

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ADA 124235

12

TN NO: N - 1649

TITLE: A MODEL FOR ON-OFFSHORE SEDIMENT
TRANSPORT IN THE SURFZONE

AUTHOR: James A. Bailard

DATE: December 1982

SPONSOR: NAVAL FACILITIES ENGINEERING COMMAND

PROGRAM NO: ZR000-01-183 and YF 60.536.091.01.A101

TECHNICAL

NOTE

NAVAL CIVIL ENGINEERING LABORATORY
PORT HUENEME, CALIFORNIA 93043

Approved for public release; distribution unlimited.

DTIC
FEB 9 1983

DTIC FILE COPY

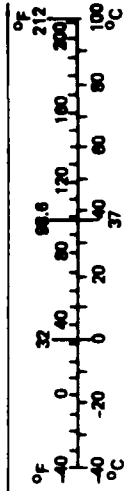
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cup	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

When You Know	Multiply by	To Find	Symbol
	LENGTH		
millimeters	0.04	inches	in
centimeters	0.4	inches	in
meters	3.3	feet	ft
kilometers	1.1	yards	yd
	0.6	miles	mi
	AREA		
square centimeters	0.16	square inches	in ²
square meters	1.2	square yards	yd ²
square kilometers	0.4	square miles	mi ²
hectares (10,000 m ²)	2.5	acres	
	MASS (weight)		
grams	0.035	ounces	oz
kilograms	2.2	pounds	lb
tonnes (1,000 kg)	1.1	short tons	
	VOLUME		
milliliters	0.03	fluid ounces	fl oz
liters	2.1	pints	pt
liters	1.06	quarts	qt
liters	0.26	gallons	gal
cubic meters	35	cubic feet	ft ³
cubic meters	1.3	cubic yards	yd ³
	TEMPERATURE (exact)		
Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1 REPORT NUMBER TN 1649	2 GOVT ACCESSION NO DN187254	3 RECIPIENT'S CATALOG NUMBER AD-A124235
4 TITLE (and Subtitle) A MODEL FOR ON-OFFSHORE SEDIMENT TRANSPORT IN THE SURFZONE		5 TYPE OF REPORT & PERIOD COVERED Final; Oct 81 -- Jun 82
		6 PERFORMING ORG REPORT NUMBER
7 AUTHOR/s James A. Bailard		8 CONTRACT OR GRANT NUMBER
9 PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL CIVIL ENGINEERING LABORATORY Port Hueneme, California 93043		10 PROGRAM ELEMENT PROJECT TASK AREA & WORK UNIT NUMBER ZR000-01-183, 61152N, YF60.536.091.01.A101.62760N
11 CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		12 REPORT DATE December 1982
14 MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13 NUMBER OF PAGES 53
		15 SECURITY CLASSIFICATION OF THIS REPORT Unclassified
16 DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17 DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18 SUPPLEMENTARY NOTES		
19 KEY WORDS (Continue on reverse side if necessary and identify by block number) Sediment transport, surfzone, on-offshore, wave velocity, energetics.		
20 ABSTRACT (Continue on reverse side if necessary and identify by block number) An energetics-based surfzone sediment transport model is evaluated for its ability to predict on-offshore sediment movements using nearshore sediment transport study current meter and beach volume measurements. The magnitude and distribution of pertinent wave velocity moments are also evaluated from the same data set. The latter were found to be linear functions of the significant wave height. Results of the study showed that the current meter data were of insufficient length to evaluate the sediment transport model's validity.		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

continued

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. Continued

A simplified version of the model coupled with estimated wave velocity moment regression equations was found to mimic observed beach volume variations as a function of wave height.

Library Card

Naval Civil Engineering Laboratory
A MODEL FOR ON-OFFSHORE SEDIMENT TRANSPORT IN
THE SURFZONE (Final) by James A. Bailard
TN-1649 53 pp illus December 1982 U.classified

1. Sediment transport 2. Surfzone I. ZR000-01-183 II. YF60.536.091.01.A101

An energetics-based surfzone sediment transport model is evaluated for its ability to predict on-offshore sediment movements using nearshore sediment transport study current meter and beach volume measurements. The magnitude and distribution of pertinent wave velocity moments are also evaluated from the same data set. The latter were found to be linear functions of the significant wave height. Results of the study showed that the current meter data were of insufficient length to evaluate the sediment transport model's validity. A simplified version of the model coupled with estimated wave velocity moment regression equations was found to mimic observed beach volume variations as a function of wave height.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

INTRODUCTION

Waves breaking on a beach cause sediment to be transported both parallel to (longshore) and perpendicular to (on-offshore) a beach. Recognizing the importance of these processes to Navy operations, the Independent Research Program of the Naval Civil Engineering Laboratory (NCEL) has sponsored research to develop improved sediment transport models for the surfzone. The present study deals only with on-offshore transport.

Although on-offshore and longshore sediment transports are manifestations of the same process, past investigations have generally treated them separately for reasons of simplicity. Fortunately, this separate treatment has been relatively successful for the following two reasons:

1. Wave refraction generally causes the waves to have near normal incidence to the beach at breaking.

2. The mean longshore and on-offshore currents are generally much weaker than the oscillatory velocity magnitude.

As a result, the longshore transport has been found to be relatively well modeled (e.g., Inman and Bagnold, 1963; Komar, 1971) as the product of an oscillatory velocity-induced sediment load and a transport velocity proportional to the longshore current. Similarly, the on-offshore transport may be modeled as a balance between gravity, the asymmetry of the oscillatory velocity distribution, and the on-offshore steady current (e.g., Inman and Frautschy, 1966; Bowen, 1980; Bailard, 1981).

Although the above processes have been qualitatively understood for some time, relatively greater progress has been made in quantitatively predicting the longshore transport as opposed to predicting the on-offshore transport. Several aspects of the latter process tend to make modeling efforts more difficult. These include:

1. A breaking wave/bore propagation model suitable for predicting oscillatory velocity asymmetries and mean on-offshore currents inside the surfzone has been lacking.

2. The effect of the downslope component of the sediment load on the on-offshore sediment transport has generally not been adequately represented in the sediment transport model used.

3. The dynamic near-equilibrium of on-offshore transport on a stable beach tends to magnify the importance of second order effects such as the vertical velocity structure or the threshold criteria for sediment movement.

Because of these difficulties, a number of past models have sought to correlate on-offshore sediment transport with average incident wave conditions, without considering many of the details of the fluid-sediment motions. Some examples of this type of approach are discussed in Seymour and King (1982) and include: the wave steepness models by Dean (1973) and Hattori and Kawamoto (1981); the wave height models by Saville (1957), Aubrey (1978) and Short (1978); and the wave power model by Short (1978). A few models have included some degree of detail of the fluid sediment motions. Examples of models which consider wave velocity asymmetry, downslope sediment loads, and mean on-offshore currents include those by Inman and Frautschy (1966), Bowen (1980) and Bailard (1981). These three models are based on adaptations of Bagnold's (1963, 1966) sediment transport model for streams. Bailard's (1981) model is the most complete in that nonnormal wave incidence is permitted as is the presence of longshore currents.

A common aspect of Bowen's (1980) and Bailard's (1981) energetics-based models is the importance of several surfzone velocity moments in determining the direction and magnitude of the on-offshore sediment transport. These moments are defined in terms of idealized monochromatic waves. However, they can be extended to spectral wave inputs using the techniques described in Guza and Thornton (in review). Using Stokes' second-order wave solution and Longuet-Higgins' (1953) bottom streaming model to estimate the wave velocity asymmetry and mean on-offshore

current, respectively, Bowen (1980) and Bailard (1981) were able to qualitatively describe the equilibrium beach profile as a function of the incident wave amplitude a ; the wave frequency σ ; and sediment fall velocity W (Figure 1). Small amplitude, long period waves were found to produce a steep beach while large amplitude, short period waves were found to produce a flat beach. Large diameter sand grains with high fall velocities were also observed to produce steeper beaches than smaller diameter sand grains with lower fall velocities. These results qualitatively confirm observed beach behavior, but neither the nonlinear wave solution nor the mean current solutions are valid inside the surfzone. Unfortunately other wave shoaling models are equally invalid inside the surfzone due to the dissipation of energy and the generation of turbulence associated with the breaking wave.

Because of the inability of existing wave shoaling models to accurately describe wave velocity asymmetry and mean on-offshore currents inside the surfzone, little is known about these quantities. Two recent studies have described limited field measurements of these quantities (Huntley and Bowen, 1975; Guza and Thornton, in review). These studies suggest that the magnitudes of these quantities may be a function of the incident wave conditions, the beach slope, and the local water depth.

Because of a lack of good field data, very few comparative evaluations have been made of existing on-offshore sediment transport models. Recently, however, a series of large-scale field experiments have been conducted as part of the Nearshore Sediment Transport Study (NSTS). The first of these experiments was conducted at Torrey Pines Beach, Calif., during November 1978. During this time, simultaneous measurements of deepwater wave characteristics, surfzone nearbottom velocity distributions, and beach profile changes were measured. Details of the experiment are described in Gable (1979). Seymour and King (1982) utilized this data set to evaluate a variety of on-offshore sediment transport models. Although none of the models showed great ability to predict the measured beach volume changes, the simple models utilizing incident wave height, wave power, or wave steepness could account for between 25% to 35% of the total variance in the beach volume measurements. The only energetics-based model evaluated was a bedload model developed by Bailard and Inman (1981) which performed rather poorly by comparison.

For two reasons the poor performance of Bailard and Inman's bedload model is not surprising. First, studies by Bowen (1980) and Bailard (1981) have suggested that most of the transport in the surfzone is by nearbottom suspension. Second, the velocity moments controlling on-offshore sediment movements in Bailard and Inman's (1981) bedload model are very sensitive to infrequent data errors that are present on the tapes. Without a careful prescreening of the data, the estimated on-offshore sediment transports must be viewed as suspect.

The success of Bowen's (1980) and Bailard's (1981) total load surfzone models in qualitatively describing the variation of the equilibrium beach slope with wave and sediment characteristics suggested that Bagnold's energetics approach may have some ability to quantitatively predict on-offshore sediment transport. Consequently, a study was initiated to explore the ability of Bailard's (1981) total load sediment transport model to predict daily beach volume changes using data from the NSTS experiment at Torrey Pines Beach, Calif., in November 1978. The objectives of the study were threefold. First, the model was tested in its ability to predict daily beach volume changes using relatively short (1- to 2-hour) surfzone current meter records. Second, a relationship was sought between average values of surfzone velocity moments and incident wave characteristics. Lastly, these average surfzone velocity moments were used to predict on-offshore sediment transport as a function of significant wave height.

SEDIMENT TRANSPORT MODEL

Bailard's (1981) total load sediment transport model is based on an adaptation of Bagnold's (1963, 1966) energetics-based total load sediment transport model for streams. The latter is generalized for time-varying flow over an arbitrarily sloping bottom, resulting in

$$\begin{aligned}
 \langle \vec{i}_t \rangle = & \rho c_f \frac{\epsilon_B}{\tan \phi} \left[\langle |\vec{u}_t|^2 \vec{u}_t \rangle - \frac{\tan \beta}{\tan \phi} \langle |\vec{u}_t|^3 \rangle \hat{i} \right] \\
 & + \rho c_f \frac{\epsilon_S}{W} \left[\langle |\vec{u}_t|^3 \vec{u}_t \rangle - \frac{\epsilon_S}{W} \tan \beta \langle |\vec{u}_t|^5 \rangle \hat{i} \right] \quad (1)
 \end{aligned}$$

where \vec{i}_t = instantaneous sediment transport rate vector
 ρ = density of water
 c_f = drag coefficient of the bed
 ϵ_B = the bedload efficiency factor
 ϕ = internal angle of friction of the sediment
 $\tan \beta$ = the bed slope
 ϵ_S = suspended load efficiency factor
 W = is the fall velocity of the sediment
 \vec{u}_t = instantaneous nearbottom fluid velocity vector
 \hat{i} = unit vector directed upslope
 $\langle \rangle$ = time-average

Note that for both the bedload (first bracketed quantity) and the suspended load (second bracketed quantity), the transport consists of a primary component directed parallel to the instantaneous fluid velocity vector and a secondary component directed downslope. The latter is associated with the downslope gravity component of the sediment load.

Figure 2 depicts a plane contour beach with the x-axis directed shoreward and normal to the beach and the y-axis directed parallel to the beach. The slope of the beach is $\tan \beta$. Considering only the on-offshore sediment transport, Equation 1 becomes

$$\begin{aligned} \langle \vec{i}_x \rangle = & \rho c_f \frac{\epsilon_B}{\tan \phi} \left[\langle |\vec{u}_t|^2 \vec{u}_t \cdot \hat{i} \rangle - \frac{\tan \beta}{\tan \phi} \langle |\vec{u}_t|^3 \rangle \right] \\ & + \rho c_f \frac{\epsilon_S}{W} \left[\langle |\vec{u}_t|^3 \vec{u}_t \cdot \hat{i} \rangle - \frac{\epsilon_S}{W} \tan \beta \langle |\vec{u}_t|^5 \rangle \right] \end{aligned} \quad (2)$$

Equation 2 is assumed to be valid for any nearbottom velocity field and can be directly used with data from a two-axis (x and y) current meter to predict the time-averaged on-offshore transport rate at the current meter location.

For modeling, it is convenient to use a monochromatic wave representation for the nearbottom water velocity field. Bailard (1981) assumed a velocity field composed of an oscillatory velocity component \tilde{u} oriented at an angle α to the x-axis and a steady velocity component \bar{u} oriented at an angle θ to the x-axis (Figure 2). The total velocity vector \vec{u}_t then becomes

$$\vec{u}_t = (\tilde{u} \cos \alpha + \bar{u} \cos \theta) \hat{i} + (\tilde{u} \sin \alpha + \bar{u} \sin \theta) \hat{j} \quad (3)$$

In addition, the oscillatory velocity component is assumed to be asymmetrical being composed of a primary component u_m with frequency σ and a secondary harmonic u_{m2} with frequency 2σ so that

$$\tilde{u} \sim u_m \cos \sigma t + u_{m2} \cos 2\sigma t + \dots \quad (4)$$

Substituting Equations 3 and 4 into Equation 2, Bailard (1981) obtained the idealized on-offshore transport equation

$$\begin{aligned} \langle i_x \rangle = \rho c_f u_m^3 \left\{ \frac{\epsilon_B}{\tan \phi} \left[\psi_1 \cos \alpha + \delta_u^3 + \delta_u \left(\frac{1}{2} + \cos^2 \alpha + \delta_v^2 \right) \right. \right. \\ \left. \left. + \delta_v \sin \alpha \cos \alpha - \frac{\tan \beta}{\tan \phi} u_3^* \right] + \frac{u_m}{W} \epsilon_S \left[\psi_2 \cos \alpha \right. \right. \\ \left. \left. + \delta_u u_3^* - \frac{u_m}{W} \epsilon_S \tan \beta u_5^* \right] \right\} \quad (5) \end{aligned}$$

where

$$\delta = \frac{\bar{u}}{u_m} \quad (6)$$

$$\delta_u = \delta \cos \theta \quad (7)$$

$$\delta_v = \delta \sin \theta \quad (8)$$

$$\psi_1 = \frac{\langle \tilde{u}^3 \rangle}{u_m^3} \quad (9)$$

$$\psi_2 = \frac{\langle |\vec{u}_t|^3 \tilde{u} \rangle}{u_m^4} \quad (10)$$

$$u_3^* = \frac{\langle |\vec{u}_t|^3 \rangle}{u_m^3} \quad (11)$$

$$u_5^* = \frac{\langle |\vec{u}_t|^5 \rangle}{u_m^5} \quad (12)$$

For weak mean currents, Snell's law and the spilling wave hypothesis are sufficient for obtaining estimates of α , u_m , u_3^* , and u_5^* throughout the surfzone as a function of incident wave conditions.† Moreover, a longshore current model (e.g., Longuet-Higgins, 1970) is sufficient for estimating the magnitude of δ_v . Unfortunately, the two skewness parameters ψ_1 and ψ_2 , as well as the normalized mean onshore current δ_u , cannot be estimated from present surfzone wave shoaling models. Well outside the surfzone, where a rippled bottom generally invalidates the present sediment transport model, ψ_1 , ψ_2 and δ_u may be estimated from Stokes' second-order wave solution and Longuet-Higgins' (1953) bottom-streaming solution. Assuming negligible longshore currents, weak on-offshore currents and normal incidence, Bowen (1980) and Bailard (1981) used these solutions to obtain the previously discussed solution for the equilibrium beach slope.

Neither Stokes' second-order wave solution nor Longuet-Higgins' (1953) bottom-streaming solution, however, are valid inside the surfzone. Other wave shoaling models are invalid there as well. One of the objectives of this study was to examine measured surfzone values of ψ_1 , ψ_2 , and δ_u using data from the NSTS Torrey Pines experiment (Gable, 1979).

†Note, however, that Guza and Thornton (in review) found that the commonly assumed spilling wave hypothesis did not lead to an accurate estimate of u_m .

