SAVE LOCATION OF GUTTERS IN ORIGINAL ORDER
      DO 382 I=1,M
      SAVE(I)=STEG(I)
```

```
  382 CONTINUE
C
C
C     SORT GUTTERS BY INCREASING STATIONS
      MM1=M-1
      DO 386 J=1,M
      DO 384 I=1,MM1
      SMALL=AMIN1(STEG(I),STEG(I+1))
      BIG=AMAX1(STEG(I),STEG(I+1))
      STEG(I)=SMALL
      STEG(I+1)=BIG
  384 CONTINUE
  386 CONTINUE
C
C
C     FIND THE ELEVATIONS ASSOCIATED WITH EACH OF THE GUTTERS
      DO 390 J=1,M
      DO 388 I=1,M
      IF(SAVE(I).EQ.STEG(J))NS=I
  388 CONTINUE
      SELZ(J)=ELZ(NS)
  390 CONTINUE
C
C
C      PRINT HEADING FOR PART6
      WRITE(6,910)
      WRITE(6,915)
C
C
C      FLAG GUTTERS LOCATED IN AREAS ABOVE SURGE FOR LATER ELIMINATION
      DO 398 I1=1,NFO
      DO 396 I2=1,M
      IF(SA(I1,5).NE.AS)GO TO 396
      IF(STEG(I2).GT.SA(I1,1).AND.STEG(I2).LT.SA(I1,2))STEG(I2)=-10.0
  396 CONTINUE
  398 CONTINUE
C
C
C      FLAG GUTTERS THAT ARE DUPLICATES FOR LATER ELIMINATION
      DO 410 I=1,MM1
      IF(STEG(M-I+1).EQ.STEG(M-I))STEG(M-I+1)=-10
  410 CONTINUE
C
C
C      DETERMINE THE FETCH OR OBSTRUCTION ASSOCIATED WITH EACH GUTTER
      DO 418 J=1,M
      NSE(J)=0
      DO 417 I=1,NFOM1
      IF(STEG(J).GE.GS(I).AND.STEG(J).LT.GS(I+1))NSE(J)=I
  417 CONTINUE
  418 CONTINUE
      IF(STEG(M).EQ.GS(NFO))NSE(M)=NFOM1
```

```
C
C
C     FIND THE AREAS OVER WHICH THE WEIGHTED AVERAGE CALCULATIONS
C     ARE TO BE MADE FOR A ZONE NUMBER DETERMINATIONS
C
      K=0
      IF(N.NE.0)GO TO 425
      IF(HBW(1).GT.3.0)GO TO 445
      K=1
      SBP(K)=GS(1)
      SEP(K)=GS(NFO)
      GO TO 445
  425 IF(VZNE(1).EQ.WIND)GO TO 430
      K=1
      SBP(K)=GS(1)
      SEP(K)=STVG(1)
  430 DO 440 I=1,N
      IF(VZNE(I).EQ.BLEE)GO TO 440
      K=K+1
      SBP(K)=STVG(I)
      IF(I.EQ.N)SEP(K)=GS(NFO)
      IF(I.EQ.N)GO TO 440
      SEP(K)=STVG(I+1)
  440 CONTINUE
C
C
C      DETERMINE THE ZONE DESIGNATION AND FLOOD HAZARD FACTOR FOR EACH ZONE
C      AND PRINT THE RESULTS AS THEY ARE DETERMINED
C
  445 WRITE(6,920)GS(1),EW(1)
      DO 500 I=1,MM1
      IF(STEG(I).EQ.-10)GO TO 500
      INDEX=I+1
  450 IF(INDEX.GT.M)GO TO 500
      IF(INDEX.EQ.M.AND.STEG(INDEX).EQ.-10)GO TO 500
      IF(STEG(INDEX).EQ.-10)INDEX=INDEX+1
      IF(STEG(INDEX).EQ.-10)GO TO 450
      INDX=NSE(I)+1
      IF(SA(INDX,5).EQ.AS.AND.SA(INDX,1).EQ.STEG(I))WRITE(6,920)
     1STEG(INDEX),SELZ(INDEX)
      IF(SA(INDX,5).EQ.AS.AND.SA(INDX,1).EQ.STEG(I))GO TO 500
C
C G&O 3/87 COMMENTTED OUT
C
C     IF(K.EQ.0)GO TO 460
C
C G&O 3/87 END COMMENTED OUT
C
      AZONE=.FALSE.
      VZONE=.FALSE.
C
C G&O 3/87 INSERT
```

```
C
      IF(K.EQ.0)GO TO 460
C
C G&O 3/87 END INSERT
C
      DO 455 J=1,K
      IF(STEG(I).GE.SBP(J).AND.STEG(I).LT.SEP(J))AZONE=.TRUE.
      IF(STEG(I).GE.SBP(J).AND.STEG(I).LT.SEP(J))INDX=J
  455 CONTINUE
      IF(AZONE)GO TO 462
  460 VZONE=.TRUE.
      TSG1=SA(NSE(I),3)+SA(NSE(I)+1,3)
      TSG2=SA(NSE(INDEX),3)+SA(NSE(INDEX)+1,3)
      HSG1=SA(NSE(I),4)+SA(NSE(I)+1,4)
      HSG2=SA(NSE(INDEX),4)+SA(NSE(INDEX)+1,4)
      TSG=(TSG1+TSG2)/4.0
      HSG=(HSG1+HSG2)/4.0
      DIFF=1.55*(HSG-TSG)
      GO TO 470
  462 BP=SBP(INDX)
      EP=SEP(INDX)
      START=BP
      STOP=EP
      IF(NAP.EQ.0)GO TO 468
      DO 464 J=1,NAP
      IF(AP(J).GT.BP.AND.AP(J).LE.STEG(I))START=AP(J)
  464 CONTINUE
      J=NAP
  465 IF(AP(J).GE.STEG(INDEX).AND.AP(J).LT.EP)GO TO 466
      IF(J.EQ.1)GO TO 468
      J=J-1
      GO TO 465
  466 STOP=AP(J)
  468 CALL AVG(START,STOP,AER,ATS)
      DIFF=AER-ATS
  470 BP=STEG(I)
      EP=STEG(INDEX)
      CALL AVG(BP,EP,AER,ATS)
      ITRNK=INT(AER)
      TST=AER-ITRNK
      IF(TST.LT..5)IELZ=ITRNK
      IF(TST.GE..5)IELZ=ITRNK+1
      IF(DIFF.GE.0.AND.DIFF.LT..75)INSZ=1
      BEG=.75
      DO 480 I1=2,19
      END=BEG+.5
      IF(DIFF.GE.BEG.AND.DIFF.LT.END)INSZ=I1
      BEG=BEG+.5
  480 CONTINUE
      IF(DIFF.GE.9.75.AND.DIFF.LT.10.5)INSZ=20
      BEG=10.5
      DO 490 I1=21,30
```

```
      END=BEG+1.0
      IF(DIFF.GE.BEG.AND.DIFF.LT.END)INSZ=I1
      BEG=BEG+1.0
  490 CONTINUE
      IF(DIFF.GE.20.5)INSZ=30
      IF(INSZ.LE.20)IFHF=5*INSZ
      IF(INSZ.GT.20)IFHF=100+(10*(INSZ-20))
      IF(AZONE)WRITE(6,925) INSZ,IELZ,IFHF
      IF(VZONE)WRITE(6,927) INSZ,IELZ,IFHF
      WRITE(6,920)STEG(INDEX),SELZ(INDEX)
  500 CONTINUE
      WRITE(6,980)
C     CHECK FOR NON-BLANK TITLE CARD OF NEXT DATA SET
  505 READ(10,805)(TITLE(I),I=1,80)
      TEST=.TRUE.
      DO 510 I=1,80
      IF(TITLE(I).NE.BLANK)TEST=.FALSE.
  510 CONTINUE
      IF(TEST)GO TO 1010
C     IF THE TITLE CARD IS NOT BLANK READ IN THE NEXT TRANSECT
      GO TO 4
  780 FORMAT(5X,46H GROUND ELEVATION GREATER THAN SURGE ELEVATION,1X,
     124HENCOUNTERED. JOB DUMPED.)
  790 FORMAT(5X,42H AVERAGE DEPTH LESS THAN OR EQUAL TO ZERO.,1X,
     111HJOB DUMPED.)
  805 FORMAT(80A1)
  810 FORMAT(A2,F6.0,9F8.0)
  815 FORMAT(10X,A2,10F11.3)
  820 FORMAT(10X,39HTHE ABOVE CARD CONTAINS ILLEGAL DATA IN,1X,
     120HTHE FIRST 2 COLUMNS.)
  830 FORMAT(1H1,///,30X,29H WAVE HEIGHT COMPUTATIONS FOR,1X,
     153HFLOOD INSURANCE STUDIES (VERSION 3.0, SEPTEMBER 1988) )
  835 FORMAT(30X,80A1)
  840 FORMAT(///,60X,12H PART1 INPUT,/)
  860 FORMAT(5X,40HTRANSMITTED WAVE HEIGHT AT LAST FETCH OR,1X,
     113HOBSTRUCTION =F5.2,
     119H WHICH EXCEEDS 0.5.)
  870 FORMAT(///,48X,34H PART2 WAVE HEIGHTS AND ELEVATIONS)
  880 FORMAT(/,42X,10HLOCATION   ,6X,11HWAVE HEIGHT,2X,
     114HWAVE ELEVATION)
  885 FORMAT(///,50X,31HPART4 LOCATION OF SURGE CHANGES)
  890 FORMAT(/,40X,A2,F11.2,2F13.2)
  895 FORMAT(///,40X,44HPART3 LOCATION OF AREAS ABOVE 100-YEAR SURGE)
  900 FORMAT(///,55X,26HPART5  LOCATION OF V ZONES)
  905 FORMAT(/,45X,F15.2,15X,2A4)
  910 FORMAT(///,51X,34HPART6 NUMBERED A ZONES AND V ZONES)
  915 FORMAT(/,40X,17HSTATION OF GUTTER,2X,9HELEVATION,2X,
     116HZONE DESIGNATION,3X,3HFHF,/)
  920 FORMAT(/,35X,F16.2,F15.2,/)
  925 FORMAT(74X,1HA,I2,2X,3HEL=,I2,5X,I3)
  927 FORMAT(74X,1HV,I2,2X,3HEL=,I2,5X,I3)
  940 FORMAT(/,45X,17HSTATION OF GUTTER,10X,
```

```
     116HLOCATION OF ZONE)
  950 FORMAT(/,45X,7HBETWEEN,F10.2,1X,3HAND,F10.2)
  960 FORMAT(/,35X,F11.2,10X,F11.2,10X,F11.2)
  970 FORMAT(/,40X,46HNO AREAS ABOVE 100-YEAR SURGE IN THIS TRANSECT)
  975 FORMAT(/,50X,33HNO SURGE CHANGES IN THIS TRANSECT)
  980 FORMAT(//,50X,34HZONE TERMINATED AT END OF TRANSECT)
  985 FORMAT(/,40X,7HSTATION,10X,13H10-YEAR SURGE,10X,14H100-YEAR SURGE)
  990 FORMAT(A2,78A1)
  995 FORMAT(/,10X,38HARRAY DIMENSIONS EXCEEDED. JOB DUMPED.)
C      IN CASE OF ERROR SKIP TO NEXT TRANSECT
 1000 READ(10,990)TOF,(TITLE(I),I=1,78)
  822 FORMAT(F10.2,6X,'V',I2,7X,I2)
  823 FORMAT(F10.2,6X,'A',I2,7X,I2)
  817 FORMAT(2F10.2)
      IF(TOF.NE.ET)GO TO 1000
      GO TO 505
 1010 STOP
      END
      SUBROUTINE FETCH(WPI,TEST,WPT,W)
C
C     THIS SUBROUTINE COMPUTES THE WAVE HEIGHTS AND ELEVATIONS FOR
C     INLAND AND OVERWATER FETCHES AND STORES THE RESULTS FOR FURTHER
C     ANALYSIS BY THE REST OF THE PROGRAM.  WAVE HEIGHTS AND ELEVATIONS
C     ARE COMPUTED USING THE CONSERVATION OF WAVE ACTION EQUATION WITH A
C     VARIABLE GRID SPACING TO PERMIT ACCURATE  LINEAR INTERPOLATION OF
C     WAVE HEIGHTS AND
C     ELEVATIONS FOR DETERMINING FLOOD INSURANCE DATA. THE CONSERVATION
C     OF ACTION EQUATION IS IDENTICAL TO THE ONE USED FOR MARSH GRASS
C     CALCULATION EXCEPT THAT THE PLANT ENERGY DISSIPATION IS ZERO.
C        THE SPECTRAL PEAK WAVE PERIOD IS CALCULATED USING A
C        DIFFERENTIAL FORM OF THE 1984 SPM WAVE PERIOD GROWTH
C        EQUATIONS. THIS FORM IS EQUIVALENT TO THE CONSERVATION
C        OF WAVES EQUATION. THE NET WIND ENERGY INPUT FUNCTION
C        FOR THE WAVE ACTION EQUATION IS BASED ON THE 1984 SPM
C        WAVE GROWTH EQUATIONS. THE SHOALING EFFECT IS INCLUDED
C        IN THE WAVE ACTION EQUATION.
C
C G&O 2/87
      LOGICAL TEST
C
      REAL NUTAVG
C G&O 2/87 END
C
      DIMENSION PARAM(10),FFL(10),GFL(10),GFF(10),FFF(10),HBW(500)
C
      DIMENSION AP(500),SA(500,5),GS(500),EW(500),STEG(500),ELZ(500)
C
      COMMON /FONLY/FFL,FFF,GFL,GFF
C
      COMMON /AFGV/TOF,PARAM,BSFO,BEFO,WHI,WHT,NFO,
     1HBW,AP,SET,SE,STEG,ELZ,GS,EW,SA,M,NAP
C
```

```
C G&O 2/87
      COMMON / BTSLOP / GSLB, GSLE
C G&O 2/87 END
C
C G&O SEPT 88
C
      DIMENSION SPWP(500)
C
      COMMON/ARRAY1/ SPWP
C
C END G&O SEPT 88
C
      FO=2HOF
      FI=2HIF
      DELTA1=0.0
      DELTA2=0.0
      DELTA3=0.0
      STOF=TOF
C
C         RETRIEVE DATA FROM ARRAY PARAM
C
      ESFO=PARAM(1)
      EEFO=PARAM(2)
      SETN=PARAM(3)
      SEN=PARAM(4)
C
C G&O 2/87
      ABGF = PARAM(10)
C G&O END
C
C
C         SET TOF PARAMETER
C
      IF( TOF .EQ. FI ) TOF= 1.0
      IF( TOF .EQ. FO ) TOF= 2.0
C
C**   THE BOTTOM SLOPE AT END OF TRANSECT SEGMENT,GSLE, AND BOTTOM
C**   SLOPE AT BEGINNING OF SEGMENT, GSLB, HAVE BEEN SET PRIOR TO
C**   ENTERING THIS SUBROUTINE
C
C     CHECK FOR INVALID DATA
      IF(ESFO.GT.BSFO)GO TO 10
      IF( W .EQ. 60. ) WRITE(6,500)
      IF( W .EQ. 80. ) WRITE(6,500)
      TEST=.TRUE.
   10 CONTINUE
C
      IF(TEST)GO TO 90
C
C     SET DEFAULT FOR WF1
      IF(WF1.EQ.0)WF1=1
C
```

```
C      SET DEFAULT SURGE VALUES
       IF(SETN.EQ.0)SETN=SET
       IF(SEN.EQ.0)SEN=SE
C
C
C      CHECK FOR ZERO WAVE PERIOD
    90 IF(WPI.GT.0)GO TO 95
       WRITE(6,600)
       TEST=.TRUE.
C
C      RETURN IF ERROR FLAG IS SET
    95 IF(.NOT.TEST)GO TO 100
       WRITE(6,580)
       REWIND 8
       REWIND 9
       RETURN
   100 CONTINUE
C
C      SET MINIMUM WAVE PERIOD TO .1 SECONDS
       IF(WPI.LT..1)WPI=.1
C
C G&O 2/87
C
C**  EVALUATE VARIOUS CONSTANTS NEEDED FOR EVALUATION
C
C    W = WINDSPEED IN STATUTE MILES PER HOUR. IT IS READ IN AS ONE OF
C    THE SUBROUTINE ARGUMENTS.
C
         CA = (5.28)*(.589)/3.6
C
         UA = CA*(W**1.23)
C
         ATS = 7.54
C
         SIGT = .0379
C
         G = 32.2
C
         AH = 0.283
C
         GAMH = 0.53
C
         SIGH = .00565
C
         GAMT = 0.833
C
         PI = 3.1415926536
C
C
         CTAU = ((ATS*SIGT)**3)*UA/(G*G)
C
         CRSTR = AH*UA*UA/G
```

```
C
      CWPF = ATS*UA/G
C
        CNUT = (SIGT**3)/(SIGH*SIGH)
C
        CBETH = GAMH*((G/(UA*UA))**0.75)
C
        CBETT = GAMT*((G/(UA*UA))**0.375)
C
        PI2 = 2*PI
C
      PID2 = PI * 0.5
C
        CL0 = G/PI2
C
        PI4 = 4*PI
C
        CAAVG = ((SIGH*AH)**2)*(UA*UA)/G
C
      CBAVG = (SIGH**2)*G/(UA*UA)
C
        CPAVG = ((SIGT*ATS)**2)/PI4
C
        CCAVG = 1./(3.*PI*SQRT(2.0))
C
        C1D3 =1./3.
        CFNUT =  ( CBETH/(CBETT**2) )**2
C G&O 2/87 END
C
C
C      SOLVE DIFFERENTIAL EQUATION
C
C      DETERMINE DELTA X
       DX=25
       X=ESFO-BSFO
       IF(X.LT.500)DX=X/20.0
C
C      EVALUATE COMMON FACTORS OUTSIDE THE LOOP
       DTS=DX*(SETN-SA(NFO,3))/X
       DS=DX*(SEN-SA(NFO,4))/X
       DG=DX*(EEFO-BEFO)/X
C G&O 2/87
         DGSL=DX*(GSLE-GSLB)/X
C G&O 2/87 END
       SIG=.0125
       GOU2=.00415806
       OOM=2.38095
C      PI=3.14159
C      G=32.2
       C1LOG= ALOG10(2.0)
       C2LOG= .394528 * C1LOG
       DSOOM=.68057
```

```
C
C     INITIALIZE VARIABLES
      XSUM=0
      XOLD=0
      TSOLD=SA(NFO,3)
      SOLD=SA(NFO,4)
      GOLD=BEFO
C
C G&O 2/87
      GSLOLD=GSLB
      WPOLD=WPI
      DOLD=SOLD-GOLD
      DOLDSTR=AMAX1(0.01,SOLD-GOLD)
      IPASS = 0
      TDX = AMIN1( 2*DX, X )
C G&O 2/87 END
C
      YNEW=0
C
C     CONVERT CONTROLLING WAVE HEIGHT TO
C     ZERO MOMENT WAVE HEIGHT
C
C G&O SEPT 88
C
C                 STATEMENT BELOW COMMENTED OUT AND THEN
C                 CORRECTED
C
C     YOLD=HM0(WHI,SOLD-BEFO,WPI)
C
C                 THERE ARE TWO CASES CORRESPONDING TO
C                 BREAKING AND NON-BREAKING WAVES.
C
      HBM = SHBM( WPI, GSLOLD, DOLDSTR )
C
      IF( WHI .GE. HBM ) THEN
C
C                 WAVE IS BREAKING
C
      WHI  = HBM
      YOLD = HM0( WHI, SOLD-BEFO, WPI)
C
      ELSE
C
C                 WAVE IS NOT BREAKING
C
      YOLD = HM0NB( WHI, SOLD-BEFO , WPI )
C
      ENDIF
C
C END G&O SEPT 88
C
C     CHECK FOR EXIT CONDITION
```

```
C
C G&O COMMENT OUT 2/87
C 110 XNEW=XOLD+2*DX
C END G&O COMMENT OUT
C
C G&O 2/87
 110  CONTINUE
C
      XNEW = XOLD + TDX
C G&O 2/87 END
C
      IF(XNEW.GT.X)GO TO 135
C
C G&O 2/87
      IF( XNEW .EQ. X ) IPASS = 1
C G&O 2/87 END
C
C     DETERMINE COEFFFICIENTS
      TSAVG=TSOLD+DTS
      SAVG=SOLD+DS
      GAVG=GOLD+DG
      DAVG=SAVG-GAVG
CG&O 2/87
      DAVGSTR=AMAX1(0.01,DAVG)
      GSLAVG=GSLOLD+DGSL
      GSLNEW=GSLAVG+DGSL
      DXN=2.*DX
      DNEW=DAVG+(DS-DG)
      DNEWSTR=AMAX1(0.01,DNEW)
C
      TSNEW = TSAVG + DTS
      SNEW  = SAVG + DS
      GNEW  = GAVG + DG
C
C               CALCULATE COEFFICIENTS PREPARATORY TO CALCULATING WPNEW
C
        BETHAVG = TANH(CBETH*(DAVGSTR**0.75))
C
        BETTAVG = TANH(CBETT*(DAVGSTR**0.375))
      IF(BETTAVG.GT.0.1)THEN
      FNUT = ( BETHAVG/(BETTAVG**2) )**2
      ELSE
      FNUT = CFNUT
      ENDIF
C
      BETTOLD = TANH(CBETT*(DOLDSTR**0.375))
      WPFOLD = CWPF*BETTOLD
C
C
      NUTAVG = CNUT*(BETTAVG)*FNUT
C
      RSTRAVG =  ( CRSTR*BETHAVG )**2
```

```
C
      ROLD = YOLD*YOLD
C     RAT1 = AMIN1((ROLD/RSTRAVG),1.0)
C
      RAT2 = ROLD/RSTRAVG
      RAT1= AMIN1(RAT2,1.0)
      FTAVG = (1.-RAT1)**NUTAVG
C
      DLTAOLD=1
      IF((RAT2.GE.1) .OR. (WPOLD.GE.WPFOLD)) DLTAOLD=0.0
C
      IF(RAT2. LE. 1.0) THEN
        DLTAPLD = 1.0
      ELSE
        DLTAPLD = 1.0/RAT2
      ENDIF
C
      IF( RAT2 .LT. 1.0 ) THEN
         DLTAPPD = 1.0
      ELSE
         DLTAPPD = 0.0
      ENDIF
C
      DELTAU = DXN*CTAU*FTAVG*DLTAOLD
C
      TAUOLD = WPOLD**3
C
      TAUNEW = TAUOLD+DELTAU
C
C       CALCULATE SPECTRAL PEAK WAVE PERIOD AT END OF GRID CELL, WPNEW
C
      WPNEW = TAUNEW**C1D3
C
C        CALCULATE ADDITIONAL FACTORS PREPARATORY TO CALCULATING
C        THE NEW HMO, YNEW
C
C        RESET DLTAOLD TO 1 AND SET DLTAPLD AND DLTAPPD TO 1
C
      DLTAOLD = 1.0
      DLTAPLD = 1.0
      DLTAPPD = 1.0
C
C        CALCULATE OTHER FACTORS
C
      BAVG = CBAVG / (BETHAVG**2)
C
      WLOOLD = CLO*WPOLD*WPOLD
      WLOOLD = AMAX1(0.1,WLOOLD)
C
      WLONEW = CLO*WPNEW*WPNEW
      WLONEW = AMAX1(0.1,WLONEW)
C
```

