# CHAPTER NINETY NINE

## A SIMPLIFIED MODEL FOR LONGSHORE SEDIMENT TRANSPORT

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## ABSTRACT

An energetics-based longshore sediment transport model is developed which takes the form of a modification to the wave power equation. Instead of being constant, the wave power coefficient is a function of the breaker angle and the ratio of the orbital velocity magnitude and the sediment fall velocity. This modification extends the range of application of the wave power equation to include both field and laboratory conditions.

## INTRODUCTION

Waves, breaking at an angle to the shore, cause sand to be moved laterally along the beach. On a straight beach with parallel contours, the longshore sand transport is spatially uniform and no planform changes in the beach will occur. If, however, the longshore sand transport is interrupted by a groin or a jetty, sand will accumulate on the updrift side of the structure and erosion will occur on the downdrift side. Coastal engineers are often required to predict the rate of accretion and erosion associated with a structure, thus there is a need for an accurate and easily applied longshore transport model.

Although the wave power equation was developed more than 20 years ago (Inman and Bagnold, 1963), this equation remains the most widely accepted method today for predicting the longshore sediment transport rate (SPM, 1977). The wave power equation linearly relates the spatially-integrated immersed weight longshore sediment transport rate, I, to what has been termed the longshore component of wave energy flux,  $P_{\varrho}$ , i.e.

 $I_{\ell} = K P_{\ell}$ (1)

where the wave power coefficient, K, is generally assumed to

be a constant equal to 0.77 (Komar and Inman, 1970). The factor  $P_{\,0}$  can be expressed as

$$P_{\ell} = (E C_n)_b \sin \alpha_b \cos \alpha_b$$
(2)

where E is the energy of the incident waves, Cn is the goup velocity of the waves,  $\alpha$  is the incident wave angle, and the subscript b denotes the value at breaking.

In spite of its widespread application, the wave power equation accurately predicts the longshore sediment transport rate only over a narrow wide range of conditions. For example, laboratory measurements of K suggest a value of approximately 0.2, while field measurements suggest a value closer to 0.8 (see Figure 1). This difficulty is in part the result of the relative simplicity of the wave power equation. For example, the assumption of a constant wave power coefficient prevents any differentiation between the bedload and the suspended load transports, nor does it allow any accounting of the sediment grain size or the beach slope.

More complex, analytically-based longshore sediment transport models have been proposed which predict the distribution of the longshore transport rate across the surfzone. These models are based on adaptations of stream-based sediment transport models, and include traction-based models (eg. Ostendorf and Madsen, 1976; Swart, 1976), and energetics-based models (e.g. Komar, 1971, 1977; Thornton, 1973; Bowen, 1980; Bailard, 1981). I order to predict the distribution of the longshore sediment Τn transport rate across the surfzone, all of the above models incorporate some form of a breaking wave model and a longshore current model. The resulting equations are generally cumbersome, incorporating a number of undetermined coefficients, and require numerical solution. As a result of the added complexity of these models, none have had widespread application.

The objective of this study was to develop a sediment transport model which preserves the general form and simplicity of the wave power equation, but which extends its range of application. The basis for the model was a simplification of Bailard's (1981) energetics-based longshore transport model. Simplifying assumptions used in the model development were based on an analysis of Nearshore Sediment Transport Study (NSTS) field data (see Gable, 1979, 1980). Both laboratory and field measurements of longshore sediment transport rates were used to calibrate the model.



Figure 1. The wave power equation, shown by the solid line, overpredicts laboratory measurements of longshore transport rate when a constant wave power coefficient is assumed (from Komar and Inman, 1970).



Figure 2. Schematic diagram showing the velocity field parameters in the surfzone.

#### THEORY

Generalized Transport Equation

The basis for the model development was a generalized form of Bagnold's (1963, 1966) sediment transport model for streams. Bagnold's model assumes that sediment is transported in two modes, bedload and suspended load. The bedload transport is assumed to occur as a thin graular-fluid layer which is supported by the bed via grain to grain collisions. The suspended load transport is assumed to take place above the bedload layer, with the sediment supported by fluid turbulence. In both cases, energy is expended by the stream in transporting the Bagnold assumed that the rate of sediment sediment. transport was proportional to the rate of energy dissipation in the stream, with separate proportionality constants, termed efficiency factors, associated with the bedload and suspended load transports respectively.

