SEDTRANS92: RE-EVALUATION AND UPGRADE OF THE AGC SEDIMENT TRANSPORT MODEL

by

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Open File 2769
August, 1993

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Énergie, Mines et Ressources, Canada

Geological Survey of Canada
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LIST OF SYMBOLS

A_b	near-bed wave orbital amplitude
A_{gr}	Ackers-White critical sediment mobility number
c	suspended sediment concentration
c_r	wave-to-current strength ratio
D	sediment grain diameter
d_{cw}	thickness of wave-current boundary layer
D_{gr}	Ackers-White dimensionless grain size
f_c	current friction factor
f_{cw}	combined wave-current friction factor
F_{gr}	Ackers-White sediment mobility number
f_w	wave friction factor
g	gravity acceleration
G_{gr}	Ackers-White transport parameter
h	water depth
H	wave height
H_r	ripple height
i_s	bedform transport rate
k	wave number
K	proportionality coefficient in Bagnold formula
k_b	bottom roughness height
k_s	sediment grain roughness height
k_o	deep-water wave number

L	wave length
L_r	ripple wave length
L_o	deep-water wave length
P	proportionality coefficient for cohesive sediment erosion
P_s	resuspension probability for cohesive sediments
q_s	volume rate of sediment transport
r_d	deposition rate of cohesive sediments
r_e	erosion rate of cohesive sediments
R_e	Reynolds number
R_{gr}	Ackers-White special Reynolds number
s	sediment specific gravity
S	normalized excess shear velocity
t	time for bedload sediment transport
t_s	time for suspended load sediment transport
u_a	instantaneous combined velocity at top of the wave-current boundary layer
u_b	near-bed maximum wave orbital velocity
u_{cr}	critical mean velocity
u_{cs}	critical mean velocity for suspended load transport
u_m	maximum combined bottom velocity
u_z	mean velocity at height z above the bottom
u_{100}	mean velocity at 1 m above the bottom
u_*	shear velocity
u_{*c}	current shear velocity
u_{*cr}	critical shear velocity

u_{*crs}	critical shear velocity for suspended load transport
u_{*cw}	combined wave-current shear velocity
u_{*wm}	maximum wave shear velocity
V	mean velocity
W_n	natural settling velocity
W_s	spherical settling velocity
W_{sc}	cohesive sediment settling velocity
z	height above the bottom
z_o	bottom roughness
z_{oc}	apparent bottom roughness
β	grain size coefficient in modified Bagnold formula
θ_c	current Shields parameter
θ_w	wave Shields parameter
θ_t	(critical) Shields parameter
κ	von Karman constant
μ	dynamic viscosity
ν	kinematic viscosity
ρ	fluid density
ρ_s	sediment density
τ_b	bottom shear stress
τ_{cr}	critical shear stress
τ_{crs}	critical shear stress for suspended load transport
τ_{cw}	combined wave-current shear stress
τ_d	critical deposition shear stress for cohesive sediments

τ_e	critical erosion shear stress for cohesive sediments
τ_y	yield stress for cohesive sediments
ϕ_b	angle between wave and current in the wave-current boundary layer
ω	wave angular frequency
$\sqrt{\Xi}$	Yalin parameter

SUMMARY

The Atlantic Geoscience Centre sediment transport model has been under development over the last nine years. This model basically provides solutions of bed stress using either Grant and Madsen (1979, 1986) or Smith (1977) boundary layer theory for combined flow conditions and then predicts the sediment transport rates using different algorithms chosen by the user. In the present report, this model is thoroughly re-evaluated and upgraded in light of latest advances of the combined wave-current boundary layer theory and recently-available field data measured on Sable Island Bank, the Scotian Shelf. The prediction of bottom friction factor and combined wave-current shear stress has been upgraded according to the most recent Grant and Madsen theory. Shear velocity instead of the mean reference velocity has been used in the calculations of the sediment thresholds and times of sediment transport modes over a wave cycle so that the threshold criterion for the initiation of sediment transport will not vary with the change of the wave-current conditions. Skin-friction shear stress is used in all transport rate formulae for combined flow conditions. The predicted sediment transport rates reasonably agree with the available field measurements.

Ripple roughness plays important roles in controlling stress partitioning and sand resuspension. A tested ripple predictor under combined flow should be included in a future version of the model. Bed-load and total-load sediment transport rates predicted by the various formulae of the model do not differ significantly. This indicates that the suspended sediment concentration profiles should be predicted separately and multiplied by the velocity profiles to obtain the suspended load transport rate.

1. INTRODUCTION

Many processes on continental shelves and in the nearshore are influenced by the friction, turbulent mixing and fluid shearing near seabeds under combined wave-current conditions. Sediment transport modelling under combined flows is thus important to physical, biological, chemical and geological oceanographers, as well as coastal engineers and environmental managers (Grant and Madsen, 1986; Cacchione and Drake, 1990). The Atlantic Geoscience Centre sediment transport model (SEDTRANS90) has been under development for the last nine years (Martec Ltd., 1984,1987; Davidson and Amos, 1985). This model basically provides solutions of bed stress using either Grant and Madsen (1979) or Smith (1977) boundary layer theory for combined flow conditions and then predicts the sediment transport rates using different algorithms chosen by the user. Cohesive sediment transport prediction and sediment accretion-erosion estimation were added to the model in recent modifications (Martec Ltd., 1990).

The model uses Engelund and Hansen (1967), Bagnold (1963) and Ackers and White (1973) for total load prediction. Methods of Einstein-Brown (Brown, 1950) and Yalin (1963) are used for bedload estimation. An attempt was made originally to calibrate the program codings of these formulae with hand calculations. Convergence between observations and predictions could only be achieved when the total flow stress, which includes form drag as well as sediment grain skin friction, was used to predict sediment transport rate (Amos et al., in review). However, it has been generally agreed that the skin-friction component of the total stress should be responsible for the initiation and transport of sediments. When the skin-friction shear stress was used in the model, the predicted sediment transport rates were found to be one to two orders of magnitude lower than the measured transport rates from ripple migration data (Amos, et al., 1988a). The Grant and Madsen (1979) combined wave-current bottom boundary layer theory has been advanced considerably from the original version (Grant and Madsen, 1986; Glenn and Grant, 1987). Wave-current dynamics and bedform migration data collected on the Scotian shelf using an instrumented tripod should provide valuable in-situ field data that is badly needed for calibrating shelf sediment transport models. Thus a thorough re-evaluation and upgrade of the AGC sediment transport model is needed in light of recent advances in boundary layer theory and available field data for model calibration.

This is a summary report on the re-evaluation and upgrade of the AGC continental shelf sediment transport model (SEDTRANS90). The prediction of bottom friction factor (f_{cw}) and combined wave-current shear stress have been upgraded according to the most recent Grant and Madsen theory (GM hereafter). Shear velocity instead of the mean reference velocity has been used in the calculations of the sediment thresholds and times of sediment transport modes over a wave cycle so that the threshold criterion for the initiation of sediment transport will not vary with the change of the wave-current conditions. Skin-friction shear stress is used in all transport rate formulae for combined flow conditions. Finally, the predicted sediment transport rates are compared with the field data for a primary calibration of the upgraded model and conclusions and recommendations will be given about future work and possible further improvement of the model. The program source codes are given in Appendix 1 at the end of the report.