```
      CDNEW = DNEWSTR/WLONEW
C
      CDOLD = DOLDSTR/WLOOLD
C
C   WLOLD IS THE SPECTRAL PEAK WAVE LENGTH AT THE BEGINNING OF THE
C   SEGMENT
C
      WLOLD = WLOOLD*SQRT(TANH(PI2*CDOLD))
      WLOLD = AMAX1(0.1,WLOLD)
C
C   WLNEW IS THE SPECTRAL PEAK WAVLENGTH AT THE END OF THE SEGMENT
C
      WLNEW = WLONEW*SQRT(TANH(PI2*CDNEW))
      WLNEW = AMAX1(0.1,WLNEW)
        WLI=WLNEW
C
      SLOLD = PI4*DOLDSTR/WLOLD
      SLOLD = AMAX1(0.01,SLOLD)
C
      SLNEW = PI4*DNEWSTR/WLNEW
      SLNEW = AMAX1(0.01,SLNEW)
C
      IF(SLOLD.GT.0.04)THEN
      FLOLD = SLOLD/SINH(AMIN1(50.0,SLOLD))
      ELSE
      FLOLD = 1.0
      ENDIF
C
      IF(SLNEW.GT.0.04)THEN
      FLNEW = SLNEW/SINH(AMIN1(50.0,SLNEW))
      ELSE
      FLNEW = 1.0
      ENDIF
C
C   CGTOLD IS THE PRODUCT OF THE SPECTRAL PEAK PERIOD AND WAVE GROUP
C   VELOCITY AT THE BEGINNING OF THE SEGMENT
C
C   CGTNEW IS THE PRODUCT AT THE END OF THE GRID
C
      CGTOLD = 0.5*WLOLD*(1.0+FLOLD)
C
      CGTNEW = 0.5*WLNEW*(1.0+FLNEW)
C
C         CALCULATE VARIOUS FACTORS AT THE MIDPOINT OF THE
C         GRID CELL. THESE ARE DESIGNATED BY AN "AVG" AT THE
C         END.
C
      WLOAVG = 0.5*CLO*((WPOLD**2)+(WPNEW**2))
      WLOAVG = AMAX1(0.1,WLOAVG)
C
      CDAVG = DAVGSTR/WLOAVG
C
```

```
      DPAVG = PI2 * CDAVG
      SDPAVG = AMIN1( 1.E9 , SINH( AMIN1(50.0,DPAVG) ) )
      CDPAVG = AMIN1( 1.E9 , COSH( AMIN1(50.0,DPAVG) ) )
C
      FDAVG = SQRT(TANH(PI2*CDAVG))
C
      WLAVG = WLOAVG*FDAVG
      WLAVG = AMAX1(0.1,WLAVG)
C
      SLAVG = PI4*DAVGSTR/WLAVG
      SLAVG = AMAX1( 0.01 , SLAVG )
C
      SSLAVG = AMIN1( 1.E9 , SINH(AMIN1(50.0,SLAVG) ) )
      CSLAVG = AMIN1( 1.E9 , COSH(AMIN1(50.0,SLAVG) ) )
C
      IF(SLAVG.GT.0.04)THEN
      FLAVG = SLAVG/SSLAVG
      ELSE
      FLAVG = 1.0
      ENDIF
C
      IF( SLAVG .GT. 0.04 ) THEN
         FL1AVG = (SSLAVG - (SLAVG*CSLAVG) ) / (SSLAVG**2)
         FL5AVG = 1.0 + ( (FLAVG**2)*CSLAVG )
      ELSE
         FL1AVG = 0.0
         FL5AVG = 2.0
      ENDIF
C
      IF( DPAVG .GT. 0.04 ) THEN
      T2AVG = SQRT((WLOAVG*CDAVG)/(SDPAVG*(CDPAVG**3)))
      ELSE
         T2AVG = SQRT( WLOAVG/PI2 )
      ENDIF
C
      T4AVG = PI2 * FL1AVG
      T5AVG = PID2 * FL5AVG * T2AVG
C
      CGTAVG = 0.5*WLAVG*(1.+FLAVG)
C
      IF( DPAVG .GT. 0.04 ) THEN
         T78AVG = ( SQRT(DAVGSTR) )/CGTAVG
      ELSE
         T78AVG = 1./SQRT( PI2*WLOAVG )
      ENDIF
C
      T7AVG = 2. * T4AVG * T78AVG
      T8AVG = T5AVG * T78AVG
C
      AAVG = CAAVG
C
C    WPAVG IS THE SPECTRAL PEAK PERIOD AT THE MIDPOINT OF THE SEGMENT
```

```
C
      WPAVG = 0.5*(WPOLD+WPNEW)
C
C   CAPGAM IS CAPITAL GAMMA, THE PLANT PARAMETER FACTOR MULTIPLIES
C   HM0**3 IN THE EXPRESSION FOR THE WAVE ENERGY DISSIPATION DUE TO
C   MARSH GRASS
C
C        ZERO OUT CAPGAM AND CAVG SINCE THIS SUBROUTINE DOES
C        NOT HANDLE MARSH PLANTS
C
      CAPGAM = 0.0
C
      CAVG =   0.0
C
      BPAVG = ( BAVG + (CAVG*YOLD) ) * DXN
C
      P = -BPAVG
C
      Q2A = AAVG * DXN
C
      EFAVG = EXP(P)
C
      IF( ABS(P) .GT. 0.001 ) THEN
         Q3 = ( 1.-EFAVG )/BPAVG
      ELSE
         Q3 = 1.0
      ENDIF
C
      Q27 = EXP( -T7AVG*( SQRT(DNEWSTR) - SQRT(DAVGSTR) ) )
      Q17 = EXP( -T7AVG*( SQRT(DNEWSTR) - SQRT(DOLDSTR) ) )
C
      Q28 = (DAVGSTR/DNEWSTR)**T8AVG
      Q18 = (DOLDSTR/DNEWSTR)**T8AVG
C
C        CALCULATE RNEW AND YNEW AT END OF GRID CELL
C
      RNEW = (ROLD*Q18*Q17*EFAVG) + (Q2A*Q28*Q27*Q3)
      YNEW = SQRT(RNEW)
C
C   YNEW IS THE HM0 AT END OF GRID CELL
C
      WPI=WPNEW
C
CG&O 2/87 END
C
CG&O 2/87 COMMENTED OUT  *****
C     WL0=5.12*(WPI**2)
C     WL=SQRT(2*PI*DAVG*WL0)/(1+1.25*DAVG/WL0)
C     IF(DAVG/WL.LT..04)CG=SQRT(G*DAVG)
C     IF(DAVG/WL.GT..5)CG=G*WPI/(4*PI)
C     IF(DAVG/WL.GE..04.AND.DAVG/WL.LE..5)CG=
C    1(.5+(2*PI*DAVG/WL)/SINH(4*PI*DAVG/WL))*(WL/WPI)
```

```
C      CP=(1/(CG*3*PI))*APP(DEF,DAVG,NPLTS,WPI,WL)
C      BETA=TANH(.530*(GOU2*DAVG)**.75)
C      A=DSOOM*GOU2
C      B=((SIG/BETA)**OOM)*GOU2
C
C  THE CONSTANT IN THE NEXT LINE IS THE PRODUCT OF SQUARE ROOT 2
C  AND M = 0.42.
C
C      C=CP/0.5939696
C      P=-(B+C*YOLD)*2*DX
C
C      DETERMINE NEW VALUES OF VARIABLES
C
C      R=((YOLD**OOM)*EXP(P))+((A/(B+C*YOLD))*(1-EXP(P)))
C      YNEW=R**.42
C      IF(YNEW.LE.YOLD)GO TO 115
C      F1=EFL(YOLD,DAVG)
C      IF(F1.EQ.-1)GO TO 115
C      F2=EFL(YNEW,DAVG)
C      IF(F2.EQ.-1)GO TO 115
C      F=F2-F1
C      IF(F.GT.2*DX)F=2*DX
C      WPI=T(WPI,F,88.0,DAVG)
C
C
C          THE NEXT 5 LINES OF CODE HAVE BEEN COMMENTED OUT SINCE
C          THEY ARE IN THE WRONG PLACE. THEY HAVE BEEN REWRITTEN
C          IN THEIR PROPER PLACES.
C
C 115  TSNEW=TSAVG+DTS
C      SNEW=SAVG+DS
C      GNEW=GAVG+DG
C
C      XSUM=XSUM+(2*DX)
C
C          STORE RESULTS AT 100 FT. INTERVALS OR GREATER
C
C      IF(XSUM.LT.100)GO TO 120
C
C      CONVERT ZERO MOMENT WAVE HEIGHT TO
C      ZERO MOMENT WAVE HEIGHT
C
C   COMMENT OUT NEXT 3 LINES SINCE WLI HAS PREVIOUSLY BEEN SET
C
C      DNEW=SNEW-GNEW
C      WLO=5.12*(WPI**2)
C      WLI=SQRT(2*PI*DNEW*WLO)/(1+1.25*DNEW/WLO)
C G&O 2/87 END COMMENTING OUT******************************
C
C          CONVERT ZERO MOMENT WAVE HEIGHT YNEW TO SIGNIFICANT
C          WAVE HEIGHT HS
C
```

```
      WLISTR = AMAX1( 0.1 , WLI )
C
        EPP=YNEW/(4*WLISTR*.002)
      EPP = AMAX1( 1.0E-4 , EPP )
C
      WPISTR = AMAX1( 0.1 , WPI )
C
C G&O 2/87 COMMENTED OUT
C     DD=DNEW/(G*WPI**2)
C G&O 2/87 END COMMENTED OUT
C
      DD=DNEWSTR/(G*(WPISTR**2))
C
C
C G&O SEPT 88
C
C          COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C          THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C          ARTICLE
C
C     DC=5.5722E-5
C     PART1=.9+(.42707*ALOG10(DD/DC))
C     IF(EPP.LE.2)PHI=PART1-(1.411296*ALOG10(EPP))
C     IF(EPP.GT.2)PHI=PART1-C2LOG-(1.016768*ALOG10(EPP))
C
C G&O 9/88 END
C
      D0=1.357E-3
      RAV=1.477+.477*(((D0/DD)**.8557)-1)
      IF(RAV.GT.1.7)RAV=1.7
      IF( RAV .LT. 1.0 ) RAV= 1.0
C
C G&O SEPT 88
C
C          COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C          THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C          ARTICLE
C
C     IF(PHI.LT.1)PHI=1
C     IF(PHI.GT.RAV)PHI=RAV
C
C G&O 9/88 END
C
C G&O 9/88   SET PHI TO CORRECT EXPRESSION
C
      PHI = RAV
C
C G&O 9/88 END
C
      HS=PHI*YNEW
C
C     CONVERT SIGNIFICANT WAVE HEIGHT TO
```

```
C     CONTROLLING WAVE HEIGHT WHT
      WHT=1.6*HS
C
C G&O 2/87
C
C         IF THE CONTROLLING WAVE BREAKS, COMPUTE THE EQUIV-
C         ALENT ZERO MOMENT WAVE HEIGHT.
C
      HBM = SHBM( WPNEW, GSLNEW , DNEWSTR )
C
C G&O SEPT 88
C
C                      THE STATEMENT BELOW IS COMMENTED OUT AND
C                      CORRECTED
C
C     IF( WHT .GT. HBM ) THEN
C
      IF( WHT .GE. HBM ) THEN
C
C END G&O SEPT 88
C
         WHT = HBM
         YNEW = HMO( WHT, DNEWSTR , WPI )
      ENDIF
C
 115  CONTINUE
C
C                      STORE RESULTS AT 100 FT. INTERVALS OR GREATER OR
C         AT END OF TRANSECT SEGMENT
C
      XSUM = XSUM + TDX
C
      IF(XSUM.LT.100)GO TO 120
C G&O 2/87 END
C
C     INCREMENT ARRAY SUBSCRIPT AND CHECK AGAINST
C     ARRAY DIMENSION
      NFO=NFO+1
      IF(NFO.GT.500)WRITE(6,995)
      IF(NFO.GT.500)STOP
C
C     COMPUTE NEW GROUND STATION,WAVE HEIGHT, AND
C     WAVE ELEVATION AND STORE RESULTS
      GS(NFO)=BSFO+XNEW
C
CG&O 2/87
      HBM=SHBM(WPNEW,GSLNEW,DNEWSTR)
      WHM=HBM
C     WHM=.78*(SNEW-GNEW)
CG&O 2/87 END
C
      IF(WHT.GT.WHM)WHT=WHM
```

```
      HBW(NFO)=WHT
C
C G&O 2/87
      STMP=GNEW+DNEW
C     EW(NFO)=.7*HBW(NFO)+SAVG
      EW(NFO)=.7*HBW(NFO)+STMP
C G&O 2/87 END
C
C G&O SEPT 88
C
      SPWP(NFO) = WPNEW
C
C END G&O SEPT 88
C
      NFOM1=NFO-1
      SA(NFO,1)=GS(NFOM1)
      SA(NFO,2)=GS(NFO)
      SA(NFO,3)=TSNEW
      SA(NFO,4)=SNEW
C
C G&O 2/87
C     SA(NFO,5)=1
C
      IF( GS(NFO) .EQ. ESFO ) THEN
         SA( NFO,5 ) = STOF
      ELSE
         SA( NFO,5 ) = TOF
      ENDIF
C G&O 2/87 END
C
      XSUM=0
C
C G&O 2/87 COMMENTED OUT
C
C        THE NEXT TWO LINES ARE COMMENTED OUT SINCE THEY ARE
C        IN THE WRONG PLACE
C
C     IF THE CONTROLLING WAVE BREAKS, COMPUTE THE
C     EQUIVALENT ZERO MOMENT WAVE HEIGHT
C
C     IF(1.6*HS.LE.WHM)GO TO 120
C     YNEW=HMO(WHT,DNEW,WPI)
C G&O 2/87 END COMMENTED OUT
C
  120 CONTINUE
C
C G&O 2/87
C
C        IF IPASS .EQ. 1, THEN THIS IS LAST PASS THROUGH THE
C        LOOP. EXIT LOOP
C
      IF( IPASS .EQ. 1 ) GO TO 135
```

```
C
C G&O 2/87 END
C
C                   ADJUST STEP SIZE
C
      YTEST=ABS(YNEW-YOLD)
C
C G&O 2/87
          TDXMAX = X - XNEW
      DXMAX  = 0.5 * TDXMAX
C G&O 2/87 END
C
      IF( YTEST .GT. .05 ) GO TO 125
C
C G&O 2/87
C     DX=2*DX
C
      DXOLD = DX
      DXNEW = AMIN1( 2.*DX ,DXMAX )
      RATX  = 0.5 * DXNEW/DXOLD
      DX    = DXNEW
      TDX   = AMIN1( 2.*DX, TDXMAX)
C
C
      DTS=2*DTS*RATX
      DS=2*DS*RATX
      DG=2*DG*RATX
      DGSL=2.*DGSL*RATX
C G&O 2/87 END
C
      GO TO 130
C
C G&O 2/87
  125 IF( YTEST .LT. 0.1 ) GO TO 1000
      IF( DX    .LT. 5.0 ) GO TO 1000
C
C     DX=.5*DX
C
      DXOLD = DX
      DXNEW = AMIN1( 0.5*DX,DXMAX )
      RATX =  2. * DXNEW/DXOLD
      DX   = DXNEW
      TDX  = AMIN1( 2.*DX,TDXMAX )
C
      DTS=.5*DTS*RATX
      DS=.5*DS*RATX
      DG=.5*DG*RATX
      DGSL=0.5*DGSL*RATX
C
      GO TO 130
C
 1000 CONTINUE
```

```
C
      DXOLD = DX
      DXNEW = AMIN1( DX,DXMAX )
         RATX  = DXNEW/DXOLD
        DX     = DXNEW
        TDX    = AMIN1( 2.*DX,TDXMAX )
C
      DTS=DTS*RATX
      DS=DS*RATX
      DG=DG*RATX
      DGSL=DGSL*RATX
C G&O 2/87 END
C
C     UPDATE RECURSIVE VARIABLES AND LOOP BACK
  130 XOLD=XNEW
      YOLD=YNEW
      TSOLD=TSNEW
      SOLD=SNEW
      GOLD=GNEW
C
C G&O 2/87
      GSLOLD=GSLNEW
      WPOLD=WPNEW
      DOLD=DNEW
      DOLDSTR=AMAX1(0.01,DOLD)
C G&O 2/87 END
C
      GO TO 110
C
C                    STORE FINAL VALUE IF IT HAS NOT ALREADY BEEN STORED
C
  135 IF(GS(NFO).EQ.ESFO)GO TO 140
      NFO=NFO+1
      GS(NFO)=ESFO
C
C G&O 2/87
      HBM=SHBM(WPNEW,GSLNEW,DNEWSTR)
      WHM=HBM
C     WHM=.78*(SE-EEFO)
      WHT=AMIN1(WHT,WHM)
C G&O 2/87 END
C
      HBW(NFO)=AMIN1(WHT,WHM)
      STMP=GNEW+DNEW
C     EW(NFO)=.7*HBW(NFO)+SAVG
      EW(NFO)=.7*HBW(NFO)+STMP
C
C
C G&O SEPT 88
C
      SPWP(NFO) = WPNEW
C
```

```
C END G&O SEPT 88
C
C
      SA(NFO,1)=XOLD
      SA(NFO,2)=ESFO
      SA(NFO,3)=SETN
      SA(NFO,4)=SEN
C
C G&O 2/87
C 140 SA(NFO,5)=2HVH
C
      SA( NFO,5 ) = STOF
C
  140 CONTINUE
C G&O 2/87 END
C
C                   INSERT ABGF IF REQUIRED
C
      IF(ABGF.NE.1)GO TO 150
      NAP=NAP+1
      AP(NAP)=ESFO
      M=M+1
      STEG(M)=GS(NFO)
      ELZ(M)=EW(NFO)
C
C     GET READY FOR NEXT FETCH OR OBSTRUCTION AND RETURN
  150 BSFO=ESFO
      BEFO=EEFO
C
C G&O 2/87   **  COMMENTTED OUT AND INSERT ***
C     WHI=HBW(NFO)
      WPT=WPNEW
C G&O 2/87   **  END OF COMMENTTED OUT AND INSERT ***
      RETURN
  500 FORMAT(/,10X,34HINVALID DATA IN FIELD 1 OF IF CARD)
  520 FORMAT(/,10X,34HINVALID DATA IN FIELD 1 OF OF CARD)
  580 FORMAT(/,10X,11HJOB DUMPED.)
  600 FORMAT(/,10X,'WAVE PERIOD LESS THAN OR EQUAL TO ZERO',/
     1          10X,'IN SUBROUTINE FETCH.ABORT RUN')
  995 FORMAT(/,10X,38HARRAY DIMENSIONS EXCEEDED. JOB DUMPED.)
      END
      SUBROUTINE VEG(WPI,TEST,WPT,W)
C     THIS SUBROUTINE READS MG CARDS ASSOCIATED WITH
C     MARSH GRASS OR OTHER PLANT COMMUNITIES AND DETERMINES
C     WAVE HEIGHTS AND ELEVATIONS.
C
C         THIS VERSION OF VEG SOLVES THE WAVE ACTION EQUATION
C         WITH SHOALING EFFECTS. THE NET WIND ENERGY INPUT
C         FUNCTION IS BASED ON AN APPROXIMATE FORM OF THE 1984
C         SPM WAVE GROWTH EXPRESSIONS. THE SPECTRAL PEAK WAVE
C         PERIOD IS COMPUTED USING AN APPROXIMATE FORM OF 1984
C         SPM WAVE PERIOD GROWTH EXPRESSIONS IN DIFFERENTIAL
```

```
C        FORM. THE WAVE PERIOD APPROACH IS TANTAMOUNT TO USING
C        THE CONSERVATION OF WAVES EQUATION IN DIFFERENTIAL FORM
C
      LOGICAL TEST
C
C G&O 2/87
      REAL NUTAVG
C G&O 2/87 END
C
      DIMENSION CDE(10),FCOV(10),HBI(10),PPSF(10),SDB(10),
     1SDM(10),SDT(10),TYPE(10),FAR(10),DEF1(10,8),DEF2(10,8),DEF(10,8)
C
      DIMENSION PARAM(10),HBW(500),AP(500),
     1STEG(500),ELZ(500),GS(500),EW(500),SA(500,5)
C
      COMMON /AFGV/TOF,PARAM,BSFO,BEFO,WHI,WHT,NFO,
     1HBW,AP,SET,SE,STEG,ELZ,GS,EW,SA,M,NAP
C
      COMMON /PP/NPLTS,TYPE,CDE,FCOV,HBI,PPSF,SDB,SDM,SDT,FAR
CG&O 2/87
      COMMON /BTSLOP/GSLB,GSLE
CG&O 2/87 END
C
C G&O SEPT 88
C
      DIMENSION SPWP(500)
C
      COMMON/ARRAY1/ SPWP
C
C END G&O SEPT 88
C
C     RETRIEVE DATA FROM ARRAY PARAM
      ESFO=PARAM(1)
      EEFO=PARAM(2)
      REG1=PARAM(3)
      WF1=PARAM(4)
      REG2=PARAM(5)
      NPLTS=PARAM(6)
      SETN=PARAM(7)
      SEN=PARAM(8)
      ABGF=PARAM(10)
C G&O 2/87
C
C        SET STOF AND RESET TOF
C
      STOF = TOF
      TOF = 1.0
C
C END G&O 2/87
C
C**  THE BOTTOM SLOPE AT END OF TRANSECT SEGMENT,GSLE, AND BOTTOM
C**  SLOPE AT BEGINNING OF SEGMENT, GSLB, HAVE BEEN SET PRIOR TO
```

```
C**  ENTERING THIS SUBROUTINE
C
C     CHECK FOR INVALID DATA
      IF(ESFO.GT.BSFO)GO TO 10
      WRITE(6,500)
      TEST=.TRUE.
   10 IF(REG1.LE.8.AND.REG2.LE.8)GO TO 20
      WRITE(6,520)
      TEST=.TRUE.
   20 IF(REG1.EQ.INT(REG1).AND.REG2.EQ.INT(REG2))GO TO 25
      WRITE(6,520)
      TEST=.TRUE.
   25 IF(REG1.GE.1.AND.REG2.GE.0)GO TO 30
      WRITE(6,520)
      TEST=.TRUE.
   30 IF(WF1.LE.1.AND.WF1.GE.0)GO TO 40
      WRITE(6,530)
      TEST=.TRUE.
   40 IF(NPLTS.LE.10.AND.NPLTS.GT.0)GO TO 60
      WRITE(6,540)
      TEST=.TRUE.
   60 CONTINUE
      IF(TEST)GO TO 90
C
C     SET DEFAULT FOR WF1
      IF(WF1.EQ.0)WF1=1
C
C     SET DEFAULT SURGE VALUES
      IF(SETN.EQ.0)SETN=SET
      IF(SEN.EQ.0)SEN=SE
C
C     READ MG CARDS
      DO 80 I=1,NPLTS
      READ(10,560)TOF,(PARAM(J),J=1,10)
      IF(TOF.EQ.2HMG)GO TO 70
      TEST=.TRUE.
      WRITE(6,570)
      BACKSPACE 5
      GO TO 90
   70 WRITE(6,590)TOF,(PARAM(J),J=1,10)
      WRITE(8,590)TOF,(PARAM(J),J=1,10)
      TYPE(I)=PARAM(1)
      CDE(I)=PARAM(2)
      FCOV(I)=PARAM(3)
      HBI(I)=PARAM(4)
      PPSF(I)=PARAM(5)
      SDB(I)=PARAM(6)/12.0
      SDM(I)=PARAM(7)/12.0
      SDT(I)=PARAM(8)/12.0
      FAR(I)=PARAM(9)
      IF(FCOV(I).LE.NPLTS)GO TO 80
      TEST=.TRUE.
```

```
      WRITE(6,545)
80    CONTINUE
C
C     LOOK UP DEFAULT PLANT PARAMETERS
      IF(REG2.NE.0)GO TO 85
      CALL LOOKUP(DEF,REG1,TEST)
      GO TO 90
   85 CALL LOOKUP(DEF1,REG1,TEST)
      CALL LOOKUP(DEF2,REG2,TEST)
C
C     COMPUTE WEIGHTED AVERAGE
      CALL WAVG(DEF1,DEF2,DEF,WF1,REG1,REG2,NPLTS,TYPE,TEST)
C
C     CHECK FOR ZERO WAVE PERIOD
   90 IF(WPI.GT.0)GO TO 95
      WRITE(6,600)
      TEST=.TRUE.
C
C     RETURN IF ERROR FLAG IS SET
   95 IF(.NOT.TEST)GO TO 100
      WRITE(6,580)
      REWIND 8
      REWIND 9
      RETURN
  100 CONTINUE
C
C     WRITE PLANT PARAMETERS TO SCRATCH FILE
      DO 105 I=1,NPLTS
      WRITE(9,610)TYPE(I),(DEF(I,J),J=1,8)
  105 CONTINUE
C
C     SET MINIMUM WAVE PERIOD TO .1 SECONDS
      IF(WPI.LT..1)WPI=.1
C
C G&O 2/87
C
C**  EVALUATE VARIOUS CONSTANTS NEEDED FOR EVALUATION
C
C    W = WINDSPEED IN STATUTE MILES PER HOUR. IT IS READ IN AS ONE OF
C    THE SUBROUTINE ARGUMENTS.
C
         CA = (5.28)*(.589)/3.6
C
         UA = CA*(W**1.23)
C
         ATS = 7.54
C
         SIGT = .0379
C
         G = 32.2
C
         AH = 0.283
```