In this respect, the present study was a continuation of the study by Guza and Thornton (in review), who showed that the quantities defined in Equation 5 are meaningful only for monochromatic waves incident from a single direction α . On an actual beach the incident waves compose a spectrum with varying energy content at different frequencies and wave angles. As a result, Guza and Thornton (in review) defined equivalent quantities for Ψ_1 , Ψ_2 , u_m , u_3^* and u_5^* , which may be estimated from the measured current meter data. In addition, a series of six equivalent wave angles, α_1 to α_6 , are defined for the different quantities in Equation 5. Equation 5 then becomes (Guza and Thornton, in review)

$$\begin{aligned} \langle i_x \rangle = \rho c_f u_m^3 & \left\{ \frac{\epsilon_B}{\tan \phi} \left[\Psi_1 \cos \alpha_1 + \delta_u^3 + \delta_u \left(\frac{1}{2} + \cos^2 \alpha_2 \right. \right. \right. \\ & \left. \left. \left. + \delta_v^2 \right) + \delta_v \sin \alpha_3 \cos \alpha_3 - \frac{\tan \beta}{\tan \phi} u_3^* \right] + \frac{u_m}{W} \epsilon_S \right. \\ & \left. \left[\Psi_2 \cos \alpha_5 + \delta_u u_3^* - \frac{u_m}{W} \epsilon_S \tan \beta u_5^* \right] \right\} \end{aligned} \quad (13)$$

where

$$u_m^2 = 2 (\langle \tilde{u}^2 \rangle + \langle \tilde{v}^2 \rangle) \quad (14)$$

$$u_m^3 \Psi_1 = \left[\langle \tilde{u}(\tilde{u}^2 + \tilde{v}^2) \rangle^2 + \langle \tilde{v}(\tilde{u}^2 + \tilde{v}^2) \rangle^2 \right]^{1/2} \quad (15)$$

$$u_m^4 \Psi_2 = \left[\langle |\vec{u}_t|^3 \tilde{u} \rangle^2 + \langle |\vec{u}_t|^3 \tilde{v} \rangle^2 \right]^{1/2} \quad (16)$$

$$u_m^3 u_3^* = \langle |\vec{u}_t|^3 \rangle = \left[\bar{u}_T^2 + \tilde{u}_t^2 + 2\tilde{u}_t \bar{u}_T \cos(\alpha_4 - \theta) \right]^{3/2} \quad (17)$$

$$u_m^5 u_5^* = \langle |\vec{u}_t|^5 \rangle = \left[\bar{u}_T^2 + \tilde{u}_t^2 + 2\tilde{u}_t \bar{u}_T \cos(\alpha_6 - \theta) \right]^{5/2} \quad (18)$$

with

$$\tilde{u}_t^2 = \tilde{u}^2 + \tilde{v}^2 \quad \text{and} \quad \bar{u}_T^2 = \bar{u}^2 + \bar{v}^2$$

In addition, the equivalent angles α_1 , α_2 , α_3 , and α_5 may be calculated as follows

$$\tan \alpha_1 = \frac{\langle \tilde{v}^3 + \tilde{u}^2 \tilde{v} \rangle}{\langle \tilde{u}^3 + \tilde{u} \tilde{v}^2 \rangle} \quad (19)$$

$$\tan \alpha_2 = \left(\frac{\langle \tilde{v}^2 \rangle}{\langle \tilde{u}^2 \rangle} \right)^{1/2} \quad (20)$$

$$\sin 2\alpha_3 = \frac{4 \langle \tilde{u} \tilde{v} \rangle}{u_m^2} \quad (21)$$

$$\tan \alpha_5 = \frac{\langle \left| \frac{\vec{u}_t}{u_t} \right|^3 \tilde{v} \rangle}{\langle \left| \frac{\vec{u}_t}{u_t} \right|^3 \tilde{u} \rangle} \quad (22)$$

Guza and Thornton (in review) analyzed 2 days of NSTS Torrey Pines data and presented estimated values for ψ_1 , ψ_2 , u_m , δ_u , u_3^* , u_5^* , α_1 , α_2 , α_3 , and α_5 as a function of depth. They found that for the conditions studied $\delta_u \ll 1$, $\delta_v \ll 1$, and α_2 and α_3 were small. In addition, the present study has shown generally that $\cos \alpha_1 \sim 1$ and $\cos \alpha_5 \sim \pm 1$. As a result for conditions such as those at Torrey Pines Beach, Equation 13 can be simplified to

$$\langle i_x \rangle \approx \rho c_f u_m^3 \left\{ \frac{\epsilon_B}{\tan \phi} \left[\psi_1 + \frac{3}{2} \delta_u - \frac{\tan \beta}{\tan \phi} u_3^* \right] + \frac{u_m}{W} \epsilon_S \left[\psi_2 + \delta_u u_3^* - \frac{u_m}{W} \epsilon_S \tan \beta u_5^* \right] \right\} \quad (23)$$

where ψ_1 and ψ_2 are assumed to be equal to $\psi_1 \cos \alpha_1$ and $\psi_2 \cos \alpha_5$, respectively, and can thus take on negative (offshore-directed) values.

Using Equation 23, estimating the on-offshore sediment transport rate becomes a relatively simple matter of estimating u_m , ψ_1 , ψ_2 , δ_u , u_3^* , and u_5^* . One of the objectives of the present study was to determine whether these parameters can be estimated from average gross characteristics of the incident waves.

DATA ANALYSIS

Data Set Description

In November 1978, a month-long field experiment was conducted at Torrey Pines Beach as part of the Nearshore Sediment Transport Study (NSTS). Torrey Pines Beach, Calif., is a plane-contoured beach with a concave profile. The slope of the beach face is approximately 0.05, decreasing to about 0.02 within the surfzone (Figure 3). The sand on the beach is moderately well sorted with a mean diameter of 0.17 mm. The beach exhibits no bar-trough features. The experiment consisted of the simultaneous measurement of incident wave conditions, nearbottom water velocities distributions, sand tracer movements, and beach profile changes. The incident wave climate was measured in 10 meters of water with a linear array of pressure sensors. Nearbottom water velocities were measured using dual-axis (x and y) electromagnetic current meters, while the beach profiles were measured with a rod and transit onshore and a fathometer offshore.

The current meters were placed in a cross-shaped pattern within the nearshore area. Referring to Figure 4, 7 current meters formed a line perpendicular to the beach and ranging in depth from 0.25 meters to 6 meters relative to mean sea level (MSL). Ten other current meters formed a line parallel to the beach at a depth of about 1 meter relative to MSL. The beach profiles were measured at five ranges along the beach. Further details of the measurements and the experiment can be found in Gable (1979).

Model Evaluation

One of the objectives of the present study was to evaluate the ability of Equation 2 to predict daily beach volume changes using NSTS data. The approach used to evaluate Equation 2 was the same as that used by Seymour and King (1982). The daily beach volume changes were computed by integrating the beach profile changes across 100 meters of beach face. The seaward extremity of the integration interval roughly

coincided with the location of the shore-parallel current meters so that a simple box model analysis could be used to estimate the beach volume changes. In the present study the flux of sand into or out of the box was predicted by Equation 2 using the measured current meter data from each shore parallel current meter. The measured volume changes used in the present study are those tabulated by Seymour and King (1982).

Equation 2 has 3 free parameters: the bed friction coefficient c_f , the bedload efficiency factor ϵ_B , and the suspended load efficiency factor ϵ_S . In the present study, a value of 0.005 was selected for c_f , based on an analysis of longshore current data at Silver Strand Beach, Calif., (Bailard, 1981). This beach has a bed slope similar to that at Torrey Pines Beach (0.034) and is located 15 miles to the south. On the other hand, Thornton and Guza (1982) examined longshore currents at Torrey Pines Beach and concluded that $c_f = 0.01 \pm 0.01$. As evidenced by the large uncertainty interval, Thornton and Guza concluded that the Torrey Pines data set was not particularly good for estimating the size of c_f .

The bedload and suspended load efficiency factors ϵ_B and ϵ_S are the remaining two free parameters in Equation 2. Rewriting Equation 2 to isolate these factors, we obtain

$$\langle i_x \rangle = \epsilon_B I_A + \epsilon_S I_B - \epsilon_S^2 I_C \quad (24)$$

where

$$I_A = \frac{\rho c_f}{\tan \phi} \left[\langle |\vec{u}_t|^2 \vec{u}_t \cdot \hat{i} \rangle - \frac{\tan \beta}{\tan \phi} \langle |\vec{u}_t|^3 \rangle \right] \quad (25)$$

$$I_B = \frac{\rho c_f}{W} \langle |\vec{u}_t|^3 \vec{u}_t \cdot \hat{i} \rangle \quad (26)$$

$$I_C = \frac{\rho c_f}{W^2} \tan \beta \langle |\vec{u}_t|^5 \rangle \quad (27)$$

Equation 24 expresses the on-offshore transport rate in terms of immersed weight transport. The volumetric transport rate Q_x may be related to the immersed weight transport rate $\langle i_x \rangle$ by the following equation

$$Q_x = \frac{\langle i_x \rangle}{(\rho_s - \rho) g N_o} \quad (28)$$

where ρ_s = density of the sand grains

g = gravity

N_o = "at rest" volume concentration of sediment assumed here to be 0.6

The procedure used to estimate the bedload and suspended load efficiencies ϵ_B and ϵ_S was as follows. First, daily estimates of I_A , I_B and I_C were obtained from 64-minute records for each of the 10 shore-parallel current meters. These estimates were averaged together to form a single daily estimate that was assumed to be representative of the general experiment area. Table 1 contains a summary of the estimated values for I_A , I_B , and I_C . Next, a correlation analysis was conducted to determine the lag time between the predicted volume changes and the measured changes. To do this, previously estimated values of $\epsilon_B = 0.21$ and $\epsilon_S = 0.025$ obtained from longshore transport data (Bailard, 1981) were used with Equation 24. Following the rationale of Seymour and King (1982), only lag times of zero and 1 day were considered. The maximum correlation ($R^2 = 0.19$) occurred with a lag time of 1 day, as was found by Seymour and King (1982) for a number of other models using the same data set. The lag time result was relatively insensitive to different values of ϵ_B and ϵ_S , although R^2 varied as would be expected.

The relatively small value of R^2 (0.19) means that only 19% of the observed variance in the measured beach volume changes is accounted for by the model. By comparison, using the same data set, Seymour and King (1982) found R^2 values as high as 0.35 for a simple model relating the wave steepness to on-offshore sediment movements. Possible reasons for the relatively poor performance of the present model are discussed below.

A nonlinear least-squares estimation procedure (Draper and Smith, 1966), was used to estimate ϵ_B and ϵ_S from the data in Table 1. The estimation procedure required constructing a contour map of the mean square error S , defined as

$$S(\epsilon_B, \epsilon_S) = \frac{1}{n-2} \sum_{i=1}^n (v_{\text{meas}} - v_{\text{pred}})^2 \quad (29)$$

where n = number of data pairs (17)

v_{meas} = measured beach volume change with a 1-day lag time

v_{pred} = predicted beach volume change

Figure 5 shows a plot of S versus ϵ_B and ϵ_S . The minimum mean square error occurred at $\epsilon_B = 0.10$ and $\epsilon_S = 0.02$. These estimates are quite similar in size to those estimated by Bailard (1981) ($\epsilon_B = 0.21$ and $\epsilon_S = 0.025$) based on longshore transport data. Figure 5 also shows that 95% confidence limits on ϵ_B and ϵ_S . The limits are much broader than for those in Bailard (1981) and reflect, in part, the low degree of correlation between the measured and predicted beach volume changes. In both cases, however, the predicted values of ϵ_B and ϵ_S fall within each other's areas of uncertainty.

The low degree of correlation between measured and predicted beach volume changes raises questions about the ability of Bailard's (1981) sediment transport model to predict on-offshore sediment transports. It should be recognized, however, that predicting on-offshore sediment transport rates is a severe test of a model because the net transport represents a small difference between two relatively large instantaneous on and offshore sediment transports. Small biases in either the onshore or offshore direction can significantly influence the predicted direction and magnitude of the net transport. In addition, a sensitivity analysis was performed whereby, for selected days, estimates of the on-offshore transport rate were calculated for consecutive 64-minute segments of time. For a day with moderate waves (November 4), the standard deviation of these estimates was 22% of the predicted mean for four consecutive segments. For a day with large waves (November 12), this value increased to 46% for three consecutive segments. In addition, individual current meters showed a much wider range of variation (up to 800%) between consecutive hours. These results suggest that although

the beach may generally be in a state of near dynamic equilibrium, small changes in the incident wave conditions or the tide may strongly influence short-term local on-offshore movements. As a result, for the data set studied, short current meter records of 1 to 4 hours may not be of sufficient duration to estimate the daily beach volume changes. Alternatively, the model may simply be unable to estimate on-offshore sediment movements. The present data set is insufficient to resolve this question.

Velocity Moment Magnitudes

The above discussion concerned the ability of Equation 2 to predict on-offshore sediment transports. Equation 2, however, requires a full knowledge of the surfzone velocity field and is, therefore, not very useful for modeling. Equation 23 is a greatly simplified version of Equation 2, which is potentially more useful for modeling on-offshore sediment transports. Unfortunately, this equation still contains a number of surfzone velocity moments, about which little is known. These include the wave velocity skewness parameters Ψ_1 and Ψ_2 (Equations 9 and 10), the normalized onshore current δ_u (Equation 7), and the normalized velocity magnitudes u_3^* and u_5^* (Equations 11 and 12).

As previously discussed, only u_m , u_3^* , and u_5^* can be estimated using linear wave theory. For normally incident monochromatic waves and weak mean currents, u_3^* and u_5^* are equal to 0.424 and 0.339, respectively, while for a Gaussian input with the same total variance their values become 0.562 and 1.13, respectively (Guza and Thornton, in review). Guza and Thornton found that a Gaussian distribution was most nearly correct.

Assuming wave saturation and spilling waves, linear wave theory suggests that

$$u_m = \frac{\gamma}{2} \sqrt{g h} \quad (30)$$

where $\gamma = H/h$

h = local water depth

H = local wave height

Equation 30 suggests that u_m should decrease from a maximum at the breakpoint to zero at the beach. In fact, field measurements show (Guza and Thornton, in review) that u_m was almost constant across the surfzone, due to the presence of low frequency surf beat motions within the inner part of the surfzone. The remaining parameters in Equation 23 (Ψ_1 , Ψ_2 , and δ_u) are zero for linear waves but nonzero for nonlinear waves. Measurements (Huntley and Bowen, 1975, Guza and Thornton, in review) have shown that they are in fact nonzero under actual field conditions and may vary in magnitude and sign with varying incident wave conditions.

One of the objectives of the present study was to investigate the magnitudes of these surfzone parameters using the NSTS Torrey Pines data set and determine whether their magnitudes and distributions across the surfzone could be estimated from incident wave conditions. Values for the parameters Ψ_1 , Ψ_2 , δ_u , u_3^* and u_5^* were estimated from 64-minute-long records for each of the seven shore perpendicular current meters closest to shore. Because of the variability of these quantities, mean surfzone values were obtained by averaging the results of all seven current meters. Table 2 is a summary of these average surfzone velocity parameters and the incident wave characteristics for each of the 9 days investigated. The wave characteristics were obtained from Guza and Thornton (1980; in review) who analyzed pressure sensor records measured in 10 meters of water. In addition, Seymour and King (1982) reported significant deep water wave steepnesses for each day. These too are tabulated in Table 2.

Linear and second-order wave theory suggests that the even velocity moments u_m , u_3^* , and u_5^* should be related to the significant wave height, while the odd velocity moments Ψ_1 , Ψ_2 , and δ_u should also be related to the deep water wave steepness and the average beach slope. Recent studies of surfzone wave dynamics by Wright et al. (1978, 1982), Guza and Thornton (1982), Bowen (1980), Huntley and Bowen (1975) and others suggest that long period surfzone motions due to edge waves, surf beat and other infra-gravity wave motions may influence nearshore velocity fields and the resulting nearshore topography. The amplitudes of these

motions are thought to be sensitive to a surf similarity parameter ϵ introduced by Battjes (1974), Guza and Inman (1975), and others. The parameter is defined as

$$\epsilon = a \sigma^2 / g \tan^2 \beta \quad (31)$$

where a = half the breaking wave height

For small values of ϵ , less than 2.0 to 2.5, reflective conditions with surging breakers are observed and subharmonic edge wave generation may be present. For larger values of ϵ , dissipative conditions should prevail, and surf beat may be present.

For the conditions of Torrey Pines Beach, dissipative conditions prevailed, with spilling waves and a wide surfzone. The range of significant wave heights varied from 55 to 140 cm; however the peak wave period varied much less, ranging from approximately 10 to 14 seconds. The variation in mean beach slope during the experiment was also very small, so that the slope was approximately a constant 0.02. As a result, the deep water wave steepness H_S/L_0 and the surf similarity parameter ϵ were primarily a function of the significant wave height H_S . This suggested that for the Torrey Pines data set, a relationship might be sought between all of the relevant surfzone velocity moments and the significant wave height H_S .

Figures 6 through 11 show plots of mean surfzone values of Ψ_1 , Ψ_2 , δ_u , u_m , u_3^* and u_5^* versus H_S . Lacking more data, a linear relationship was sought between variables; the linear regression lines are shown in each figure. These lines are described by the following equations:

$$\Psi_1 = 0.303 - 0.00144 H_S \quad (32)$$

$$\Psi_2 = 0.603 - 0.00510 H_S \quad (33)$$

$$\delta_u = 0.458 - 0.00157 H_S \quad (34)$$

$$u_m = 31.9 + 0.403 H_S \quad (35)$$

$$u_3^* = 0.548 + 0.000733 H_S \quad (36)$$

$$u_5^* = 1.50 + 0.00346 H_S \quad (37)$$

where u_m is measured in cm/sec and H_S in cm.

Figures 6 through 11 also suggest that for the conditions found at Torrey Pines Beach, Ψ_1 , Ψ_2 and δ_u decrease markedly with increasing wave height. This is in direct contrast to Stokes' second-order wave solution and Longuet-Higgins' (1953) bottom-streaming solutions, which predict increasing values of these variables for increasing wave height. The remaining parameters, u_m , u_3^* , and u_5^* , behaved more as would be predicted by linear wave theory. The mean orbital velocity magnitude u_m was found to increase with increasing wave height, while u_3^* and u_5^* were relatively constant. Typical values of u_3^* and u_5^* were 0.6 and 1.2, respectively (very close to the theoretical values based on a Gaussian wave distribution).

Velocity Moment Distributions

While the average surfzone magnitudes of the different velocity moments discussed above are critical in determining general on-offshore sediment movements, spatial details of these movements are reflected by the distribution of the moments across the surfzone. In order to examine these distributions, it was first necessary to normalize the moments by appropriate quantities. For the variables Ψ_1 , δ_u , u_m , u_3^* , and u_5^* , the mean surfzone value of each variable was an appropriate normalizing quantity. The skewness parameter Ψ_2 was more difficult because its mean value changed sign. As a result, a new variable Ψ_2' was defined as follows:

$$\Psi_2' = \Psi_2 - \bar{\Psi}_2 \quad (38)$$

This variable was then normalized by its standard deviation and defined as

$$\Psi_2'^{sd} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n \Psi_2'^2} \quad (39)$$

where n = number of days examined

Figure 12 shows a plot of $\Psi_2'^{sd}$ versus significant wave height.

Figures 13 through 18 are plots of the surfzone distribution of the normalized parameters $\hat{\Psi}_1$, $\hat{\Psi}'_2$, $\hat{\delta}_u$, \hat{u}_m , \hat{u}_3^* , and \hat{u}_5^* as a function of the normalized surfzone position x^* , which is defined as the distance from shore divided by the nominal surfzone width. For the present study, the surfzone width was taken as the distance from the breakpoint to the still water shoreline. Moreover, the breakpoint depth was assumed to be equal to $H_s/0.78$. A cursory examination of Figures 13 to 18 reveals that there is considerably more scatter in the plots of $\hat{\Psi}'_2$ and $\hat{\delta}_u$ than in the plots of the other variables. These two parameters are closely related and the variability in $\hat{\Psi}'_2$ is believed to primarily be a reflection of the variability in $\hat{\delta}_u$. As previously mentioned, the mean on-offshore current was the most variable surfzone quantity examined. This was again the case in the surfzone distributions.

Considering the surfzone distributions of $\hat{\Psi}_1$, \hat{u}_m , \hat{u}_3^* , and \hat{u}_5^* (Figures 13, and 16 through 18), each variable appears to have a predictable distribution. Whereas $\hat{\Psi}_1$, \hat{u}_3^* , and \hat{u}_5^* increase with increasing distance from shore, \hat{u}_m is seen to decrease with increasing distance from shore. The data for $\hat{\Psi}'_2$ and $\hat{\delta}_u$ are so scattered that no definite trends are evident.

ON-OFFSHORE TRANSPORT SIMULATION

The simplified on-offshore sediment transport model Equation 23 was found to contain several surfzone velocity moments about which little was known. These moments included the wave velocity skewness parameters Ψ_1 and Ψ_2 , the mean on-offshore current δ_u , the orbital velocity magnitude u_m , and the normalized total velocity magnitudes u_3^* and u_5^* . For the wave and beach conditions present during the NSTS Torrey Pines experiment, average surfzone values for those parameters were found to be linearly related to the significant wave height H_s through Equations 32 to 37. Combining Equation 23 with Equations 32 to 37, the average surfzone on-offshore transport rate and direction can be predicted as a function of the significant wave height and the sediment fall velocity. The

other free parameters in Equation 23 include the bed drag coefficient c_f , the bedload efficiency ϵ_B , and the suspended load efficiency ϵ_S . For the present study these variables were assumed to be equal to 0.005, 0.21, and 0.025, respectively. These values were selected on the basis of an analysis of field and laboratory longshore transport data as discussed by Bailard (1981). Other similar values can be selected without qualitatively changing the results.