2. THE MODEL

The AGC sediment transport model (Martec Ltd., 1984; Davidson and Amos, 1985) included both a one-dimensional and a two-dimensional model, SED1D and SED2D. This report concerns only the one-dimensional model and a corresponding upgrade of SED2D can be easily done following the upgraded SED1D. A tracer study was conducted, but an effort to use the results to calibrate the model was not successful (Martec Ltd., 1986). The original model only used sediment transport algorithms of Engelund-Hansen, Einstein-Brown, Bagnold and Yalin. The total load prediction of Ackers-White and suspended load prediction of Smith (1977) for current-dominant mixed flows were added to the model during subsequent modifications (Martec Ltd., 1986,1987). A latest modification (Martec Ltd., 1990) incorporated the cohesive sediment transport algorithm of Amos and Greenberg (1980) in the model to supplement the six existing non-cohesive sediment transport formulae.

The model is written in Fortran V. It can be run either interactively or in batch mode. The source codes of the model are made modular so that the computation process can be broken down into module form and each component is contained in a separate subroutine. This structure allows each subroutine to be modified separately without changing the whole program. There are ten subroutines in the program. These are given below with their main functions:

1. Main Program, IAFSED (interactive mode) and BCHSED (batch mode): controls passage of information among subroutines.
2. Data Input, READIN and READBCH: reads user-supplied data required to run the model.
3. Subroutine INOUT: prints the input data both to the terminal and to the output file.
4. Subroutine OSCIL: computes the required wave parameters using linear wave

theory.

5. Subroutine FRICFAC: calculates the bottom friction factor and various shear stresses required by the program.
6. Subroutine THRESH: calculates the threshold shear velocities for both bedload and suspended load sediment transport.
7. Subroutine TIMING: calculates the times during a wave cycle when the respective threshold shear velocities are exceeded.
8. Subroutine TRANSPO: computes the time-averaged net sediment transport according to one of the seven available algorithms.
9. Subroutine OUTOUT: prints the selected output parameters from all the subroutines.
10. Subroutine BEDFORM: predicts the type and dimension of the possible bedforms.

For a given set of wave, current and seabed conditions, the instantaneous bottom shear stress is first estimated through subroutines OSCIL and FRICFAC. Subroutine THRESH is then run to determine the threshold conditions for the initiation of bedload and suspended load sediment transport respectively. Based on the results from the above operations, duration of sediment transport over a wave cycle is calcuated in subroutine TIMING and net sediment transport is integrated over this time period using subroutine TRANSPO.

3. MODEL RE-EVALUATION AND UPGRADE

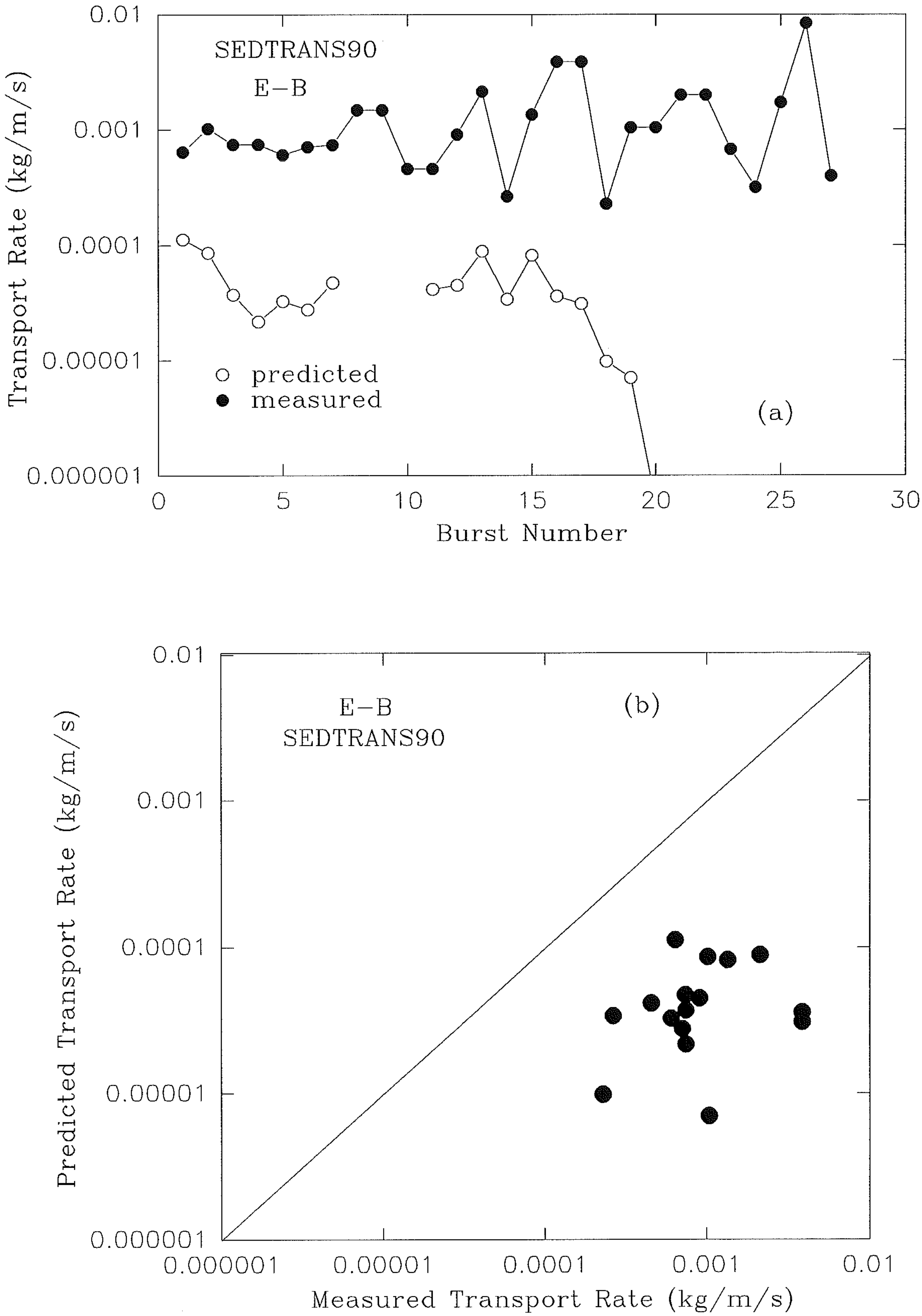
When sediment transport occurs over bedforms, the total drag felt by the flow consists of contributions from bedload transport, the resistance due to bedforms, as well as the sediment grain skin friction. It has generally been accepted that only the skin friction component causes sediment transport (Dyer, 1986; Cacchione and Drake, 1990). A recent deployment of an instrumented tripod (RALPH) collected bed state, ripple migration and near-bed wave-current conditions on Sable Island Bank, the Scotian Shelf. Measured ripple migration data were used to calculate the bedform transport rates. Time series of these measured bedform transport rates and those predicted by the original model SEDTRANS90 using the skin-friction shear stress are plotted in Fig.1a for selected bursts. Their scatter plot is shown in Fig.1b. These plots show that the model-predicted transport rates are one to two orders of magnitude lower than the observed bedform transport rates. The model also predicts zero transport for bursts in which strong currents occurred. This casted doubts about the validity of the model and so a thorough re-evaluation of the model was performed.