```
C
      GAMH = 0.53
C
      SIGH = .00565
C
      GAMT = 0.833
C
      PI = 3.1415926536
C
C
      CTAU = ((ATS*SIGT)**3)*UA/(G*G)
C
      CRSTR = AH*UA*UA/G
C
     CWPF = ATS*UA/G
C
      CNUT = (SIGT**3)/(SIGH*SIGH)
C
      CBETH = GAMH*((G/(UA*UA))**0.75)
C
      CBETT = GAMT*((G/(UA*UA))**0.375)
C
      PI2 = 2*PI
C
     PID2 = PI * 0.5
C
      CLO = G/PI2
C
      PI4 = 4*PI
C
      CAAVG = ((SIGH*AH)**2)*(UA*UA)/G
C
     CBAVG = (SIGH**2)*G/(UA*UA)
C
      CPAVG = ((SIGT*ATS)**2)/PI4
C
      CCAVG = 1./(3.*PI*SQRT(2.0))
C
      C1D3 =1./3.
      CFNUT =  ( CBETH/(CBETT**2) )**2
C G&O 2/87 END
C
C
C     SOLVE DIFFERENTIAL EQUATION
C
C G&O SEPT 88
C
C              CALCULATE INITIAL DELTA X. NOTE THAT THIS
C              INITIAL DELTA X STARTS OFF 5 TIME SMALLER FOR
C              VH CARDS THAN IF OR OF CARDS. COMMENT OUT
C              STATEMENTS WHICH WERE ORIGINALLY USED TO
C              SET INITIAL DELTA X AND REPLACE WITH REVISED
```

```
C                   STATEMENTS.
C
C     DETERMINE DELTA X
C     DX=25
      DX= 5
      X=ESFO-BSFO
C     IF(X.LT.500)DX=X/20.0
      IF(X.LT.100)DX=X/20.0
C
C END G&O SEPT 88
C
C     EVALUATE COMMON FACTORS OUTSIDE THE LOOP
      DTS=DX*(SETN-SA(NFO,3))/X
      DS=DX*(SEN-SA(NFO,4))/X
      DG=DX*(EEFO-BEFO)/X
C G&O 2/87
        DGSL=DX*(GSLE-GSLB)/X
C G&O 2/87 END
      SIG=.0125
      GOU2=.00415806
      OOM=2.38095
C     PI=3.14159
C     G=32.2
      C1LOG= ALOG10(2.0)
      C2LOG= .394528 * C1LOG
      DSOOM=.68057
C
C     INITIALIZE VARIABLES
      XSUM=0
      XOLD=0
      TSOLD=SA(NFO,3)
      SOLD=SA(NFO,4)
      GOLD=BEFO
C
C G&O 2/87
      GSLOLD=GSLB
      WPOLD=WPI
      DOLD=SOLD-GOLD
      DOLDSTR=AMAX1(0.01,SOLD-GOLD)
      IPASS = 0
      TDX = AMIN1( 2*DX, X )
C G&O 2/87 END
C
      YNEW=0
C
C     CONVERT CONTROLLING WAVE HEIGHT TO
C     ZERO MOMENT WAVE HEIGHT
C
C G&O SEPT 88
C
C                   STATEMENT BELOW COMMENTED OUT AND THEN
C                   CORRECTED
```

```
C
C     YOLD=HMO(WHI,SOLD-BEFO,WPI)
C
C                THERE ARE TWO CASES CORRESPONDING TO
C                BREAKING AND NON-BREAKING WAVES.
C
      HBM = SHBM( WPI, GSLOLD, DOLDSTR )
C
      IF( WHI .GE. HBM ) THEN
C
C                WAVE IS BREAKING
C
      WHI  = HBM
      YOLD = HMO( WHI, SOLD-BEFO, WPI)
C
      ELSE
C
C                WAVE IS NOT BREAKING
C
      YOLD = HMONB( WHI, SOLD-BEFO , WPI )
C
      ENDIF
C
C END G&O SEPT 88
C
C     CHECK FOR EXIT CONDITION
C
C G&O COMMENT OUT 2/87
C 110 XNEW=XOLD+2*DX
C END G&O COMMENT OUT
C
C G&O 2/87
 110  CONTINUE
C
      XNEW = XOLD + TDX
C G&O 2/87 END
C
      IF(XNEW.GT.X)GO TO 135
C
C G&O 2/87
      IF( XNEW .EQ. X ) IPASS = 1
C G&O 2/87 END
C
C     DETERMINE COEFFFICIENTS
      TSAVG=TSOLD+DTS
      SAVG=SOLD+DS
      GAVG=GOLD+DG
      DAVG=SAVG-GAVG
CG&O 2/87
      DAVGSTR=AMAX1(0.01,DAVG)
      GSLAVG=GSLOLD+DGSL
      GSLNEW=GSLAVG+DGSL
```

```
      DXN=2.*DX
      DNEW=DAVG+(DS-DG)
      DNEWSTR=AMAX1(0.01,DNEW)
C
      TSNEW = TSAVG + DTS
      SNEW  = SAVG + DS
      GNEW  = GAVG + DG
C
C              CALCULATE COEFFICIENTS PREPARATORY TO CALCULATING WPNEW
C
        BETHAVG = TANH(CBETH*(DAVGSTR**0.75))
C
        BETTAVG = TANH(CBETT*(DAVGSTR**0.375))
      IF(BETTAVG.GT.0.1)THEN
      FNUT = ( BETHAVG/(BETTAVG**2) )**2
      ELSE
      FNUT = CFNUT
      ENDIF
C
      BETTOLD = TANH(CBETT*(DOLDSTR**0.375))
      WPFOLD = CWPF*BETTOLD
C
C
      NUTAVG = CNUT*(BETTAVG)*FNUT
C
      RSTRAVG =  ( CRSTR*BETHAVG )**2
C
      ROLD = YOLD*YOLD
C     RAT1 = AMIN1((ROLD/RSTRAVG),1.0)
C
      RAT2 = ROLD/RSTRAVG
      RAT1= AMIN1(RAT2,1.0)
      FTAVG = (1.-RAT1)**NUTAVG
C
      DLTAOLD=1
      IF((RAT2.GE.1) .OR. (WPOLD.GE.WPFOLD)) DLTAOLD=0.0
C
      IF(RAT2. LE. 1.0) THEN
        DLTAPLD = 1.0
      ELSE
        DLTAPLD = 1.0/RAT2
      ENDIF
C
      IF( RAT2 .LT. 1.0 ) THEN
         DLTAPPD = 1.0
      ELSE
         DLTAPPD = 0.0
      ENDIF
C
      DELTAU = DXN*CTAU*FTAVG*DLTAOLD
C
      TAUOLD = WPOLD**3
```

```
C
      TAUNEW = TAUOLD+DELTAU
C
C       CALCULATE SPECTRAL PEAK WAVE PERIOD AT END OF GRID CELL, WPNEW
C
      WPNEW = TAUNEW**C1D3
C
C        CALCULATE ADDITIONAL FACTORS PREPARATORY TO CALCULATING
C        THE NEW HMO, YNEW
C
C        RESET DLTAOLD TO 1 AND SET DLTAPLD AND DLTAPPD TO 1
C
      DLTAOLD = 1.0
      DLTAPLD = 1.0
      DLTAPPD = 1.0
C
C        CALCULATE OTHER FACTORS
C
      BAVG = CBAVG / (BETHAVG**2)
C
      WLOOLD = CLO*WPOLD*WPOLD
      WLOOLD = AMAX1(0.1,WLOOLD)
C
      WLONEW = CLO*WPNEW*WPNEW
      WLONEW = AMAX1(0.1,WLONEW)
C
      CDNEW = DNEWSTR/WLONEW
C
      CDOLD = DOLDSTR/WLOOLD
C
C    WLOLD IS THE SPECTRAL PEAK WAVE LENGTH AT THE BEGINNING OF THE
C    SEGMENT
C
      WLOLD = WLOOLD*SQRT(TANH(PI2*CDOLD))
      WLOLD = AMAX1(0.1,WLOLD)
C
C    WLNEW IS THE SPECTRAL PEAK WAVLENGTH AT THE END OF THE SEGMENT
C
      WLNEW = WLONEW*SQRT(TANH(PI2*CDNEW))
      WLNEW = AMAX1(0.1,WLNEW)
        WLI=WLNEW
C
      SLOLD = PI4*DOLDSTR/WLOLD
      SLOLD = AMAX1(0.01,SLOLD)
C
      SLNEW = PI4*DNEWSTR/WLNEW
      SLNEW = AMAX1(0.01,SLNEW)
C
      IF(SLOLD.GT.0.04)THEN
      FLOLD = SLOLD/SINH(AMIN1(50.0,SLOLD))
      ELSE
      FLOLD = 1.0
```

```
      ENDIF
C
      IF(SLNEW.GT.0.04)THEN
      FLNEW = SLNEW/SINH(AMIN1(50.0,SLNEW))
      ELSE
      FLNEW = 1.0
      ENDIF
C
C   CGTOLD IS THE PRODUCT OF THE SPECTRAL PEAK PERIOD AND WAVE GROUP
C   VELOCITY AT THE BEGINNING OF THE SEGMENT
C
C   CGTNEW IS THE PRODUCT AT THE END OF THE GRID
C
      CGTOLD = 0.5*WLOLD*(1.0+FLOLD)
C
      CGTNEW = 0.5*WLNEW*(1.0+FLNEW)
C
C        CALCULATE VARIOUS FACTORS AT THE MIDPOINT OF THE
C        GRID CELL. THESE ARE DESIGNATED BY AN "AVG" AT THE
C        END.
C
      WLOAVG = 0.5*CLO*((WPOLD**2)+(WPNEW**2))
      WLOAVG = AMAX1(0.1,WLOAVG)
C
      CDAVG = DAVGSTR/WLOAVG
C
      DPAVG = PI2 * CDAVG
      SDPAVG = AMIN1( 1.E9 ,  SINH( AMIN1(50.0,DPAVG) ) )
      CDPAVG = AMIN1( 1.E9 ,  COSH( AMIN1(50.0,DPAVG) ) )
C
      FDAVG = SQRT(TANH(PI2*CDAVG))
C
      WLAVG = WLOAVG*FDAVG
      WLAVG = AMAX1(0.1,WLAVG)
C
      SLAVG = PI4*DAVGSTR/WLAVG
      SLAVG = AMAX1( 0.01 , SLAVG )
C
      SSLAVG = SINH(AMIN1(50.0,SLAVG))
      CSLAVG = COSH(AMIN1(50.0,SLAVG))
C
      IF(SLAVG.GT.0.04)THEN
      FLAVG = SLAVG/SSLAVG
      ELSE
      FLAVG = 1.0
      ENDIF
C
      IF( SLAVG .GT. 0.04 ) THEN
         FL1AVG = (SSLAVG - (SLAVG*CSLAVG) ) / (SSLAVG**2)
         FL5AVG = 1.0 + ( (FLAVG**2)*CSLAVG )
      ELSE
         FL1AVG = 0.0
```

```
            FL5AVG = 2.0
         ENDIF
C
         IF( DPAVG .GT. 0.04 ) THEN
         T2AVG = SQRT((WLOAVG*CDAVG)/(SDPAVG*(CDPAVG**3)))
         ELSE
            T2AVG = SQRT( WLOAVG/PI2 )
         ENDIF
C
         T4AVG = PI2 * FL1AVG
         T5AVG = PID2 * FL5AVG * T2AVG
C
         CGTAVG = 0.5*WLAVG*(1.+FLAVG)
C
         IF( DPAVG .GT. 0.04 ) THEN
            T78AVG = ( SQRT(DAVGSTR) )/CGTAVG
         ELSE
            T78AVG = 1./SQRT( PI2*WLOAVG )
         ENDIF
C
         T7AVG = 2. * T4AVG * T78AVG
         T8AVG = T5AVG * T78AVG
C
         AAVG = CAAVG
C
C   WPAVG IS THE SPECTRAL PEAK PERIOD AT THE MIDPOINT OF THE SEGMENT
C
         WPAVG = 0.5*(WPOLD+WPNEW)
C
C   CAPGAM IS CAPITAL GAMMA, THE PLANT PARAMETER FACTOR MULTIPLIES
C   HMO**3 IN THE EXPRESSION FOR THE WAVE ENERGY DISSIPATION DUE TO
C   MARSH GRASS
C
CG&O END
C
         CAPGAM = APP(DEF,DAVGSTR,NPLTS,WPAVG,WLAVG)
C
         CAVG = CCAVG*CAPGAM*(WPOLD+WPNEW)/CGTAVG
C
         BPAVG = ( BAVG + (CAVG*YOLD) ) * DXN
C
         P = -BPAVG
C
         Q2A = AAVG * DXN
C
         EFAVG = EXP(P)
C
         IF( ABS(P) .GT. 0.001 ) THEN
            Q3 = ( 1.-EFAVG )/BPAVG
         ELSE
            Q3 = 1.0
         ENDIF
```

```
C
      Q27 = EXP( -T7AVG*( SQRT(DNEWSTR) - SQRT(DAVGSTR) ) )
      Q17 = EXP( -T7AVG*( SQRT(DNEWSTR) - SQRT(DOLDSTR) ) )
C
      Q28 = (DAVGSTR/DNEWSTR)**T8AVG
      Q18 = (DOLDSTR/DNEWSTR)**T8AVG
C
C         CALCULATE RNEW AND YNEW AT END OF GRID CELL
C
      RNEW = (ROLD*Q18*Q17*EFAVG) + (Q2A*Q28*Q27*Q3)
      YNEW = SQRT(RNEW)
C
C   YNEW IS THE HM0 AT END OF GRID CELL
C
      WPI=WPNEW
CG&O 2/87 END
C
C
CG&O 2/87 COMMENTED OUT  *****
C     WL0=5.12*(WPI**2)
C     WL=SQRT(2*PI*DAVG*WL0)/(1+1.25*DAVG/WL0)
C     IF(DAVG/WL.LT..04)CG=SQRT(G*DAVG)
C     IF(DAVG/WL.GT..5)CG=G*WPI/(4*PI)
C     IF(DAVG/WL.GE..04.AND.DAVG/WL.LE..5)CG=
C    1(.5+(2*PI*DAVG/WL)/SINH(4*PI*DAVG/WL))*(WL/WPI)
C     CP=(1/(CG*3*PI))*APP(DEF,DAVG,NPLTS,WPI,WL)
C     BETA=TANH(.530*(GOU2*DAVG)**.75)
C     A=DSOOM*GOU2
C     B=((SIG/BETA)**OOM)*GOU2
C
C  THE CONSTANT IN THE NEXT LINE IS THE PRODUCT OF SQUARE ROOT 2
C  AND M = 0.42.
C
C     C=CP/0.5939696
C     P=-(B+C*YOLD)*2*DX
C
C     DETERMINE NEW VALUES OF VARIABLES
C
C     R=((YOLD**OOM)*EXP(P))+((A/(B+C*YOLD))*(1-EXP(P)))
C     YNEW=R**.42
C     IF(YNEW.LE.YOLD)GO TO 115
C     F1=EFL(YOLD,DAVG)
C     IF(F1.EQ.-1)GO TO 115
C     F2=EFL(YNEW,DAVG)
C     IF(F2.EQ.-1)GO TO 115
C     F=F2-F1
C     IF(F.GT.2*DX)F=2*DX
C     WPI=T(WPI,F,88.0,DAVG)
C
C
C         THE NEXT 5 LINES OF CODE HAVE BEEN COMMENTED OUT SINCE
C         THEY ARE IN THE WRONG PLACE. THEY HAVE BEEN REWRITTEN
```

```
C          IN THEIR PROPER PLACES.
C
C 115 TSNEW=TSAVG+DTS
C     SNEW=SAVG+DS
C     GNEW=GAVG+DG
C
C     XSUM=XSUM+(2*DX)
C
C        STORE RESULTS AT 100 FT. INTERVALS OR GREATER
C
C     IF(XSUM.LT.100)GO TO 120
C
C     CONVERT ZERO MOMENT WAVE HEIGHT TO
C     ZERO MOMENT WAVE HEIGHT
C
C   COMMENT OUT NEXT 3 LINES SINCE WLI HAS PREVIOUSLY BEEN SET
C
C     DNEW=SNEW-GNEW
C     WLO=5.12*(WPI**2)
C     WLI=SQRT(2*PI*DNEW*WLO)/(1+1.25*DNEW/WLO)
C G&O 2/87 END COMMENTING OUT******************************
C
C        CONVERT ZERO MOMENT WAVE HEIGHT YNEW TO SIGNIFICANT
C        WAVE HEIGHT HS
C
      WLISTR = AMAX1( 0.1 , WLI )
C
C
        EPP=YNEW/(4*WLISTR*.002)
      EPP = AMAX1( 1.0E-4 , EPP )
C
      WPISTR = AMAX1( 0.1 , WPI )
C
C G&O 2/87 COMMENTED OUT
C     DD=DNEW/(G*WPI**2)
C G&O 2/87 END COMMENTED OUT
C
      DD=DNEWSTR/(G*(WPISTR**2))
C
CG&O 9/88 COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C         THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C         ARTICLE
C
C     DC=5.5722E-5
C     PART1=.9+(.42707*ALOG10(DD/DC))
C     IF(EPP.LE.2)PHI=PART1-(1.411296*ALOG10(EPP))
C     IF(EPP.GT.2)PHI=PART1-C2LOG-(1.016768*ALOG10(EPP))
C
CG&O 9/88 END
C
      DO=1.357E-3
      RAV=1.477+.477*(((DO/DD)**.8557)-1)
```

```
      IF(RAV.GT.1.7)RAV=1.7
      IF( RAV .LT. 1.0 ) RAV= 1.0
C
CG&O 9/88 COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C         THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C         ARTICLE
C
C     IF(PHI.LT.1)PHI=1
C     IF(PHI.GT.RAV)PHI=RAV
C
CG&O 9/88 END
C
CG&O 9/88   SET PHI TO CORRECT EXPRESSION
C
      PHI = RAV
C
CG&O 9/88 END
C
      HS=PHI*YNEW
C
C     CONVERT SIGNIFICANT WAVE HEIGHT TO
C     CONTROLLING WAVE HEIGHT WHT
      WHT=1.6*HS
C
C G&O 2/87
C
C        IF THE CONTROLLING WAVE BREAKS, COMPUTE THE EQUIV-
C        ALENT ZERO MOMENT WAVE HEIGHT.
C
      HBM = SHBM( WPNEW, GSLNEW , DNEWSTR )
C
C
C G&O SEPT 88
C
C                 THE STATEMENT BELOW IS COMMENTED OUT AND
C                 CORRECTED
C
C     IF( WHT .GT. HBM ) THEN
C
      IF( WHT .GE. HBM ) THEN
C
C END G&O SEPT 88
C
         WHT = HBM
         YNEW = HM0( WHT, DNEWSTR , WPI )
      ENDIF
C
 115  CONTINUE
C
C                 STORE RESULTS AT 100 FT. INTERVALS OR GREATER OR
C        AT END OF TRANSECT SEGMENT
C
```

```
      XSUM = XSUM + TDX
C
      IF(XSUM.LT.100)GO TO 120
C G&O 2/87 END
C
C     INCREMENT ARRAY SUBSCRIPT AND CHECK AGAINST
C     ARRAY DIMENSION
      NFO=NFO+1
      IF(NFO.GT.500)WRITE(6,995)
      IF(NFO.GT.500)STOP
C
C     COMPUTE NEW GROUND STATION,WAVE HEIGHT, AND
C     WAVE ELEVATION AND STORE RESULTS
      GS(NFO)=BSFO+XNEW
C
CG&O 2/87
      HBM=SHBM(WPNEW,GSLNEW,DNEWSTR)
      WHM=HBM
C     WHM=.78*(SNEW-GNEW)
CG&O 2/87 END
C
      IF(WHT.GT.WHM)WHT=WHM
      HBW(NFO)=WHT
C
C G&O 2/87
      STMP=GNEW+DNEW
C     EW(NFO)=.7*HBW(NFO)+SAVG
      EW(NFO)=.7*HBW(NFO)+STMP
C G&O 2/87 END
C
C        G&O SEPT 88
C
      SPWP(NFO) = WPNEW
C
C        END G&O SEPT 88
C
      NFOM1=NFO-1
      SA(NFO,1)=GS(NFOM1)
      SA(NFO,2)=GS(NFO)
      SA(NFO,3)=TSNEW
      SA(NFO,4)=SNEW
C
C G&O 2/87
C     SA(NFO,5)=1
C
      IF( GS(NFO) .EQ. ESFO ) THEN
         SA( NFO,5 ) = STOF
      ELSE
         SA( NFO,5 ) = 1.0
      ENDIF
C G&O 2/87 END
C
```

```
      XSUM=0
C
C G&O 2/87 COMMENTED OUT
C
C        THE NEXT TWO LINES ARE COMMENTED OUT SINCE THEY ARE
C        IN THE WRONG PLACE
C
C     IF THE CONTROLLING WAVE BREAKS, COMPUTE THE
C     EQUIVALENT ZERO MOMENT WAVE HEIGHT
C
C     IF(1.6*HS.LE.WHM)GO TO 120
C     YNEW=HM0(WHT,DNEW,WPI)
C G&O 2/87 END COMMENTED OUT
C
  120 CONTINUE
C
C G&O 2/87
C
C        IF IPASS .EQ. 1, THEN THIS IS LAST PASS THROUGH THE
C        LOOP. EXIT LOOP
C
      IF( IPASS .EQ. 1 ) GO TO 135
C
C G&O 2/87 END
C
C                 ADJUST STEP SIZE
C
      YTEST=ABS(YNEW-YOLD)
C
C G&O 2/87
         TDXMAX = X - XNEW
      DXMAX  = 0.5 * TDXMAX
C G&O 2/87 END
C
      IF( YTEST .GT. .05 ) GO TO 125
C
C G&O 2/87
C     DX=2*DX
C
      DXOLD = DX
      DXNEW = AMIN1( 2.*DX ,DXMAX )
      RATX  = 0.5 * DXNEW/DXOLD
      DX    = DXNEW
      TDX   = AMIN1( 2.*DX, TDXMAX)
C
C
      DTS=2*DTS*RATX
      DS=2*DS*RATX
      DG=2*DG*RATX
      DGSL=2.*DGSL*RATX
C G&O 2/87 END
C
```

```
      GO TO 130
C
C G&O 2/87
  125 IF( YTEST .LT. 0.1 ) GO TO 1000
      IF( DX    .LT. 5.0 ) GO TO 1000
C
C     DX=.5*DX
C
      DXOLD = DX
      DXNEW = AMIN1( 0.5*DX,DXMAX )
      RATX =  2. * DXNEW/DXOLD
      DX   = DXNEW
      TDX  = AMIN1( 2.*DX,TDXMAX )
C
      DTS=.5*DTS*RATX
      DS=.5*DS*RATX
      DG=.5*DG*RATX
      DGSL=0.5*DGSL*RATX
C
      GO TO 130
C
 1000 CONTINUE
C
      DXOLD = DX
      DXNEW = AMIN1( DX,DXMAX )
          RATX  = DXNEW/DXOLD
         DX     = DXNEW
         TDX    = AMIN1( 2.*DX,TDXMAX )
C
      DTS=DTS*RATX
      DS=DS*RATX
      DG=DG*RATX
      DGSL=DGSL*RATX
C G&O 2/87 END
C
C     UPDATE RECURSIVE VARIABLES AND LOOP BACK
  130 XOLD=XNEW
      YOLD=YNEW
      TSOLD=TSNEW
      SOLD=SNEW
      GOLD=GNEW
C
C G&O 2/87
      GSLOLD=GSLNEW
      WPOLD=WPNEW
      DOLD=DNEW
      DOLDSTR=AMAX1(0.01,DOLD)
C G&O 2/87 END
C
      GO TO 110
C
C                     STORE FINAL VALUE IF IT HAS NOT ALREADY BEEN STORED
```