Figure 19 shows a plot of the predicted on-offshore sediment transport rate as a function of the significant wave height. The sediment fall velocity was assumed to be equal to 4 cm/sec, which is appropriate for the sand found at Torrey Pines Beach. The bedload-transport rate is depicted by the dashed line, the suspended load transport rate by the dotted line, and the total load transport rate by the solid line. Figure 19 suggests that, for conditions similar to those at Torrey Pines Beach during the NSTS experiment, sand is moved onshore when the significant wave height is less than approximately 90 cm and offshore when it is greater. The maximum onshore transport rate ($0.8 \text{ m}^3 \text{ m}^{-1} \text{ day}^{-1}$) occurs when H_s is equal to approximately 59 cm. For waves with a significant wave height greater than approximately 150 cm, the transport rate is larger by a factor of 10 and directed offshore. Under most conditions, the predicted bedload and suspended load transports are both in the same direction. Near the null point ($H_s \sim 90 \text{ cm}$), however, the bedload is directed offshore while the suspended load is directed onshore.

Qualitatively, Figure 19 tends to confirm some aspects of observed beach behavior. During prolonged periods of small waves, a beach is seen to slowly accrete. With the appearance of the first large swell, however, the beach can cut back dramatically within a few days. Figure 19 supports this observation. In addition, Figure 19 qualitatively supports Short's (1978) observations at several Australian beaches that the neutral point wave height separating accretion from erosion was equal to 120 cm. Although the present study suggests a neutral point wave height of 90 cm, the magnitudes are similar.

Because the wave velocity characteristics are independent of grain size, the effect of different sediment fall velocities on the total load sediment transport rate may be predicted as well (Figure 20). Increasing

the fall velocity is seen to decrease the magnitude of the on-offshore transport rate without seriously affecting the value of the neutral point wave height. As a result, beaches with fine sand would be expected to experience greater changes in volume than equivalent beaches with coarse sand.

DISCUSSION

The applicability of these results to other sites and to other wave conditions is unknown; however, it is hypothesized that the results may be relatively site and time specific. Generally speaking, for monochromatic waves and plane contour beaches, the surfzone hydrodynamics should be a function of the incident wave height, direction, and period, as well as the beach slope. For random waves, the shapes of the energy and directional spectrums may also be important. During the NSTS Torrey Pines experiment, the waves were almost normally incident with a near uniform period. Moreover the beach slope changed little during the month. The only parameter that varied to any significant degree was the wave height, which varied by a factor of 3. As a result, Figures 19 and 20 cannot be directly extended to more general conditions. Neglecting for a moment the effects of incident wave angle and wave period, physical reasoning suggests that there should be a family of curves similar in shape to those in Figures 19 and 20 that vary with beach slope. The primary difference between different curves would be the position of their neutral point wave height. For flat beaches typical of large wave conditions, the neutral point wave height would be larger, while for steeper beach conditions the neutral point wave height would be smaller. Figures 19 and 20 are believed to represent transition conditions. Partial support for this hypothesis is provided in the study by Aubrey (1978), who found that future beach profiles at Torrey Pines Beach were best predicted when the existing beach profile shape and the incident wave height were known. Clearly, more data sets with a wider range of beach slope and wave conditions are needed to develop a useful beach profile predictive capability.

Further discussion is also needed concerning possible errors in the estimated surfzone velocity moments. The odd moment quantities Ψ_1 , Ψ_2 , and δ_u , in effect, represent small differences between large numbers, so they are especially sensitive to small errors in the measured current meter data. Because of this sensitivity, considerable care was exercised in prescreening the data. The quantity u_5^* was found to be particularly sensitive to data errors and was used as an indicator of bad sections of data. In spite of this care, the data itself could be subject to an inherent bias due to current meter inaccuracies.

One error in particular may be that the mean on-offshore currents were a manifestation of a current meter rectification process.* Some evidence, however, suggests that rectification may not have been too significant. First, if rectification were important the mean offshore current might be expected to be a function of u_m . The latter was found to be relatively constant across the surfzone, while the mean offshore currents varied significantly. This tends not to support a rectification hypothesis. Moreover, Wright et al. (1978) reported measuring onshore currents in the upper part of the water column inside the surfzone and offshore currents near the bottom. These measurements were made with small ducted fan current meters unlike the electromagnetic current meters used in the NSTS experiments and, presumably, would not be subject to the same rectification characteristics. Nevertheless, until more exhaustive studies are done on the response of the electromagnetic current meters, the magnitudes and directions of the mean on-offshore currents must be suspect.

It is disappointing that the present sediment transport model is not more accurate at predicting the measured beach volume changes. The reason for its lack of accuracy is unknown. The variability in the estimated on-offshore transport rates between consecutive hourly data sets suggests, however, that the on-offshore transport rate may vary significantly on an hourly basis due to small changes in the incident wave field and the tide. The latter changes the position of the surfzone relative to the existing beach profile, which can significantly

*From personal communication with R. T. Guza and D. G. Aubrey.

alter the breaking wave characteristics. As a result, it may be intrinsically difficult to test the capability of an on-offshore sediment transport model to predict daily beach volume changes using current meter records of very limited duration.

In addition, some of the measured beach volume changes seem to be anomalous in light of our present limited knowledge. In particular, the large on-offshore rates of sand movements during periods of small waves on November 6, 7, and 20 are difficult to understand. It would appear that wave energy should have been insufficient to generate this volume of sediment transport. One possible explanation may be a temporary local convergence or divergence of the longshore transport rate. Another explanation may be inaccuracies in the beach profile measurements.

CONCLUSIONS

Based on the results of this study, the following conclusions can be made:

1. A thorough evaluation of Bailard's (1981) surfzone sediment transport model using daily beach volume measurements was not possible due to inadequate surfzone current meter record lengths and to possible inaccuracies in the beach profile measurements.
2. Predicting beach volume changes using a highly simplified form of Bailard's (1981) surfzone sediment transport model appears promising. Analysis of additional surfzone current meter data sets having different wave and beach slope characteristics is necessary before a useful predictive capability can be developed.
3. Average surfzone wave velocity moments were found to be a linear function of significant wave height. Additional data sets are needed to determine their relationships to wave period and average beach slope.

4. Except for the mean on-offshore current $\hat{\delta}_u$, and the second skewness parameter $\hat{\Psi}_2$, the normalized surfzone distributions of the wave velocity moments appear to exhibit a predictable form of behavior.

5. Without analysis of additional data sets, the degree of generality of these results is unknown.

RECOMMENDATIONS

The following research is needed to develop a more generally valid on-offshore sediment transport model:

1. Investigate pertinent surfzone velocity moments on beaches with significantly different beach slopes and wave periods than those encountered at Torrey Pines Beach. The NSTS Leadbetter Beach data set does provide a beach with a steeper beach slope, so this would be a likely first candidate.

2. The significance of ignoring threshold of motion effects in the present model must be critically evaluated.

3. A more detailed treatment of the drag coefficient c_f may be warranted. Ideally, the coefficient should be estimated from longshore current data.

4. Sand tracer studies over a very limited area (several meters) in conjunction with a single current meter might be beneficial in evaluating potential sediment transport models.

REFERENCES

Aubrey, D. G. (1978). Statistical and dynamical prediction of changes in natural sand beaches, Ph. D. thesis, University of California at San Diego. San Diego, Calif., 1978.

Bagnold, R. A. (1963). "Mechanics of marine sedimentation," *The Sea: Ideas and Observations*, vol 3. New York, N.Y., Interscience Publishers, 1963, pp. 507-526.

Bagnold, R. A. (1966). "An approach to the sediment transport problem from general physics," U.S. Geological Survey Professional Paper, no. 422-I, 1966, 37 pp.

Bailard, J. A. (1981). "An energetics total load sediment transport model for a plane sloping beach," *Journal of Geophysical Research*, vol 86, no. C11, 1981, pp 10938-10954.

Bailard, J. A., and D. L. Inman (1981). "An energetics bedload transport model for a plane sloping beach; local transport," *Journal of Geophysical Research*, vol 86, no. C3, 1981, pp 2035-2043.

Battjes, J. A. (1974). "Surf similarity," in *Proceedings of the Fourteenth Coastal Engineering Conference*, Copenhagen, Denmark, Jun 24-28, 1974. New York, American Society of Civil Engineers, 1975, pp 466-479.

Bowen, A. J. (1980). "Simple models of nearshore sedimentation; beach profiles and longshore bias," in *Proceedings of the Conference on Coastline of Canada*, Halifax, 1978. Geological Survey of Canada, 1980.

Dean, R. G. (1973). "Heuristic models of sand transport in the surf zone," in *Proceedings of the Conference on Engineering Dynamics in the Surf Zone*, Sydney, Australia. New York, American Society of Civil Engineers, 1973, 7 pp.

Draper, N. R., and H. Smith (1966). *Applied regression analysis*. New York, N.Y., John Wiley & Co., 1966, 407 pp.

Gable, C. G., Editor (1979). *Report on data from the nearshore sediment transport study experiment at Torrey Pines Beach, California, November-*

December, 1978. University of California at San Diego, Institute of Marine Resources, IMR Reference No. 79-8. San Diego, Calif., 1979, 142 pp.

Guza, R. T., and D. L. Inman (1975). "Edge waves on beach cusps," *Journal of Geophysical Research*, vol 80, no. 21, pp 2997-3012.

Guza, R. T., and E. B. Thornton (1980). "Local and shoaled comparisons of sea surface elevations, pressures and velocities," *Journal of Geophysical Research*, vol 85, no. C3, 1980, pp 1524-1530.

Guza, R. T., and E. B. Thornton (1982). "Swash oscillations on a natural beach," *Journal of Geophysical Research*, vol 87, no. C1, pp 483-491.

Guza, R. T., and E. B. Thornton (in review). "Velocity moments in the surf zone," *Journal of Coastal Engineering*.

Hattori, M., and R. Kawamata (1981). "Onshore-offshore transport and beach profile change," in *Proceedings of the Conference on Coastal Engineering, Sydney, Australia, Mar 23-28, 1980*. New York, American Society of Civil Engineers, pp 1175-1194.

Huntley, D. A., and A. J. Bowen (1975). "Comparisons of the hydrodynamics of steep and shallow beaches," *Nearshore Sediment Dynamics and Sedimentation*. New York, N.Y., John Wiley & Co., 316 pp.

Inman, D. L., and R. A. Bagnold (1963). "Littoral processes," *The Sea: Ideas and Observations*, vol 3. New York, N.Y., Interscience Publishers, 1963, pp 529-533.

Inman, D. L., and J. D. Frautschy (1966). "Littoral processes and the development of shorelines," in *Proceedings of Coastal Engineering, Santa Barbara, Calif.* New York, American Society of Civil Engineers, Specialty Conference, pp 511-536.

Komar, P. D. (1971). "The mechanics of sand transport on beaches," *Journal of Geophysical Research*, vol 76, no. 3, 1971, pp 713-721.

Longuet-Higgins, M. S. (1953). "Mass transport in water waves," *Philosophical Transactions of the Royal Society, London, England, Series A*, vol 245, 1953, pp 535-581.

Longuet-Higgins, M. S. (1970). "Longshore currents generated by obliquely incident sea waves, 2," *Journal of Geophysical Research*, vol 75, no. 33, 1970, pp 6790-6801.

Saville, T., Jr. (1957). "Scale effects in two-dimensional beach studies," in *Proceedings of International Association of Hydraulics Research*, Lisbon, Portugal, 1957.

Seymour, R. J., and D. B. King (1982). "Field comparisons of cross-shore transport models," *Journal of Waterway Port, Coastal and Ocean Engineering*, American Society of Civil Engineers, vol 108, no. WW2, pp 163-179.

Short, A. D. (1978) "Wave power and beach stages: A global model," in *Proceedings of the Sixteenth Coastal Engineering Conference*, Hamburg, Germany, Aug 27-Sep 3, 1978, vol 11. New York, American Society of Civil Engineers, 1978, pp 1145-1162.

Thornton, E. B., and R. T. Guza (1982). "Longshore currents and bed shear stress," *Directional Wave Spectra Applications, '81, Specialty Conference*, Berkeley, Calif. New York, American Society of Civil Engineers, 1982, pp 67-385.

Wright, L. D., B. G. Thom, and J. Chappel (1978). "Morphodynamic variability of high-energy beaches," in *Proceedings of the Sixteenth Conference Coastal Engineering*, Hamburg, Germany, Aug 27-Sep 3, 1978. New York, American Society Civil Engineers, 1978, pp 1180-1194.

Wright, L. D., R. T. Guza, and A. D. Short (1982). "Dynamics of a high-energy dissipative surfzone," *Marine Geology*, vol 45, pp 41-62.

Table 1. Estimated and Measured Beach Volume Changes and Incident Wave Characteristics

Day (Nov 1978)	I_A (dyne $cm^{-1} sec^{-1}$ $\times 10^6$)	I_B (dyne $cm^{-1} sec^{-1}$ $\times 10^4$)	I_C (dyne $cm^{-1} sec^{-1}$ $\times 10^4$)	V_{pred} ($m^3 m^{-1} day^{-1}$)	V_{meas} (lagged 1 day) ($m^3 m^{-1} day^{-1}$)
4	9.87	3.76	4.00	0.72	0.21
5	-14.8	1.18	6.42	0.32	-0.28
6	-9.78	0.65	3.05	0.02	-8.2
7	10.2	2.54	1.78	0.52	9.3
8	-17.5	0.66	1.94	-0.27 ^a	1.45
10	-61.5	-10.6	10.2	-2.41 ^a	1.08
11	-115	-15.6	12.1	-3.74 ^a	1.08
12	-121	-16.1	21.6	-3.9	-13.4
13	-5.53	2.47	6.62	0.36	0.05
14	15.7	5.05	5.72	1.0	3.9
15	12.1	6.00	4.92	1.12	-2.05
16	-4.32	0.86	1.99	0.10	1.05
17	11.3	4.10	4.20	0.79 ^a	0.78
18	-1.36	3.21	5.50	0.52 ^a	0.78
19	1.83	2.00	4.25	0.34	-1.99
20	-33.0	-2.84	5.00	-0.79	11.2

^aEstimated as half the 2-day change.

Table 2. Average Surfzone Velocity Parameters
and Incident Wave Characteristics

Date (Nov 1978)	H (cm)	S	ψ_1	ψ_2	δ_u	u_m (cm sec ⁻¹)	u_3^*	u_5^*
4	55	0.00126	0.206	0.204	-0.131	58.2	0.550	1.25
6	65	0.00148	0.197	0.240	-0.124	59.2	0.603	1.20
7	59	0.00117	0.234	0.362	-0.088	51.8	0.594	1.35
10	101	0.00163	0.097	-0.019	-0.160	69.8	0.731	1.26
11	99	0.00303	0.106	-0.152	-0.250	78.4	0.687	1.11
12	140	0.00341	0.134	-0.035	-0.210	87.2	0.574	0.940
13	91	0.00124	0.222	0.326	-0.100	69.3	0.587	1.27
17	62	0.00194	0.232	0.352	-0.081	56.9	0.574	1.24
19	73	0.00128	0.223	0.350	-0.070	56.1	0.574	1.28

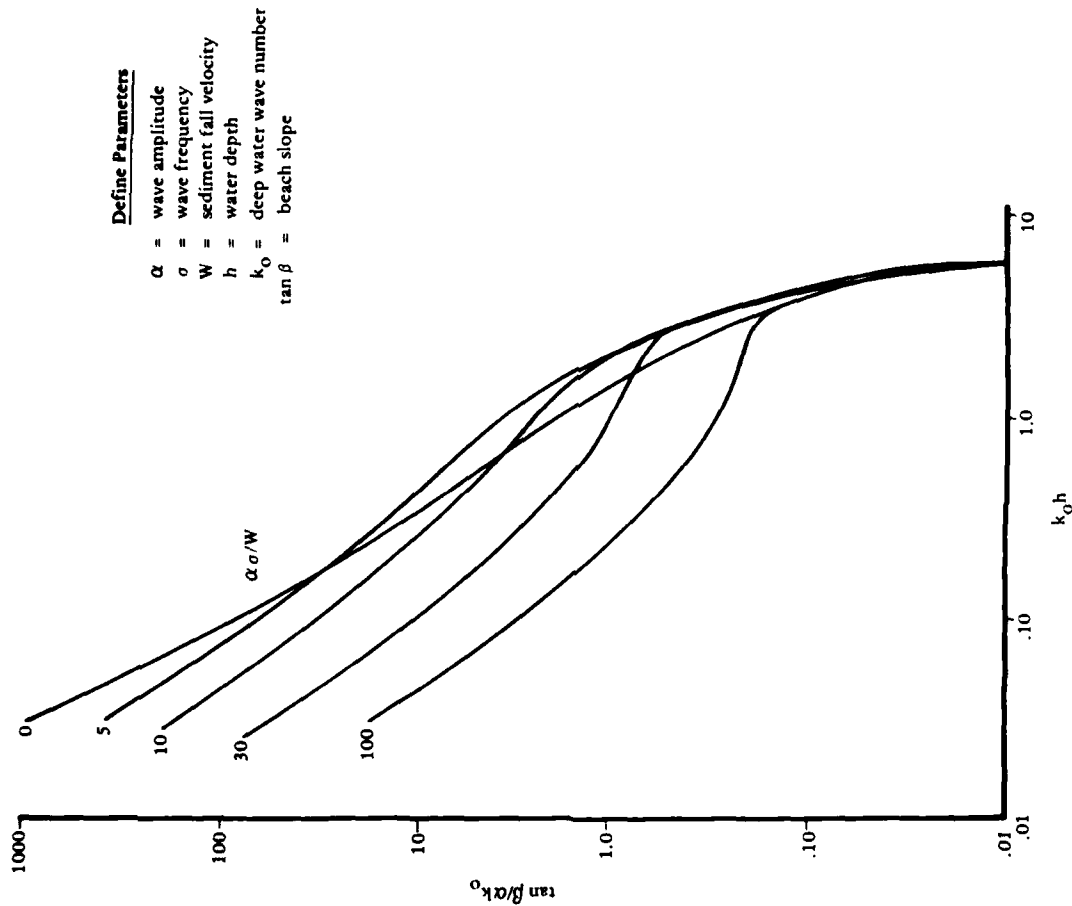


Figure 1. Predicted normalized equilibrium beach slope, $\tan \beta / \alpha k_0$, as a function of the normalized depth $k_0 h$ and the wave amplitude parameter $\alpha \sigma / W$ (from Bailard, 1981).