Step-by-step checking of the model showed that problems existed in key subroutines FRICFAC, THRESH, TIMING and TRANSPO. These subroutines thus have been modified and the whole model has been upgraded based on new advances of the GM theory and recently-available field data.

3.1 Subroutine OSCIL

Waves usually are described by water depth (h), wave height (H) and wave period (T). The calculation of bottom stress, however, requires the maximum wave orbital velocity (u_b) and maximum water particle displacement (A_b) at seabed to be known. Linear wave theory has been used in this

Figure 1. Time series and scatter plots of sediment transport rates predicted by SEDTRANS90 and from measured ripple migration rates for selected bursts of the Sable Island data. Einstein-Brown formula is used in the model.



SEDTRANS90
E-B
Transport Rate (kg/m/s)
0.01
0.001
0.0001
0.00001
0.000001
predicted
measured
(a)
0
5
10
15
20
25
30
Burst Number
E-B
SEDTRANS90
(b)
Predicted Transport Rate (kg/m/s)
0.000001
0.00001
0.0001
0.001
0.01
Measured Transport Rate (kg/m/s)

Figure 1

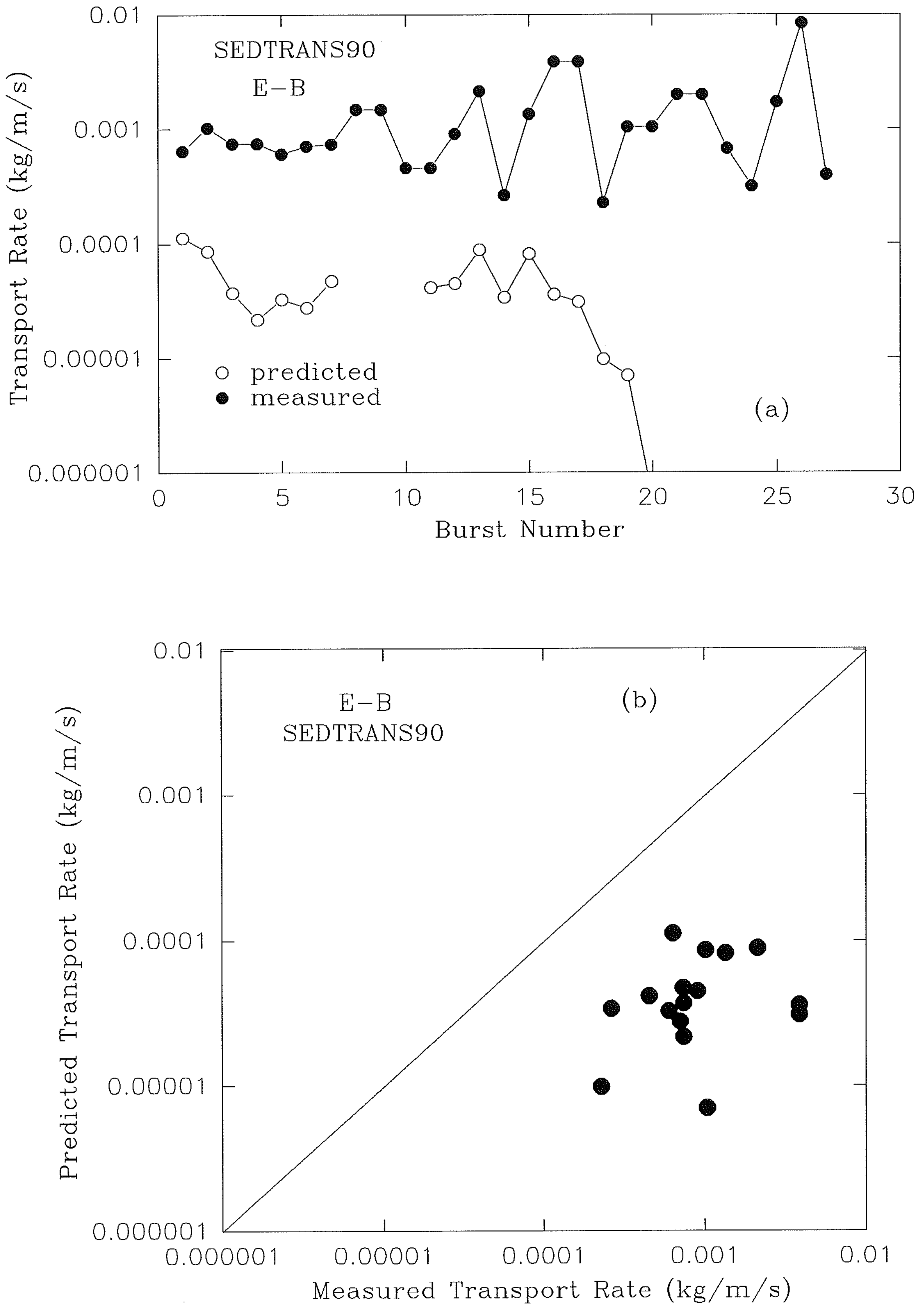

0.01
0.001
0.0001
0.00001
0.000001
Transport Rate (kg/m/s)
SEDTRANS90
E-B
predicted
measured
(a)
0
5
10
15
20
25
30
Burst Number
0.01
0.001
0.0001
0.00001
0.000001
Predicted Transport Rate (kg/m/s)
E-B
SEDTRANS90
(b)
0.000001
0.00001
0.0001
0.001
0.01
Measured Transport Rate (kg/m/s)

Figure 1

model to calculate u_b and A_b in subroutine OSCIL.