```
C
  135 IF(GS(NFO).EQ.ESFO)GO TO 140
      NFO=NFO+1
      GS(NFO)=ESFO
C
C G&O 2/87
      HBM=SHBM(WPNEW,GSLNEW,DNEWSTR)
      WHM=HBM
C     WHM=.78*(SE-EEFO)
      WHT=AMIN1(WHT,WHM)
C G&O 2/87 END
C
      HBW(NFO)=AMIN1(WHT,WHM)
      STMP=GNEW+DNEW
C     EW(NFO)=.7*HBW(NFO)+SAVG
      EW(NFO)=.7*HBW(NFO)+STMP
C
C         G&O SEPT 88
C
      SPWP(NFO) = WPNEW
C
C         END G&O SEPT 88
C
      SA(NFO,1)=XOLD
      SA(NFO,2)=ESFO
      SA(NFO,3)=SETN
      SA(NFO,4)=SEN
C
C G&O 2/87
C 140 SA(NFO,5)=2HVH
C
      SA( NFO,5 ) = 2HVH
C
 140  CONTINUE
C G&O 2/87 END
C
C                 INSERT ABGF IF REQUIRED
C
      IF(ABGF.NE.1)GO TO 150
      NAP=NAP+1
      AP(NAP)=ESFO
      M=M+1
      STEG(M)=GS(NFO)
      ELZ(M)=EW(NFO)
C
C     GET READY FOR NEXT FETCH OR OBSTRUCTION AND RETURN
  150 BSFO=ESFO
      BEFO=EEFO
C
C G&O 2/87   **  COMMENTTED OUT AND INSERT ***
C     WHI=HBW(NFO)
      WPT=WPNEW
```

```
C G&O 2/87   **  END OF COMMENTTED OUT AND INSERT ***
      RETURN
  500 FORMAT(/,10X,34HINVALID DATA IN FIELD 1 OF VH CARD)
  520 FORMAT(/,10X,45HINVALID DATA IN FIELD 3 OR FIELD 5 OF VH CARD)
  530 FORMAT(/,10X,34HINVALID DATA IN FIELD 4 OF VH CARD)
  540 FORMAT(/,10X,34HINVALID DATA IN FIELD 6 OF VH CARD)
  545 FORMAT(/,10X,34HINVALID DATA IN FILED 3 OF MG CARD)
  560 FORMAT(A2,2X,A4,9F8.0)
  570 FORMAT(/,10X,
     154HMISSING MG CARD OR INCORECT DATA IN FIELD 6 OF VH CARD)
  580 FORMAT(/,10X,11HJOB DUMPED.)
  590 FORMAT(10X,A2,7X,A4,9F11.3)
  600 FORMAT(/,10X,'WAVE PERIOD LESS THAN OR EQUAL TO ZERO',/
     1           10X,'IN SUBROUTINE VEG.  ABORT RUN')
  610 FORMAT(A4,8F16.8)
  995 FORMAT(/,10X,38HARRAY DIMENSIONS EXCEEDED. JOB DUMPED.)
      END
C
C G&O 2/87  **   INSERT  **
C
      FUNCTION SHBM(WPI,SLOPE,DNEW)
C
C     WRITTEN    FEBRUARY 1987 BY:
C
C                      GREENHORNE AND O'MARA, INC.
C                      GREENBELT, MARYLAND
C
C     BASED ON IMPROVED BREAKING WAVE HEIGHT EQUATION SUPPLIED
C     BY DR. BARRY E. HERCHENRODER OF THE SAME FIRM.
C
C**   THIS FUNCTION SUBROUTINE CALCULATES THE UPDATED MAXIMUM
C**   CONTROLLING BREAKING WAVE HEIGHT TAKING INTO ACCOUNT
C**   THE EFFECT OF BOTTOM SLOPE AND PEAK WAVE PERIOD.
C**   EQUATIONS 2-92 THROUGH 2-94 IN THE 1984 SHORE
C**   PROTECTION MANUAL (CERC, 1984) ARE USED. IT IS ASSUMED
C**   THAT THE BREAKING WAVE HEIGHT REFERRED TO IN THESE
C**   EQUATIONS IS THE 1% WAVEHEIGHT AND CAN THEREFORE BE
C**   EQUATED WITH FEMA'S CONTROLLING WAVE HEIGHT. THIS
C**   ASSUMPTION IS BACKED UP BY CALCULATIONS PERFORMED
C**   USING THORNTON AND GUZA'S DATA (JGR,1983) THAT SHOW
C**   THAT HRMS=0.42*(STILLWATER DEPTH) DERIVED BY THESE
C**   AUTHORS IS A DIRECT CONSEQUENCE OF USING THE BREAKING
C**   LAW IN THIS ROUTINE, AN OBSERVED BOTTOM SLOPE OF ZERO,
C**   AND A RATIO OF 1% WAVE HEIGHT TO SIGNIFICANT WAVE
C**   HEIGHT IN THE INNER SURF ZONE OF 1.3.
C
C**    WPI:  SPECTRAL PEAK WAVE PERIOD AT END OF TRANSECT
C            SEGMENT OR AT END OF GRID CELL WITHIN A TRANSECT
C            SEGMENT.
C**  SLOPE:  BOTTOM SLOPE AT END OF TRANSECT SEGMENT OR AT
C            END OF GRID CELL WITHIN A TRANSECT SEGMENT
C**   DNEW:  100 YEAR STILL WATER DEPTH AT END OF TRANSECT
```

```
C               SEGMENT OR AT END OF GRID CELL WITHIN A TRANSECT
C               SEGMENT.
C
C*******************************************************************
C
C           REVISED IN JUNE AND JULY, 1987 TO RESTORE THE ORIGINAL 0.78
C           BREAKING CRITERIA PER INSTRUCTION BY THE FEDERAL
C           EMERGENCY MANAGEMENT AGENCY
C
C*******************************************************************
C
C      SLOPE=ABS(SLOPE)
C      AP=1.-EXP(-19.5*SLOPE)
C      BP=1.-EXP(-19.0*SLOPE)
C      AP=1.-0.5*AP
C      WPI=AMAX1(0.1,WPI)
C      BP=1.+1.36*BP*DNEW/(WPI**2)
C      GAMA=0.78/(AP*BP)
C      GAMMA = AMAX1( 0.78,GAMA )
       GAMMA=0.78
       SHBM=GAMMA*DNEW
       SHBM=AMAX1(0.0,SHBM)
       RETURN
       END
       FUNCTION HIN(WHI,AFL,W,D,WPT)
C
C     THIS FUNCTION COMPUTES THE TRANSMITTED CONTROLING WAVE HEIGHT
C     "HIN" FROM THE INCIDENT CONTROLING WAVE HEIGHT "WHI", FETCH
C     LENGTH "AFL", 10M 10MINUTE WIND SPEED "W", 100 YEAR STILLWATER
C     DEPTH "D", AND TRANSMITTED WAVE PERIOD "WPT".  THE 1984 SPM EQUA-
C     TIONS ARE USED TO CALCULATE HM0, THE THOMPSON-VINCENT CURVES (IN
C     PARAMETERIZED FORM) ARE USED TO CALCULATE THE SIGNIFICANT WAVE
C     HEIGHT HS FROM HM0, AND THE CONTROLLING WAVE HEIGHT IS 1.6 TIMES
C     HS.
C
       PI=3.14159
       G=32.2
C
       WPTSTR = AMAX1( .01 , WPT )
       DSTR   = AMAX1( .01 , D   )
C
C     IT IS ASSUMED THAT W IS INPUT AS UNADJUSTED WINDSPEED IN
C     FEET PER SECOND
C
C     CALCULATE U, THE ADJUSTED WINDSPEED IN FEET PER SECOND
C
       CA=(3.6/5.28)**0.23
       U=0.589*CA*(W**1.23)
C
C          CONVERT WHI TO ZERO MOMENT WAVEHEIGHT YI
C
C
```

```
C G&O SEPT 88
C
C                 THE STATEMENT BELOW IS COMMENTED OUT AND
C                 CORRECTED
C
C     YI = HMO( WHI , DSTR , WPTSTR )
C
C                 THERE ARE TWO CASES CORRESPONDING TO
C                 BREAKING AND NON-BREAKING WAVES.
C
      HBM = 0.78 * DSTR
C
      IF( WHI .GE. HBM ) THEN
C
C                 WAVE IS BREAKING
C
      WHI   = HBM
      YI    = HMO( WHI, DSTR, WPTSTR )
C
      ELSE
C
C                 WAVE IS NOT BREAKING
C
      YI    = HMONB( WHI, DSTR, WPTSTR )
C
      ENDIF
C
C        END G&O SEPT 88
C
C    IT IS ALSO ASSUMED THAT AFL (FETCH DISTANCE), WHI (THE INCIDENT
C    WAVELENGTH), AND D (THE STILLWATER DEPTH) ARE IN FEET
C
C     COMPUTE COMMON FACTORS
      ALPHA=(.283/G)*U*U
      BETA=TANH(.53*((G*D/(U**2))**.75))
      X=YI/(ALPHA*BETA)
C
C     CHECK TO SEE IF MAXIMUM WAVE HEIGHT HAS BEEN ACHIEVED
      IF(X.LT.1)GO TO 20
      YNEW = YI
      GO TO 100
C
C     COMPUTE EQUIVELENT FETCH LENGTH CORRESPONDING TO INCIDENT
C     WAVE HEIGHT
C
   20 CONTINUE
      TANHI=.5*LOG((1+X)/(1-X))
      EFL=(((BETA/.00565)*TANHI)**2)*(U**2)/G
C
C      COMPUTE TOTAL FETCH LENGTH
      F=EFL+AFL
C
```

```
C     COMPUTE TRANSMITTED WAVE HEIGHT HM0
      YNEW=ALPHA*BETA*TANH((.00565/BETA)*SQRT((G*F/(U**2))))
C
 100  CONTINUE
C
C   CALCULATE THE WAVELENGTH WLNEW PREPARATORY TO CALCULATING HS
C
      PI2=2.*PI
      WLONEW=(G/PI2)*WPTSTR*WPTSTR
      WLONEW=AMAX1(0.1,WLONEW)
C
      DNEWSTR=AMAX1(0.01,D)
      CDNEW=DNEWSTR/WLONEW
      WLNEW=WLONEW*SQRT(TANH(PI2*CDNEW))
      WLNEW = AMAX1( 0.01 , WLNEW )
C
C   CALCULATE REMAINING PARAMETERS
C
      WPI = WPTSTR
      WLI=WLNEW
      C2LOG=.394528*ALOG10(2.0)
C
C   CALCULATE HS AND CONTROLLING WAVE HEIGHT WHT
C
      EPP=YNEW/(4*WLI*.002)
      EPP = AMAX1( 1.0E-4 , EPP )
C
      DD=DNEWSTR/(G*(WPI**2))
C
CG&O 9/88 COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C         THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C         ARTICLE
C
C     DC=5.5722E-5
C     PART1=.9+(.42707*ALOG10(DD/DC))
C     IF(EPP.LE.2)PHI=PART1-(1.411296*ALOG10(EPP))
C     IF(EPP.GT.2)PHI=PART1-C2LOG-(1.016768*ALOG10(EPP))
C
CG&O 9/88 END
C
      D0=1.357E-3
      RAV=1.477+.477*(((D0/DD)**.8557)-1)
      IF(RAV.GT.1.7)RAV=1.7
      IF( RAV .LT. 1.0 ) RAV= 1.0
C
CG&O 9/88 COMMENTED OUT TO MAKE EXPRESSION FOR HS CONSISTENT WITH
C         THOMPSON & VINCENT'S HS EXPRESSION IN 1985 WATERWAYS & HARBOR
C         ARTICLE
C
C     IF(PHI.LT.1)PHI=1
C     IF(PHI.GT.RAV)PHI=RAV
C
```

```
CG&O 9/88 END
C
CG&O 9/88   SET PHI TO CORRECT EXPRESSION
C
      PHI = RAV
C
CG&O 9/88 END
C
      HS=PHI*YNEW
C
C     CONVERT SIGNIFICANT WAVE HEIGHT TO
C     CONTROLLING WAVE HEIGHT
      WHT=1.6*HS
C
C G&O SEPT 88
C
C                 IF THE CONTROLLING WAVEHEIGHT WHT BREAKS,
C                 RESET IT TO THE BREAKING WAVEHEIGHT
C
      HBM = 0.78 * DSTR
      WHT = AMIN1( WHT,HBM )
C
C END G&O SEPT 88
C
      HIN=WHT
C
      RETURN
C
C G&O 2/87 END INSERT
C
      END
      SUBROUTINE AVG(BP,EP,AER,ATS)
C     THIS SUBROUTINE DETERMINES THE WEIGHTED AVERAGE 10 YEAR SURGE
C     ELEVATION (ATS) AND WEIGHTED AVERAGE 100 YEAR WAVE ELEVATION (AER)
C     GIVEN THE BEGIN POINT (BP) AND END POINT (EP) OVER WHICH THE
C     AVERAGE IS TO BE TAKEN.
      DIMENSION PARAM(10),HBW(500),STEG(500),ELZ(500),
     1GS(500),EW(500),SA(500,5),AP(500)
      COMMON /AONLY/NFOM1
      COMMON /AFGV/TOF,PARAM,BSFO,BEFO,WHI,WHT,NFO,
     1HBW,AP,SET,SE,STEG,ELZ,GS,EW,SA,M,NAP
      AS= 'AS'
      WT=0
      ICPS=0
      ICPE=0
      DO 10 I=1,NFOM1
      IF(BP.GE.GS(I).AND.BP.LT.GS(I+1))ICPS=I+1
      IF(EP.GT.GS(I).AND.EP.LE.GS(I+1))ICPE=I
   10 CONTINUE
      A1=0
      A2=0
      ICPEM1=ICPE-1
```

```
      IF(ICPEM1.LE.ICPS)GO TO 25
      DO 20 I=ICPS,ICPEM1
      IF(SA(I+1,5).EQ.AS)GO TO 20
      HGHT1=SA(I,3)+SA(I+1,3)
      HGHT2=EW(I)+EW(I+1)
      WIDTH=GS(I+1)-GS(I)
      WT=WT+WIDTH
      A1=A1+(HGHT1*WIDTH/2.0)
      A2=A2+(HGHT2*WIDTH/2.0)
   20 CONTINUE
   25 IF(ICPS.EQ.ICPEM1)GO TO 30
      IF(ICPS.EQ.ICPE)GO TO 40
      IF(ICPS.GT.ICPE)GO TO 50
      GO TO 60
   30 IF(SA(ICPE,5).EQ.AS)GO TO 60
      HGHT1=SA(ICPS,3)+SA(ICPE,3)
      HGHT2=EW(ICPS)+EW(ICPE)
      WIDTH=GS(ICPE)-GS(ICPS)
      WT=WIDTH
      A1=HGHT1*WIDTH/2.0
      A2=HGHT2*WIDTH/2.0
      GO TO 60
   40 SLOPE1=(EW(ICPE)-EW(ICPEM1))/(GS(ICPE)-GS(ICPEM1))
      SLOPE2=(EW(ICPE+1)-EW(ICPE))/(GS(ICPE+1)-GS(ICPE))
      Y1=SLOPE1*(BP-GS(ICPEM1))+EW(ICPEM1)
      Y2=SLOPE2*(EP-GS(ICPE))+EW(ICPE)
      Y3=SA(ICPEM1,3)+SA(ICPE,3)
      Y4=SA(ICPE,3)+SA(ICPE+1,3)
      WIDTH1=GS(ICPE)-BP
      WIDTH2=EP-GS(ICPE)
      WT=WIDTH1+WIDTH2
      A1=(((Y3*WIDTH1)+(Y4*WIDTH2)))/2.0
      A2=((Y1+EW(ICPE))*WIDTH1+((Y2+EW(ICPE))*WIDTH2))/2.0
      GO TO 70
   50 X=((BP+EP)/2.0)-GS(ICPE)
      SLOPE=(EW(ICPS)-EW(ICPE))/(GS(ICPS)-GS(ICPE))
      Y1=(SA(ICPS,3)+SA(ICPE,3))/2.0
      Y2=SLOPE*X+EW(ICPE)
      WIDTH=EP-BP
      WT=WIDTH
      A1=Y1*WIDTH
      A2=Y2*WIDTH
      GO TO 70
   60 SLOPE1=(EW(ICPS)-EW(ICPS-1))/(GS(ICPS)-GS(ICPS-1))
      SLOPE2=(EW(ICPE+1)-EW(ICPE))/(GS(ICPE+1)-GS(ICPE))
      Y1=SLOPE1*(BP-GS(ICPS-1))+EW(ICPS-1)
      Y2=SLOPE2*(EP-GS(ICPE))+EW(ICPE)
      Y3=(SA(ICPS-1,3)+SA(ICPS,3))/2.0
      Y4=(SA(ICPE+1,3)+SA(ICPE,3))/2.0
      WIDTH1=GS(ICPS)-BP
      WIDTH2=EP-GS(ICPE)
      A1=A1+(Y3*WIDTH1+(Y4*WIDTH2))
```

```
      A2=A2+((Y1+EW(ICPS))*WIDTH1/2.0)+((Y2+EW(ICPE))*WIDTH2/2.0)
      WT=WT+WIDTH1+WIDTH2
   70 ATS=A1/WT
      AER=A2/WT
      RETURN
      END
      SUBROUTINE READIN
C     THIS SUBROUTINE READS IN TABULAR DATA ON MARSH GRASS
      DIMENSION HDN(8,8,7),PPSD(8,3),PLTYP(8)
      COMMON /PPT/HDN,PPSD,PLTYP
C
C     REWIND UNIT 7, THE UNIT WITH THE MARSH GRASS DATA
C
      REWIND(7)
C
C     READ IN DATA FOR HEIGHT,DIAMETER,AND NUMBER DENSITY
      DO 20 I=1,7
      DO 20 J=1,8
      READ(7,500)(HDN(I,J,K),K=1,7)
   20 CONTINUE
C
C     NO MARSH GRASS IN REGION 8
      DO 30 I=1,8
      DO 30 J=1,7
      HDN(8,I,J)=0
   30 CONTINUE
C
C     READ IN DATA ON PLANT PARAMETERS THAT ARE SPECIES DEPENDENT
      DO 40 I=1,8
      READ(7,510)(PPSD(I,J),J=1,3)
   40 CONTINUE
C
C     READ IN MARSH GRASS PLANT TYPES
      READ(7,520)(PLTYP(I),I=1,8)
C
C     RETURN TO MAIN PROGRAM
      RETURN
  500 FORMAT(7F8.0)
  510 FORMAT(3F8.0)
  520 FORMAT(8(4X,A4))
      END
      FUNCTION APP(DEF,D,NPLTS,WPI,WL)
C     THIS FUNCTION COMPUTES THE AVERAGE PLANT PARAMETER
C     WHICH IS RELATED TO THE NET DRAG FORCE FOR ALL PLANT
C     TYPES PRESENT FOR A GIVEN DEPTH
C
      DIMENSION DEF(10,8)
      PI=3.14159
      G2=1036.84
      G=32.2
C
C     DETERMINE PLANT PARAMETERS
```

```
      APP=0
      DO 60 I=1,NPLTS
C
C     UNLOAD DEF ARRAY
      CDE=DEF(I,1)
      FCOV=DEF(I,2)
      HBI=DEF(I,3)
      PPSF=DEF(I,4)
      SDB=DEF(I,5)
      SDM=DEF(I,6)
      SDT=DEF(I,7)
      FAR=DEF(I,8)
C
C     COMPUTE NON DEPTH DEPENDENT QUANTITIES
      ABMS=(SDB+SDM)*HBI*.25
      AAMS=(SDM+SDT)*HBI*.25
      TAS=ABMS+AAMS
      ACPL=(2/PI)*FAR*TAS
C
C     COMPUTE FACTOR WHICH ADJUSTS FOR THE EFFECTS
C     OF WAVE PERIOD
      HF=.5*HBI
      IF(HF.GT.D)HF=D
      IF(D/WL.LT..04)GO TO 5
      IF(D/WL.GT..5)GO TO 10
      WPF=G2*((WPI/WL)*COSH(2*PI*HF/WL)/COSH(2*PI*D/WL))**3
      GO TO 15
    5 WPF=SQRT(G/D)
      GO TO 15
   10 Z=HF-D
      WPF=(8/G)*((PI/WPI)*EXP(2*PI*Z/WL))**3
C
C     COMPUTE FRONTAL AREA BELOW THE WATER SURFACE
C     FOR EACH PLANT TYPE AND COMBINE WITH OTHER
C     PLANT PARAMETERS
   15 IF(HBI.NE.0)GO TO 20
      AT=0
      GO TO 50
   20 IF(D.GT..5*HBI)GO TO 25
      SDI=SDB+((SDM-SDB)/(.5*HBI))
      A1=(SDB+SDI)*.5*D
      A2=ACPL*(D/HBI)
      AT=A1+A2
      GO TO 50
   25 IF(D.GT.HBI)GO TO 30
      SDI=SDM+(((SDT-SDM)/(HBI*.5))*(D-(HBI*.5)))
      A1=(SDM+SDI)*.5*(D-(.5*HBI))
      A2=ACPL*(D/HBI)
      AT=ABMS+A1+A2
      GO TO 50
   30 AT=TAS+ACPL
   50 APP=APP+(FCOV*PPSF*CDE*AT)*WPF
```

```
   60 CONTINUE
      RETURN
      END
      SUBROUTINE ECHO
C     THIS SUBROUTINE PRODUCES AN ANOTATED INPUT LISTING
C
      DIMENSION PARAM(10)
      DATA EI,BU,DU,VE,FI,FO,AS,VH,GM,ET / 'IE','BU','DU',
     1'VE','IF','OF','AS','VH','MG','ET'/
C
C     REWIND SCRATCH FILES AND ADVANCE TO TOP OF PAGE
      REWIND 8
      REWIND 9
      WRITE(6,730)
C
C     READ CARD AND BRANCH TO APPROPRIATE PROGRAM SEGMENT
   10 READ(8,505)TOF,(PARAM(I),I=1,10)
      IF(TOF.EQ.EI)GO TO 50
      IF(TOF.EQ.BU)GO TO 100
      IF(TOF.EQ.DU)GO TO 150
      IF(TOF.EQ.VE)GO TO 200
      IF(TOF.EQ.FI)GO TO 250
      IF(TOF.EQ.FO)GO TO 250
      IF(TOF.EQ.AS)GO TO 250
      IF(TOF.EQ.VH)GO TO 300
      IF(TOF.EQ.ET)GO TO 350
C
C     PRINT INITIAL ELEVATIONS HEADINGS AND DATA
   50 WRITE(6,530)
      WRITE(6,540)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      GO TO 10
C
C     PRINT BUILDING HEADINGS AND DATA
  100 WRITE(6,550)
      WRITE(6,560)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      GO TO 10
C
C     PRINT DUNE HEADINGS AND DATA
  150 WRITE(6,565)
      WRITE(6,570)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      GO TO 10
C
C     PRINT VEGETATION HEADINGS AND DATA
  200 WRITE(6,580)
      WRITE(6,590)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      GO TO 10
C
C     PRINT FETCH OR ABOVE SURGE HEADINGS AND DATA
```

```
  250 WRITE(6,600)
      WRITE(6,610)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      GO TO 10
C
C     PRINT SPECIAL VEGETATION HEADINGS AND DATA
  300 WRITE(6,640)
      WRITE(6,650)
      WRITE(6,500)TOF,(PARAM(I),I=1,10)
      NPLTS=PARAM(6)
      DO 310 J=1,NPLTS
      READ(8,515)TOF,(PARAM(I),I=1,10)
      WRITE(6,660)
      WRITE(6,670)
      WRITE(6,510)TOF,(PARAM(I),I=1,10)
  310 CONTINUE
C
C     PRINT PLANT PARAMETERS INCLUDING DEFAULTS
      WRITE(6,700)
      DO 330 I=1,NPLTS
      WRITE(6,660)
      WRITE(6,670)
      READ(9,680)TYPE,(PARAM(J),J=1,8)
      PARAM(5)=PARAM(5)*12
      PARAM(6)=PARAM(6)*12
      PARAM(7)=PARAM(7)*12
      WRITE(6,520)TYPE,(PARAM(J),J=1,8)
  330 CONTINUE
      WRITE(6,710)
      GO TO 10
C
C     PRINT END OF TRANSECT MESSAGE AND EXPLANATORY NOTE
  350 WRITE(6,720)
      WRITE(6,740)
      WRITE(6,750)
C
C     REWIND SCRATCH FILES, ADVANCE PAGE, AND RETURN
      REWIND 8
      REWIND 9
      WRITE(6,730)
      RETURN
  500 FORMAT(2X,A2,10F11.3)
  505 FORMAT(10X,A2,10F11.3)
  510 FORMAT(2X,A2,7X,A4,9F11.3)
  515 FORMAT(10X,A2,7X,A4,9F11.3)
  520 FORMAT(11X,A4,9F11.3)
  530 FORMAT(//,T13,3HEND,T24,3HEND,T33,5HFETCH,T39,10HSURGE ELEV,
     1T50,10HSURGE ELEV,T64,7HINITIAL,T75,7HINITIAL,
     2T98,6HBOTTOM,T108,7HAVERAGE)
  540 FORMAT(T9,7HSTATION,T18,9HELEVATION,T32,6HLENGTH,T42,7H10-YEAR,
     1T52,8H100-YEAR,T61,11HWAVE HEIGHT,T74,9HW. PERIOD,
     1T99,5HSLOPE,T108,7HA-ZONES)
```