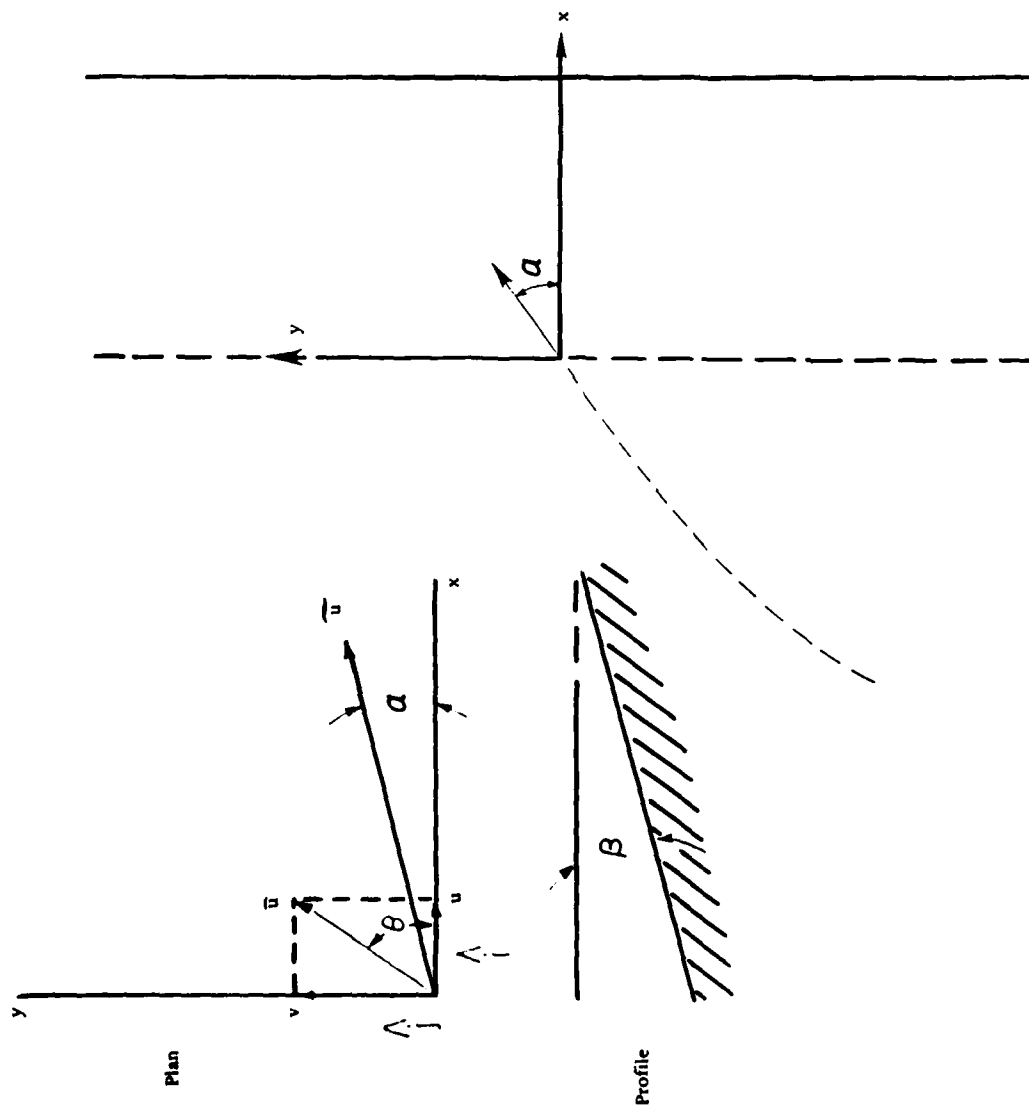


Figure 2. Schematic diagram showing the position of the beach (solid line), the breakpoint (dashed line), the wave angle α and the oscillatory and steady water velocities \bar{u} and u (from Bailard and Inman, 1980, with permission).

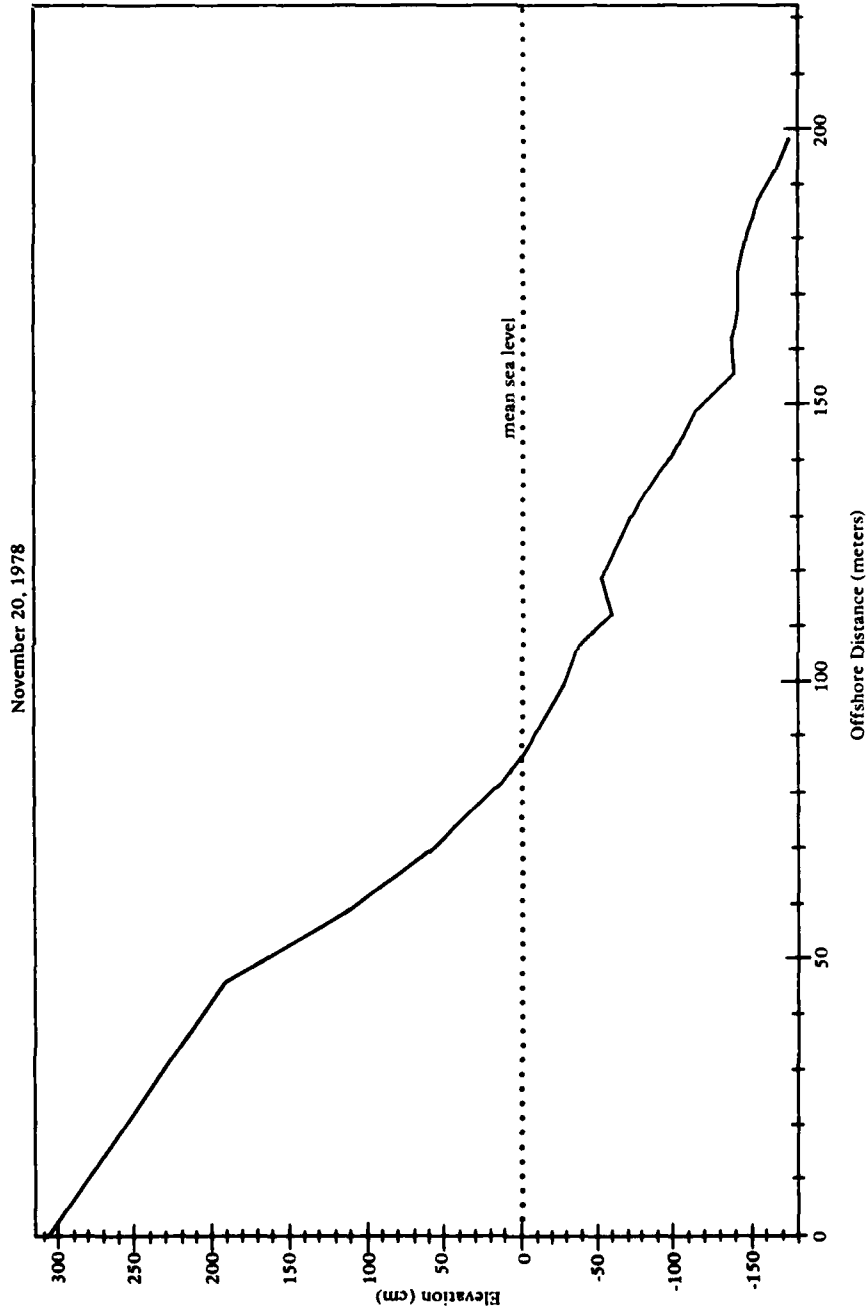


Figure 3. Representative beach profiles for Torrey Pines Beach measured on November 20, 1978 (adapted from Guza and Thornton, NCEL Contract Report).

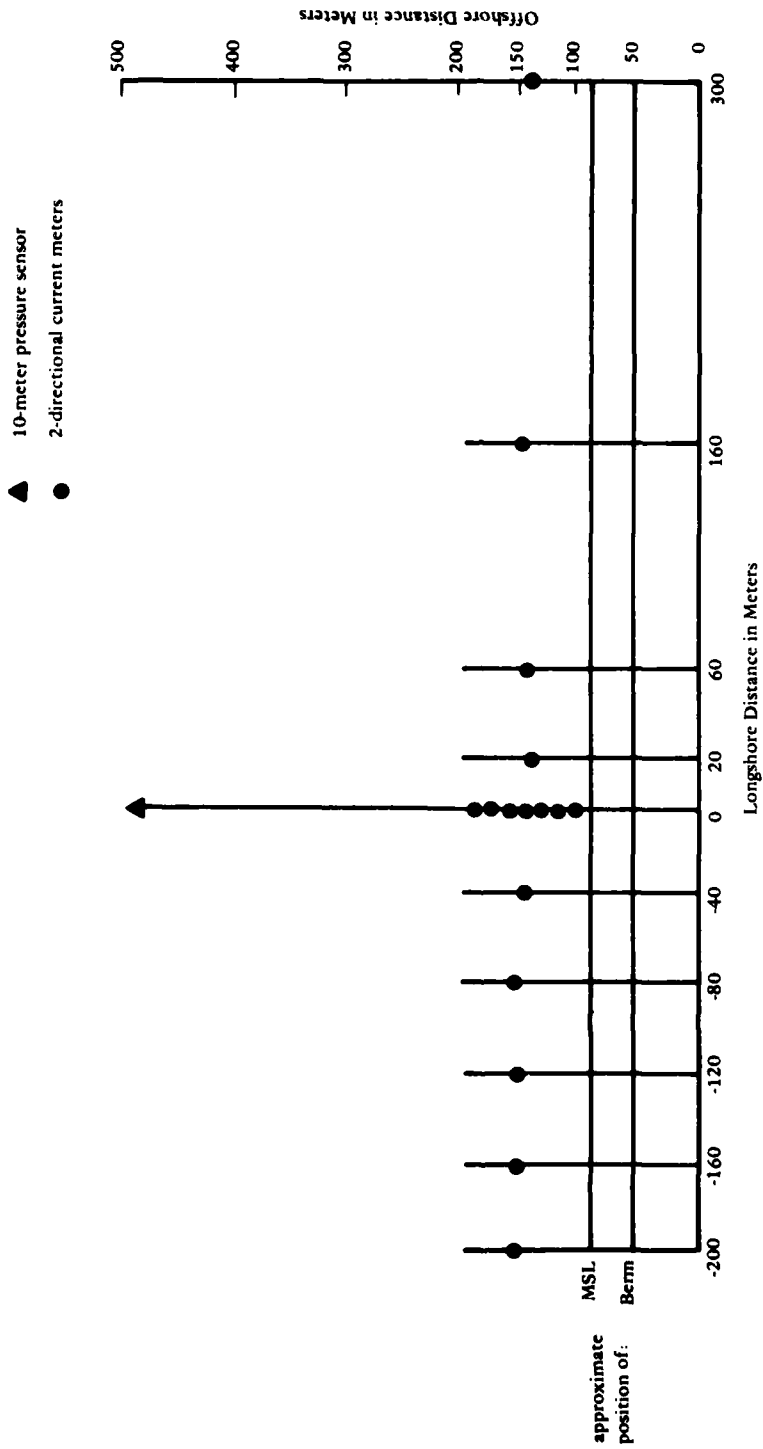


Figure 4. Relative current meter and pressure sensor positions for the NSTS Torrey Pines experiment (adapted from Seymour and King, 1982).

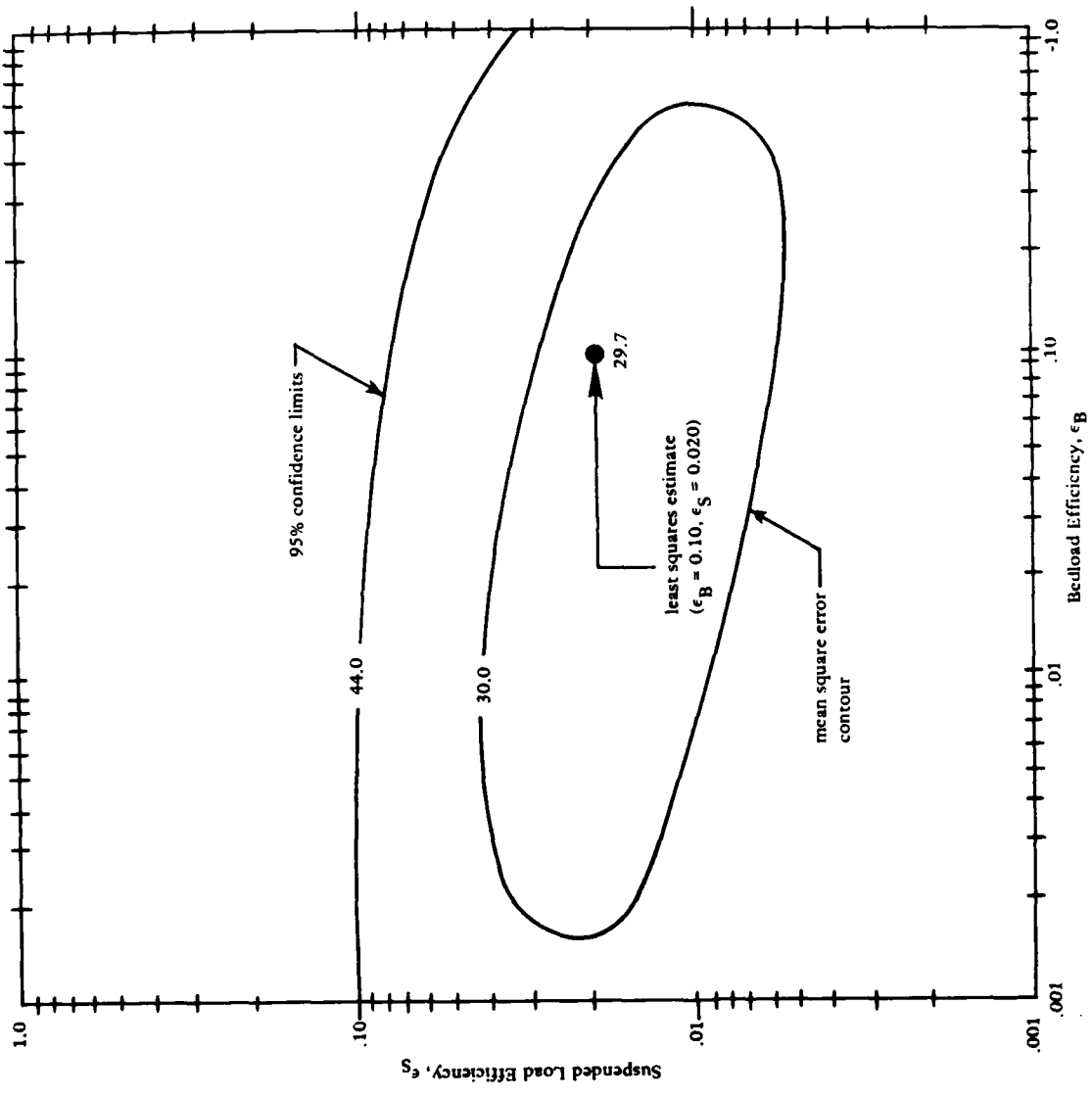


Figure 5. Least squares estimated bedload and suspended load efficiency factors, ϵ_B and ϵ_S .

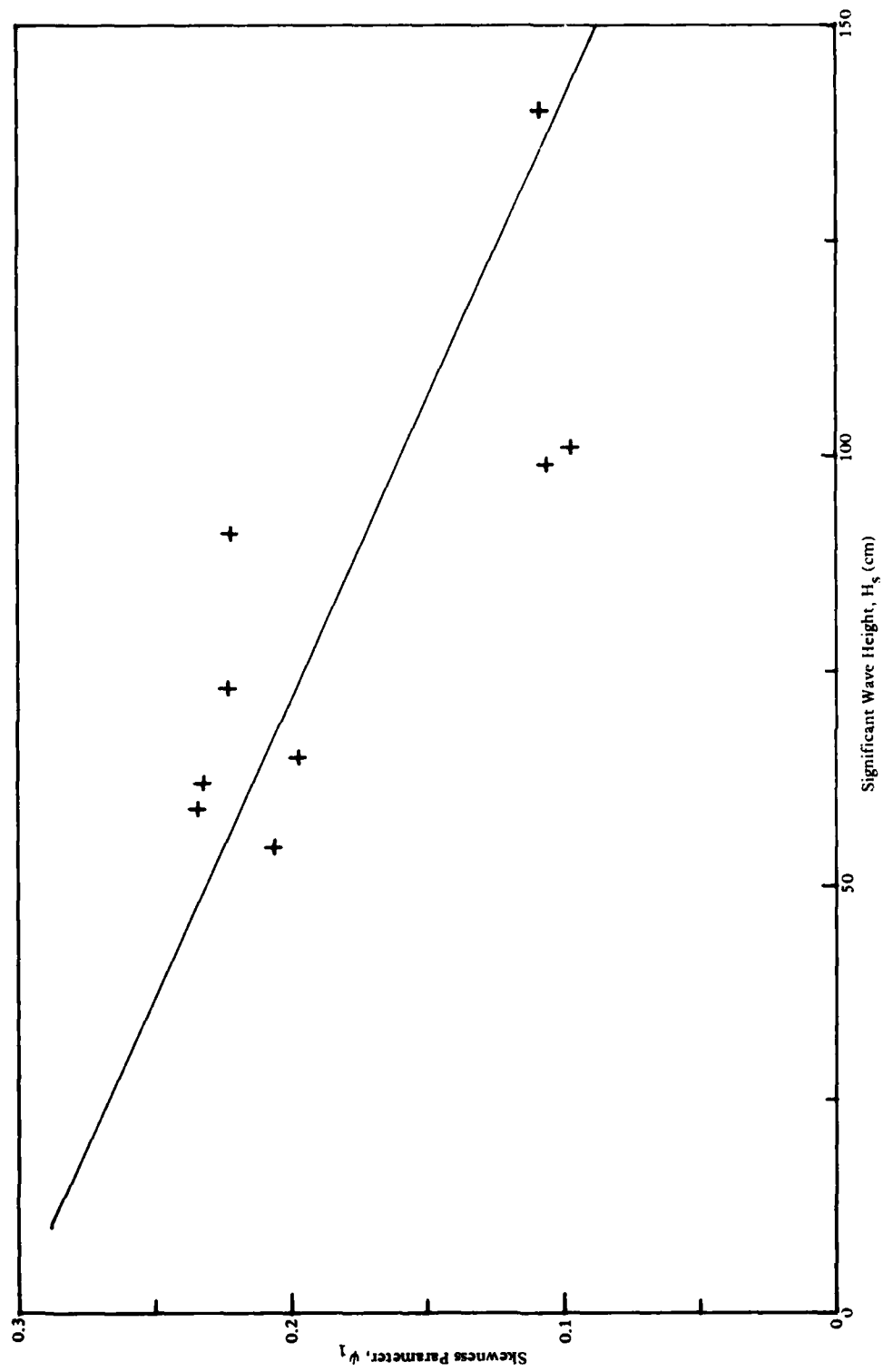


Figure 6. Average surfzone values of the skewness parameter ψ_1 versus significant wave heights computed from single 64-minute current meter records. The straight line is a least-squares fit to the data.