Waves do not affect the sea bed in the deep water case, thus u_b and A_b are assumed to be zero when deep water criterion $h/L_o>2$ is met, where $L_o=gT^2/2\pi$ is the deep-water wave length. Wave number k is computed from the linear wave dispersion equation:

$$\omega^2 = gk \tanh(kh) \tag{1}$$

where ω is the wave angular frequency ($\omega=2\pi/T$). Due to the transcendental nature of equation (1), iterative calculation is required to solve for k. Newton-Raphson method is used in this model to solve equation (1). If x_1 is assumed to be the first-estimated root to function f(x), then successive estimates can be obtained from $x_{n+1} = x_n - f(x_n)/f'(x_n)$. Equation (1) can be re-written as:

$$f(kh) = 1/\tanh(kh) - kh/k_oh \tag{2}$$

where $k_o=\omega^2/g$ is the deep water wave number. Based on equation (2), the Newton-Raphson solution can be written as:

$$\begin{aligned}(kh)_{n+1} &= (kh)_n + f(kh)_n/f'(kh)_n \\ &= (kh)_n - [1/\tanh(kh)_n - (kh)_n/k_oh] \\ &\quad /[1/\sinh^2(kh)_n + 1/(kh)_n]\end{aligned} \tag{3}$$

The deep water parameter k_oh is used as the first estimate of kh and a new estimate is obtained from equation (3). If this new kh is still significantly different from the first estimate, the procedure is repeated till kh converges to a steady solution. The final kh is then used in the following equation to determine wave length:

$$L = L_o \tanh(kh) \tag{4}$$

and u_b and A_b are then calculated from the following relationships:

$$u_b = \pi H/[T*\sinh(kh)] \tag{5}$$

$$A_b = u_b/\omega \tag{6}$$

3.2 Subroutine FRICFAC

The friction factor computation for either the pure wave or the steady current case is not changed in this version of the model. Steady-current friction factor f_c is taken to be 0.006 based on field experiments of Sternberg (1972), while pure-wave friction factor f_w is calculated according to Jonsson (1966) as modified by Nielsen (1979):

$$f_w = \exp[5.213(k_b/A_b)^{0.194}-5.977] \qquad A_b/k_b>1.7 \qquad (7)$$

$$f_w = 0.28 \qquad A_b/k_b\leq 1.7 \qquad (8)$$

where k_b is the bottom roughness height. A quadratic law is used to compute the bottom shear stress τ_b. For pure waves:

$$\tau_b = 0.5\rho f_w u_b^2 \qquad (9)$$

and for steady currents:

$$\tau_b = 0.5\rho f_c u_{100}^2 \qquad (10)$$

where ρ is the fluid density and u_{100} is the mean velocity measured at 1 m above the bottom. If u_z is measured at height z other than 1 m above the bottom, then u_{100} is obtained from a logarithmic profile:

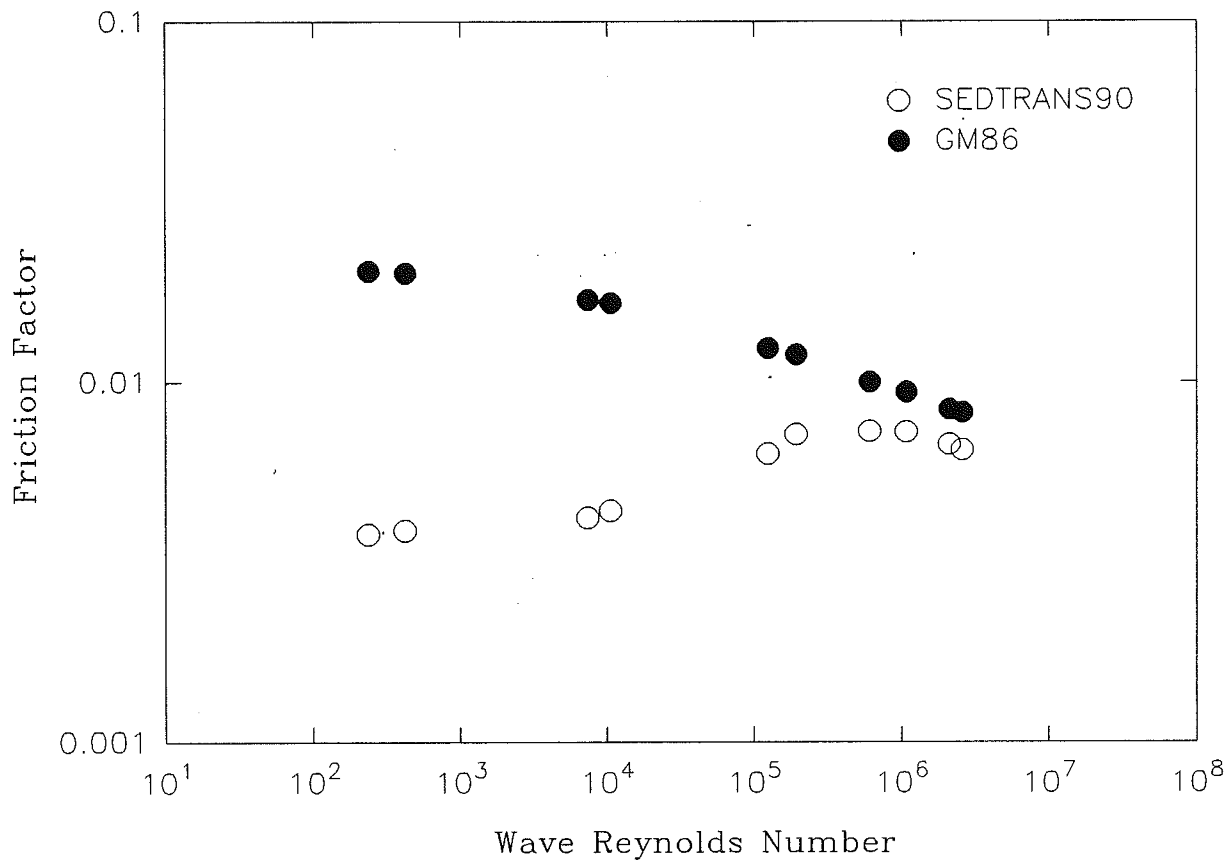
$$u_{100} = u_z\log(30/k_b)/\log(30z/k_b) \qquad (11)$$

Major changes are made in the computation of friction factor under combined wave-current flows. The prediction of friction factor f_{cw} in SEDTRANS90 is based on the work of Grant and Madsen (1979, GM79 hereafter) and this theory has been advanced significantly since then (Grant and Madsen, 1986; GM86 hereafter). Two sets of synthetic data have been used to test the interpretation and source codes in subroutine FRICFAC of SEDTRANS90 (Table 1). Data set 1 is for fixed wave and increasing currents and data set 2 for fixed current and increasing waves. Sediment grain size D is taken to be 0.23 mm. Ripple height and length are assumed to be H_r=0.03 m and L_r=0.3 m, respectively. The f_{cw} values computed from SEDTRANS90 and GM86 method are plotted in Fig.2 against the wave Reynolds number $R_{ew}=u_bA_b/\nu$, where ν is the kinematic viscosity. Figure 2 shows that

Table 1. Synthetic input data for testing friction factor predictions. u is the mean velocity measured at 1 m above seabed, f_{cw}-SED is the friction factor given by SEDTRANS90, and f_{cw}-GM86 is the friction factor obtained from Grant and Madsen (1986). Waves and currents are angled by 30°.

sample#	u(cm/s)	period(s)	height(cm)	f_{cw}-SED	f_{cw}-GM86
set 1					
1	10	8	60	0.00946	0.0126
2	15	8	60	0.00860	0.0123
3	20	8	60	0.00714	0.0119
4	30	8	60	0.00460	0.0113
5	40	8	60	0.00357	0.0107
6	50	8	60	0.00302	0.0102
7	60	8	60	0.00269	0.00985
8	70	8	60	0.00247	0.00952
9	80	8	60	0.00230	0.00923
10	100	8	60	0.00206	0.00874
set 2					
1	20	5	30	0.00376	0.0203
2	20	5	40	0.00384	0.0201
3	20	6	50	0.00418	0.0169
4	20	6	60	0.00437	0.0166
5	20	8	80	0.00630	0.0125
6	20	8	100	0.00714	0.0119
7	20	10	120	0.00728	0.0100
8	20	10	140	0.00725	0.00938
9	20	12	160	0.00669	0.00841
10	20	12	200	0.00644	0.00821

Figure 2. Friction factor predicted by SEDTRANS90 and Grant-Madsen'86 as a function of the wave Reynolds number, $A_b u_b/\nu$.