Bailard (1981) generalized Bagnold's energetics-based stream model for time-varying flow over an arbitrarily sloping bottom. The resulting sediment transport equation was

$$\langle \vec{i}_{t} \rangle = \rho c_{f} \frac{\varepsilon_{B}}{\tan \phi} \left[ \langle \left| \vec{u}_{t} \right|^{2} \vec{u}_{t} \rangle - \frac{\tan \beta}{\tan \phi} \langle \left| \vec{u}_{t} \right|^{3} \rangle \hat{i} \right]$$

$$+ \rho c_{f} \frac{\varepsilon_{s}}{W} \left[ \langle \left| \vec{u}_{t} \right|^{3} \vec{u}_{t} \rangle - \frac{\varepsilon_{s}}{W} \tan \beta \langle \left| \vec{u}_{t} \right|^{5} \rangle \hat{i} \right]$$

$$(3)$$

where  $\vec{1}_t$  is the instantaneous sediment transport rate vector,  $\vec{u}_i$  is the instanteous nearbottom velocity vector,  $\rho$  is the density of water,  $c_f$  is the drag coefficient of the bed,  $\epsilon_B$ is the bedload efficiency factor,  $\epsilon_S$  is the suspended load efficiency factor,  $\phi$  is the internal angle of friction of the sediment,  $\tan\beta$  is the bedslope, W is the fall velocity of the sediment,  $\hat{1}$  is the unit vector directed downslope, and  $\langle \rangle$  indicates a time-averaged quantity.

An important feature of the above equation is that the bedload transport (first bracketed quantity) and the suspended load transport (second bracketed quantity) both consist 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 component of the sediment load.

# Local Surfzone Transport Equations

In order to predict the sediment transport rate in the surfzone, the local surfzone velocity field must first be specified. Figure 2 depicts a plane contour beach with the x-axis directed shoreward and the y-axis directed parallel to the beach. The slope of the beach is  $\tan\beta$  and the local

wave angle is  $\boldsymbol{\alpha}$  .

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For simplicity, the nearbottom velocity field was assumed to be composed of an oscillatory component  $\vec{u}$ , oriented at angle  $\alpha$  to the x axis, and steady velocity components u and v, directed parallel to the x- and y-axes respectively. The total velocity vector,  $\vec{u}_{+}$ , becomes

$$\vec{u}_{t} = (\tilde{u} \cos \alpha + u) \hat{i} + (\tilde{u} \sin \alpha + v) \hat{j}$$
(4)

where  $\hat{i}$  and  $\hat{j}$  are the unit vectors assolcated with the xand y-axes. In addition, the oscillatory velocity component was assumed to be composed of a primary component um with frequency  $\sigma$ , and higher harmonic u  $_{2m}$  with frequency  $2\sigma$ , etc, so that

$$u \cong u_m \cos \sigma t + u_{m2} \cos 2 \sigma t + \dots$$
 (5)

Substituting Equation 4 into Equation 3 and assuming that

$$u/u_{m} \ll 1; \quad v/u_{m} \ll 1; \quad \cos \alpha \cong 1; \quad \langle i_{x} \rangle \ll \langle i_{y} \rangle$$
 (6)

the local time-averaged longshore sediment transport rate becomes

$$\langle i_{y} \rangle = \rho c_{f} u_{m}^{3} \frac{\varepsilon_{B}}{\tan \phi} \left[ \delta_{v} + \delta_{v}^{3} + \frac{\tan \beta}{\tan \phi} u_{3}^{*} \tan \alpha \right]$$

$$+ \rho c_{f} u_{m}^{4} \frac{\varepsilon_{s}}{W} \left[ \delta_{v} u_{3}^{*} + \frac{u_{m}}{W} \varepsilon_{s} \tan \beta u_{5}^{*} \tan \alpha \right]$$

$$(7)$$

where

$$\zeta_{v} = v/u_{m}; \qquad u_{3}^{*} = \langle |\vec{u}_{t}|^{3} \rangle / u_{m}^{3}; \qquad u_{5}^{*} = \langle |\vec{u}_{t}|^{5} \rangle / u_{m}^{5}$$
(8)

With the exception of  $c_f$ ,  $\epsilon_B$ , and  $\epsilon_S$ , all of the parameters in Equation 8 can be predicted from one of the several breaking wave and longshore current models available (e.g. Longuett-Higgins, 1970). In its full complexity, this procedure results in a complex expression for the cross-shore distribution of the longhore sediment transport rate (Bailard, 1981). Spatial integration of the distribution yields an expression similar in form to the wave power equation except that the wave power coefficient is a complex the incident wave, beach, and sediment properties. The complexity of this expression, and

the fact that it requires numerical evaluation has prevented any widespread use of the model.