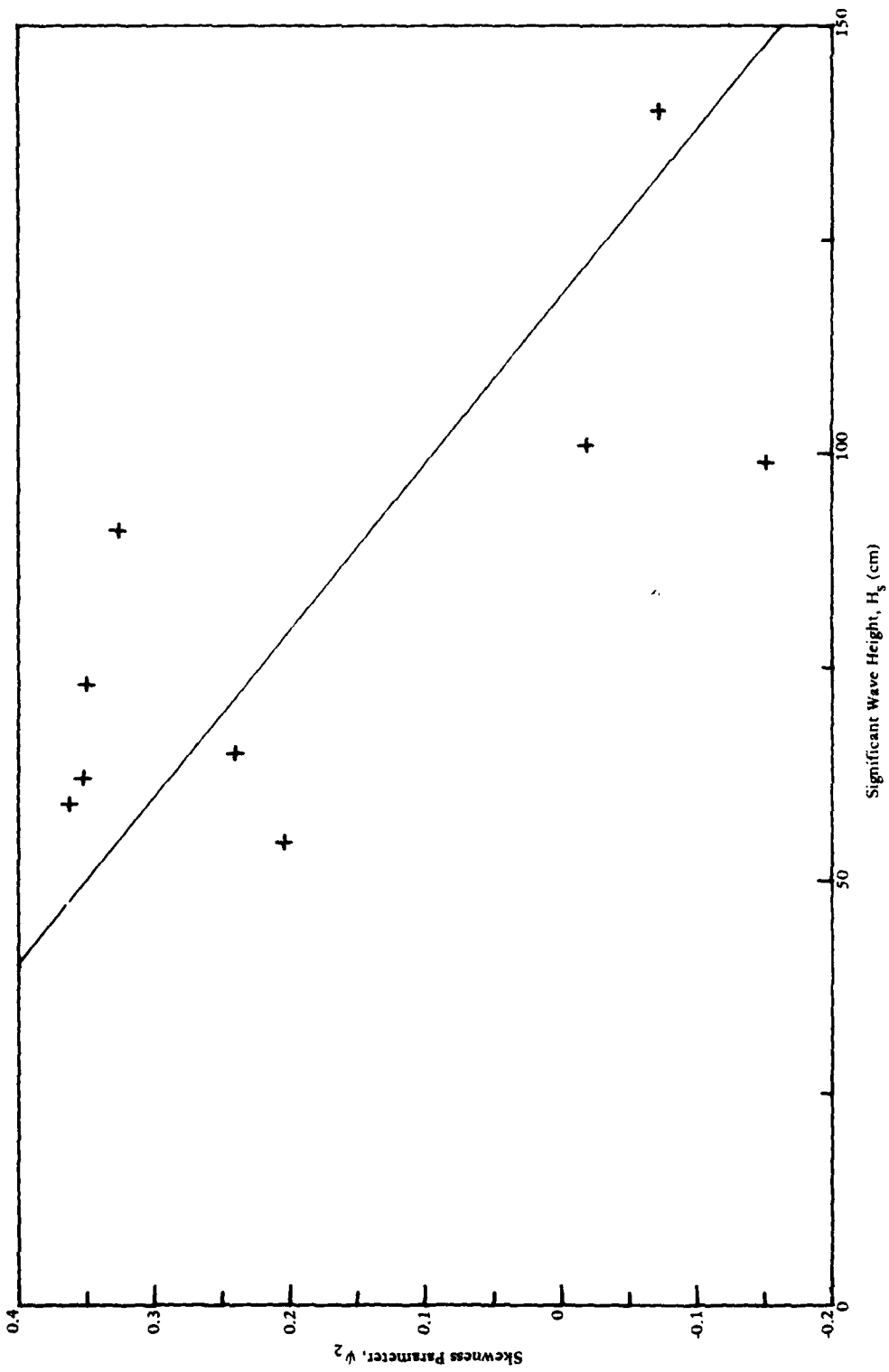


Figure 7. Average surfzone values of the skewness parameter ψ_2 versus significant wave height computed from single 64-minute records. The straight line is a least-squares fit to the data.

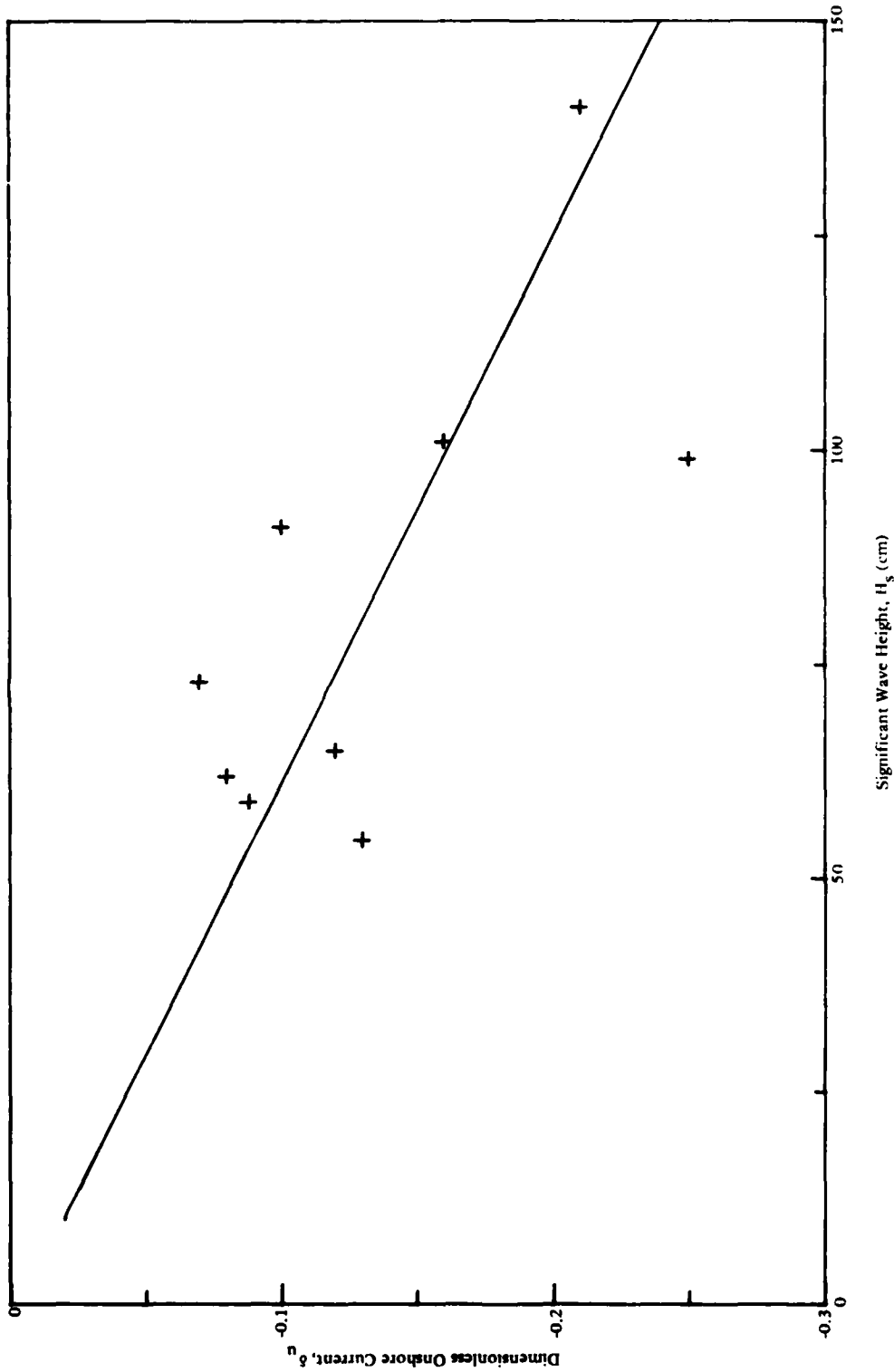


Figure 8. Average surfzone values of the normalized mean onshore current δ_u versus significant wave height computed from single 64-minute records. The straight line is a least-squares fit to the data.

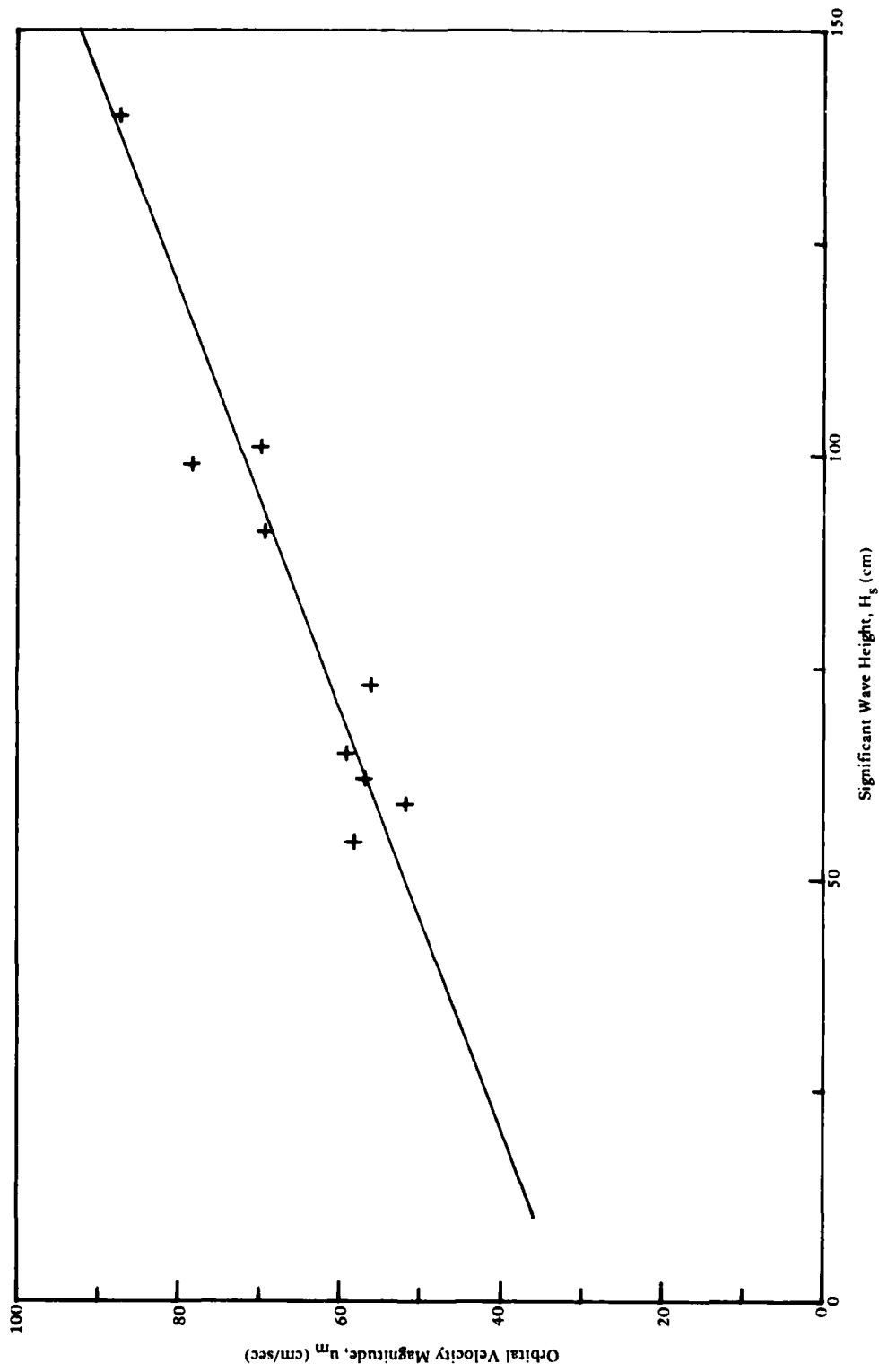


Figure 9. Average surfzone values of the orbital velocity magnitude u_m versus significant wave height computed from single 64-minute records. The straight line is a least-squares fit to the data.

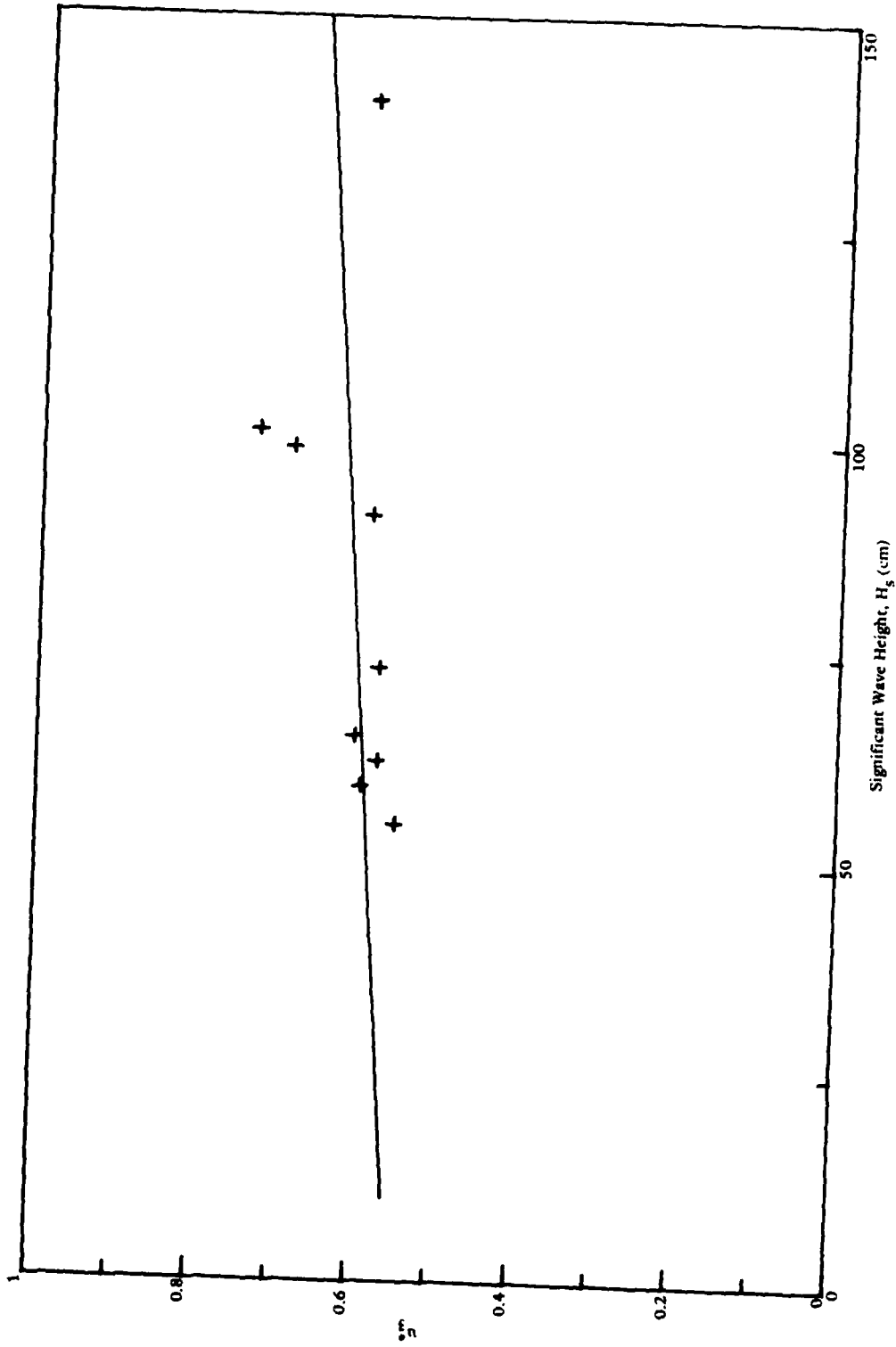


Figure 10. Average surfzone values of u_3 versus significant wave height computed from single 64-minute records. The straight line is a least-squares fit to the data.

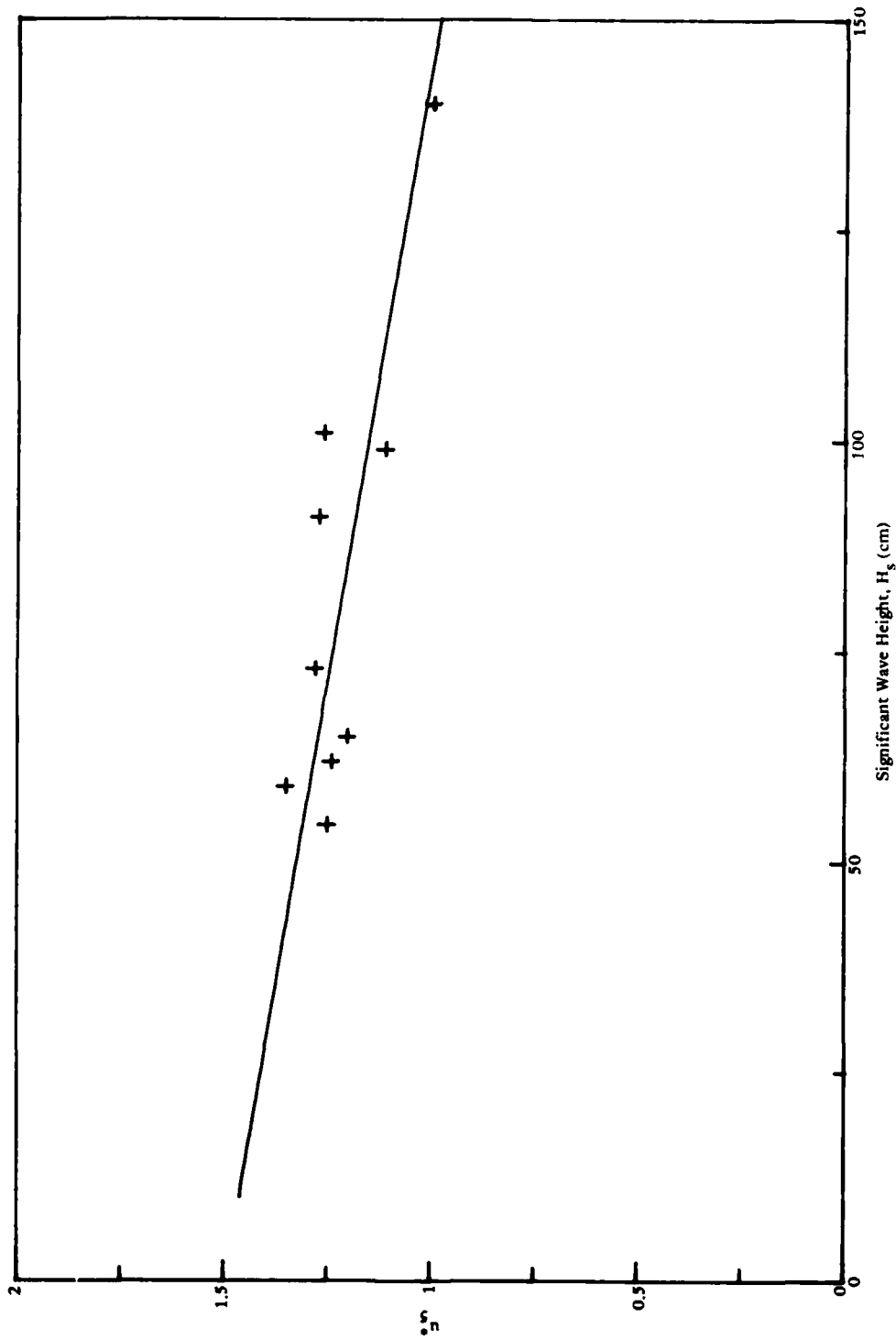


Figure 11. Average surfzone values of u_s versus significant wave height computed from single 64-minute records. The straight line is a least-squares fit to the data.