0.1
0.01
0.001
Friction Factor
SEDTRANS90
GM86
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
Wave Reynolds Number

Figure 2

f_{cw} predicted by SEDTRANS90 is nearly one order of magnitude lower than that calculated from GM86. According to Jonsson (1966), f_{cw} decreases with increases in wave Reynolds number. f_{cw} prediction of GM86 follows this trend, but f_{cw} values computed from SEDTRANS90 basically increase as R_{ew} is increased. For the maximum A_b and u_b of the test data, Jonsson's f_w diagram gives a minimum value of 0.006 which is still significantly higher than 0.003 predicted by SEDTRANS90 model. Due to the very low f_{cw} values, a default value of 0.006 has to be used in SEDTRANS90 when predicted f_{cw} is smaller than this, but this forced default does not have any theoretical basis. These results in general suggest that either the interpretation of GM79 theory or the source code of subroutine FRICFAC was incorrect, but it is beyond the scope of this report to determine the cause.

The algorithm for f_{cw} computation in SEDTRANS92 is based on GM86. The basic theory and procedures of this latest method are described below:

(1) Initial estimate of f_{cw}: An arbitrary value is first assumed for the wave-to-current strength ratio C_r. The current-wave friction factor f_{cw} can then be obtained by iteration from:

$$1/(4f_{cw}^{0.5}) + \log[1/(4f_{cw}^{0.5})\}$$

$$= \log(C_r u_b/\omega z_o) + 0.14(4f_{cw}^{0.5}) - 1.65 \quad (12)$$

where z_o=k_b/30 is the bottom roughness.

(2) Estimate u_{*wm}, u_{*cw} and u_{*c}: The maximum wave shear velocity u_{*wm} is calculated using C_r and f_{cw} from above:

$$u_{*wm} = (C_r f_{cw} u_b^2/2)^{0.5} \quad (13)$$

and combined wave-current shear velocity is obtained from:

$$u_{*cw} = u_{*wm} C_r^{0.5} \quad (14)$$

The equations governing the near-bottom flow describe boundary layer velocity profiles as:

$$u_z = (u_{*c}/\kappa)(u_{*c}/u_{*cw})\ln(z/z_o) \qquad z \le d_{cw} \quad (15)$$

$$u_z = (u_{*c}/\kappa)\ln(z/z_{oc}) \qquad z \ge d_{cw} \quad (16)$$

where u_{*c} is the current shear velocity, κ is the von Karman constant (=0.4), z_{oc} is the apparent roughness experienced by the current in the presence of waves, and $d_{cw}=2\kappa u_{*cw}/\nu$ is the thickness of the wave-current boundary layer. By matching the current of the outer-layer and the wave boundary layer at d_{cw}, current shear velocity u_{*c} can be computed from the following:

$$u_z = (u_{*c}/\kappa)[(u_{*c}/u_{*cw})\ln(d_{cw}/z_o) + \ln(z/d_{cw})] \tag{17}$$

where u_z is the measured velocity at height z above the bottom.

(3) Iteration and final estimates: Results from step 2 are used to compute a new value of C_r according to:

$$C_r = [1+2(u_{*c}/u_{*wm})^2\cos\phi_b + (u_{*c}/u_{*wm})^4]^{0.5} \tag{18}$$

where ϕ_b is the angle between wave and current in the boundary layer. This new C_r is then used to repeat steps 1 to 3 till a convergence of C_r is achieved and the final values of f_{cw}, u_{*c}, u_{*wm}, u_{*cw} and d_{cw} are determined.

(4) u_{100} calculation: Procedures described above are repeated twice. Grain roughness height k_s is first used to get the skin-friction f_{cw} and shear velocities. Total roughness height k_t (including contributions from both sediment grains and bedform drag) is used in the second iteration to calculate the total f_{cw} and various shear velocities. Grain roughness height is defined as 2.5 times the median grain size of the sediment, while the total roughness height k_t is given by:

$$k_t = k_s + 27.7H_r(H_r/L_r) \tag{19}$$

Based on parameters calculated using the total roughness, apparent roughness z_{oc} is obtained as:

$$z_{oc} = d_{cw}*\exp[-(u_{*c}/u_{*cw})\ln(d_{cw}/z_o)] \tag{20}$$

where z_o now is the total bottom roughness defined as $k_t/30$. The mean velocity 1 m above the sea bed finally is computed from:

$$u_{100} = (u_{*c}/\kappa)(u_{*c}/u_{*cw})\ln(30*1/z_o) \qquad d_{cw}>1 \text{ m} \tag{21a}$$

$$u_{100} = (u_{*c}/\kappa)\ln(1/z_{oc}) \qquad d_{cw}\leq 1 \text{ m} \tag{21b}$$

The Smith (1977) method for computing combined wave-current boundary shear stress is for the cases where currents dominate over waves. By assuming that the combined wave-current eddy viscosity is equivalent to that based on the sum of the two, the momentum equations are solved independently and the results are added to determine the maximum combined velocity u_m and boundary shear stress τ_{cw}. Assuming a quadratic drag law, the friction factor of the Smith method is computed from:

$$f_{cw} = 2\tau_{cw}/\rho u_m^2 \qquad (22)$$

Detailed description of the method was given in Martec Ltd. (1987) and is included in Appendix 2 of this report.