Spatially-Integrated Longshore Transport Equation

The principal obstacle to obtaining a closed-form solution for K in Bailard's (1981) model were the complex expressions for the wave velocity moments u3\* and u5\*. Guza and Thornton (1981) have shown, however, that for weak mean currents and a gaussian orbital velocity distribution, u3\* and u5\* are constants equal to 0.58 and 1.13 respectively. Estimates from NSTS field data generally support these findings except that measured values are closer to 0.60 and 1.25. Based on these findings, one of the simplifying assumptions used in the present model development was that u3\* and u5\* are constants equal to 0.60 and 1.25.

The longshore current model used in the present development was the radiation stress-based model by Ostendorf and Madsen (1979). In order to keep the solution as simple as possible, a number of simplifications were made with relationship to the model's provisions for finite breaker height and longshore current strength. The resulting expression for the longshore current, v, is as follows

$$\mathbf{v} = \mathbf{v}_{\mathrm{C}} \mathbf{v}^{\mathrm{A}} \tag{9}$$

where  $v_c$  is a characteristic longshore current strength and  $v^*$  is the dimensionless longshore current distribution expressed as follows (P#0.4)

$$\mathbf{v}^{*} = C_{1} \left( \frac{1 - C_{2}}{C_{2} - C_{3}} \right) \mathbf{x}^{*} + C_{1} \mathbf{x}^{*} \qquad \mathbf{x}^{*} \leq 1$$

$$\mathbf{v}^{*} = C_{1} \left( \frac{1 - C_{3}}{C_{2} - C_{3}} \right) \mathbf{x}^{*} \qquad (10)$$

The parmeters Cl, C2, and C3 are the following functions of the lateral mixing parameter, P,

- 1

$$C_{1} = (1 - 2.5 P)^{1}$$

$$C_{2} = -\frac{1}{8} - \left(\frac{1}{64} + \frac{1}{P}\right)^{1/2}$$

$$C_{3} = -\frac{3}{4} + \left(\frac{9}{16} + \frac{1}{P}\right)^{1/2}$$
(11)

and the dimensionless surfzone position,  $x^{\star}$ , is defined as

$$\mathbf{x}^{\star} = \frac{\mathbf{x} - \mathbf{x}_{s}}{\mathbf{x}_{b} - \mathbf{x}_{s}} \tag{12}$$

where  $x_{\rm c}$  and  $x_{\rm b}$  are the positions of the shoreline and the break-point on the x-axis respectively.

The characteristic longshore current strength,  $\mathbf{v}_{\mathsf{C}}$  , is defined as

$$\mathbf{v}_{c} = \delta_{c} \mathbf{u}_{mb} \tag{13}$$

where  $\mathbf{u}_{\mbox{mb}}$  is the oscillatory velocity magnitude, obtained from shallow water wave theory, i.e,

$$u_{\rm m} = \frac{\gamma}{2} \sqrt{g h} \tag{14}$$

and  $~\delta_{\textbf{C}}$  is the relative longshore current strength parameter defined as

$$\delta_{\rm c} = \frac{5 \pi \tan \Delta \sin \alpha_{\rm b}}{8 c_{\rm f}}$$
(15)

The parameter  $\tan \Delta$  is equal to the average beach slope,  $\tan \beta$ , modified for wave setup, i.e.

$$\tan \Delta = \frac{\tan \beta}{1 + \frac{3}{8} \gamma_b^2}$$
(16)