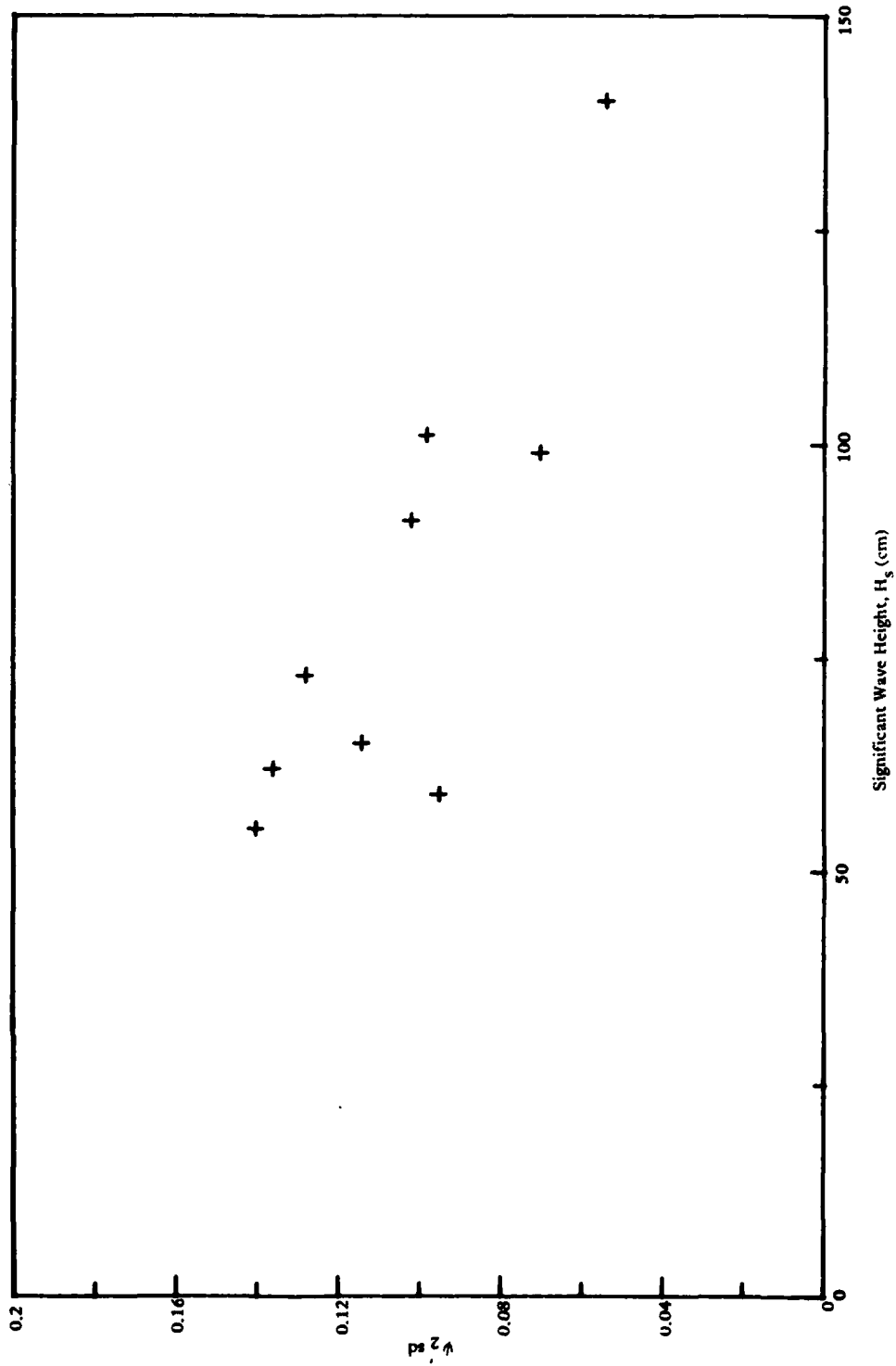


Figure 12. Average surfzone values of the standard deviation ψ_{2sd} , versus significant wave height computed from single 64-minute records.

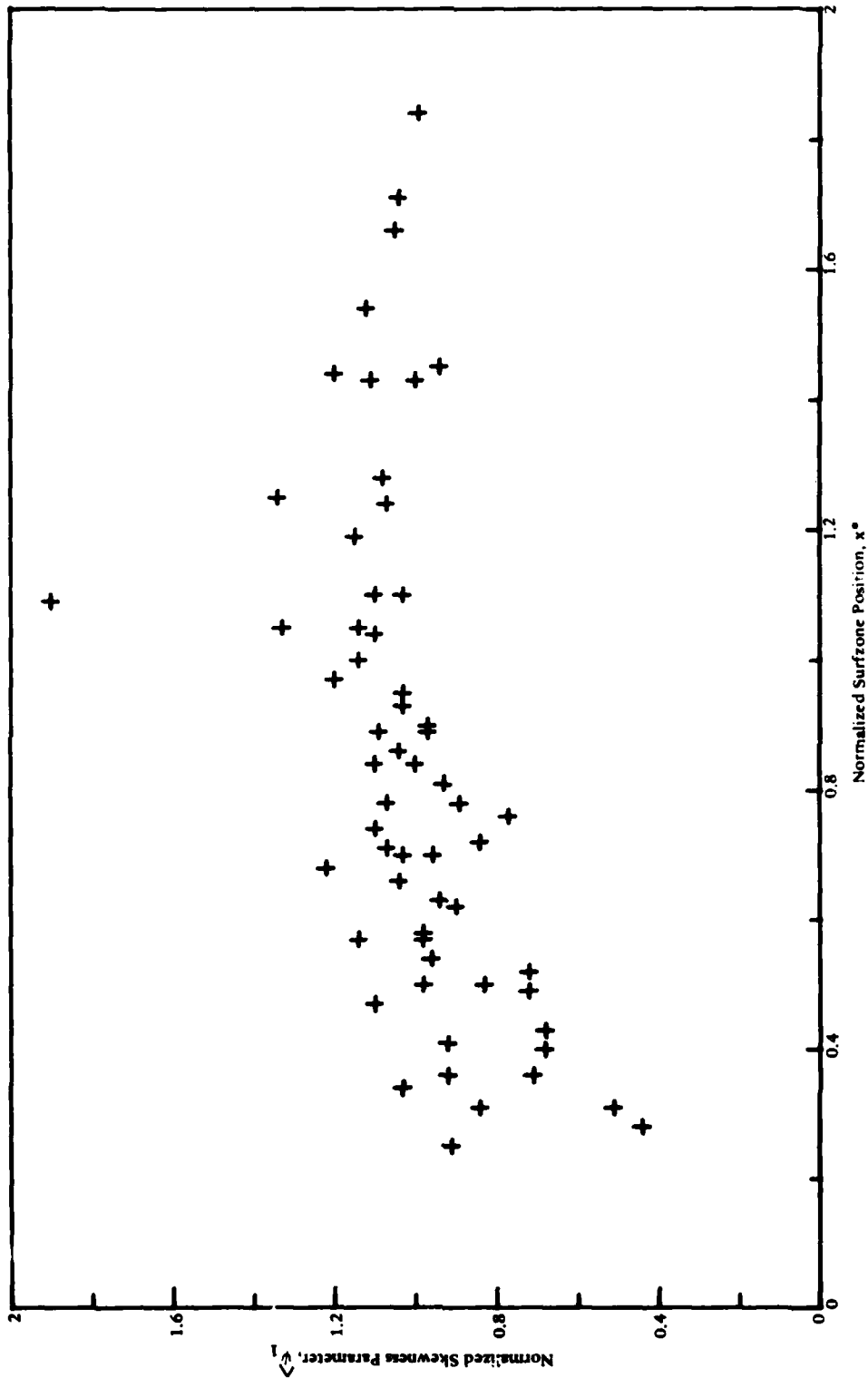


Figure 13. Surfzone distribution of the normalized skewness parameter ψ_1 computed from single 64-minute records using 7 different current meters and 9 different days of data.

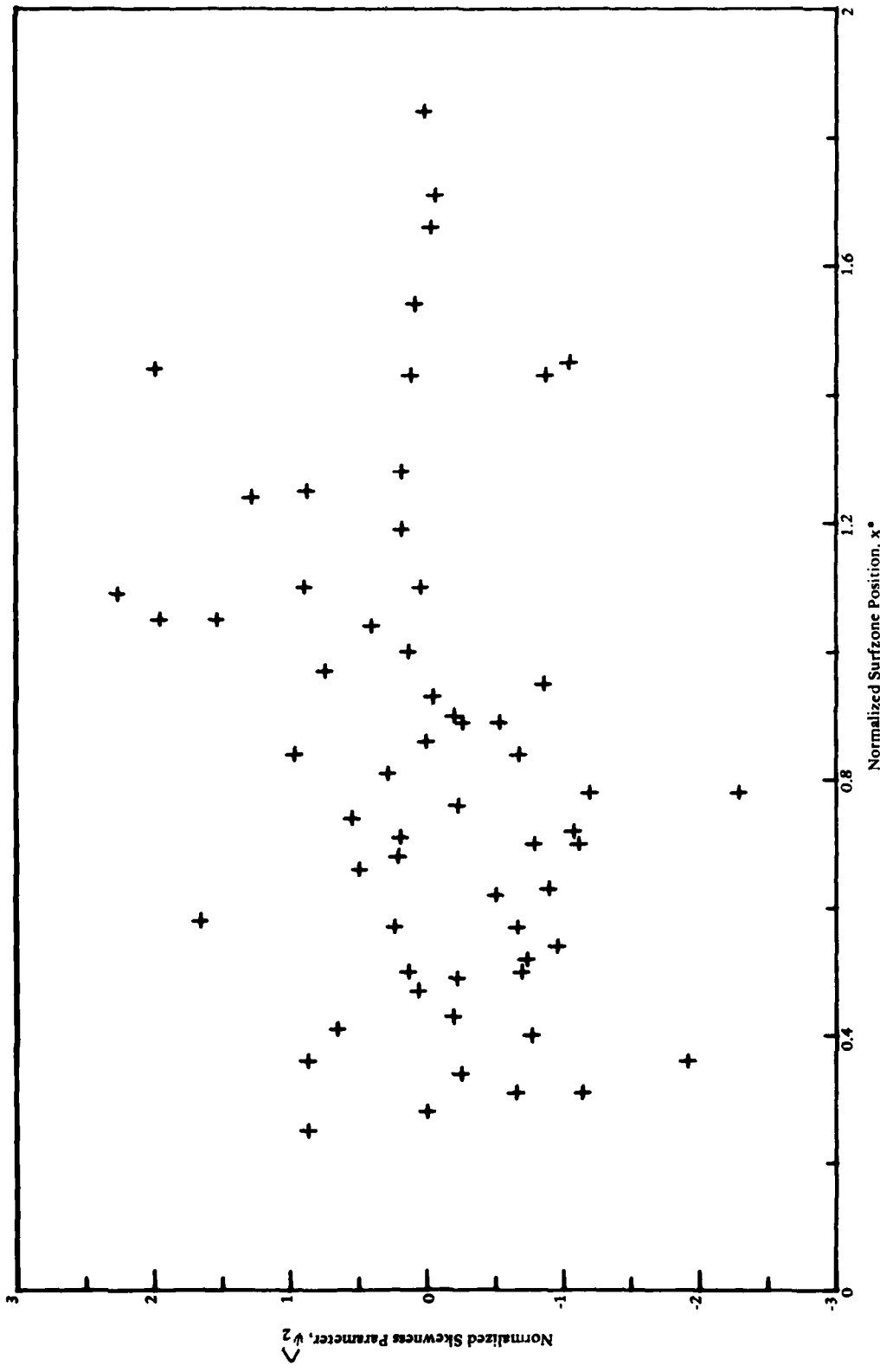


Figure 14. Surfzone distribution of the normalized skewness parameter $\hat{\psi}_2$ computed from single 64-minute records using 7 different current meters and 9 different days of data.

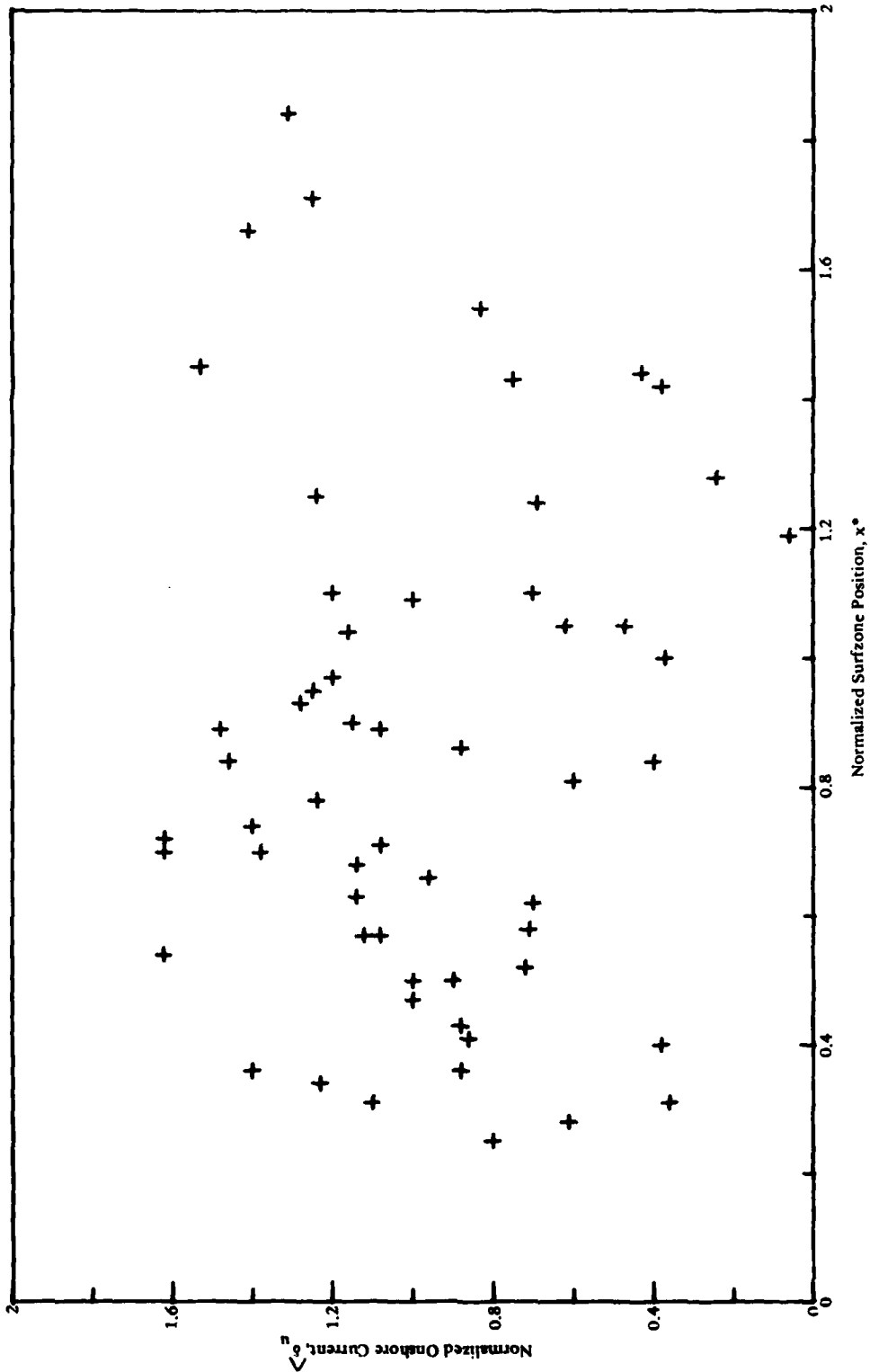


Figure 15. Surfzone distribution of the normalized onshore current δ_u computed from single 64-minute records using 7 different current meters and 9 different days of data. Note that a positive normalized current is directed offshore.

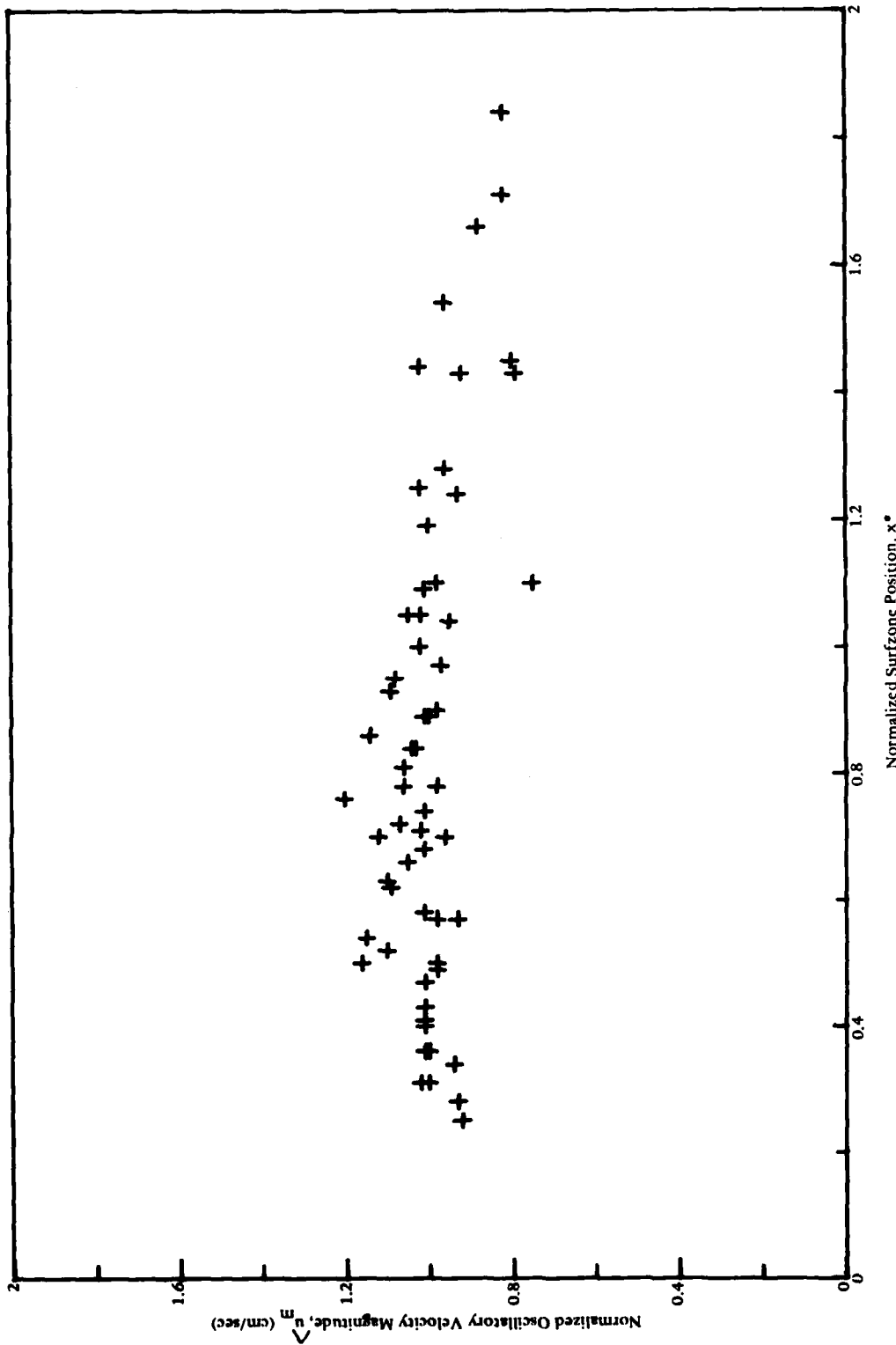


Figure 16. Surfzone distribution of the normalized orbital velocity magnitude \hat{u}_m computed from single 64-minute records using 7 different current meters and 9 different days of data.