```
 550 FORMAT(//,T13,3HEND,T24,3HEND,T28,10HOPEN SPACE,T43,6HNO. OF,T51,
    19HNEW SURGE,T62,9HNEW SURGE,T98,6HBOTTOM,T108,7HAVERAGE)
 560 FORMAT(T9,7HSTATION,T18,9HELEVATION,T33,5HRATIO,T45,4HROWS,T53,
    17H10-YEAR,T63,8H100-YEAR,T99,5HSLOPE,T108,7HA-ZONES)
 565 FORMAT(//,T6,10HDUNE CREST,T17,10HDUNE CREST,T31,7HDUNE OR,T40,
    19HNEW SURGE,T51,9HNEW SURGE,T98,6HBOTTOM,T108,7HAVERAGE)
 570 FORMAT(T9,7HSTATION,T18,9HELEVATION,T31,7HSEAWALL,T42,
    17H10-YEAR,T52,8H100-YEAR,T99,5HSLOPE,T108,7HA-ZONES)
 580 FORMAT(//,T13,3HEND,T24,3HEND,T31,7HAVERAGE,T42,7HAVERAGE,T53,
    17HAVERAGE,T67,4HDRAG,T73,9HNEW SURGE,T84,9HNEW SURGE,
    1T98,6HBOTTOM,T108,7HAVERAGE)
 590 FORMAT(T9,7HSTATION,T18,9HELEVATION,T30,8HDIAMETER,T43,6HHEIGHT,
    1T53,7HSPACING,T65,6HCOEFF.,T75,7H10-YEAR,T85,8H100-YEAR,
    1T99,5HSLOPE,T108,7HA-ZONES)
 600 FORMAT(//,T13,3HEND,T24,3HEND,T29,9HNEW SURGE,T40,9HNEW SURGE,
    1T98,6HBOTTOM,T108,7HAVERAGE)
 610 FORMAT(T9,7HSTATION,T18,9HELEVATION,T31,7H10-YEAR,T41,8H100-YEAR,
    1T99,5HSLOPE,T108,7HA-ZONES)
 640 FORMAT(//,T13,3HEND,T24,3HEND,T41,8HREGION 1,T65,6HNO. OF,T73,
    19HNEW SURGE,T84,9HNEW SURGE,T98,6HBOTTOM,T108,7HAVERAGE)
 650 FORMAT(T9,7HSTATION,T18,9HELEVATION,T30,8HREGION 1,T43,6HWEIGHT,
    1T52,8HREGION 2,T61,11HPLANT TYPES,T75,7H10-YEAR,T85,8H100-YEAR,
    1T99,5HSLOPE,T108,7HA-ZONES)
 660 FORMAT(//,T11,5HPLANT,T23,4HDRAG,T30,8HCOVERAGE,T40,9HAVG. STEM,
    1T54,6HNUMBERT62,9HBASE STEM,T74,8HMID STEM,T85,8HTOP STEM,
    1T96,9HLEAF-STEM)
 670 FORMAT(T12,4HTYPE,T21,6HCOEFF.,T33,5HRATIO,T43,6HHEIGHT,T53,
    17HDENSITYT63,8HDIAMETER,T74,8HDIAMETER,T85,8HDIAMETER,
    1T95,10HAREA RATIO)
 680 FORMAT(A4,8F16.8)
 700 FORMAT(//,2X,112(1H-),/,T27,31HPLANT CHARACTERISTICS INCLUDING,
    1 31H VALUES SUPPLIED BY THE PROGRAM)
 710 FORMAT(//,2X,112(1H-))
 720 FORMAT(//,2X,48(1H-),15HEND OF TRANSECT,49(1H-))
 730 FORMAT(1H1)
 740 FORMAT(//,2X,5HNOTE:)
 750 FORMAT(/,2X,43HSURGE ELEVATION INCLUDES CONTRIBUTIONS FROM,
    11X,29HASTRONOMICAL AND STORM TIDES.)
      END
      FUNCTION T(WPI,AFL,W,D)
C
C     THIS FUNCTION COMPUTES THE TRANSMITTED WAVE PERIOD FROM
C     THE INCIDENT WAVE PERIOD,FETCH LENGTH,10M. 10MIN. WIND-
C     SPEED AND 100 YEAR STILLWATER DEPTH.
      PI=3.14159
      G=32.2
      C13=.333333333
C
C   IT IS ASSUMED THAT W IS INPUT AS UNADJUSTED WINDSPEED IN
C   FEET PER SECOND
C
C   CALCULATE U, THE ADJUSTED WINDSPEED IN FEET PER SECOND
```

```
C
      CA=(3.6/5.28)**0.23
      U=0.589*CA*(W**1.23)
C
C IT IS ALSO ASSUMED THAT AFL, THE FETCH DISTANCE IS IN FEET AND
C  WPI IS IN SECONDS
C
C     COMPUTE COMMON FACTORS
      ALPHA=(7.54/G)*U
      BETA=TANH(.833*((G*D/(U**2))**.375))
      X=WPI/(ALPHA*BETA)
C
C     CHECK TO SEE IF MAXIMUM WAVE PERIOD HAS BEEN ACHIEVED
      IF(X.LT.1)GO TO 20
      T=WPI
      GO TO 100
C
C     COMPUTE EQUIVELENT FETCH LENGTH CORESPONDING TO INCIDENT
C     WAVE PERIOD
   20 TANHI=.5*LOG((1+X)/(1-X))
      EFL=(((BETA/.0379)*TANHI)**3)*(U**2)/G
C
C      COMPUTE TOTAL FETCH LENGTH
      F=EFL+AFL
C
C     COMPUTE TRANSMITTED WAVE PERIOD
      T=ALPHA*BETA*TANH((.0379/BETA)*((G*F/(U**2))**C13))
  100 RETURN
      END
      SUBROUTINE WAVG(DEF1,DEF2,DEF,WF1,REG1,REG2,NPLTS,TYPE,TEST)
C     THIS SUBROUTINE COMPUTES THE WEIGHTED AVERAGE VALUE OF PLANT
C     PARAMETERS COMBINING DATA FOR REGION 1 AND REGION 2
C
      LOGICAL TEST
      DIMENSION DEF1(10,8),DEF2(10,8),DEF(10,8),TYPE(10)
      IREG1=REG1
      IREG2=REG2
C
C     REPEAT COMPUTATIONS FOR EACH PLANT TYPE
      DO 90 I=1,NPLTS
C
C     FOR STEM PARAMETERS WHICH SHOULD NOT BE ZERO USE RESULTS
C     FROM THE OTHER REGION
      DO 20 J=3,7
      IF(J.EQ.4)GO TO 20
C
C     IF PARAMETERS ARE ZERO FOR BOTH REGIONS PRINT ERROR MESSAGE
      IF(DEF1(I,J).EQ.0.AND.DEF2(I,J).EQ.0)GO TO 10
C
C     USE RESULTS FORM THE OTHER REGION
      IF(DEF1(I,J).EQ.0)DEF1(I,J)=DEF2(I,J)
      IF(DEF2(I,J).EQ.0)DEF2(I,J)=DEF1(I,J)
```

```
      GO TO 20
C
C     SET ERROR FLAG AND PRINT ERROR MESSAGES
   10 TEST=.TRUE.
      IF(J.EQ.3)WRITE(6,110)TYPE(I),IREG1,IREG2
      IF(J.EQ.5)WRITE(6,120)TYPE(I),IREG1,IREG2
      IF(J.EQ.6)WRITE(6,130)TYPE(I),IREG1,IREG2
      IF(J.EQ.7)WRITE(6,140)TYPE(I),IREG1,IREG2
      WRITE(6,100)
   20 CONTINUE
C
C     COMPUTE WEIGHTED AVERAGE
      DO 90 J=1,8
      DEF(I,J)=WF1*DEF1(I,J)+(1-WF1)*DEF2(I,J)
   90 CONTINUE
      RETURN
  100 FORMAT(/,10X,19HINVALID INPUT DATA.)
  110 FORMAT(/,10X,45HHEIGHT BELOW INFLORESENCE = 0 FOR PLANT TYPE ,
     1A4,10H IN REGION,I2,11H AND REGION,I2)
  120 FORMAT(/,10X,38HBASE STEM DIAMATER = 0 FOR PLANT TYPE ,
     1A4,10H IN REGION,I2,11H AND REGION,I2)
  130 FORMAT(/,10X,37HMID STEM DIAMATER = 0 FOR PLANT TYPE ,
     1A4,10H IN REGION,I2,11H AND REGION,I2)
  140 FORMAT(/,10X,37HTOP STEM DIAMATER = 0 FOR PLANT TYPE ,
     1A4,10H IN REGION,I2,11H AND REGION,I2)
      END
C
C        G&O SEPT 88
C
      FUNCTION HMONB(WHI,DNEW,WPI)
C
C     THIS FUNCTION CONVERTS THE CONTROLLING WAVE HEIGHT, WHI
C     TO THE ZERO MOMENT WAVE HEIGHT, HMO WHEN WAVE IS NOT BREAKING.
C     DNEW IS THE STILLWATER DEPTH AND WPI IS THE SPECTRAL PEAK WAVE
C     PERIOD AT THE LOCATION OF INTEREST.
C
      IF(WHI.EQ.0)HMONB=0
      IF(WHI.EQ.0)RETURN
C
C        SET PRELIMINARY CONSTANTS OR FACTORS
C
      G=32.2
C
C                 CALCULATE THE SIGNIFICANT WAVE HEIGHT HS.
C                 NOTE THAT (1./1.6)=.625
C
      HS = WHI * 0.625
C
C                 CALCULATE RAV
C
      DNEWSTR = AMAX1( 0.01,DNEW )
      WPISTR  = AMAX1(  0.1,WPI  )
```

```
      DD = DNEWSTR/( G*(WPISTR**2) )
      D0= 1.357E-3
C
      RAV=1.477+.477*(((D0/DD)**.8557)-1)
C
      IF(RAV.GT.1.7)RAV=1.7
      IF(RAV.LT.1)RAV=1
C
C                 CALCULATE HM0 FROM HS AND RAV
C
      HM0 = HS/RAV
C
      HM0NB = HM0
C
      RETURN
      END
C
C        END G&O SEPT 88
C
      FUNCTION HM0(WHI,DNEW,WPI)
C
C     THIS FUNCTION CONVERTS THE CONTROLLING WAVE HEIGHT, WHI
C     TO THE ZERO MOMENT WAVE HEIGHT, HM0 WHEN WAVE IS BREAKING
C
      IF(WHI.EQ.0)HM0=0
      IF(WHI.EQ.0)RETURN
C
C        SET PRELIMINARY CONSTANTS OR FACTORS
C
      PI=3.14159
      G=32.2
C
C G&O 2/87
      DNEWSTR = AMAX1( 0.01,DNEW )
      PI2     = 2. * PI
C G&O 2/87 END
C
      HS=WHI/1.6
      NMAX= 25
      D0= 1.357E-3
      DC= 5.5722E-5
      C1LOG= ALOG10(2.0)
      C2LOG= .394528 * C1LOG
      C3LOG= 1.411296 * C1LOG
C
C        CP1= 1.0/1.016768
C
      CP1= .983508529
C
C        CP2= 1.0/1.411296
C
      CP2= .708568578
```

```
C
C         CP3= 10**(-1.0/1.0167683)
C
      CP3= .10387032
C
C         CP4= 10**(-1.0/1.411296)
C
      CP4= .195628183
C
C G&O 2/87
C     DD=DNEW/(G*WPI**2)
      WL0=5.12*(WPI**2)
C     WLI=SQRT(2*PI*DNEW*WL0)/(1+1.25*DNEW/WL0)
      DD = DNEWSTR/(G*WPI*WPI)
      WL0 = AMAX1( WL0,0.1 )
      CDNEW = DNEWSTR/WL0
      WLI   = WL0 * SQRT( TANH( PI2*CDNEW ) )
C G&O 2/87 END
C
      CL1= .008 * WLI
C
C         CL2= .016 * WLI
C
      CL2= 2. * CL1
      CL3= 1.25/WLI
C
C         EPSP= HS/(.002*4*WLI)
C
      EPSP= HS/CL1
C
C         CALC RAV AND PHIE
C
      RAV=1.477+.477*(((D0/DD)**.8557)-1)
      IF(RAV.GT.1.7)RAV=1.7
      IF(RAV.LT.1)RAV=1
C
      PHIE= RAV
C
C         CALC DDP,PHIB,AKAPA,AKAPC
C
      DDP= DD/DC
      PART1= .9 + ( .42707*ALOG10(DDP) )
      PHIB= PART1 - C3LOG
      AKAPA= .2303028/(DDP**.302608)
      AKAPC= .170474016/ (DDP**.420026987)
C
C         CALC HMOE. THERE ARE 2 CASES
C
      IF( PHIB - PHIE ) 30 , 20 , 20
 20   CONTINUE
C
C         PHIB .GE. PHIE
```

```
C
      HMOE= (CL1/AKAPC) * (10**(-CP1*PHIE))
      GO TO 40
C
 30   CONTINUE
C
C        PHIB .LT. PHIE
C
      HMOE= (CL1/AKAPA) * (10**(-CP2*PHIE))
C
 40   CONTINUE
C
C        CALC. HSE
C
      HSE= PHIE * HMOE
C
C        SET PHID TO 1.0
C
      PHID= 1.0
C
C        CALC HMOD. THERE ARE 2 CASES
C
      IF( PHIB - 1.0 ) 60 , 50 , 50
 50   CONTINUE
C
C        PHIB .GE. 1.0
C
      HMOD= (CL1/AKAPC) * CP3
      GO TO 70
 60   CONTINUE
C
C        PHIB .LT. 1.0
C
      HMOD= (CL1/AKAPA) * CP4
C
 70   CONTINUE
C
C        CALC HSD
C
      HSD= HMOD
C
C        CALC HMOB AND HSB
C
      HMOB= CL2
      HSB= HMOB * PHIB
C
C        CALC HMO AND EPP. THERE ARE 3 CASES.
C
      IF( HS .GE. HSD ) GO TO 220
      IF( HS .LE. HSE ) GO TO 230
C
C        IF WE GET HERE, HSE .LT. HS .LT. HSD. JUMP TO THAT
```

```
C        SECTION
C
      GO TO 240
C
  220 CONTINUE
C
C        CASE 1--HS .GE. HSD. CALC HM0 AND EPP.
C
      HM0= HS
      EPP= HM0/CL1
      GO TO 320
C
  230 CONTINUE
C
C        CASE 2--HS .LE. HSE. CALC HM0 AND EPP
C
      HM0=HS/PHIE
      EPP= HM0/CL1
      GO TO 320
C
  240 CONTINUE
C
C        CASE 3--HSE .LT. HS .LT. HSD.  CALC HM0 AND EPP. THERE
C        ARE 3 SUBCASES.
C
      IF( HSB - HS ) 80 , 140 , 150
   80 CONTINUE
C
C        SUBCASE 1--HSB .LT. HS
C
C        CALC RATSTAR. THERE ARE 2 SUB-SUB-CASES.
C
      IF( PHIB - PHIE ) 90 , 100 , 100
   90 CONTINUE
C
C        SUB-SUB-CASE 1--PHIB .LT. PHIE
C
      RATSTAR= ( HM0B - HM0D )/( HSB - HSD )
      GO TO 110
C
  100 CONTINUE
C
C        SUB-SUB-CASE 2--PHIB .GE. PHIE
C
      RATSTAR= ( HM0E - HM0D )/( HSE - HSD )
  110 CONTINUE
C
C        USING RATSTAR, CALC INITIAL APPROX TO HM0, I.E.
C        HM0INIT
C
      HM0INIT= HM0D + ( RATSTAR * ( HS - HSD ) )
C
```

```
C         CALC INITIAL APPROX TO EPP, I.E. EPPINIT
C
      EPPINIT= HM0INIT/CL1
C
C         INITIALIZE VARIABLES BEFORE NEWTON ITERATION WHICH
C         CALCULATES EPP.
C
      EPPN= EPPINIT
C
C         BEGIN ITERATION
C
      DO 120 N = 1 , NMAX
C
      PHIC= -1.016768 * ALOG10( AKAPC*EPPN )
      QC= (EPPN*PHIC) - EPSP
      DERIVQC= PHIC - .441576731
      DELEPPN= -QC/DERIVQC
      EPPNP1= EPPN + DELEPPN
C
C         CHECK AND SEE OF CONVERGENCE ACHIEVED.
C
      IF( ABS(DELEPPN) .LT. CL3 ) GO TO 130
C
C         CONVERGENCE NOT ACHIEVED. RESET EPPN AND TRY AGAIN.
C
      EPPN= EPPNP1
  120 CONTINUE
C
C         END OF ITERATION LOOP. IF WE GET HERE, CONVERGENCE
C                NOT ACHIEVED. USE LATEST VALUE OF EPPNP1.
C
  130 CONTINUE
C
C         IF WE JUMP HERE OUT OF ITERATION LOOP, THEN CONVERGENCE
C         HAS BEEN ACHIEVED.
C
C         SET EPP AND HM0
C
      EPP= EPPNP1
      HM0= CL1 * EPP
C
C         END OF CALC OF HM0 AND EPP FOR SUB-CASE HSB .LT. HS.
C
      GO TO 310
C
  140 CONTINUE
C
C         HSB=HS SUB-CASE
C
C         CALC HM0 AND EPP BY DEFINING RELATIONSHIPS FOR THIS
C         SUB-CASE
C
```

```
      HM0= CL2
      EPP= 2.0
C
C        END OF CALC OF HM0 FOR HSB=HS SUB-CASE
C
      GO TO 310
C
  150 CONTINUE
C
C        HSB .GT. HS SUB-CASE
C
C        CALC RATSTAR. THERE ARE 2 SUB-SUB-CASES.
C
      IF( PHIB - PHID ) 160 , 160 , 170
  160 CONTINUE
C
C        PHIB .LE. PHID SUB-SUB-CASE
C
      RATSTAR= ( HM0D - HM0E )/( HSD - HSE )
      GO TO 180
C
  170 CONTINUE
C
C        PHIB .GT. PHID SUB-SUB-CASE
C
      RATSTAR= ( HM0B - HM0E )/( HSB - HSE )
  180 CONTINUE
C
C        USING RATSTAR, CALC INITIAL APPROX TO HM0, I.E.
C        HM0INIT
C
      HM0INIT= HM0E + ( RATSTAR * ( HS - HSE ) )
C
C        CALC INITIAL APPROX TO EPP, I.E. EPPINIT
C
      EPPINIT= HM0INIT/CL1
C
C        INITIALIZE VARIABLES BEFORE NEWTON ITERATION WHICH
C        CALCULATES EPP.
C
      EPPN= EPPINIT
C
C        BEGIN ITERATION
C
      DO 190 N = 1 , NMAX
C
      PHIA= -1.411296 * ALOG10( AKAPA*EPPN )
      QA= (EPPN*PHIA) - EPSP
      DERIVQA= PHIA - .612918065
      DELEPPN= -QA/DERIVQA
      EPPNP1= EPPN + DELEPPN
C
```

```
C         CHECK AND SEE OF CONVERGENCE ACHIEVED.
C
      IF( ABS(DELEPPN) .LT. CL3 ) GO TO 300
C
C         CONVERGENCE NOT ACHIEVED. RESET EPPN AND TRY AGAIN.
C
      EPPN= EPPNP1
  190 CONTINUE
C
C         END OF ITERATION LOOP. IF WE GET HERE, CONVERGENCE
C                NOT ACHIEVED. USE LATEST VALUE OF EPPNP1.
C
  300 CONTINUE
C
C         IF WE JUMP HERE OUT OF ITERATION LOOP, THEN CONVERGENCE
C         HAS BEEN ACHIEVED.
C
C         SET EPP AND HMO
C
      EPP= EPPNP1
      HMO= CL1 * EPP
C
C         END OF CALC OF HMO AND EPP FOR SUB-CASE HSB .GT. HS.
C
  310 CONTINUE
C
C         END OF CALC OF HMO AND EPP FOR CASE
C         HSE .LT. HS .LT. HSD
C
  320 CONTINUE
C
C         END OF CALC OF HMO AND EPP
      RETURN
      END
C
      SUBROUTINE LOOKUP(DEF,REG,TEST)
C
C THIS SUBROUTINE BELONGS TO WHAFIS2.F77
C
C MODIFIED ON MAY 1985, BY AMIR RAZAVI PER RKC REQUEST.
C
C MODIFICATION WAS MADE TO MATCH W2.F77 OPERATION.
C
C THE COMMON STRUCTURE FOR /PP/ AND /PPT/ HAS ADDITIONAL VARIABLES IN
C W2 PROGRAM.  THOSE VARIABLES ARE NOT USED IN WHAFIS2.F77 AND THEREFORE
C THE COMMON AREAS ARE NOT MODIFIED.
C
C THE MODIFIED LINES HAVE A "CAHR" AT THE BEGINING.
C THE ADDED BLOCKS ARE IDENTIFIED BY "CAHR START" AND "CAHR END"
C
      LOGICAL TEST,TEST1,TEST2
C     THIS SUBROUTINE LOOKS UP DEFAULT MARSH GRASS PLANT PARAMETERS
```

```
C     FOR A GIVEN REGION AND PLANT TYPE
      DIMENSION CDE(10),FCOV(10),HBI(10),PPSF(10),SDB(10),
     1SDM(10),SDT(10),TYPE(10),FAR(10),DEF(10,8)
      DIMENSION HDN(8,8,7),PPSD(8,3),PLTYP(8)
      DIMENSION ITYP(10)
      COMMON /PP/NPLTS,TYPE,CDE,FCOV,HBI,PPSF,SDB,SDM,SDT,FAR
      COMMON /PPT/HDN,PPSD,PLTYP
      IREG=REG
C
C     SET DEFAULT VALUES FOR EACH PLANT TYPE
      TEST1=.FALSE.
C
CAHR START
      FCOVCUM=0.0
CAHR END
C
      DO 230 I1=1,NPLTS
C
C     INITIALIZE ARRAY DEF
      DEF(I1,1)=CDE(I1)
      DEF(I1,2)=FCOV(I1)
      DEF(I1,3)=HBI(I1)
      DEF(I1,4)=PPSF(I1)
      DEF(I1,5)=SDB(I1)
      DEF(I1,6)=SDM(I1)
      DEF(I1,7)=SDT(I1)
      DEF(I1,8)=FAR(I1)
C
C     INITIALIZE ERROR FLAG
      TEST2=.FALSE.
C
C     IF FCOV=0 REVISE DEFAULT
CAHR START
C     IF(COV(I1).EQ.0)TEST1=.TRUE.
C
      IF(FCOV(I1)) 1000, 1010, 1020
C
 1000 CONTINUE
C
C         FCOV(I) IS NEGATIVE. SET ERROR FLAG AND PRINT
C         MESSAGE.
C
      TEST2=.TRUE.
      WRITE(6,1005)I
 1005 FORMAT(/10X,"FCOV WAS FOUND TO BE NEGATIVE FOR PLANT TYPE= ",
     1   I2)
      GOTO 1030
C
 1010 CONTINUE
C
C         FCOV=0. USE DEFAULT FCOV FOR THIS PLANT TYPE.
C
```