The parameter  $\gamma$  is defined as the ratio of the surfzone wave height, H, to the water depth, h, and is assumed to have the following distribution

$$\gamma = \gamma_{b} \qquad x^{*} \leq 1$$

$$\gamma = \gamma_{b} \left(\frac{h_{b}}{h}\right)^{5/4} \qquad (17)$$

$$x^{*} > 1$$

where  $\gamma_b$  is assumed to be equal to 0.8

Combining Equations 8 and 9 and assuming that Snells Law applies, the following equation was obtained for the cross-shore distribution of the longshore transport rate

$$\langle \mathbf{i}_{\mathbf{y}} \rangle = \rho c_{\mathbf{f}} u_{\mathbf{m}b}^{3} \frac{\varepsilon_{\mathbf{B}}}{\tan \phi} \left[ \frac{1}{2} \left( \frac{\gamma}{\gamma_{\mathbf{b}}} \right)^{2} \delta_{\mathbf{c}} v^{*} x^{*} + \delta_{\mathbf{c}}^{3} v^{*} \right]$$

$$+ \frac{\tan \beta}{\tan \phi} \left( \frac{\gamma}{\gamma_{\mathbf{b}}} \right)^{3} u_{3}^{*} x^{*^{2}} \tan \alpha_{\mathbf{b}} \right]$$

$$+ \rho c_{\mathbf{f}} u_{\mathbf{m}b}^{4} \frac{\varepsilon_{\mathbf{s}}}{W} \left[ \left( \frac{\gamma}{\gamma_{\mathbf{b}}} \right)^{3} \delta_{\mathbf{c}} u_{3}^{*} v^{*} x^{*^{3}} \right]$$

$$+ \tan \beta \frac{u_{\mathbf{m}b}}{W} \varepsilon_{\mathbf{s}} \left( \frac{\gamma}{\gamma_{\mathbf{b}}} \right)^{5} u_{5}^{*} x^{*^{3}} \tan \alpha_{\mathbf{b}} \right]$$

$$(18)$$

The spatially integrated longshore transport rate,  $I_{\ell},$  was obtained by spatially integrating Equation 18, i.e.

$$I_{\ell} = \frac{h_b}{\tan \Delta} \int_0^{\infty} \langle i_y \rangle \, dx^*$$
(19)

Noting that K = I  $_{\ell}/P_{\ell}$  ,  $\tan\alpha_b\simeq sin\alpha_b$  , and

$$\rho c_{f} \frac{h_{b}}{\tan \Delta} u_{mb}^{3} \delta_{c} = \frac{5 \pi}{8} \gamma_{b} P_{\ell}$$
(20)

then the wave power coefficient K can be expressed as

$$K = \varepsilon_{B} K_{1} + \varepsilon_{s} K_{2} + \varepsilon_{s}^{2} K_{3}$$
(21)

where

$$K_{1} = \frac{5}{8} \frac{\pi}{\left(\frac{\gamma_{b}}{\tan \phi}\right)} \left\{ \frac{c_{1}}{2(c_{2}-c_{3})} \left[ \frac{1-c_{2}}{c_{3}+2} + \frac{c_{2}-c_{3}}{3} - \frac{1-c_{3}}{c_{2}-\frac{1}{2}} \right] + \frac{25}{256} \left(1 + \frac{3}{8} \gamma_{b}^{2}\right)^{-2} \left(\frac{\tan \beta}{c_{f}}\right)^{2} \sin^{2} 2 \alpha_{b} c_{1}^{3} \left[ \frac{\left(\frac{1-c_{2}}{c_{2}-c_{3}}\right)^{3}}{3c_{3}+1} + \frac{3\left(\frac{1-c_{2}}{c_{2}-c_{3}}\right)^{2}}{2c_{3}+2} + \frac{3\left(\frac{1-c_{2}}{c_{2}-c_{3}}\right)}{c_{3}+3} + \frac{1}{4} - \frac{\left(\frac{1-c_{3}}{c_{2}-c_{3}}\right)}{3c_{2}+1} \right] + \frac{8}{15\pi} \left(\frac{\tan \beta}{\tan \phi}\right) \left(\frac{c_{f}}{\tan \beta}\right) \left(1 + \frac{3}{8} \gamma_{b}^{2}\right) u_{3}^{\pm} \right\}$$

$$K_{2} = \frac{5\pi}{8} \gamma_{b} u_{3}^{\pm} \frac{u_{mb}}{W} \left(\frac{c_{1}}{c_{2}-c_{3}}\right) \left[ \frac{1-c_{3}}{c_{3}+\frac{5}{2}} + \frac{c_{2}-c_{3}}{7/2} - \frac{1-c_{3}}{c_{2}-\frac{5}{4}} \right]$$
(23)

and

$$K_{3} = \frac{25}{36} \gamma_{b} \tan \beta \left( \frac{c_{f}}{\tan \beta} \right) \left( 1 + \frac{3}{8} \gamma_{b}^{2} \right) u_{5}^{*} \left( \frac{u_{m}}{W} \right)^{2}$$
(24)