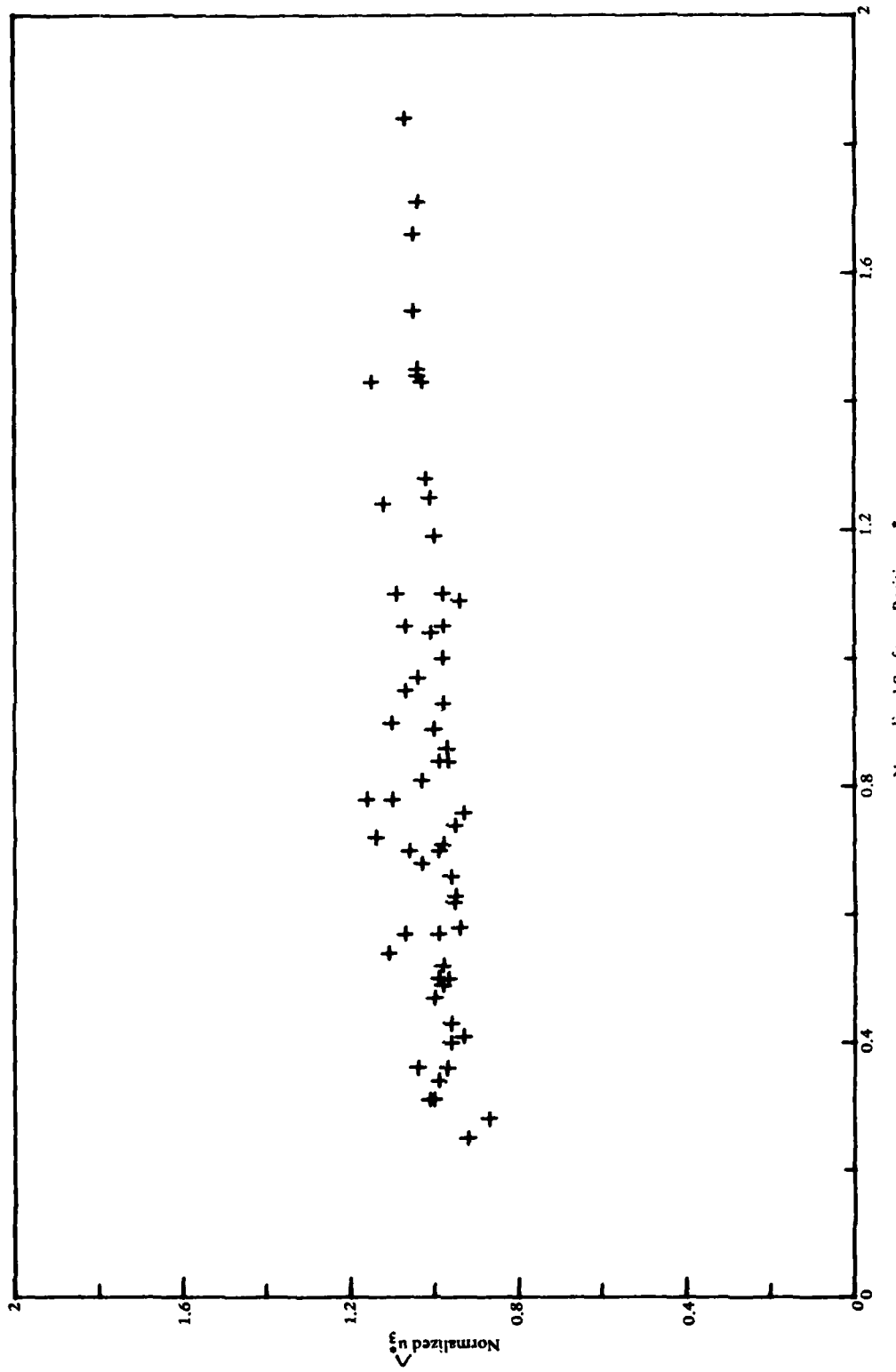


Figure 17. Surfzone distribution of the normalized parameter u_3^* , computed from single 64-minute records using 7 different current meters and 9 different days of data.

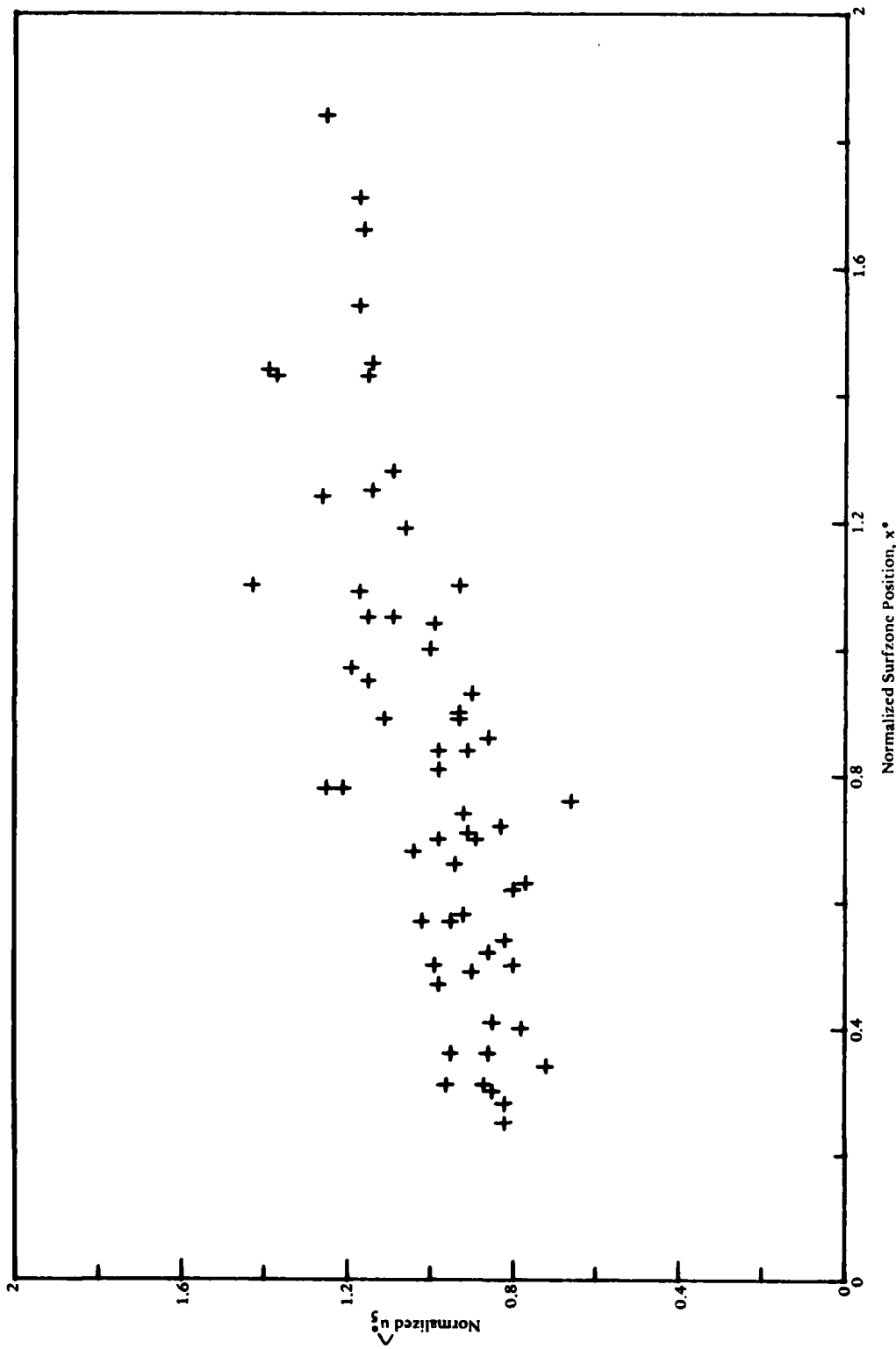


Figure 18. Surfzone distribution of the normalized parameter u_s^* , computed from single 64-minute records using 7 different current meters and 9 different days of data.

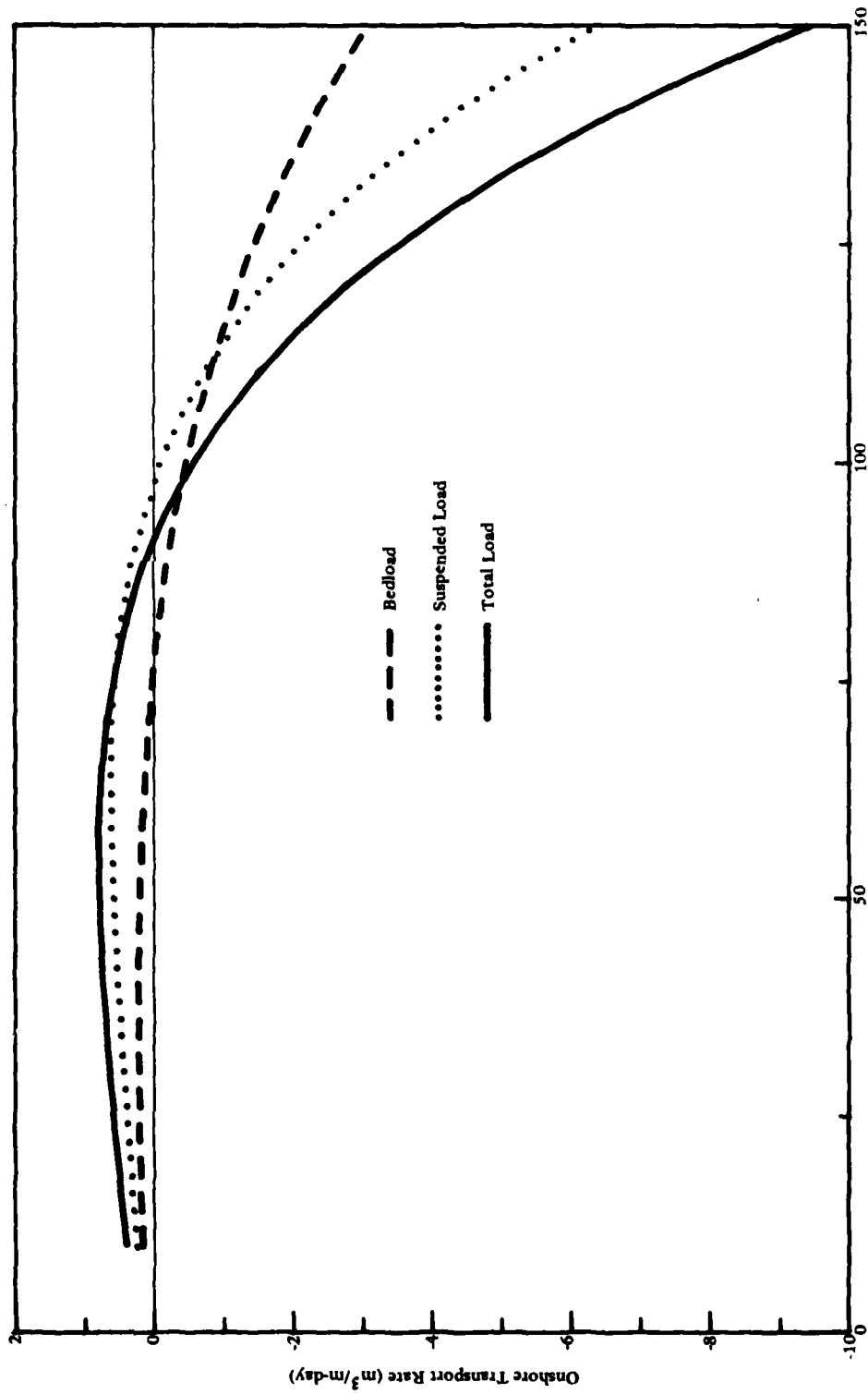


Figure 19. Predicted on-offshore sediment transport rate as a function of significant wave height. The individual contributions of the bedload and suspended load transports to the total transport are shown by the dashed and dotted lines, respectively. The point of neutral transport (equilibrium) occurs at a significant wave height of 90 cm.

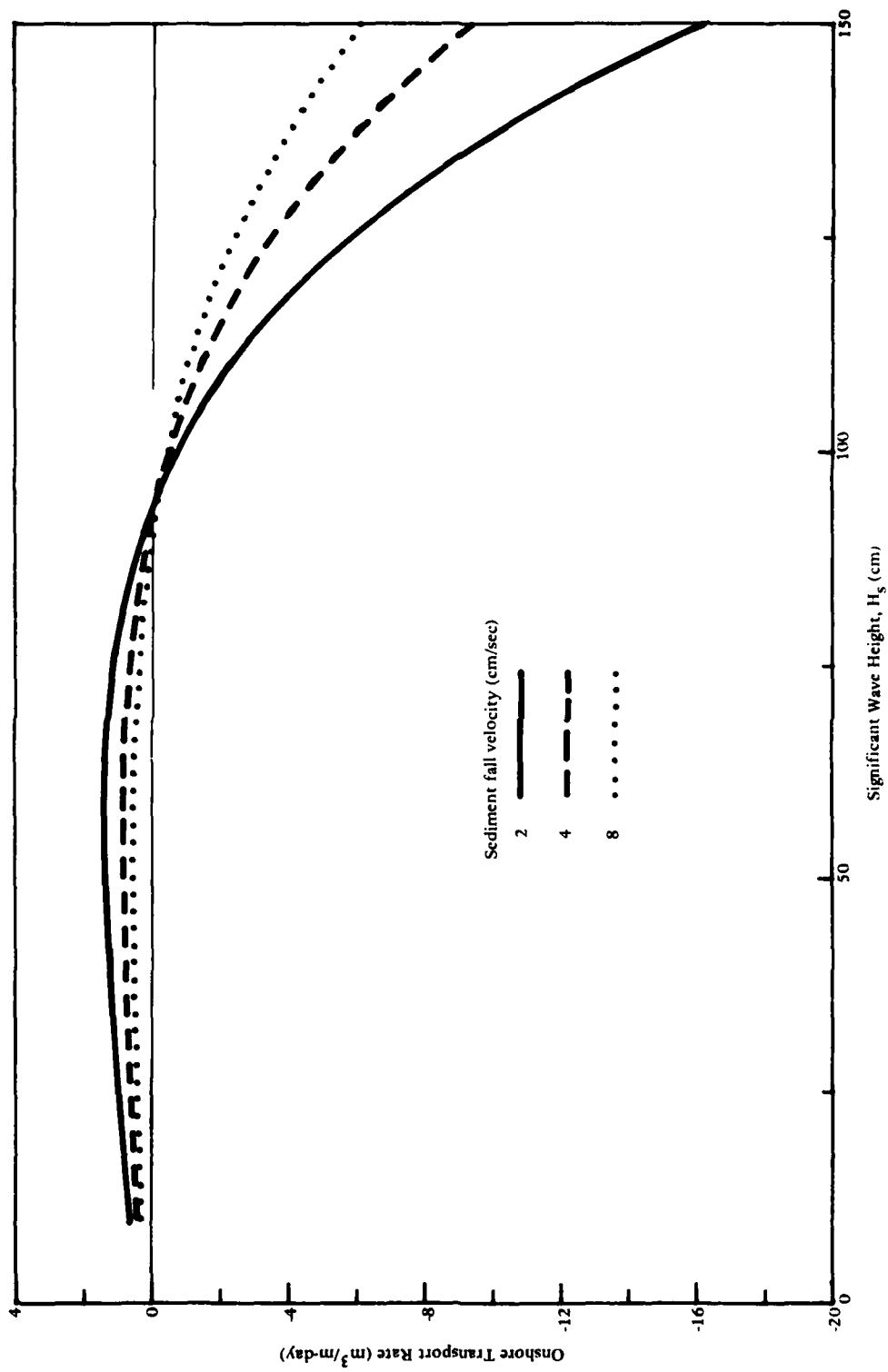


Figure 20. Predicted total load on-offshore sediment transport rate as function of significant wave height and sediment fall velocity. Greater rates of transport are found for smaller sized sediments.

DISTRIBUTION LIST

AFB AF Tech Office (Mgt & Ops), Tyndall, FL; AUL/LSE 63-465, Maxwell AL; CESCH, Wright-Patterson;
Stinfo Library, Offutt NE
ARCTICSUBLAB Code 54, San Diego, CA
ARMY BMDSC-RE (H. McClellan) Huntsville AL; DAEN-MPE-D Washington DC
ARMY COASTAL ENGR RSCH CEN Fort Belvoir VA; R. Jachowski, Fort Belvoir VA
ARMY COE Philadelphia Dist. (LIBRARY) Philadelphia, PA
ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA
ARMY CRREL A. Kovacs, Hanover NH
ARMY DARCOM Code DRCMM-CS Alexandria VA
ARMY ENG WATERWAYS EXP STA Library, Vicksburg MS
ARMY ENGR DIST. Library, Portland OR
ARMY ENVIRON. HYGIENE AGCY HSE-EW Water Qual Eng Div Aberdeen Prov Grnd MD
ARMY MAT SYS ANALYSIS ACT Code DRXSY-CM (M Ogorzalek) Aberdeen Proving Grnd MD
ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Leno, Watertown MA
ARMY MOBIL EQUIP R&D COM DRDME-MR (J. Sargent) Ft. Belvoir VA
ARMY MTMC Trans Engr Agency MTT-CE, Newport News, VA
ARMY TRANSPORTATION SCHOOL Code ATSP0 CD-TE Fort Eustis, VA
ARMY TRNG & DOCTRINE CMD Code ATCD-SL Fort Monroe, VA
ASST SECRETARY OF THE NAVY Spec. Assist Submarines, Washington DC
BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO
CINCLANT CIV ENGR SUPP PLANS OFFR NORFOLK, VA
CINCPAC Fac Engrng Div (J44) Makalapa, HI
CNM Code 03462, Washington DC; Code 043 Washington DC; Code MAT-04, Washington, DC; MAT-0718,
Washington, DC; NMAT - 044, Washington DC
CNO Code NOP-964, Washington DC; Code OP 323, Washington DC; Code OP 405, Washington DC; Code OP
405, Washington, DC; Code OP 414, Washington DC; Code OP 97 Washington DC; Code OP 97
Washington, DC; Code OP 987 Washington DC; Code OP323 Washington DC; Code OPNAV (99B24 (H);
Code OPNAV 22, Wash DC; Code OPNAV 23, Wash DC; OP-411F, Wash DC; OP987J, Washington, DC
COMCBPAC Operations Off, Makalapa HI
COMNAVBEACHPHIBREFTRAGRU ONE San Diego CA
COMNAVMARIANAS Code N4, Guam
COMNAVSURFLANT Norfolk, VA
COMOCEANSYPAC SCE, Pearl Harbor HI
COMRNCF Nicholson, Tampa, FL; Nicholson, Tampa, FL
COMSUBDEVGRUONE Operations Offr, San Diego, CA
NAVSURFPAC Code N-4, Coronado
COMOPTEVFOR CMDR, Norfolk, VA; Code 705, San Diego, CA
DEFUELSUPPCEN DFSC-OWE (Term Engrng) Alexandria, VA; DFSC-OWE, Alexandria VA
DLSIE Army Logistics Mgt Center, Fort Lee, VA
DNA STTL, Washington DC
DTIC Defense Technical Info Ctr/Alexandria, VA
DTNSRDC Anna Lab (Code 1175) Annapolis MD; Anna Lab (Code 119) Annapolis MD; Anna Lab (Code
1568) Annapolis MD
FMFLANT CEC Offr, Norfolk VA
FMFPAC CG(FEO) Camp Smith, HI
GSA Assist Comm Des & Cnst (FAIA) D R Dibner Washington, DC
LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)
MARINE CORPS BASE 1st For Serv Supp Gru (CSS-5) Camp Pendleton CA; PWO, Camp Pendleton CA;
PWO, Camp S. D. Butler, Kawasaki Japan
MCAS Facil. Engr. Div. Cherry Point NC; Facs Maint Dept - Operations Div, Cherry Point
MCDEC M&L Div Quantico VA; NSAP REP, Quantico VA
MCRD SCE, San Diego CA
MILITARY SEALIFT COMMAND Washington DC
NAF PWO, Atsugi Japan
NARF Equipment Engineering Division (Code 61000), Pensacola, FL
NAS Dir of Engrng, PWD, Corpus Christi, TX; Dir. Util. Div., Bermuda; Lead. Chief. Petty Offr. PW/Self
Help Div. Beeville TX; PW (J. Maguire), Corpus Christi TX; PWD - Engr Div, Oak Harbor, WA; PWD
Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWO Belle
Chasse, LA; PWO Key West FL; PWO, Glenview IL
NAVFACENGCOM CONTRACTS ROIC Key West FL
NAS SCE Norfolk, VA
NATL BUREAU OF STANDARDS Kovacs, Washington, D.C.; R Chung Washington, DC