```
      TEST1=.TRUE.
      NCOV=NCOV+1
      GOTO 1030
C
 1020    CONTINUE
C
C        FCOV IS GREATER THAN ZERO
C
      FCOVCUM=FCOVCUM+FCOV(I1)
C
 1030 CONTINUE
C
C     CHECK AND SEE IF PLANT TYPE I1 IS MARSH GRASS. IF IT IS,
C        CONTINUE ON. IF IT IS NOT, JUMP TO LABEL 225, IE.
C        RIGHT ABOVE END OF LOOP.
C
      DO 1040 I2=1,8
         IF(TYPE(I1).EQ.PLTYP(I2)) GOTO 1050
1040  CONTINUE
C
C        IF WE GET HERE PLANT TYPE IS NOT MARSH GRASS. JUMP TO
C        END OF LOOP.
C
      GOTO 225
C
 1050 CONTINUE
C
C     IF WE GET HERE, PLANT TYPE IS MARSH GRASS. CONTINUE ON.
C
C     NEXT LINE IS FOR DIAGNOSTIC PURPOSES.
C     WRITE(6,1060)
C1060 FORMAT(1X/1X,"PLANT TYPE IS RECOGNIZED AS MARSH GRASS",/)
C
CAHR END
C
CAHR  IF(FCOV(I1).EQ.0)TEST1=.TRUE.
C
C     IF CDE=0 REVISE DEFAULT
      IF(CDE(I1).EQ.0)DEF(I1,1)=.1
C
C     RELATE PLANT TYPE TO ARRAY INDEX
      ITYP(I1)=9
      DO 20 I2=1,8
      IF(TYPE(I1).EQ.PLTYP(I2))ITYP(I1)=I2
   20 CONTINUE
C
C     IF SDB=0 REVISE DEFAULT
      IF(SDB(I1).NE.0)GO TO 120
      IF(ITYP(I1).LT.9.AND.REG.NE.0)GO TO 90
      TEST2=.TRUE.
      GO TO 120
   90 IF(HBI(I1).NE.0)GO TO 100
```

```
      DEF(I1,5)=HDN(IREG,ITYP(I1),2)
      GO TO 120
  100 A=HDN(IREG,ITYP(I1),3)
      B=HDN(IREG,ITYP(I1),4)
      DEF(I1,5)=A*HBI(I1)**B
  120 CONTINUE
C
C     IF PPSF=0 REVISE DEFAULT
      IF(PPSF(I1).NE.0)GO TO 150
      IF(ITYP(I1).LT.9.AND.REG.NE.0)GO TO 130
      TEST2=.TRUE.
      GO TO 150
  130 IF(HBI(I1).NE.0)GO TO 140
      DEF(I1,4)=HDN(IREG,ITYP(I1),5)
      GO TO 150
  140 A=HDN(IREG,ITYP(I1),6)
      B=HDN(IREG,ITYP(I1),7)
      DEF(I1,4)=A*HBI(I1)**B
  150 CONTINUE
C
C     IF HBI=0 REVISE DEFAULT
      IF(HBI(I1).NE.0)GO TO 160
      IF(ITYP(I1).LT.9.AND.REG.NE.0)GO TO 155
      TEST2=.TRUE.
      GO TO 160
  155 DEF(I1,3)=HDN(IREG,ITYP(I1),1)
  160 CONTINUE
C
C     IF SDM=0 REVISE DEFAULT
      IF(SDM(I1).NE.0)GO TO 180
      IF(ITYP(I1).LT.9)GO TO 170
      TEST2=.TRUE.
      GO TO 180
  170 DEF(I1,6)=DEF(I1,5)*PPSD(ITYP(I1),1)
  180 CONTINUE
C
C     IF SDT=0 REVISE DEFAULT
      IF(SDT(I1).NE.0)GO TO 200
      IF(ITYP(I1).LT.9)GO TO 190
      TEST2=.TRUE.
      GO TO 200
  190 DEF(I1,7)=DEF(I1,5)*PPSD(ITYP(I1),2)
  200 CONTINUE
C
C     IF FAR=0 REVISE DEFAULT
      IF(FAR(I1).NE.0)GO TO 220
      IF(ITYP(I1).LT.9)GO TO 210
      TEST2=.TRUE.
      GO TO 220
  210 DEF(I1,8)=PPSD(ITYP(I1),3)
  220 CONTINUE
CAHR START
```

```
  225 CONTINUE
CAHR END
C
C     PRINT ERROR MESSAGE IF REQUIRED
      IF(TEST2)WRITE(6,500)TYPE(I1),IREG
C
C     SET ERROR FLAG IF REQUIRED
      IF(TEST2)TEST=.TRUE.
C
C     CLOSE OFF MAIN DO LOOP
  230 CONTINUE
C
C     REVISE FCOV IF REQUIRED AND RETURN
CAHR  IF(.NOT.TEST1)GO TO 250
      IF(.NOT.TEST1)GO TO 270
CAHR START
C
C     IF WE GET HERE, NCOV SHOULD BE GREATER THAN ZERO.
C     TEST AND MAKE SURE.
C
      IF(NCOV.GT.0)GOTO 2010
C
      WRITE(6,2000)
 2000 FORMAT(/10X,"NCOV IS .LE. ZERO IN SUB. LOOKUP WHEN IT SHOULD",
     1   " BE .GT. ZERO. ABORT RUN.")
      STOP
C
 2010 CONTINUE
      IF(FCOVCUM.GT.0.0)GOTO 250
C
C     IF WE GET HERE, ALL PLANTS USE DEFAULT FCOV VALUE.
C
      FCOVFLT=1.0/FLOAT(NPLTS)
C
CAHR END
      DO 240 I2=1,NPLTS
CAHR  DEF(I2,2)=1/FLOAT(NPLTS)
      DEF(I2,2)=FCOVFLT
  240 CONTINUE
CAHR START
C
      GOTO 270
 250  CONTINUE
C
C         AT LEAST ONE PLANT SPECIES DOES NOT HAVE A DEFAULT
C         FCOV VALUE. WE ASSUME MULTIPLE COVERGE SO THAT SUM
C         OF FCOV FOR SPECIES WITH DEFAULT IS 1.0
C
      FCOVFLT=1.0/FLOAT(NCOV)
C
      DO 260 I2=1, NPLTS
         IF(FCOV(I2).EQ.0.0)DEF(I2,2)=FCOVFLT
```

```
 260  CONTINUE
 270  CONTINUE
C
CAHR END

CAHR 250 RETURN
  500 FORMAT(/,10X,41HNO DEFAULT DATA AVAILABLE FOR PLANT TYPE ,A4,
     110H IN REGION,I2)
      END
C
C**************************
      SUBROUTINE SCANE
C****************************************************************
C
C     DEVELOPED FEBRUARY 1987 BY
C
C                 GREENHORNE AND O'MARA, INC.
C                 GREENBELT, MARYLAND
C
C   THIS SUBROUTINE IS CALLED AT THE BEGINNING OF THE MAIN PROGRAM
C   TO PERFORM THE STILLWTER ELEVATION INTERPOLATION.
C
C   THE INTERPOLATION SCHEME IS PERFORMED WITHIN A TRANSECT SEGMENT
C   DEFINED AS THE STATIONING INTERVAL OF SURGE ELEVATION CHANGES.
C   THE STILLWATER ELEVATIONS IN THE SEGMENT ARE LINEAR INTERPOLATED
C   USING TWO GIVIN SURGES AT THE BEGINNING AND THE END OF A SEGMENT.
C
C   THE LINEAR INTERPOLATED VALUES AT EACH STATION WITHIN THIS SEGMENT
C   ARE THEN COMPARED WITH THE CORRESPONDING GROUND ELEVATIONS. IF THE
C   INTERPOLATED ELEVATION ARE ABOVE THE CORRESPONDING GROUND
C   ELEVATIONS (I.E., NO GROUND CUT OFF), THE INTERPOLATED VALUES
C   ARE USED AS THE STILLWATE ELEVATIONS FOR THE COMPUTATION OF
C   THE WAVE HEIGHT.
C   OTHERWISE, THE STILLWATER ELEVATIONS WILL BE DETERMINED BY
C   THE CONCEPT SIMILAR TO THE "FLOW OVER A BARRIER" ALGORITHM USED
C   IN THE FEMA'S SURGE MODEL.
C
C   AT THE END OF THIS SUBROUTINE, THE WEIGHT AVERAGED BOTTOM SLOPE
C   AT EACH STATION ARE COMPUTED AND STORED IN THE NINETH PARAMETER,
C   I.E., PARAM(J,9), WHICH WILL BE UTILIZED IN THE WAVE ENERGY
C   EQUATION PERFORMED IN THE MAIN PROGRAM
C
C********************************************************************
C
      LOGICAL TEST,TEST1
      DIMENSION TOF(500),PARAM(500,10),TITLE(80),SGOLD(200),
     A            SGNEW(200),JM(2),ELMX(2)
C
      DATA EI,DU,BU,VE,FI,FO,ET/ 'IE','DU','BU','VE','IF','OF','ET'/
      DATA AS,VH,GM,BLANK/ 'AS','VH','MG',' '/
C
      NPLTS=0
```

```
      NVH=0
      NVH1=0
      NVH2=0
C
   1  READ(5,805)  (TITLE(I),I=1,80)
      TEST=.TRUE.
C
      DO 510 I=1,80
      IF(TITLE(I). NE. BLANK) TEST=.FALSE.
  510 CONTINUE
C
      IF(TEST) THEN
      WRITE(10,805) BLANK
      REWIND 10
      RETURN
      ENDIF
C
      WRITE(6,806)  (TITLE(I),I=1,80)
  806 FORMAT(1H1,10X,'***  THE FOLLOWING MESSAGES ARE THE RESULTS ',
     A       'FROM THE 100-YR ELEVATION INTERPOLATION FOR THE ',
     B       'TRANSECT:',//,10X,80A1)
C
C**   CHECK IF THE FIRST CARD IS EI CARD
C
      READ(5,810) TOF(1),(PARAM(1,I),I=1,10)
      NB=1
      IF(TOF(1). NE. EI) THEN
       WRITE(6,820)
  820  FORMAT(10X,'  THE FIRST CARD IS NOT AN IE CARD, THIS'
     A ' TRANSECT IS ABORTED.  CONTINUED TO NEXT TRANSECT'/)
       DO 3 J=1,500
       READ(5,810) TOF(J)
       IF(TOF(J).EQ.ET) GO TO 1
    3  CONTINUE
      ENDIF
C
C**   GIVING INITIAL STATIONING, BED ELEVATION, AND 100-YEAR ELEVATION
C
      BFO=PARAM(1,1)
      BEL=PARAM(1,2)
      BSEN=PARAM(1,5)
      SGOLD(1)=BSEN
      SGNEW(1)=BSEN
C
C**   CHECK IF BED ELEVATION BEL IS GREATER THAN 100-YEAR ELEVATION BSEN
C**   ON EI CARD
C
      IF(BEL. GT. BSEN) THEN
        WRITE(6,780)
  780   FORMAT(5X,'GROUND ELEVATION GREATER THAN SURGE ELEVATION AT'
     A  ' IE CARD. JOB DUMPED.'/)
        DO 4 J=1,500
```

```
        READ(5,810) TOF(J)
        IF(TOF(J).EQ.ET) GO TO 1
    4   CONTINUE
      ENDIF
C
C*********   START SCANNING 100-YR ELE. CHANGES   ********
C
C**  ASSUMING THE CURRENT STATION IS THE END STATION OF THE
C**  INTERPOLATION SEGMENT
C
C**  FIRST READ INPUT FROM. UNIT N5
C
      NFO=1
    5 NFO = NFO + 1
      READ(5,810) TOF(NFO),(PARAM(NFO,I),I=1,10)
C
C**   SET END SEGMENT STATIONING AND CORRESPONDING BED ELEVATION
C
      EFO=PARAM(NFO,1)
      EEL=PARAM(NFO,2)
C
C**   BRANCH TO VARIOUS PROGRAM SEGMENT ACCORDING TO CARD TYPE & SET THE
C**   READ IN 100 YEAR STILLWATER ELEVATION ESEN
C
      IF(TOF(NFO).EQ.DU) GO TO  50
      IF(TOF(NFO).EQ.BU) GO TO 100
      IF(TOF(NFO).EQ.VE. OR. TOF(NFO).EQ.VH) GO TO 150
      IF(TOF(NFO).EQ.FI. OR. TOF(NFO).EQ.FO) GO TO 200
      IF(TOF(NFO).EQ.AS) GO TO 250
      IF(TOF(NFO).EQ.ET) THEN
        NE=NFO
        GO TO 400
      ENDIF
C
C**  DUNE (DU) CARD
C
   50 ESEN=PARAM(NFO,5)
      GO TO 350
C
C**  BUILDING (BU) CARD
C
  100 ESEN=PARAM(NFO,6)
      GO TO 350
C
C** VEGETATION (VE) OR MARSH GRASH (VH) CARD
C
  150 ESEN=PARAM(NFO,8)
C
      IF(TOF(NFO).EQ.VE) GO TO 350
C
C* FOR VH CARD, READ NPLTS TIMES OF MG CARDS
C
```

```
      HIGH=AMAX1(BSEN,ESEN)
      IF(EEL. GT. HIGH)  THEN
         WRITE(6,781) EFO,TOF(NFO)
      ENDIF
C
      SGOLD(NFO)=ESEN
      SGNEW(NFO)=ESEN
C
      IF(ESEN.EQ.0.) THEN
        SGOLD(NFO)=SGOLD(NFO-1)
        SGNEW(NFO)=SGOLD(NFO)
      ENDIF     .
C
      KPLTS=NPLTS
C
      NPLTS=PARAM(NFO,6)
      DO 155 I=1,NPLTS
      NFO = NFO + 1
      READ(5,560) TOF(NFO),(PARAM(NFO,K),K=1,10)
      SGOLD(NFO)=SGOLD(NFO-1)
      SGNEW(NFO)=SGOLD(NFO)
  155 CONTINUE
C
      IF(ESEN.NE.0.) THEN
      NVH=1
      NE=NFO-NPLTS
C
      IF(NE. EQ. 2) THEN
              NVH1=NE
            GO TO 400
      ENDIF
C
      ENDIF
C
      IF(NVH. EQ. 1) THEN
      NVH=0
      NVH2=NFO-NPLTS-KPLTS
C
      IF(NVH2. EQ. NVH1+1) THEN
             NVH1=NE
           GO TO 400
        ENDIF
C
        NVH1=NE
C
      ENDIF
C
      IF(ESEN.EQ.0.) GO TO 5
      GO TO 351
C
C**  INLAND FETCH (IF) OR OVER-WATER FETCH (OF) CARD
C
```

```
  200 ESEN=PARAM(NFO,4)
      GO TO 350
C
C**  ABOVE SURGE (AS) CARD
C
  250 ESEN=PARAM(NFO,4)
C
C  FOR AS CARD RESET BEGINNING SEGMENT COUNTER
C
      NE=NFO
C
C**  AND RESET 100-YR ELEVATION
C
      IF(ESEN.EQ.0.) THEN
         SGOLD(NFO)=SGOLD(NFO-1)
         SGNEW(NFO)=SGOLD(NFO)
      ELSE
         SGOLD(NFO)=ESEN
         SGNEW(NFO)=ESEN
      ENDIF
      GO TO 400
C
C****************************************************
C**   SCANNING FOR 100-YR SURGE ELEVATION CHANGES   *
C****************************************************
C
C**   FIRST CHECK WHETHER THE GROUND ELEVATION IS GREATER THAN
C**   THE STILLWATER ELEVATION.  IF IT IS, THEN FLAG THE MESSAGE.
C
  350 CONTINUE
      HIGH=AMAX1(BSEN,ESEN)
      IF(EEL. GT. HIGH)  THEN
         WRITE(6,781) EFO,TOF(NFO)
  781    FORMAT(10X,'****  THE SURGE ELEVATION AT THIS STATION',
     A         ' (STATIONING ',F8.0,' ), WHICH IS ',A2,' CARD,',
     B         ' IS LESS THAN THE GROUND ELEVATION.'/,
     C       10X,'THE INTERPOLATION PROCESS CONTINUED.',//
     D        5X,'***  PLEASE DOUBLE-CHECK THE SURGE AND GROUND',
     E           ' ELEVATIONS IN THE VICINITY OF THIS STATION',
     F           ' !!!!!!'//)
C
      END IF
C
C**   SECOND,  IF THERE IS NO SURGE ELEVATION CHANGE, GO TO 5 TO
C**            READ NEXT CARD.
C**            IF THE SURGE ELEVATION CHANGES, DO INTERPOLATION
C
      SGOLD(NFO)=ESEN
      SGNEW(NFO)=ESEN
      IF(ESEN.EQ.0.) THEN
      SGOLD(NFO)=SGOLD(NFO-1)
        SGNEW(NFO)=SGOLD(NFO)
```

```
      GO TO 5
      ENDIF
C
C*******************************************
C**  PREPARING FOR LINEAR INTERPOLATION   *
C*******************************************
C
      NE=NFO
  351 DX=EFO-BFO
      DSG=ESEN-BSEN
      DDSG=DSG/DX
C
C*****************************
C**  LINEAR  INTERPOLATION  *
C*****************************
C
      NME=NE-1
      NMB=NB+1
C
      IF(NME. LT. NMB) GO TO 400
C
      DO 360 J=NMB,NME
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=SGOLD(J)+DDSG*(PARAM(J,1)-BFO)
      ENDIF
  360 CONTINUE
C
C** CHECK IF THE LINEAR INTERPOLATION LINE CUT OFF ANY
C** HIGH GROUND BED ELEVATION BELOW FOR STATIONS
C** BETWEEN  NB  AND  NE
C
      NK=0
      ELMX(1)=0.
      ELMX(2)=0.
      TEST1=.TRUE.
C
      DO 370 J=NMB,NME
C
      IF(TOF(J). EQ. GM) GO TO 370
      IF(SGNEW(J). GE. PARAM(J,2)) GO TO 365
C
      IF(TEST1) THEN
        NK=NK+1
        TEST1=.FALSE.
      ENDIF
C
C*  IF THE INTERPOLATION LINE CUTS MORE THAN TWO PORTIONS OF
C*  HIGH GROUND RIDGE, STOP THIS TRANSECT, GO TO NEXT TRANSECT
C
      IF(NK. GT. 2) THEN
```

```
        WRITE(6,899)
  899   FORMAT(10X,'INTERPOLATION LINE CUTS OFF MORE THAN',
     A     ' TWO PORTIONS OF HIGH GROUND RIDGE'//,
     B    10X,'THIS TRANSECT IS ABORTED, RE-ASSIGN 100-YR ',
     C        'ELEVATIONS AT HIGH GROUND STATIONS'///)
        DO 363  I = 1, 500
        READ(5,810) TOF(I)
        IF(TOF(I). EQ. ET) GO TO 1
  363   CONTINUE
      END IF
C
      IF(PARAM(J,2). GE. ELMX(NK)) THEN
        ELMX(NK)=PARAM(J,2)
        JM(NK)=J
      ENDIF
      GO TO 370
C
  365 TEST1=.TRUE.
C
  370 CONTINUE
C
C**  IF THERE IS NO CUT OFF FROM INTERPOLATION LINE THEN
C**  GO TO WRITE TO SCRATCH FILE SEGMENT
C
      IF(NK. EQ. 0) GO TO 400
C
C**  IF THE 100-YR ELE. AT STATION NE IS GREATER THAN THE
C**  100-YR ELE. AT STATION NB, THEN BRANCH TO 600
C
      IF(DSG. GT. 0.) GO TO 600
C
C**  THE FOLLOWING SEGMENT FOR THE CASE THAT THE 100-YR ELE. AT
C**  STATION NE IS LESS THAN OR EQUAL TO THE 100-YR ELE. AT
C**  STATION NB.
C
      IF(NK. EQ. 1) GO TO 380
C
C**  IF THE HIGHEST GROUND ELEVATIONS OF THE SECOND HUMP IS LOWER
C**  THAN THE FIRST HIGHEST HUMP GROUND ELEVATION, THEN BRANCH TO
C**  STATEMENT 390
C
      IF(PARAM(JM(2),2). LT. PARAM(JM(1),2)) GO TO 390
      JM(1)=JM(2)
C
C** RESET 100-YR ELE. TO BE THE SAME AS BSEN, THE ELE. AT
C** THE BEGINING OF THIS INTERPOLATION SEGMENT
C
C** FOR STATIONS FROM NMB TO THE HIGHEST BED STATION, JM(1)
C
  380 DO 373 J=NMB,JM(1)
      SGNEW(J)=BSEN
      IF(TOF(J). EQ. GM) GO TO 373
```

```
C
C**  IF THE NEW SURGE ELEVATION IS STILL LESS THEN THE BED
C**  ELEVATION, ABORT THIS TRANSECT, GIVING ERROR MESSAGE.
C
       IF(SGNEW(J).GE.PARAM(J,2)) GO TO 373
         WRITE(6,782) PARAM(J,1),TOF(J)
  782    FORMAT(//10X,'****  UNREASONABLE HIGH GROUND ELEVATION',
     A     ' AT STATION (',F8.2,' ) WHICH IS ',A2,' CARD.'/,10X,
     B     'THIS TRANSECT IS ABORTED, CONTINUED TO NEXT TRANSECT'//,
     C      10X,'***  DOUBLE-CHECK THE SURGE AND GROUND ELEVATIONS',
     D          ' IN THE VICINITY OF THIS STATION.  IF THE GROUND'/,
     E      15X,' ELEVATIONS ARE CORRECT, EITHER ASSIGN A HIGHER',
     F          ' SURGE ELEVATION OR USE AS CARDS !!!!'//)
C
          DO 371 KK=1,500
          READ(5,810) TOF(KK)
          IF(TOF(KK).EQ.ET) GO TO 1
  371     CONTINUE
C
  373 CONTINUE
C
C**  FOR THE REST STATIONS AFTER JM(1) TO THE END STATION OF
C**  THIS SEGMENT, THE 100-YR ELE. WILL BE THE BED ELEVATION,
C**  PARAM(J,2), PLUS THE WATER DEPTH, D, SITTING ON THE HIGHEST
C**  BED ELEVATION STATION
C**  UNTIL THE 100-YR ELE. AT THE END STATION OF THIS SEGMENT
C**  IS MET
C
      D=SGNEW(JM(1))-PARAM(JM(1),2)
      JMB=JM(1)+1
C
      DO 375 J=JMB,NME
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=AMAX1(PARAM(J,2)+D,ESEN)
      ENDIF
  375 CONTINUE
C
      GO TO 400
C
  390 CONTINUE
C
C**  THE FOLLOWING PROGRAM SEGMENT IS FOR THE CASE THAT THE
C**  INTERPOLATION LINE CUTS BED ELEVATIONS TWO PORTIONS IN
C**  THIS TRANSECT SEGMENT, AND THE HIGHER BED ELEVATION
C**  STATION IS BEFORE THE OTHER ONE, I.E., THE BED ELE. AT
C**  JM(1) IS GREATER THAN THE BED ELE. AT JM(2)
C
C**  FIRST RESET THE 100-YR ELE. FOR STATIONS BEFORE JM(1)
C
      DO 393 J=NMB,JM(1)
```

```
      SGNEW(J)=BSEN
      IF(SGNEW(J).GE.PARAM(J,2)) GO TO 393
        WRITE(6,782) PARAM(J,1),TOF(J)
  393 CONTINUE
C
C**  THEN LINEAR INTERPOLATION 100-YR ELE. FROM JM(1)+1 TO
C**  THE END STATION, NE, OF THIS INTERPOLATION SEGMENT
C
      D=SGNEW(JM(1))-PARAM(JM(1),2)
      DX=EFO-PARAM(JM(1),1)
      DDSG=(ESEN-BSEN)/DX
C
      JMB=JM(1)+1
      DO 395 J=JMB, NME
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=SGOLD(J)+DDSG*(PARAM(J,1)-PARAM(JM(1),1))
      ENDIF
  395 CONTINUE
C
C**  SET THE 100-YR ELE. AT STATIONS BETWEEN STATION JM(1)
C**  AND NE AS THE MAXIMUM OF: SECOND INTERPOLATION VALUE,
C**  THE BED ELEVATIONS PLUS THE WATER DEPTH AT JM(1),
C**  AND THE 100-YR ELE. AT THE END STATION OF THIS SEGMENT
C
      DO 397 J=JMB,NME
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=AMAX1(SGNEW(J),PARAM(J,2)+D,ESEN)
      ENDIF
  397 CONTINUE
C
      GO TO 400
C
C**********  END OF INTERPOLATION FOR DSG IS LESS THAN ZERO CASE
C
  600 CONTINUE
C
C***  THE FOLLOWING PROGRAM SEGMENT IS FOR THE CASE OF 100-YR ELE.
C***  AT NE IS GREATER THAN THE 100-YR ELE. AT NB.  AND THERE IS AT
C***  LEAST ONE CUT OFF PORTION FROM THE LINEAR INTERPOLATION LINE.
C
      IF(NK. EQ. 1) GO TO 605
C
      IF(PARAM(JM(1),2). LT. PARAM(JM(2),2)) GO TO 620
C
  605 CONTINUE
C
C**  RESET 100-YR ELE. TO BE THE SAME AS ESEN, THE ELE. AT THE END
C**  OF THIS INTERPOLATION SEGMENT, I.E., AT STATION NE.
```