3.3 Subroutine THRESH

Instead of the commonly-used Shields parameter, the total load formula of Ackers and White (1973) uses a special critical sediment mobility number A_{gr} for sediment threshold judgement. SEDTRANS92 adopted the source codes of SEDTRANS90, except that the partition of the critical flow velocity is no longer included in this new version. It is believed that the initiation of sediment transport is only determined by the grain size and fluid viscosity, and should not change with the angle between waves and currents. For pure currents, the critical mobility number is defined as:

$$A_{gr} = 0.17 \qquad D_{gr}>60 \qquad (23a)$$

$$A_{gr} = 0.23(D_{gr})^{-0.5} + 0.14 \qquad 1<D_{gr}<60 \qquad (23b)$$

where $D_{gr}=D[g(s-1)/\nu^2]^{1/3}$ is the dimensionless grain size, $s=(\rho_s-\rho)/\rho$ is the sediment specific gravity. Ackers-White method is not applicable when D_{gr} is less than one ($D < 0.04$ mm). For combined flows, A_{gr} is given by the following equations:

$$\log R_{gr} = 0.092(\log D_{gr})^2 + 1.158\log D_{gr} - 0.367 \qquad (24)$$

$$A_{gr} = R_{gr}D_{gr}^{-1.5} \qquad (25)$$

where R_{gr} is a special Reynolds number. The critical mobility number can be converted to critical shear stress by:

$$\tau_{cr} = \rho g D(s-1)A_{gr}^{2} \qquad (26)$$

and the critical velocity can be obtained from:

$$u_{cr} = (2\tau_{cr}/\rho f_{cw})^{0.5} \qquad (27)$$

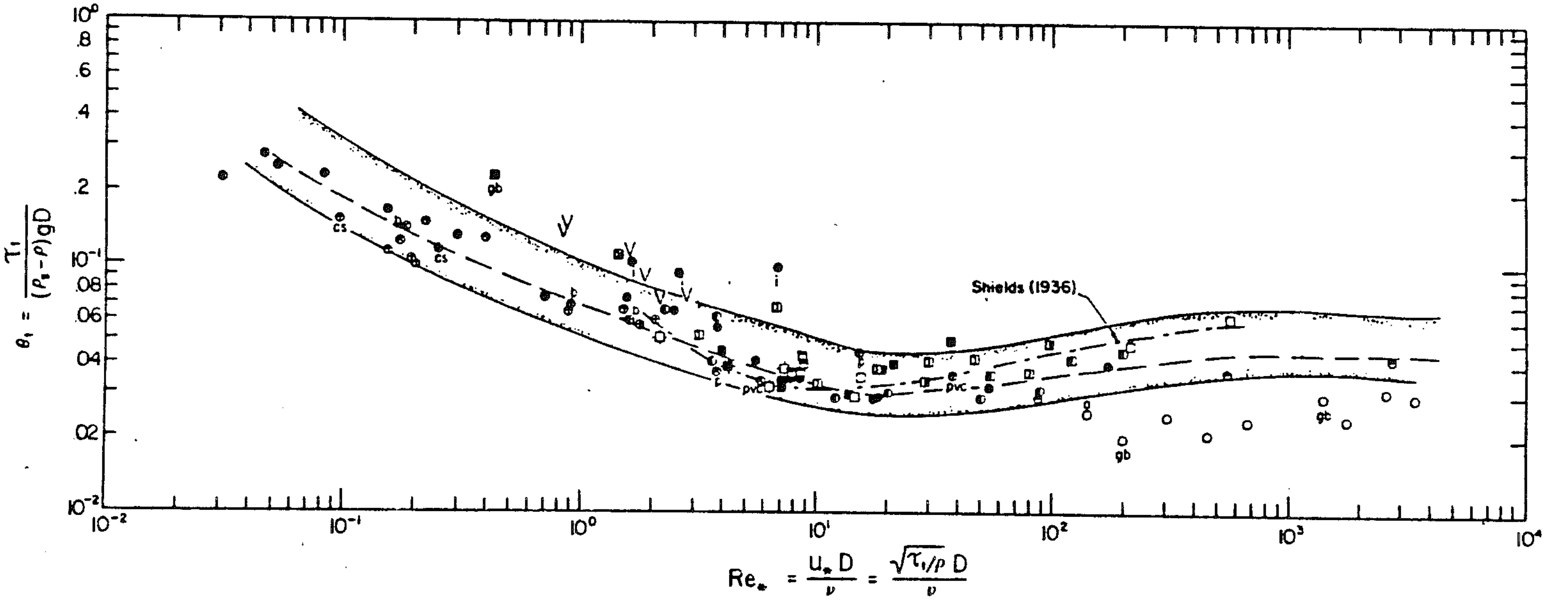
Most of the sediment transport formulae use the modified Shields curve in order to determine sediment threshold. There were several problems in subroutine THRESH of the old model. Firstly, it used the modified Shields curve (Fig.3) from Miller et al. (1977). Since threshold stress is contained in both axes, the Shields diagram requires an iterative calculation to determine the value of the critical shear stress τ_{cr}. SEDTRANS90, by mistake, used the measured shear stress to directly compute Reynolds number R_e and τ_{cr} so that τ_{cr} was also a function of the flow condition. SEDTRANS90 also assumed that the Shields parameter θ_t was equal to 0.04 for R_e>10. Figure 3 clearly shows that θ_t does not reach this constant till R_e becomes larger than about 1000. Thus 0.04 constant can not be used for R_e values between 10 to 1000. A more critical shortcoming is that SEDTRANS90 used critical mean velocity u_{cr} as the threshold criterion:

$$u_{cr} = (2\tau_{cr}/\rho f_{cw})^{0.5} \qquad (28)$$

The threshold criterion thus varies with different wave-current conditions due to the inclusion of f_{cw}, even though τ_{cr} does not change. For the selected Sable Island data set shown in Fig.1, u_{cr} varies from 0.2 m/s to 0.3 m/s. The increase in u_{cr} with decreasing f_{cw} is partially responsible for many zero transport predictions, even though the combined wave-current shear stresses for those examples were significantly higher than the threshold shear stress.

The critical shear velocity u_{*cr} was adopted as the threshold criterion in SEDTRANS92 which overcame many of the above stated problems. It should also be stated that for given fluid and sediment densities (ρ and ρ_s), sediment threshold should be affected by sediment grain size and fluid viscosity

Figure 3. The modified Shields curve from Miller et al. (1977).



$\theta_1 = \frac{\tau_1}{(\rho_s - \rho) g D}$
10^0
.8
.6
.4
.2
10^{-1}
.08
.06
.04
.02
10^{-2}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4
Shields (1936)
gb
cs
pvc
$Re_* = \frac{u_* D}{\nu} = \frac{\sqrt{\tau_1/\rho}\, D}{\nu}$

only, the latter being a function of temperature. In order to avoid the iterative computation as required by the Shields method, Yalin's (1977) method and the modified Shields curve of Madsen and Grant (1976) are widely used. The modified Shields curve of Madsen and Grant not only covers a much shorter range, but also over-predicts the Shields parameter compared to the original Shields diagram. Yalin's method according to Miller et al. (1977) thus has been used in this version of the model. Figure 4 shows the Yalin diagram in which θ_t is plotted against the Yalin parameter $\sqrt{\Xi}$. For a given grain size D and flow viscosity ν, a Shields parameter can be directly obtained from Fig.4.