NATL RESEARCH COUNCIL Naval Studies Board, Washington DC
 NAVACT PWO, London UK
 NAVAEROSPREGMFDCEN SCE, Pensacola FL
 NAVAIRDEVEN Code 813, Warminster PA
 NAVCHAPGRU CO Williamsburg VA, Operations Officer, Code 30 Williamsburg, VA
 NAVCOASTSYSCEN CO, Panama City FL; Code 715 (J Quirk) Panama City, FL; Code 715 (J. Mittleman)
 Panama City, FL; Code 772 (C B Koess) Panama City FL; Library Panama City, FL; PWO Panama City, FL
 NAVCOMMAREAMSTRSTA SCE Unit 1 Naples Italy; SCE, Wahiawa HI
 NAVCOMMSTA Code 401 Nea Makri, Greece; PWO, Fxmouth, Australia
 NAVCONSTRACEN Curriculum Instr. Sids Offr, Gulfport MS
 NAVEDTRAPRODEVEN Technical Library, Pensacola, FL
 NAVELEXSYSCOM Code PME 124-61, Washington, DC; PME 124-612, Wash DC
 NAVEODTEHCEN Code 605, Indian Head MD
 NAVFAC PWO, Centerville Bch, Ferndale CA
 NAVFACENGCOM Code 03T (Essoglou) Alexandria, VA; Code 043 Alexandria, VA; Code 044 Alexandria,
 VA; Code 044B) Alexandria, VA; Code 0451 (P W Brewer) Alexandria, Va; Code 0453 (D Potter)
 Alexandria, VA; Code 0453C, Alexandria, VA; Code 04A1 Alexandria, VA; Code 06, Alexandria VA;
 Code 09M54, Technical Library, Alexandria, VA; Code 1113, Alexandria, VA
 NAVFACENGCOM CONTRACTS ROICC, Yap; ROICC Code 495 Portsmouth VA
 NAVFACENGCOM - CHES DIV, Code 405 Wash, DC; Code 407 (D Scheesele) Washington, DC; Code
 FPO-1C Washington DC; FPO-1 Washington, DC; FPO-IEA5 Washington DC; Library, Washington, D.C.
 NAVFACENGCOM - LANT DIV, Code 405 Civil Engr BR Norfolk VA; Eur. BR Deputy Dir, Naples Italy;
 Library, Norfolk, VA; RDT&ELO 102A, Norfolk, VA
 NAVFACENGCOM - NORTH DIV, (Boretsky) Philadelphia, PA; CO; Code 09P Philadelphia PA; Code 1028,
 RDT&ELO, Philadelphia PA; Library, Philadelphia, PA; ROICC, Contracts, Crane IN
 NAVFACENGCOM - PAC DIV, CODE 09P PEARL HARBOR HI; Code 2011 Pearl Harbor, HI; Code 402,
 RDT&E, Pearl Harbor HI; Commander, Pearl Harbor, HI; Library, Pearl Harbor, HI
 NAVFACENGCOM - SOUTH DIV, Code 90, RDT&ELO, Charleston SC; Library, Charleston, SC
 NAVFACENGCOM - WEST DIV, Code 04B San Bruno, CA; Library, San Bruno, CA; O9P/20 San Bruno,
 CA; RDT&ELO Code 2011 San Bruno, CA
 NAVFACENGCOM CONTRACTS Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI;
 OICC/ROICC, Balboa Panama Canal; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX
 NAVFORCARIB Commander (N42), Puerto Rico
 NAVMAG SCE, Subic Bay, R.P.
 NAVOCEANO Library Bay St. Louis, MS
 NAVOCEANSYSCEN Code 4473 Bayside Library, San Diego, CA; Code 4473B (Tech Lib) San Diego, CA;
 Code 09 (Talkington), San Diego, CA; Code 5204 (J. Stachiw), San Diego, CA; Code 5214 (H. Wheeler),
 San Diego CA; Code 5221 (R.Jones) San Diego Ca; Code 5311 (Bachman) San Diego, CA; Hawaii Lab (R
 Yumori) Kailua, HI; Hi Lab Tech Lib Kailua HI
 NAVPGSCOL C. Morers Monterey CA; Code 61WL (O. Wilson) Monterey CA; E. Thornton, Monterey CA
 NAVPHIBASE CO, ACB 2 Norfolk, VA; COMNAVBEACHGRU TWO Norfolk VA; Code S3T, Norfolk VA;
 Dir. Amphib. Warfare Brd Staff, Norfolk, VA; Harbor Clearance Unit Two, Little Creek, VA
 NAVFACENGCOM CONTRACTS OICC/ROICC, Norfolk, VA
 NAVPHIBASE SCE Coronado, SD,CA
 NAVREGMEDCEN SCE; SCE, Guam
 NAVSCOLCECOFF C35 Port Hueneme, CA
 NAVSCSOL PWO, Athens GA
 NAVSEASYSYSCOM Code 0325, Program Mgr, Washington, DC; Code SEA OOC Washington, DC; SEA 04E (L
 Kess) Washington, DC
 NAVSECGRUACT PWO, Adak AK
 NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range); Code 202.5 (Library) Puget Sound, Bremerton
 WA; Code 380, Portsmouth, VA; Code 440 Portsmouth NH; Code 440, Puget Sound, Bremerton WA; Tech
 Library, Vallejo, CA
 NAVSTA Dir Engr Div, PWD, Mayport FL; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWO, Mayport FL;
 Utilities Engr Off, Rota Spain
 NAVTECHTRACEN SCE, Pensacola FL
 NAVWPNEN Code 2636 China Lake; Code 3803 China Lake, CA
 NAVWPNSTA PW Office Yorktown, VA
 NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWO, Charleston, SC; PWO, Seal Beach CA
 NAVWPNSUPPCEN Code 09 Crane IN
 NCTC Const. Elec. School, Port Hueneme, CA
 NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 156, Port
 Hueneme, CA; Code 1571, Port Hueneme, CA
 NCBU 411 OIC, Norfolk VA
 NCR 20, Commander; 30th Det, OIC, Diego Garcia I

NMCB 74, CO: FIVE, Operations Dept
 NOAA (Dr. T. Mc Guinness) Rockville, MD; Library Rockville, MD
 NORDA Code 410 Bay St. Louis, MS; Code 440 (Ocean Rsch Off) Bay St. Louis MS
 NRL Code 5800 Washington, DC; Code 5843 (F. Rosenthal) Washington, DC; Code 8441 (R.A. Skop),
 Washington DC
 NROTC J.W. Stephenson, UC Berkeley, CA
 NSD SCE, Subic Bay, R.P.
 NTC OICC, CBU-401, Great Lakes IL
 NUCLEAR REGULATORY COMMISSION T.C. Johnson, Washington, DC
 NUSC Code 131 New London, CT; Code 332, B-80 (J. Wilcox) New London, CT; Code EA123 (R.S. Munn),
 New London CT; Code TA131 (G. De la Cruz), New London CT
 OFFICE SECRETARY OF DEFENSE ASD (MRA&L) Code CSS/CC Washington, DC
 ONR Central Regional Office, Boston, MA; Code 481, Bay St. Louis, MS; Code 485 (Silva) Arlington, VA;
 Code 700F Arlington VA
 PERRY OCEAN ENG R. Pellen, Riviera Beach, FL
 PHIBCB 1 P&E, San Diego, CA; 1, CO San Diego, CA; 1, CSWC D Wellington, San Diego, CA
 PMTC EOD Mobile Unit, Point Mugu, CA; Pat. Counsel, Point Mugu CA
 PWC CO Norfolk, VA; CO, (Code 10), Oakland, CA; CO, Great Lakes IL; CO, Pearl Harbor HI; Code 10,
 Great Lakes, IL; Code 120, Oakland CA; Code 120C, (Library) San Diego, CA; Code 128, Guam; Code
 154, Great Lakes, IL; Code 400, Great Lakes, IL; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA;
 Code 420, Great Lakes, IL; Code 420, Oakland, CA; Code 424, Norfolk, VA; Code 700, Great Lakes, IL;
 Code 700, San Diego, CA; Commanding Officer, Great Lakes, IL; Library, Guam; Library, Norfolk, VA;
 Library, Oakland, CA; Library, Subic Bay, R.P.; Library, Pearl Harbor, HI
 SUPANX PWO, Williamsburg VA
 UCT ONE OIC, Norfolk, VA
 UCT TWO OIC, Port Hueneme CA
 U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)
 US DEPT OF INTERIOR Bur of Land Mgmt Code 583, Washington DC
 US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA
 US NATIONAL MARINE FISHERIES SERVICE Highlands NY (Sandy Hook Lab-Library)
 US NAVAL FORCES Korea (ENJ-P&O)
 USCG (G-MP-3 USP/82) Washington Dc; (Smith), Washington, DC
 USCG R&D CENTER CO Groton, CT; D. Motherway, Groton CT
 USDA Forest Service Reg 3 (R. Brown) Albuquerque, NM
 USNA ENGRNG Div. PWD, Annapolis MD; USNA/Sys Eng Dept, Annapolis, MD
 WATER & POWER RESOURCES SERVICE (Smoak) Denver, CO
 BERKELEY PW Engr Div, Harrison, Berkeley, CA
 CALIF. DEPT OF NAVIGATION & OCEAN DEV. Sacramento, CA (G. Armstrong)
 CALIF. MARITIME ACADEMY Vallejo, CA (Library)
 CALIFORNIA INSTITUTE OF TECHNOLOGY Pasadena CA (Keck Ref. Rm)
 CALIFORNIA STATE UNIVERSITY (Yen) Long Beach, CA; LONG BEACH, CA (CHELAPATI)
 CATHOLIC UNIV. Mech Engr Dept, Prof. Niedzwecki, Wash., DC
 COLORADO STATE UNIV., FOOTHILL CAMPUS Fort Collins (Nelson)
 CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.); Ithaca, NY (Civil & Environ. Engr)
 DAMES & MOORE LIBRARY LOS ANGELES, CA
 DUKE UNIV MEDICAL CENTER B. Muga, Durham NC; DURHAM, NC (VESIC)
 FLORIDA ATLANTIC UNIVERSITY Boca Raton, FL (McAllister)
 HARVARD UNIV. Dept. of Architecture, Dr. Kim, Cambridge, MA
 GEORGIA INSTITUTE OF TECHNOLOGY Atlanta GA (B. Mazanti)
 INSTITUTE OF MARINE SCIENCES Morehead City NC (Director)
 IOWA STATE UNIVERSITY Ames IA (CE Dept, Handy)
 WOODS HOLE OCEANOGRAPHIC INST. Woods Hole MA (Winget)
 LEHIGH UNIVERSITY BETHLEHEM, PA (MARINE GEOTECHNICAL LAB., RICHARDS); Bethlehem
 PA (Fritz Engr. Lab No. 13, Beedle); Bethlehem PA (Linderman Lib. No.30, Flecksteiner)
 MAINE MARITIME ACADEMY CASTINE, ME (LIBRARY)
 MICHIGAN TECHNOLOGICAL UNIVERSITY Houghton, MI (Haas)
 MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge MA (Whitman);
 Cambridge, MA (Harleman)
 NATL ACADEMY OF ENG. ALEXANDRIA, VA (SEARLE, JR.)
 NATURAL ENERGY LAB Library, Honolulu, HI
 NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM
 OREGON STATE UNIVERSITY (CE Dept Grace) Corvallis, OR; CORVALLIS, OR (CE DEPT, BELL);
 Corvallis OR (School of Oceanography)
 PENNSYLVANIA STATE UNIVERSITY STATE COLLEGE, PA (SNYDER); State College PA (Applied
 Rsch Lab); UNIVERSITY PARK, PA (GOTOLSKI)

PURDUE UNIVERSITY Lafayette IN (Leonards); Lafayette, IN (Altschaeffl); Lafayette, IN (CE Engr. Lib)
 SAN DIEGO STATE UNIV. 1. Noorany San Diego, CA
 SCRIPPS INSTITUTE OF OCEANOGRAPHY LA JOLLA, CA (ADAMS)
 SEATTLE U Prof Schwaegler Seattle WA
 SOUTHWEST RSCH INST King, San Antonio, TX; R. DeHart, San Antonio TX
 STATE UNIV. OF NEW YORK Buffalo, NY; Fort Schuyler, NY (Longobardi)
 TEXAS A&M UNIVERSITY College Station TX (CE Dept. Herbich)
 TEXAS TECH UNIVERSITY Dept of IE (Prof. Ayoub), Lubbock TX
 UNIVERSITY OF ALASKA Doc Collections Fairbanks, AK; Marine Science Inst. College, AK
 UNIVERSITY OF CALIFORNIA A-031 (Storms) La Jolla, CA; BERKELEY, CA (CE DEPT, GERWICK);
 BERKELEY, CA (CE DEPT, MITCHELL); Berkeley CA (Dept of Naval Arch.); Berkeley CA (E.
 Pearson); La Jolla CA (Acq. Dept, Lib. C-075A); M. Duncan, Berkeley CA
 UNIVERSITY OF CONNECTICUT Groton CT (Inst. Marine Sci. Library)
 UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)
 UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.)
 UNIVERSITY OF ILLINOIS (Hall) Urbana, IL; Metz Ref Rm, Urbana IL; URBANA, IL (DAVISSON);
 URBANA, IL (LIBRARY)
 UNIVERSITY OF MASSACHUSETTS (Heronemus), ME Dept, Amherst, MA
 UNIVERSITY OF MICHIGAN Ann Arbor MI (Richart)
 UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)
 UNIVERSITY OF NEW HAMPSHIRE DURHAM, NH (LAVOIE)
 UNIVERSITY OF SO. CALIFORNIA Univ So. Calif
 UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX
 UNIVERSITY OF TEXAS AT AUSTIN Austin TX (R. Olson)
 UNIVERSITY OF WASHINGTON Seattle WA (M. Sherif); SEATTLE, WA (APPLIED PHYSICS LAB);
 SEATTLE, WA (OCEAN ENG RSCH LAB, GRAY); SEATTLE, WA (PACIFIC MARINE ENVIRON.
 LAB., HALPERN); Seattle WA (E. Linger); Seattle, WA Transportation, Construction & Geom. Div
 UNIVERSITY OF WISCONSIN Milwaukee WI (Ctr of Great Lakes Studies)
 VIRGINIA INST. OF MARINE SCI. Gloucester Point VA (Library)
 ALFRED A. YEE & ASSOC. Librarian, Honolulu, HI
 AMETEK Offshore Res. & Engr Div
 ANALYTICAL TECH Lawrence, Port Hueneme, CA
 ATLANTIC RICHFIELD CO. DALLAS, TX (SMITH)
 BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)
 BETHLEHEM STEEL CO. Dismuke, Bethelhem, PA
 BRAND INDUS SERV INC. J. Buehler, Hacienda Heights CA
 BRITISH EMBASSY M A Wilkins (Sci & Tech Dept) Washington, DC
 BROWN & ROOT Houston TX (D. Ward)
 CHEVRON OIL FIELD RESEARCH CO. LA HABRA, CA (BROOKS)
 CICB O'Rourke
 COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)
 CONCRETE TECHNOLOGY CORP. TACOMA, WA (ANDERSON)
 DILLINGHAM PRECAST F. McHale, Honolulu HI
 DIXIE DIVING CENTER Decatur, GA
 DRAVO CORP Pittsburgh PA (Wright)
 EVALUATION ASSOC. INC KING OF PRUSSIA, PA (FEDELE)
 EXXON PRODUCTION RESEARCH CO Houston, TX (Chao)
 FORD, BACON & DAVIS, INC. New York (Library)
 FURGO INC. Library, Houston, TX
 GEOTECHNICAL ENGINEERS INC. Winchester, MA (Paulding)
 HALEY & ALDRICH, INC. Cambridge MA (Aldrich, Jr.)
 JAMES CO. R. Girdley, Orlando FL
 LAMONT-DOHERTY GEOLOGICAL OBSERVATORY (Selwyn) Palisades, NY; Palisades NY (McCoy)
 LOCKHEED MISSILES & SPACE CO. INC. L. Trimble, Sunnyvale CA
 MARATHON OIL CO Houston TX
 MARINE CONCRETE STRUCTURES INC. MEFAIRIE, LA (INGRAHAM)
 MC CLELLAND ENGINEERS INC Corp Library Houston, TX
 MOBIL PIPE LINE CO. DALLAS, TX MGR OF ENGR (NOACK)
 MOFFATT & NICHOL ENGINEERS (R. Palmer) Long Beach, CA
 NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)
 OPPENHEIM Los Angeles, CA
 PACIFIC MARINE TECHNOLOGY (M. Wagner) Duvall, WA
 PORTLAND CEMENT ASSOC. SKOKIE, IL (CORLEY; Skokie IL (Rsch & Dev Lab, Lib.)
 R J BROWN ASSOC (McKeehan), Houston, TX
 RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ; J. Welsh Soiltech Dept.
 Pennsauken, NJ

SANDIA LABORATORIES Library Div., Livermore CA; Seabed Progress Div 4536 (D. Talbert) Albuquerque NM
SCHUPACK ASSOC SO. NORWALK, CT (SCHUPACK)
SEATECH CORP. MIAMI, FL (PERONI)
SHANNON & WILLSON INC. Librarian Seattle, WA
SHELL DEVELOPMENT CO. Houston TX (C. Sellars Jr.); Houston TX (E. Doyle)
SHELL OIL CO. HOUSTON, TX (MARSHALL); Houston TX (R. de Castongrene); I. Boaz, Houston TX
TIDEWATER CONSTR. CO Norfolk VA (Fowler)
WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan)
WESTINTRUCORP Egerton, Oxnard, CA
WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)
WOODWARD-CLYDE CONSULTANTS (A. Harrigan) San Francisco; PLYMOUTH MEETING PA (CROSS, III)
AL SMOOTS Los Angeles, CA
ANTON TEDESKO Bronxville NY
BARA, JOHN P. Lakewood, CO
BRAHTZ La Jolla, CA
BULLOCK La Canada
F. HEUZE Alamo, CA
GERWICK, BEN C. JR San Francisco, CA
LAYTON Redmond, WA
CAPT MURPHY Sunnyvale, CA
PAULI Silver Spring, MD
R.F. BESIER Old Saybrook CT
BROWN & CALDWELL Saunders, E.M./Oakland, CA
WM TALBOT Orange CA

**DA
FIL**