```
C
      DO 610 J=JM(1),NME
      SGNEW(J)=ESEN
  610 CONTINUE
C
C**  FOR THE REST OF STATIONS FROM NMB (I.E., NB+1) TO JM(1)-1 OF
C**  THIS SEGMENT, THE 100-YR ELE. WILL BE THE GROUND ELEVATION,
C**  PARAM(JP,2), PLUS THE WATER DEPTH, D, SITTING ON THE HIGHEST
C**  GROUND ELEVATION STATION JM(1), UNTIL THE BSEN IS MET.
C
      D=SGNEW(JM(1))-PARAM(JM(1),2)
C
      JP=JM(1)-1
      DO 615 J = NMB, JP
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=AMAX1(PARAM(J,2)+D,BSEN)
      ENDIF
  615 CONTINUE
C
      GO TO 400
C
  620 CONTINUE
C
C**  THE FOLLOWING PROGRAM SEGMENT IS FOR THE CASE THAT THE
C**  INTERPOLATION LINE CUTS BED ELEVATIONS TWO PORTIONS IN
C**  THIS TRANSECT SEGMENT, AND THE HIGHER BED ELEVATION
C**  STATION IS AFTER THE OTHER ONE, I.E., THE BED ELE. AT
C**  JM(1) IS LOWER THAN THE BED ELE. AT JM(2).
C
      DO 630 J=JM(2),NME
      SGNEW(J)=ESEN
  630 CONTINUE
C
C**  THEN LINEAR INTERPOLATION 100-YR ELE. FOR STATIONS BETWEEN
C**  NB AND JM(2)
C
      D=SGNEW(JM(2))-PARAM(JM(2),2)
      DX=PARAM(JM(2),1)-BFO
      DDSG=(ESEN-BSEN)/DX
C
      JP=JM(2)-1
      DO 635 J = NMB, JP
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=ESEN+DDSG*(PARAM(J,1)-PARAM(JM(2),1))
      ENDIF
  635 CONTINUE
C
  640 CONTINUE
```

```
C
C**  SET THE 100-YR ELE. AT STATIONS BETWEEN STATIONS NB AND
C**  JM(2) AS THE MAXIMUM OF: SECOND INTERPOLATION VALUE (SGNEW),
C**  THE BED ELEVATION PLUS THE WATER DEPTH AT JM(2) (D), AND
C**  THE 100-YR ELE. AT THE BEGINNING STATION OF THIS SEGMENT
C**  BSEN (=SGNEW(NB)).
C
      JP=JM(2)-1
      DO 645 J = NMB, JP
      IF(TOF(J). EQ. GM) THEN
        SGNEW(J)=SGNEW(J-1)
      ELSE
        SGNEW(J)=AMAX1(SGNEW(J),PARAM(J,2)+D,BSEN)
      ENDIF
  645 CONTINUE
C
C******   END OF DSG GREATER THAN ZERO CASE   *****
C
C*****************************************************
C***********     END  OF  INTERPOLATION  PROCESS    ******
C*****************************************************
C
C****  STORING NEW 100-YR ELE. TO THE CORRESPONDING FILED PARAMETER
C
  400 IF(NB. NE. 1) GO TO 402
      WRITE(10,805) (TITLE(I),I=1,80)
C     WRITE(10,815) TOF(1),(PARAM(1,I),I=1,10)
  402 CONTINUE
C
      J=NB
  410 J=J+1
      IF(TOF(J). EQ. GM) GO TO 410
      IF(TOF(J). EQ. DU) GO TO 450
      IF(TOF(J). EQ. BU) GO TO 460
      IF(TOF(J). EQ. VE. OR. TOF(J). EQ. VH) GO TO 470
      IF(TOF(J). EQ. FI. OR. TOF(J). EQ. FO) GO TO 480
      IF(TOF(J). EQ. AS) GO TO 480
      GO TO 490
C
C**  DUNE (DU) CARD
C
  450 PARAM(J,5)=SGNEW(J)
      GO TO 490
C
C**  BUILDING (BU) CARD
C
  460 PARAM(J,6)=SGNEW(J)
      GO TO 490
C
C** VEGETATION (VE) OR MARSH GRASH (VH) CARD
C
  470 PARAM(J,8)=SGNEW(J)
```

```
      GO TO 490
C
C** INLAND FETCH (IF) OR OVER-WATER FETCH (OF) CARD
C
  480 PARAM(J,4)=SGNEW(J)
C
  490 IF(TOF(J). EQ. ET) GO TO 700
C
      IF(J. EQ. NE) THEN
        BSEN=SGNEW(J)
        BFO=PARAM(J,1)
        NB=NE
        GO TO 5
      ELSE
        GO TO 410
      ENDIF
C
C*******************************************************************
C                                                                  *
C**   THE FOLLOWING SEGMENT IS FOR COMPUTING THE AVERAGE BOTTOM    *
C**   SLOPE AT EACH STATION FOR THE PURPOSE OF WAVE COMPUTATION    *
C**   BY WAVE ENERGY EQUATION IN THE MAIN PROGRAM                  *
C                                                                  *
C**   THE BOTTOM SLOPE IS STORED AS PARAM(J,9) OF EACH STATION     *
C**   EXCEPT FOR MG CARD                                           *
C                                                                  *
C*******************************************************************
C
  700 CONTINUE
C
C**  STARTING FROM THE FIRST CARD, FISRT COMPUTE THE SLOPE BETWEEN
C**  STATION J AND J-1.  THE SLOPE FOR IE CARD IS THE SLOPE BETWEEN
C**  THE IE CARD AND THE SECOND CARD
C
      J=2
C
      SA=(PARAM(J,2)-PARAM(J-1,2))/(PARAM(J,1)-PARAM(J-1,1))
C
      PARAM(J-1,9)=SA
C
      JA=J-1
      JB=J+1
C
C**  IF THE NEXT CARD IS AS CARD, THE AVERAGE SLOPE IS THE SLOPE SA
C
  705 IF(TOF(JB).EQ.AS) THEN
        PARAM(J,9)=SA
        GO TO 720
      ENDIF
C
C**  IF TOF(J) IS VH CARD, SKIP ALL MG CARDS
C
```

```
      IF(TOF(J). EQ. VH) THEN
        NPLTS=PARAM(J,6)
        JB=JB+NPLTS
      ENDIF
C
C**  COMPUTE THE BOTTOM SLOPE BETWEEN THIS STATION, J, AND THE
C**  NEXT STATION, JB
C
C**  HOWEVER,IF THE NEXT STATION IS ET, END OF THE TRANSECT,
C**  THEN THE AVERAGED SLOPE IS SA
C
      IF(TOF(JB). EQ. ET) THEN
        PARAM(J,9)=SA
        GO TO 770
      ENDIF
C
      SB=(PARAM(JB,2)-PARAM(J,2))/(PARAM(JB,1)-PARAM(J,1))
C
C**  IF TOF(J) IS AS CARD, THE AVERAGE SLOPE OF THIS CARD IS THE
C**  SLOPE OF SB
C
      IF(TOF(J). EQ. AS) THEN
        PARAM(J,9)=SB
        GO TO 710
      ENDIF
C
C**  WEIGHT AVERAGED SLOPE FOR THIS STATION FROM SA AND SB
C
      SS=(PARAM(J,1)-PARAM(JA,1))*SA + (PARAM(JB,1)-PARAM(J,1))*SB
      PARAM(J,9)=SS/(PARAM(JB,1)-PARAM(JA,1))
C
C**  REPLACE SA WITH SB, AND CONTINUE TO NEXT STATION
C
  710 SA=SB
C
C**  FOR VH CARD, REARRANGE PREVIOUS AND LATER STATION COUNT
C
      IF(TOF(J).EQ. VH) THEN
        JA=J
        J=JB
        JB=J+1
        GO TO 705
      ENDIF
C
  720 J=J+1
      JA=J-1
      JB=J+1
      GO TO 705
C
C*******************************************************************
C                                                                  *
C**  COMPLETE CALCULATING AVERAGED BOTTOM SLOPE FOR THIS TRANSECT *
```

```
C                                                                *
C*****************************************************************
C
C*****************************************************************
C                                                                *
C**  START WRITING TO SCRATCH FILE -- UNIT 10                    *
C                                                                *
C*****************************************************************
C
  770 CONTINUE
C
      DO 775 J=1,500
C
      IF(TOF(J).EQ.GM) THEN
        WRITE(10,565) TOF(J),(PARAM(J,I),I=1,10)
      ELSE
C
        IF((PARAM(J,1).GE. 9999.9).OR.(PARAM(J,1).LE.-1000.)) THEN
          WRITE(10,816) TOF(J),(PARAM(J,I),I=1,10)
        ELSE
          WRITE(10,815) TOF(J),(PARAM(J,I),I=1,10)
        ENDIF
C
      ENDIF
C
      IF(TOF(J). EQ. ET) GO TO 1
  775 CONTINUE
C
  560 FORMAT(A2,2X,A4,9F8.0)
  565 FORMAT(A2,2X,A4,9F8.2)
  805 FORMAT(80A1)
  810 FORMAT(A2,F6.0,9F8.0)
C
C         G&O SEPT 88
C
C
C 815 FORMAT(A2,F6.1,7F8.2,F8.4,F8.2)
C 816 FORMAT(A2,F6.0,7F8.2,F8.4,F8.2)
C
  815 FORMAT(A2,F6.1,7F8.3,F8.4,F8.3)
  816 FORMAT(A2,F6.0,7F8.3,F8.4,F8.3)
C
C         END G&O SEPT 88
C
      END
```

APPENDIX D   Example Calculations

```
   DUVAL COUNTY, FLORIDA          T-1          12/03/87
IE   0.0      0.0   24.0     7.0   11.60      0.0     13.0
OF  350.      9.4
DU  351.     11.6
AS 1345.     8.85    4.0    8.85
VE 1445.     8.52    0.3    15.0      6.0
VE 1600.      8.0    0.3    15.0      6.0
VE 1800.      7.3    0.3    15.0      6.0
VE 2000.      6.7    0.3    15.0      6.0
VE 2200.      6.0    0.3    15.0      6.0
VE 2500.      5.0    0.3    15.0      6.0
VH 7000.      0.0    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF 7200.     -6.0
OF 8300.     -6.0
OF 8900.    -12.0
OF 9100.     -6.0
OF 9350.      0.0
VH10500.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF11300.     -6.0

OF11800.      0.0
VH13300.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF13700.     -6.0
OF14700.    -18.0
OF16000.      0.0
VH18500.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF19000.    -12.0
OF19600.      0.0
VH25000.      2.5    3.0     0.0      0.0      1.0      2.5      7.25
MG  SALT      0.0    1.0
OF26000.    -12.0
OF27200.      0.0
VH35200.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF35700.    -12.0
OF37900.     -9.0
OF38000.      0.0
VH47200.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
OF47700.    -12.0
OF48100.      0.0    3.0    6.45
VH49750.      2.5    3.0     0.0      0.0      1.0
MG  SALT      0.0    1.0
IF49850.     6.45
ET
```

```
*** THE FOLLOWING MESSAGES ARE THE RESULTS FROM THE 100-YR ELEVATION INTERPOLATION FOR THE TRANSECT:

    DUVAL COUNTY, FLORIDA        T-1         12/03/87


      WAVE HEIGHT COMPUTATIONS FOR FLOOD INSURANCE STUDIES (VERSION 3.0, SEPTEMBER 1988)
                           DUVAL COUNTY, FLORIDA        T-1         12/03/87


                                              PART1 INPUT

IE       .000      .000    24.000     7.000    11.600      .000    13.000      .000      .027      .000
OF    350.000     9.400      .000      .000      .000      .000      .000      .000      .033      .000
DU    351.000    11.600      .000      .000      .000      .000      .000      .000     2.200      .000
AS   1345.000     8.850     4.000     8.850      .000      .000      .000      .000     -.003      .000
VE   1445.000     8.520      .300    15.000     6.000      .000      .000     8.843     -.003      .000
VE   1600.000     8.000      .300    15.000     6.000      .000      .000     8.833     -.003      .000
VE   1800.000     7.300      .300    15.000     6.000      .000      .000     8.819     -.003      .000
VE   2000.000     6.700      .300    15.000     6.000      .000      .000     8.806     -.003      .000
VE   2200.000     6.000      .300    15.000     6.000      .000      .000     8.792     -.003      .000
VE   2500.000     5.000      .300    15.000     6.000      .000      .000     8.772     -.001      .000
VH   7000.000      .000     3.000      .000      .000     1.000      .000     8.468     -.002      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF   7200.000    -6.000      .000     8.454      .000      .000      .000      .000     -.005      .000
OF   8300.000    -6.000      .000     8.380      .000      .000      .000      .000     -.004      .000
OF   8900.000   -12.000      .000     8.339      .000      .000      .000      .000      .000      .000
OF   9100.000    -6.000      .000     8.325      .000      .000      .000      .000      .027      .000
OF   9350.000      .000      .000     8.309      .000      .000      .000      .000      .006      .000
VH  10500.000     2.500     3.000      .000      .000     1.000      .000     8.231     -.003      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF  11300.000    -6.000      .000     8.177      .000      .000      .000      .000     -.002      .000
OF  11800.000      .000      .000     8.143      .000      .000      .000      .000      .004      .000
VH  13300.000     2.500     3.000      .000      .000     1.000      .000     8.041     -.003      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF  13700.000    -6.000      .000     8.014      .000      .000      .000      .000     -.015      .000
OF  14700.000   -18.000      .000     7.947      .000      .000      .000      .000      .003      .000
OF  16000.000      .000      .000     7.859      .000      .000      .000      .000      .005      .000
VH  18500.000     2.500     3.000      .000      .000     1.000      .000     7.690     -.004      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF  19000.000   -12.000      .000     7.656      .000      .000      .000      .000     -.002      .000
OF  19600.000      .000      .000     7.615      .000      .000      .000      .000      .002      .000
VH  25000.000     2.500     3.000      .000      .000     1.000     2.500     7.250     -.002      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF  26000.000   -12.000      .000     7.215      .000      .000      .000      .000     -.001      .000
OF  27200.000      .000      .000     7.174      .000      .000      .000      .000      .002      .000
VH  35200.000     2.500     3.000      .000      .000     1.000      .000     6.897     -.001      .000
MG       SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF  35700.000   -12.000      .000     6.879      .000      .000      .000      .000     -.004      .000
```

```
OF 35700.000    -12.000      .000     6.879      .000      .000      .000      .000     -.004      .000
OF 37900.000     -9.000      .000     6.803      .000      .000      .000      .000      .005      .000
OF 38000.000       .000      .000     6.800      .000      .000      .000      .000      .001      .000
VH 47200.000      2.500     3.000      .000      .000     1.000      .000     6.481     -.001      .000
MG      SALT       .000     1.000      .000      .000      .000      .000      .000      .000      .000
OF 47700.000    -12.000      .000     6.464      .000      .000      .000      .000     -.003      .000
OF 48100.000       .000     3.000     6.450      .000      .000      .000      .000      .007      .000
VH 49750.000      2.500     3.000      .000      .000     1.000      .000      .000      .004      .000
MG      SALT       .000     1.000      .000      .000      .000      .000      .000      .000      .000
IF 49850.000      6.450      .000      .000      .000      .000      .000      .000      .040      .000
ET      .000       .000      .000      .000      .000      .000      .000      .000      .000      .000


      END       END     FETCH SURGE ELEV SURGE ELEV   INITIAL    INITIAL               BOTTOM   AVERAGE
  STATION ELEVATION    LENGTH   10-YEAR  100-YEAR WAVE HEIGHT W. PERIOD                 SLOPE   A-ZONES
     .000      .000    24.000     7.000    11.600      .000    13.000      .000        .027      .000


      END       END NEW SURGE NEW SURGE                                               BOTTOM   AVERAGE
  STATION ELEVATION   10-YEAR  100-YEAR                                                SLOPE   A-ZONES
  350.000     9.400      .000      .000      .000      .000      .000      .000        .033      .000


UNE CREST DUNE CREST  DUNE OR NEW SURGE NEW SURGE                                     BOTTOM   AVERAGE
  STATION ELEVATION   SEAWALL   10-YEAR  100-YEAR                                      SLOPE   A-ZONES
  351.000    11.600      .000      .000      .000      .000      .000      .000       2.200      .000


      END       END NEW SURGE NEW SURGE                                               BOTTOM   AVERAGE
  STATION ELEVATION   10-YEAR  100-YEAR                                                SLOPE   A-ZONES
 1345.000     8.850     4.000     8.850      .000      .000      .000      .000       -.003      .000


      END       END   AVERAGE   AVERAGE   AVERAGE      DRAG NEW SURGE NEW SURGE      BOTTOM   AVERAGE
  STATION ELEVATION  DIAMETER    HEIGHT   SPACING    COEFF.   10-YEAR  100-YEAR       SLOPE   A-ZONES
 1445.000     8.520      .300    15.000     6.000      .000      .000     8.843       -.003      .000


      END       END   AVERAGE   AVERAGE   AVERAGE      DRAG NEW SURGE NEW SURGE      BOTTOM   AVERAGE
  STATION ELEVATION  DIAMETER    HEIGHT   SPACING    COEFF.   10-YEAR  100-YEAR       SLOPE   A-ZONES
 1600.000     8.000      .300    15.000     6.000      .000      .000     8.833       -.003      .000


      END       END   AVERAGE   AVERAGE   AVERAGE      DRAG NEW SURGE NEW SURGE      BOTTOM   AVERAGE
  STATION ELEVATION  DIAMETER    HEIGHT   SPACING    COEFF.   10-YEAR  100-YEAR       SLOPE   A-ZONES
 1800.000     7.300      .300    15.000     6.000      .000      .000     8.819       -.003      .000


      END       END   AVERAGE   AVERAGE   AVERAGE      DRAG NEW SURGE NEW SURGE      BOTTOM   AVERAGE
  STATION ELEVATION  DIAMETER    HEIGHT   SPACING    COEFF.   10-YEAR  100-YEAR       SLOPE   A-ZONES
 2000.000     6.700      .300    15.000     6.000      .000      .000     8.806       -.003      .000
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     END        END    AVERAGE    AVERAGE    AVERAGE        DRAG  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
 STATION  ELEVATION   DIAMETER     HEIGHT    SPACING      COEFF.    10-YEAR   100-YEAR      SLOPE    A-ZONES
2200.000      6.000       .300     15.000      6.000        .000       .000      8.792      -.003       .000

     END        END    AVERAGE    AVERAGE    AVERAGE        DRAG  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
 STATION  ELEVATION   DIAMETER     HEIGHT    SPACING      COEFF.    10-YEAR   100-YEAR      SLOPE    A-ZONES
2500.000      5.000       .300     15.000      6.000        .000       .000      8.772      -.001       .000

     END        END               REGION 1                NO. OF  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
 STATION  ELEVATION   REGION 1     WEIGHT   REGION 2 PLANT TYPES    10-YEAR   100-YEAR      SLOPE    A-ZONES
7000.000       .000      3.000       .000       .000       1.000       .000      8.468      -.002       .000

   PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER   BASE STEM   MID STEM   TOP STEM  LEAF-STEM
    TYPE     COEFF.      RATIO     HEIGHT    DENSITY    DIAMETER   DIAMETER   DIAMETER AREA RATIO
    SALT       .000      1.000       .000       .000        .000       .000       .000       .000       .000
```

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                 PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

   PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER   BASE STEM   MID STEM   TOP STEM  LEAF-STEM
    TYPE     COEFF.      RATIO     HEIGHT    DENSITY    DIAMETER   DIAMETER   DIAMETER AREA RATIO
    SALT       .100      1.000      3.200     10.000        .220       .088       .044      1.590
```

```
     END        END  NEW SURGE  NEW SURGE                                                  BOTTOM    AVERAGE
 STATION  ELEVATION    10-YEAR   100-YEAR                                                   SLOPE    A-ZONES
7200.000     -6.000       .000      8.454       .000        .000       .000       .000      -.005       .000

     END        END  NEW SURGE  NEW SURGE                                                  BOTTOM    AVERAGE
 STATION  ELEVATION    10-YEAR   100-YEAR                                                   SLOPE    A-ZONES
8300.000     -6.000       .000      8.380       .000        .000       .000       .000      -.004       .000

     END        END  NEW SURGE  NEW SURGE                                                  BOTTOM    AVERAGE
 STATION  ELEVATION    10-YEAR   100-YEAR                                                   SLOPE    A-ZONES
8900.000    -12.000       .000      8.339       .000        .000       .000       .000       .000       .000

     END        END  NEW SURGE  NEW SURGE                                                  BOTTOM    AVERAGE
 STATION  ELEVATION    10-YEAR   100-YEAR                                                   SLOPE    A-ZONES
9100.000     -6.000       .000      8.325       .000        .000       .000       .000       .027       .000
```

```
      END        END  NEW SURGE  NEW SURGE                                               BOTTOM    AVERAGE
  STATION  ELEVATION    10-YEAR   100-YEAR                                                SLOPE    A-ZONES
 9350.000       .000       .000      8.309      .000       .000       .000       .000      .006       .000

      END        END                REGION 1                NO. OF  NEW SURGE  NEW SURGE   BOTTOM    AVERAGE
  STATION  ELEVATION   REGION 1      WEIGHT   REGION 2 PLANT TYPES    10-YEAR   100-YEAR    SLOPE    A-ZONES
10500.000      2.500      3.000        .000       .000      1.000       .000      8.231    -.003       .000

    PLANT       DRAG   COVERAGE   AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
     TYPE     COEFF.      RATIO      HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
     SALT       .000      1.000        .000       .000       .000       .000       .000       .000       .000

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          PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

    PLANT       DRAG   COVERAGE   AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
     TYPE     COEFF.      RATIO      HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
     SALT       .100      1.000       3.200     10.000       .220       .088       .044      1.590

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      END        END  NEW SURGE  NEW SURGE                                               BOTTOM    AVERAGE
  STATION  ELEVATION    10-YEAR   100-YEAR                                                SLOPE    A-ZONES
11300.000     -6.000       .000      8.177      .000       .000       .000       .000     -.002       .000

      END        END  NEW SURGE  NEW SURGE                                               BOTTOM    AVERAGE
  STATION  ELEVATION    10-YEAR   100-YEAR                                                SLOPE    A-ZONES
11800.000       .000       .000      8.143      .000       .000       .000       .000      .004       .000

      END        END                REGION 1                NO. OF  NEW SURGE  NEW SURGE   BOTTOM    AVERAGE
  STATION  ELEVATION   REGION 1      WEIGHT   REGION 2 PLANT TYPES    10-YEAR   100-YEAR    SLOPE    A-ZONES
13300.000      2.500      3.000        .000       .000      1.000       .000      8.041    -.003       .000

    PLANT       DRAG   COVERAGE   AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
     TYPE     COEFF.      RATIO      HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
     SALT       .000      1.000        .000       .000       .000       .000       .000       .000       .000

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          PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM
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      PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
       TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
       SALT       .100      1.000      3.200     10.000       .220       .088       .044      1.590

--------------------------------------------------------------------------------------------------------------

        END        END  NEW SURGE  NEW SURGE                                                 BOTTOM    AVERAGE
    STATION  ELEVATION    10-YEAR   100-YEAR                                                  SLOPE    A-ZONES
  13700.000     -6.000       .000      8.014       .000       .000       .000       .000      -.015       .000

        END        END  NEW SURGE  NEW SURGE                                                 BOTTOM    AVERAGE
    STATION  ELEVATION    10-YEAR   100-YEAR                                                  SLOPE    A-ZONES
  14700.000    -18.000       .000      7.947       .000       .000       .000       .000       .003       .000

        END        END  NEW SURGE  NEW SURGE                                                 BOTTOM    AVERAGE
    STATION  ELEVATION    10-YEAR   100-YEAR                                                  SLOPE    A-ZONES
  16000.000       .000       .000      7.859       .000       .000       .000       .000       .005       .000

        END        END              REGION 1                NO. OF  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
    STATION  ELEVATION   REGION 1     WEIGHT  REGION 2 PLANT TYPES    10-YEAR   100-YEAR      SLOPE    A-ZONES
  18500.000      2.500      3.000       .000       .000      1.000       .000      7.690      -.004       .000

      PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
       TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
       SALT       .000      1.000       .000       .000       .000       .000       .000       .000       .000

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                         PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

      PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
       TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
       SALT       .100      1.000      3.200     10.000       .220       .088       .044      1.590

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        END        END  NEW SURGE  NEW SURGE                                                 BOTTOM    AVERAGE
    STATION  ELEVATION    10-YEAR   100-YEAR                                                  SLOPE    A-ZONES
  19000.000    -12.000       .000      7.656       .000       .000       .000       .000      -.002       .000

        END        END  NEW SURGE  NEW SURGE                                                 BOTTOM    AVERAGE
```

```
   STATION  ELEVATION    10-YEAR   100-YEAR                                             SLOPE    A-ZONES
 19600.000       .000       .000      7.615       .000       .000       .000       .000       .002       .000


       END        END              REGION 1                  NO. OF  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
   STATION  ELEVATION   REGION 1     WEIGHT   REGION 2 PLANT TYPES    10-YEAR   100-YEAR      SLOPE    A-ZONES
 25000.000      2.500      3.000       .000       .000      1.000      2.500      7.250      -.002       .000


     PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
      TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
      SALT       .000      1.000       .000       .000       .000       .000       .000       .000       .000

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               PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM


     PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
      TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
      SALT       .100      1.000      3.200     10.000       .220       .088       .044      1.590


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       END        END  NEW SURGE  NEW SURGE                                                BOTTOM    AVERAGE
   STATION  ELEVATION    10-YEAR   100-YEAR                                                 SLOPE    A-ZONES
 26000.000    -12.000       .000      7.215       .000       .000       .000       .000      -.001       .000


       END        END  NEW SURGE  NEW SURGE                                                BOTTOM    AVERAGE
   STATION  ELEVATION    10-YEAR   100-YEAR                                                 SLOPE    A-ZONES
 27200.000       .000       .000      7.174       .000       .000       .000       .000       .002       .000


       END        END              REGION 1                  NO. OF  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
   STATION  ELEVATION   REGION 1     WEIGHT   REGION 2 PLANT TYPES    10-YEAR   100-YEAR      SLOPE    A-ZONES
 35200.000      2.500      3.000       .000       .000      1.000       .000      6.897      -.001       .000


     PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
      TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
      SALT       .000      1.000       .000       .000       .000       .000       .000       .000       .000

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               PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM


     PLANT       DRAG   COVERAGE  AVG. STEM     NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
      TYPE     COEFF.      RATIO     HEIGHT    DENSITY   DIAMETER   DIAMETER   DIAMETER AREA RATIO
```