Equations 22 through 24 were further simplified using the results of Komar (1976). Komar analyzed laboratory and field measurements of longshore currents and found that P was approximately equal to 0.2 and the ratio  $\tan\beta/c_{\rm f}$  was approximately equal to 7. Introducing these assumptions into Equations 22 through 24, the following results were obtained

$$K_1 = 0.385 + 20 \sin^2 2 \alpha_h + 0.074 \tan \beta$$
 (25)

$$K_1 = 0.228 u_{mb}/W$$
 (26)

$$K_3 = 0.123 \tan \beta (u_{mb}/W)^2$$
 (27)

# MODEL CALIBRATION

The remaining free parameters in Equation 21 which need to be specified are the bedload and suspended load efficiency factors. Bagnold (1966) found that for stream flow,  $\epsilon_B$  and  $\epsilon_S$  were equal to 0.13 and 0.01 respectively. In the present case, these factors were estimated from laboratory and field measurements of K.

The laboratory data used to estimate  $\varepsilon_B$  and  $\varepsilon_S$  were selected data from Saville (1949, 1950) and Shay and Johnson (1951). The field data were from Bruno et. al. (1980), Dean et. al. (1983), Komar and lnman (1970), Kraus et. al. (1983), and Moore and Cole (1960). Average characteristics of these data sets are summarized in Table 1.

Initially, a nonlinear least squares procedure was used to estimate  $\epsilon_B$  and  $\epsilon_S$ , however, it was quickly found that the contribution of K3 to K was negligible in relationship to K1 and K2. When K3 was eliminated from Equation 21, the resulting equation was linear in  $\epsilon_B$  and  $\epsilon_S$ , thus a multiple linear regression technique could be used. The resulting estimates for  $\epsilon_B$  and  $\epsilon_S$  and their 95% confidence intervals were

$$\varepsilon_{\rm B} = 0.13 \pm 0.009$$
(28)
 $\varepsilon_{\rm s} = 0.032 \pm 0.004$ 

Combining these estimates with Equation 21, the desired

Table 1. Characteristics of laboratory and field data sets used to calibrate the present longshore transport model.

Laboratory								
#OBS	W(cm/sec)	Umb/W	θ(deg)	Kobs				
7	4.0	8.3	6	0.16				
3	4.0	8.5	6	0,22				
	<u>#0BS</u> 7 3	Laborato #0BS W(cm/sec) 7 4.0 3 4.0	Laboratory           #OBS         W(cm/sec)         Umb/W           7         4.0         8.3           3         4.0         8.5	Laboratory #OBS W(cm/sec) Umb/W $\theta(deg)$ 7 4.0 8.3 6 3 4.0 8.5 6				

Source	#OBS	W(cm/sec)	Umb/W	θ(deg)	Kobs
Bruno et. al	7	2.5	113	0.2	0.87
Dean et. al	7	2.7	31	15	1.15
Komar & Inman					
El Moreno	10	9.5	11	9	0.82
Silver Strand	3	2.0	72	4	0.66
Kraus et. al					
Ajigaura	2	3.2	38	4	0.31
Hirono	2	9.5	16	2.5	0.11
Shimokita	1	2.7	48	6.0	0.61
Moore & Cole	1	20.5	9.3	12	0.19

Field

equation for the wave power coefficient, K, was obtained

$$K = 0.05 + 2.6 \sin^2 2 \alpha_b + 0.007 u_{mb} / W$$
 (29)

Figure 3 shows a plot of the observed values of K versus the values estimated by Equation 29. With the exception of the data from El Moreno Beach (Komar and Inman, 1970), and the single data point from Moore and Cole (1960), the fit is relatively good.

# DISCUSSION

The advantage of the present model over the wave power equation is that it can be used to predict the longshore sediment transport rate over a wider range of input conditions. Using a constant wave power coefficient equal to 0.77, the wave power equation does an adquate job of predicting the longshore transport rate provided the grain size is between 0.15 and 0.25 mm and the wave height is between 0.5 and 2.0 m. Outside of this range, particularly, under laboratory conditions or for large sand sizes in the field, the power equation is significantly in error.