It is apparent that the modified Shields curve shown in Fig.4 can be separated into three parts based on the values of the Yalin parameter $\sqrt{\Xi}$. Regression of these segments gives us the following relationships:

$$\log\theta_t = 0.041(\log\sqrt{\Xi})^2 - 0.356\log\sqrt{\Xi} - 0.977 \qquad \sqrt{\Xi}<100 \tag{29a}$$

$$\log\theta_t = 0.132\log\sqrt{\Xi} - 1.804 \qquad 100<\sqrt{\Xi}\leq 3000 \tag{29b}$$

$$\log\theta_t = 0.045 \qquad \sqrt{\Xi}>3000 \tag{29c}$$

where $\sqrt{\Xi}$ is defined as $[(\rho_s-\rho)gD^3/\rho\nu^2]^{0.5}$, g is the acceleration of gravity. Thus for given sediment grain size and fluid viscosity, the Yalin parameter is calculated and then the modified Yalin curve as described by equation (29) is used to determine the critical Shields parameter θ_t. This θ_t value can be used in turn to calculate the critical shear stress τ_{cr} from:

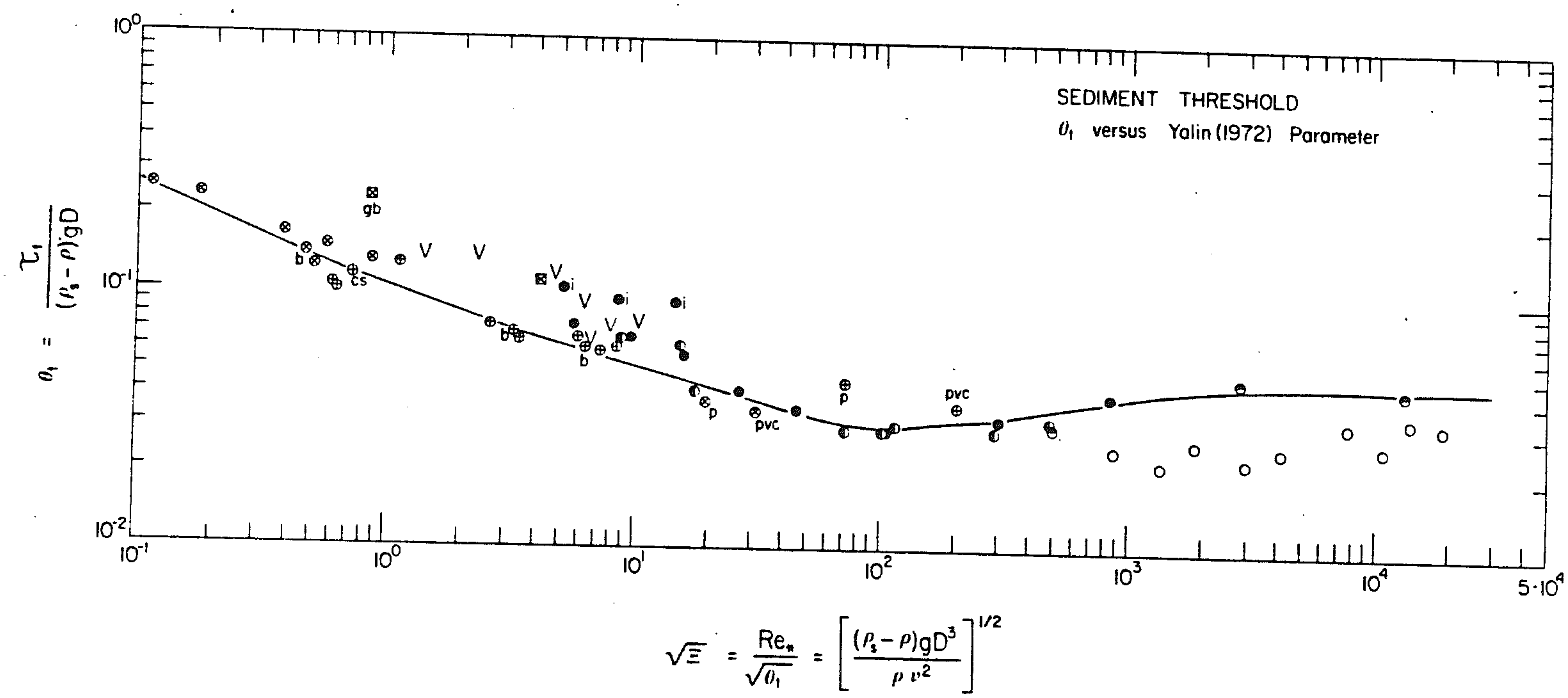
$$\tau_{cr} = \theta_t(\rho_s-\rho)gD \tag{30}$$

and the critical shear velocity u_{*cr} can finally be obtained from:

$$\tau_{cr} = \rho u^2_{*cr} \tag{31}$$

Two changes were made in the computation of the threshold condition for suspended load transport. Settling velocity of the natural grain is used to replace the spherical settling velocity as used in SEDTRANS90. As for the suspension threshold criterion, critical shear velocity is used instead of the critical mean velocity u_{cs}. Based on the work of Gibbs et al. (1971), the spherical settling velocity

Figure 4. Shields parameter θ_t plotted against the Yalin parameter $\sqrt{\Xi}$ (modified from Yalin, 1977).



SEDIMENT THRESHOLD
θ_1 versus Yalin (1972) Parameter
$\theta_1 = \frac{\tau_1}{(\rho_s - \rho) g D}$
$\sqrt{\Xi} = \frac{Re_*}{\sqrt{\theta_1}} = \left[\frac{(\rho_s - \rho) g D^3}{\rho \nu^2}\right]^{1/2}$
10^0
10^{-1}
10^{-2}
10^{1}
10^{2}
10^{3}
10^{4}
$5 \cdot 10^4$
gb
b
cs
V
i
p
pvc

of a sediment grain of diameter D can be calculated as:

$$W_s = \{-3\mu + [9\mu^2 + (gD^2/4)\rho(\rho_s-\rho)(0.0155 + 0.0992D)]^{0.5}$$
$$/[\rho(0.0116 + 0.0744D)] \quad (32)$$

where μ is the dynamic fluid viscosity. The natural settling velocity W_n is then obtained from the following empirical equation according to Baba and Komar (1981):

$$W_n = 0.977 W_s^{0.913} \quad (33)$$

The critical shear stress for the initiation of suspended load transport is finally computed from Bagnold (1966):

$$\tau_{crs} = 0.64 W_n^2 \quad (34)$$

or in velocity units:

$$u_{*crs} = (0.8/\rho) W_n \quad (35)$$

3.4 Subroutine TIMING

The duration of sediment transport phases (no transport, bedload transport, and suspended load transport) in a wave cycle is computed based on the derived values of u_{*cr} and u_{*crs}. As stated earlier, the critical flow velocities were replaced by critical shear velocities to achieve reasonable transport predictions. When waves and currents interact at small angles (<45°), subroutine TIMING of SEDTRANS90 linearly adds wave and current shear stresses to compute the time for bed-load transport. This has been changed in SEDTRANS92 so that wave and current shear velocities are always vectorially combined regardless of the angles between them.

When steady currents only exist, sediment is always transported in suspended load if current shear velocity u_{*c} exceeds the critical suspended load shear velocity u_{*crs}. Otherwise, if $u_{*cr} \leq u_{*c} < u_{*crs}$, then bedload transport exists. For the pure wave case, bedload transport time t_b and suspended load transport time t_s can be found by solving the following two equations respectively:

$$|u_{*wm} \cos(\omega t_b)| = u_{*cr} \quad (36a)$$

$$|u_{*wm} \cos(\omega t_s)| = u_{*crs} \quad (36b)$$

where u_{*wm} is the maximum skin-friction wave shear velocity. Two roots to each equation are possible, one for the passage of the wave crest and the other for the wave trough.