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      SALT      .100     1.000     3.200    10.000      .220      .088      .044     1.590

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       END       END NEW SURGE NEW SURGE                                             BOTTOM   AVERAGE
   STATION ELEVATION   10-YEAR  100-YEAR                                              SLOPE   A-ZONES
 35700.000   -12.000      .000     6.879      .000      .000      .000      .000     -.004      .000

       END       END NEW SURGE NEW SURGE                                             BOTTOM   AVERAGE
   STATION ELEVATION   10-YEAR  100-YEAR                                              SLOPE   A-ZONES
 37900.000    -9.000      .000     6.803      .000      .000      .000      .000      .005      .000

       END       END NEW SURGE NEW SURGE                                             BOTTOM   AVERAGE
   STATION ELEVATION   10-YEAR  100-YEAR                                              SLOPE   A-ZONES
 38000.000      .000      .000     6.800      .000      .000      .000      .000      .001      .000

       END       END            REGION 1                NO. OF NEW SURGE NEW SURGE    BOTTOM   AVERAGE
   STATION ELEVATION  REGION 1    WEIGHTREGION 2 PLANT TYPES   10-YEAR  100-YEAR     SLOPE   A-ZONES
 47200.000     2.500     3.000      .000      .000     1.000      .000     6.481     -.001      .000

     PLANT      DRAG  COVERAGE AVG. STEM    NUMBER BASE STEM  MID-STEM  TOP STEM LEAF-STEM
      TYPE    COEFF.     RATIO    HEIGHT   DENSITY  DIAMETER  DIAMETER  DIAMETERAREA RATIO
      SALT      .000     1.000      .000      .000      .000      .000      .000      .000      .000

----------------------------------------------------------------------------------------------------
             PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

     PLANT      DRAG  COVERAGE AVG. STEM    NUMBER BASE STEM  MID STEM  TOP STEM LEAF-STEM
      TYPE    COEFF.     RATIO    HEIGHT   DENSITY  DIAMETER  DIAMETER  DIAMETERAREA RATIO
      SALT      .100     1.000     3.200    10.000      .220      .088      .044     1.590

----------------------------------------------------------------------------------------------------

       END       END NEW SURGE NEW SURGE                                             BOTTOM   AVERAGE
   STATION ELEVATION   10-YEAR  100-YEAR                                              SLOPE   A-ZONES
 47700.000   -12.000      .000     6.464      .000      .000      .000      .000     -.003      .000

       END       END NEW SURGE NEW SURGE                                             BOTTOM   AVERAGE
   STATION ELEVATION   10-YEAR  100-YEAR                                              SLOPE   A-ZONES
 48100.000      .000     3.000     6.450      .000      .000      .000      .000      .007      .000
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      END         END              REGION 1                  NO. OF  NEW SURGE  NEW SURGE     BOTTOM    AVERAGE
  STATION   ELEVATION  REGION 1      WEIGHT  REGION 2  PLANT TYPES    10-YEAR   100-YEAR      SLOPE    A-ZONES
49750.000       2.500     3.000        .000      .000        1.000       .000       .000       .004       .000

    PLANT        DRAG  COVERAGE   AVG. STEM    NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
     TYPE      COEFF.     RATIO      HEIGHT   DENSITY   DIAMETER   DIAMETER   DIAMETER  AREA RATIO
     SALT        .000     1.000        .000      .000       .000       .000       .000       .000       .000

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                    PLANT CHARACTERISTICS INCLUDING VALUES SUPPLIED BY THE PROGRAM

    PLANT        DRAG  COVERAGE   AVG. STEM    NUMBER  BASE STEM   MID STEM   TOP STEM  LEAF-STEM
     TYPE      COEFF.     RATIO      HEIGHT   DENSITY   DIAMETER   DIAMETER   DIAMETER  AREA RATIO
     SALT        .100     1.000       3.200    10.000       .220       .088       .044      1.590

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      END         END  NEW SURGE  NEW SURGE                                                BOTTOM    AVERAGE
  STATION   ELEVATION    10-YEAR   100-YEAR                                                 SLOPE    A-ZONES
49850.000       6.450       .000       .000      .000      .000       .000       .000       .040       .000

---------------------------------------END OF TRANSECT----------------------------------------------------------

:

E ELEVATION INCLUDES CONTRIBUTIONS FROM ASTRONOMICAL AND STORM TIDES.


                                                 PART2: CONTROLLING WAVE HEIGHTS, SPECTRAL
                                                      PEAK WAVE PERIOD, AND WAVE CREST ELEVATIONS

                                           LOCATION        CONTROLLING  SPECTRAL PEAK  WAVE CREST
                                                           WAVE HEIGHT  WAVE PERIOD    ELEVATION

                                          IE       .00        9.05         13.00         17.93

                                                105.00        6.85         13.00         16.39

                                                210.00        4.65         13.00         14.85

                                                315.00        2.45         13.00         13.31
```

OF	350.00	1.72	13.00	12.80
DU	351.00	.00	.00	11.60
AS	1345.00	.00	.00	8.85
VE	1445.00	.00	.00	8.84
VE	1600.00	.00	.00	8.83
VE	1800.00	.00	.00	8.82
VE	2000.00	.00	.00	8.81
VE	2200.00	.00	.00	8.79
VE	2500.00	.00	.00	8.77
	2605.00	.61	.68	9.19
	2725.00	.89	.88	9.38
	2885.00	1.15	1.05	9.55
	3045.00	1.36	1.17	9.69
	3205.00	1.53	1.28	9.80
	3445.00	1.75	1.41	9.93
	3605.00	1.88	1.48	10.01
	3765.00	2.00	1.55	10.09
	3925.00	2.11	1.61	10.15
	4085.00	2.21	1.67	10.21
	4245.00	2.30	1.72	10.27
	4405.00	2.39	1.77	10.32
	4565.00	2.48	1.82	10.37
	4725.00	2.56	1.86	10.41
	5045.00	2.71	1.94	10.50
	5365.00	2.85	2.02	10.57
	5685.00	2.98	2.09	10.64

	6005.00	3.11	2.16	10.71
	6325.00	3.23	2.22	10.77
	6645.00	3.34	2.28	10.83
	6965.00	3.45	2.33	10.88
VH	7000.00	3.46	2.34	10.89
	7100.00	3.66	2.37	11.02
CF	7200.00	3.80	2.39	11.12
	7350.00	3.93	2.43	11.20
	7450.00	4.01	2.45	11.25
	7650.00	4.17	2.50	11.34
	7850.00	4.32	2.54	11.43
	8050.00	4.46	2.59	11.52
	8250.00	4.60	2.63	11.60
CF	8300.00	4.63	2.64	11.62
	8450.00	4.77	2.67	11.71
	8550.00	4.85	2.69	11.76
	8650.00	4.93	2.71	11.81
	8750.00	5.01	2.73	11.86
CF	8900.00	5.12	2.76	11.92
	9040.00	5.14	2.78	11.93
CF	9100.00	5.11	2.79	11.91
	9275.00	5.00	2.82	11.82
CF	9350.00	4.96	2.84	11.78
	9500.00	4.90	2.85	11.73
	9660.00	4.84	2.87	11.68
	9980.00	4.69	2.90	11.55

	10140.00	4.60	2.91	11.48
	10300.00	4.50	2.92	11.40
	10460.00	4.39	2.93	11.31
VH	10500.00	4.36	2.94	11.29
	10650.00	4.38	2.96	11.29
	10850.00	4.52	2.99	11.37
	10950.00	4.62	3.01	11.43
	11050.00	4.72	3.02	11.50
	11150.00	4.83	3.04	11.56
	11250.00	4.93	3.06	11.63
CF	11300.00	4.98	3.06	11.67
	11450.00	4.99	3.09	11.66
	11650.00	5.00	3.11	11.66
CF	11800.00	5.05	3.14	11.68
	11950.00	4.99	3.15	11.62
	12110.00	4.92	3.16	11.57
	12430.00	4.76	3.18	11.44
	12590.00	4.68	3.20	11.36
	12750.00	4.59	3.21	11.29
	12910.00	4.49	3.22	11.21
	13070.00	4.38	3.23	11.13
	13230.00	4.27	3.24	11.04
VH	13300.00	4.22	3.24	10.99
	13420.00	4.14	3.26	10.93
	13580.00	4.28	3.28	11.02
CF	13700.00	4.44	3.30	11.12

	13850.00	4.61	3.32	11.23
	13950.00	4.72	3.33	11.30
	14050.00	4.82	3.34	11.37
	14150.00	4.93	3.35	11.43
	14250.00	5.03	3.37	11.50
	14350.00	5.12	3.38	11.56
	14450.00	5.21	3.39	11.61
	14550.00	5.30	3.40	11.67
	14650.00	5.38	3.42	11.72
CF	14700.00	5.42	3.42	11.74
	14850.00	5.48	3.44	11.77
	15050.00	5.53	3.46	11.79
	15450.00	5.55	3.51	11.78
CF	16000.00	5.72	3.57	11.86
	16150.00	5.61	3.57	11.78
	16310.00	5.49	3.57	11.68
	16470.00	5.38	3.58	11.59
	16630.00	5.26	3.58	11.50
	16790.00	5.14	3.59	11.40
	16950.00	5.02	3.60	11.31
	17110.00	4.90	3.60	11.21
	17270.00	4.78	3.61	11.12
	17430.00	4.66	3.62	11.03
	17590.00	4.54	3.63	10.93
	17750.00	4.42	3.64	10.84
	17910.00	4.30	3.65	10.74

	18070.00	4.18	3.65	10.65
	18230.00	4.06	3.66	10.55
	18390.00	3.94	3.67	10.45
VH	18500.00	3.86	3.68	10.39
	18600.00	3.66	3.69	10.25
	18700.00	3.68	3.70	10.25
	18900.00	3.93	3.72	10.41
CF	19000.00	4.09	3.73	10.52
	19150.00	4.14	3.75	10.54
	19350.00	4.23	3.77	10.59
CF	19600.00	4.53	3.79	10.79
	19750.00	4.48	3.80	10.74
	19910.00	4.42	3.81	10.69
	20230.00	4.31	3.83	10.59
	20550.00	4.20	3.84	10.49
	20870.00	4.09	3.86	10.39
	21190.00	3.98	3.88	10.29
	21510.00	3.88	3.90	10.20
	21830.00	3.78	3.92	10.11
	22150.00	3.68	3.94	10.02
	22470.00	3.58	3.95	9.93
	22790.00	3.49	3.97	9.84
	23110.00	3.40	3.99	9.76
	23430.00	3.31	4.01	9.67
	23750.00	3.22	4.02	9.59
	24070.00	3.13	4.04	9.51

	24390.00	3.05	4.06	9.42
	24710.00	2.96	4.08	9.34
VH	25000.00	2.89	4.09	9.27
	25150.00	2.82	4.11	9.22
	25350.00	2.90	4.12	9.27
	25550.00	3.08	4.14	9.39
	25650.00	3.19	4.15	9.46
	25750.00	3.30	4.16	9.53
	25850.00	3.41	4.16	9.61
	25950.00	3.53	4.17	9.69
CF	26000.00	3.59	4.18	9.73
	26150.00	3.72	4.19	9.81
	26350.00	3.89	4.20	9.93
	26550.00	4.07	4.22	10.04
	26750.00	4.26	4.24	10.17
	26850.00	4.37	4.24	10.25
	26950.00	4.49	4.25	10.33
	27050.00	4.62	4.26	10.42
	27150.00	4.78	4.27	10.52
CF	27200.00	4.86	4.27	10.58
	27350.00	4.76	4.28	10.50
	27510.00	4.66	4.28	10.43
	27670.00	4.57	4.29	10.35
	27830.00	4.48	4.30	10.29
	27990.00	4.39	4.31	10.22
	28150.00	4.31	4.31	10.16

	28470.00	4.15	4.33	10.04
	28790.00	4.01	4.34	9.93
	29110.00	3.89	4.36	9.83
	29430.00	3.77	4.37	9.74
	29750.00	3.67	4.38	9.65
	30070.00	3.57	4.40	9.57
	30390.00	3.48	4.41	9.50
	30710.00	3.40	4.43	9.43
	31030.00	3.32	4.44	9.37
	31670.00	3.18	4.47	9.25
	32310.00	3.06	4.50	9.14
	32950.00	2.95	4.53	9.04
	33590.00	2.84	4.53	8.94
	34230.00	2.74	4.53	8.85
	34870.00	2.64	4.53	8.76
VH	35200.00	2.59	4.53	8.71
	35350.00	2.40	4.54	8.57
	35550.00	2.55	4.55	8.67
	35650.00	2.68	4.56	8.76
OF	35700.00	2.75	4.56	8.80
	35850.00	2.95	4.57	8.94
	35950.00	3.07	4.58	9.02
	36050.00	3.19	4.59	9.10
	36150.00	3.30	4.59	9.17
	36250.00	3.41	4.60	9.25
	36350.00	3.51	4.61	9.32

	36450.00	3.62	4.61	9.38
	36550.00	3.71	4.62	9.45
	36650.00	3.81	4.63	9.51
	36750.00	3.90	4.63	9.57
	36850.00	3.99	4.64	9.63
	36950.00	4.08	4.65	9.69
	37050.00	4.17	4.65	9.75
	37150.00	4.25	4.66	9.80
	37350.00	4.41	4.67	9.91
	37550.00	4.57	4.69	10.01
	37750.00	4.71	4.70	10.11
OF	37900.00	4.82	4.71	10.18
OF	38000.00	5.30	4.72	10.51
	38150.00	5.27	4.72	10.48
	38310.00	5.23	4.72	10.45
	38630.00	5.15	4.72	10.39
	39270.00	4.83	4.72	10.14
	39590.00	4.54	4.73	9.92
	39750.00	4.41	4.73	9.83
	39910.00	4.29	4.74	9.74
	40070.00	4.18	4.74	9.65
	40230.00	4.08	4.75	9.58
	40390.00	3.98	4.75	9.50
	40550.00	3.89	4.75	9.44
	40710.00	3.81	4.75	9.37
	41030.00	3.65	4.75	9.25

	41350.00	3.52	4.75	9.15
	41670.00	3.40	4.75	9.05
	41990.00	3.30	4.75	8.97
	42310.00	3.21	4.75	8.90
	42630.00	3.13	4.75	8.83
	43270.00	2.98	4.75	8.71
	43910.00	2.86	4.75	8.60
	44550.00	2.76	4.75	8.51
	45190.00	2.67	4.75	8.42
	45830.00	2.58	4.75	8.34
	46470.00	2.50	4.75	8.26
	47110.00	2.42	4.75	8.18
VH	47200.00	2.41	4.75	8.17
	47350.00	2.21	4.76	8.02
	47550.00	2.36	4.77	8.12
	47650.00	2.49	4.78	8.21
CF	47700.00	2.56	4.78	8.25
	47820.00	2.76	4.79	8.39
	47980.00	3.11	4.80	8.63
CF	48100.00	3.56	4.81	8.94
	48250.00	3.55	4.81	8.94
	48410.00	3.54	4.81	8.92
	48730.00	3.48	4.81	8.88
	49370.00	3.25	4.81	8.73
	49690.00	3.08	4.81	8.61
VH	49750.00	3.05	4.81	8.58

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IF   49850.00          .01         4.81         6.46


PART3 LOCATION OF AREAS ABOVE 100-YEAR SURGE

    BETWEEN    351.00 AND   1345.00


              PART4 LOCATION OF SURGE CHANGES

STATION          10-YEAR SURGE          100-YEAR SURGE

1345.00              4.00                   8.85

1445.00              4.00                   8.84

1600.00              4.00                   8.83

1800.00              4.00                   8.82

2000.00              4.00                   8.81

2200.00              4.00                   8.79

2500.00              4.00                   8.77

7000.00              4.00                   8.47

7200.00              4.00                   8.45

8300.00              4.00                   8.38

8900.00              4.00                   8.34

9100.00              4.00                   8.32

9350.00              4.00                   8.31

10500.00             4.00                   8.23

11300.00             4.00                   8.18

11800.00             4.00                   8.14

13300.00             4.00                   8.04

13700.00             4.00                   8.01

14700.00             4.00                   7.95
```

16000.00	4.00	7.86
18500.00	4.00	7.69
19000.00	4.00	7.66
19600.00	4.00	7.61
25000.00	2.50	7.25
26000.00	2.50	7.22
27200.00	2.50	7.17
35200.00	2.50	6.90
35700.00	2.50	6.88
37900.00	2.50	6.80
38000.00	2.50	6.80
47200.00	2.50	6.48
47700.00	2.50	6.46
48100.00	3.00	6.45

PART5 LOCATION OF V ZONES

STATION OF GUTTER	LOCATION OF ZONE
288.71	WINDWARD
5731.23	LEEWARD
24564.27	WINDWARD
25457.99	LEEWARD
32636.62	WINDWARD
35894.29	LEEWARD
43191.50	WINDWARD
47929.02	LEEWARD
49751.53	WINDWARD

PARTS NUMBERED A ZONES AND V ZONES

STATION OF GUTTER	ELEVATION	ZONE DESIGNATION	FHF
.00	17.93		
		V14 EL=18	70
29.57	17.50		
		V14 EL=17	70
97.76	16.50		
		V14 EL=16	70
165.96	15.50		
		V14 EL=15	70
234.15	14.50		
		V14 EL=14	70
288.71	13.70		
		A12 EL=14	60
302.35	13.50		
		A12 EL=13	60
350.25	12.50		
		A12 EL=12	60
351.00	11.60		
1345.00	8.85		
		A12 EL= 9	60
1445.00	8.84		
		A12 EL= 9	60
1600.00	8.83		

```
                              A12  EL= 9     60
1800.00         8.82
                              A12  EL= 9     60
2000.00         8.81
                              A12  EL= 9     60
2200.00         8.79
                              A12  EL= 9     60
2500.00         8.77
                              A12  EL= 9     60
2836.89         9.50
                              A12  EL=10     60
5057.99        10.50
                              A12  EL=11     60
5731.23        10.65
                              V14  EL=11     70
7000.00        10.89
                              V14  EL=11     70
7200.00        11.12
                              V14  EL=11     70
8001.87        11.50
                              V14  EL=12     70
8300.00        11.62
                              V13  EL=12     65
8900.00        11.92
                              V13  EL=12     65
9100.00        11.91
```

```
                                  V13  EL=12     65
          9350.00        11.78
                                  V13  EL=12     65
         10086.32        11.50
                                  V13  EL=11     65
         10500.00        11.29
                                  V13  EL=11     65
         11053.35        11.50
                                  V13  EL=12     65
         11300.00        11.67
                                  V13  EL=12     65
         11800.00        11.68
                                  V13  EL=12     65
         12270.56        11.50
                                  V13  EL=11     65
         13300.00        10.99
                                  V12  EL=11     60
         13700.00        11.12
                                  V12  EL=11     60
         14255.73        11.50
                                  V12  EL=12     60
         14700.00        11.74
                                  V12  EL=12     60
         16000.00        11.86
                                  V12  EL=12     60
         16625.18        11.50
```

```
                              V12  EL=11    60
18314.20        10.50
                              V11  EL=10    55
18500.00        10.39
                              V11  EL=10    55
18984.81        10.50
                              V11  EL=11    55
19000.00        10.52
                              V11  EL=11    55
19600.00        10.79
                              V11  EL=11    55
20511.00        10.50
                              V13  EL=10    65
24090.23         9.50
                              V14  EL= 9    70
24564.27         9.38
                              A14  EL= 9    70
25000.00         9.27
                              A14  EL= 9    70
25457.99         9.33
                              V15  EL= 9    75
25707.39         9.50
                              V15  EL=10    75
26000.00         9.73
                              V15  EL=10    75
27132.21        10.50
```

```
                              V14  EL=11     70
  27200.00       10.58
                              V14  EL=11     70
  27354.08       10.50
                              V14  EL=10     70
  30389.39        9.50
                              V14  EL= 9     70
  32636.62        9.09
                              A13  EL= 9     65
  35200.00        8.71
                              A13  EL= 9     65
  35700.00        8.80
                              A13  EL= 9     65
  35894.29        8.97
                              V14  EL= 9     70
  36630.08        9.50
                              V13  EL=10     65
  37900.00       10.18
                              V13  EL=10     65
  37996.17       10.50
                              V13  EL=11     65
  38000.00       10.51
                              V13  EL=11     65
  38063.37       10.50
                              V13  EL=10     65
  40399.32        9.50
```

```
                              V13  EL= 9     65

43191.50          8.73

                              A12  EL= 9     60

44600.66          8.50

                              A12  EL= 8     60

47200.00          8.17

                              A12  EL= 8     60

47700.00          8.25

                              A12  EL= 8     60

47892.44          8.50

                              A12  EL= 9     60

47929.02          8.56

                              V11  EL= 9     55

48100.00          8.94

                              V11  EL= 9     55

49751.53          8.55

                              A 9  EL= 9     45

49753.88          8.50

                              A 9  EL= 8     45

49800.89          7.50

                              A 9  EL= 7     45

49847.91          6.50

                              A 9  EL= 6     45

49850.00          6.46


                 ZONE TERMINATED AT END OF TRANSECT
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