The present model corrects the above mentioned shortcoming of the wave power equation by separately accounting for the bedload and suspended load transports. As a result, the wave power coefficient becomes a function of the incident breaker and sediment characteristics. Nevertheless, the resulting equation for K involves only parameters which are already available from the usual longshore transport calculations.

The present longshore transport model has a number of limitations which must be mentioned. First, the energetics sediment transport equations which are used in the model development are vertically integrated and ignore the vertical structure of the sediment concentration and velocity fields. Recent field measurements of vertical distributions of these parameters, substantiate their importance, particularily in relationship to cross-shore sediment transport (Jaffee et. al., 1984). Their importance in relationship to longshore transport processes is unknown.

A second limitation of the model is that the rate of energy dissipation (to which the transport rate is proportional) is computed directly from the drag at the bed. Contributions associated with the breaking wave at the surface are neglected, in spite of their overall dominance (Thornton and Guza, 1983). The implicit assumption is that the bottom boundary layer is the primary factor controlling the upward flux of sediment from the bottom, however, this is only



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conjecture. A possible improvement to the model might be to incorporate a variable drag coefficient to partially account for the energy dissipation of the breaking waves. Alternatively, the rate of energy dissipation could be directly associated with the local gradient in the energy flux (e.g. Thornton, 1973 and others).

A third limitation of the model is that threshold of motion effects for the sediment have been neglected. Seymour (1983) has shown that under most field conditions, threshold effects are not significant, while under laboratory conditions they are significant. Threshold effects could be incorporated into the present model using the statistical method developed by Seymour (1983), but the resulting equations would be more complex.

Additions limitations of the model can be summarized as follows. The distribution of the longshore transport rate was derived from the usual breaking wave assumptions. Analysis of NSTS field data has shown that some of these assumptions are clearly incorrect. For example, one common assumption is that the total velocity variance monotonically decreases towards the shore. Field measurements on dissipative beaches show instead that the velocity variance is nearly constant across the surfzone (Guza and Thornton, 1981; Bailard, 1983). This result has important ramifications concerning the distribution of the longshore current and the longshore sediment transport rate.

A related problem is that beach profile shapes have been shown to have a significant effect on the distribution of the longshore current (McDougal and Hudspeth, 1984). Moreover, proper characterization of the lateral mixing of momentum is still an unanswered question. As a result, the distribution of the longshore transport rate specified in the present model should be considered as only approximate.

The overall effect of the above mentioned limitations on the present model is not known. To some degree, many of these effects have been hidden by the processes of integration as well as by the least squares estimation procedure for determining the bedload and suspended load efficiency factors.

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions were reached as a result of this study.

1. A simple modification to the wave power equation has been developed through a systematic application of Bagnold's energetics sediment transport concepts. Instead of being

constant, the wave power coefficient is found to be a function of the incident breaker angle and the ratio of the orbital velocity at the break point divided by the sediment fall velocity.

2. The above modification was found to extend the range of application of the wave power equation. Longshore transport rates under laboratory conditions can be predicted with the same equation used for field conditions. The equation can also be applied to beaches with larger sediment sizes.

3. Although the model describes the distribution of the longshore transport rate across the surfzone, this distribution should be applied with caution. Recent measurements of surfzone waves and currents suggest that a number of the common assumptions used to develop the present model and most longshore current models are not very accurate.

4. There may be a limit to the extent that vertically-integrated energetics-based sediment transport models can be used to describe surfzone sediment transport processes. Vertical distributions of cross-shore velocities and sediment concentrations are clearly important in determining on-offshore sediment transport rates. Their importance in longshore transport processes is unknown.

5. The present model might be improved by including sediment threshold of motion effects, a variable drag-coefficient, and a different formulation for the rate of energy dissipation. While these modifications will probably provide a more accurate prediction of the longshore sediment transport rate, they will also increase the complexity of the model. Most likely, however, significant improvements in modeling surfzone sediment processes will come only through an increased understanding of the vertical structure of the sediment concentration and velocity.

Based on these findings, it is recommended that future work be focused on measuring the vertical structure of the sediment concentration and fluid velocity fields. A parallel effort should focus on developing improved models for wave bore dynamics, surfzone boundary layer dynamics, bedload, and suspended load mechanics, and time-averaged longshore and on-offshore currents in the surfzone.

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