The time computation for the combined wave and current flows is more complex. Assuming that skin-friction current shear velocity u_{*c} is separated from the wave shear velocity u_{*w} at an angle ϕ_b in the wave-current boundary layer, the initiation of bedload transport then requires:

$$[u_{*wm}\cos(\omega t) + u_{*c}\cos(\phi_b)]^2 + [u_{*c}\sin(\phi_b)]^2 = u_{*cr}^2 \quad (37)$$

The solution of time t to equation (37) is:

$$\cos(\omega t) = -(u_{*c}/u_{*wm})\cos(\phi_b) \pm \{[u_{*cr}^2 - (u_{*c}\sin\phi_b)^2]/u_{*wm}^2\}^{0.5} \quad (38)$$

The plus and minus signs in this equation represent passages of wave crests and troughs respectively. If B is used to represent the square root portion on the right-hand side of equation (38), then bedload transport occurs all the time for $B \leq 0$, that is $u_{*c}\sin(\phi_b) \geq u_{*cr}$. Under the wave crest, for $\cos(\omega t)$ to be ≥ 1, t must be zero, thus indicating that no bedload transport takes place through the wave cycle. For $\cos(\omega t) \leq -1$, t must be equal to or larger than half of the wave period. Thus it represents the second situation in which bedload transport exists all the time in a wave cycle. Finally, only if $-1 \leq \cos(\omega t) < 1$, then equation (38) is solved to obtain the time in which bedload transport occurs under the wave crest. Under wave troughs, $\cos(\omega t) \leq -1$ requires $t \geq 0.5T$ and suggests that u_{*cr} is not exceeded even at the maximum shear stress and bedload transport does not occur under wave troughs. Otherwise equation (38) is solved to determine the time of bedload transport under wave troughs.

The same procedures are repeated using u_{*crs} so that times for suspended load transport t_s may be calculated for wave crests and troughs respectively. The percent of time spent in each transport phase is calculated according to the following method:

if u_{*crs} is exceeded all the time, suspended load transport = 100% and bedload transport

= 0%;

if u_{*crs} is never exceeded and u_{*cr} always exceeded, bedload = 100% and suspended

load transport = 0%;

if both u_{*crs} and u_{*cr} are exceeded sometimes, suspended load transport = $(100t_s/T)$%

and bedload transport percent = $100(t_b/T - t_s/T)$%.

3.5 Subroutine TRANSPO

The instantaneous sediment transport is integrated through a wave cycle in this subroutine. No integration is required for the steady current case since the transport rate will be constant with time for the sampling period. The symmetry of the linear wave theory also dictates that no net sediment transport will occur for the pure wave case.

There are seven options that users can choose for the calculation of sediment transport rate. These are Engelund-Hansen (1967) total load equation; the Einstein-Brown (1950) bedload equation; the Bagnold (1963) total load equation; the Yalin (1963) bedload equation; the Ackers-White (1973) total load equation; the Smith (1977) suspended load equation, and the method of Amos and Greenberg (1980) for cohesive sediment transport. No change was made to the pure current transport and the last three methods given above. Changes made for the first four methods include the utilization of shear velocity in replacing mean flow velocity and the elimination of calling a math-library integration subroutine to make the program more straight forward and easier for debugging. The x and y components of transport are considered separately, where x is parallel to the wave direction and y is normal to the wave direction. The angle between waves and currents is used to decompose current shear velocity u_{*c} into x and y components. The x-component of u_{*c} is then added to the instantaneous skin friction wave shear velocity u_{*w}. This linearly-added x-component shear velocity is used to compute sediment transport rate in the x direction and the y component of u_{*c} is used to calculate sediment transport rate in the y direction. Sediment transport rates in the x and y directions so calculated are then added vectorially to determine the rate and direction of the total net sediment transport. Each of the seven sediment transport equations is briefly described below.

3.5.1 Engelund-Hansen Total Load Equation

The original Engelund-Hansen equation states:

$$q_s = 0.05DV^2(\rho\tau_b^3)^{0.5}/D(\Delta\rho g)^2 \tag{39}$$

where q_s is the volume rate of sediment transport per unit width of bed, V is the mean velocity, τ_b is the bottom shear stress and $\Delta\rho$ is equal to $(\rho_s-\rho)$. This equation was based on unidirectional flume experiment data and was derived for dune-covered beds with mean grain sizes larger than 0.15 mm. For continental shelf conditions, the mean velocity V is replaced by the current velocity 1 m above the bed (u_{100}) and τ_b is replaced by the corresponding shear velocities. The modified Engelund-Hansen equation reads:

$$q_s = 0.05Du_{100}^2\rho^2u_*^3/D(\Delta\rho g)^2 \tag{40}$$

3.5.2 Einstein-Brown Bedload Equation

The Einstein-Brown bedload Equation was also obtained from flume experiments under unidirectional flow over well-sorted sediment. The shear stress is replaced by the shear velocity, so this equation is:

$$q_s = 40W_nD(\rho/\Delta\rho gD)^3u_*^5|u_*| \tag{41}$$

This equation has been tested by Madsen and Grant (1976) using laboratory data. The equation was found to agree reasonably well with available data when skin friction only was used. The applicable grain size range for Einstein-Brown equation is 0.3 mm to 29 mm.

3.5.3 Bagnold Total Load Equation

Bagnold (1963) assumed that waves cause sediments to be suspended, but it is the steady current component V that causes net sediment transport since wave orbits are closed. The transport direction is assumed to be that of the steady current. The Bagnold equation is given below:

$$q_s = K\tau_{cw}V \tag{42}$$

where τ_{cw} is the maximum combined skin-friction shear stress, and K is the proportionality coefficient and is described by the following empirical equation according to Sternberg (1972):

$$K = m \exp[0.7(\tau_{cw} - \tau_{cr})/\tau_{cr}] \tag{43}$$

The original value of m is 0.005 and the mean current V was again taken to be the current velocity 1 meter above the sea bed. τ_{cr} in the denominator was omitted in SEDTRANS90 by error and this has been corrected in SEDTRANS92.

When there are pure currents only, Bagnold bedload equation modified by Gadd et al. (1978) is used:

$$q_s = (\beta/\rho_s)(u_{100} - u_{cr})^3 \tag{44}$$

where u_{cr} is the critical velocity for the initiation of bedload transport. Coefficient β is a function of grain size. Gadd et al. have analyzed data from several flume experiments and suggest that β ranges from 1.73 to 7.22×10^{-3} for grain sizes of 0.18 mm to 0.45 mm. Though data from Sea Carousel experiments (Amos et al., 1993) suggest a constant β (1.73×10^{-3}) for different grain sizes, but no final conclusion is reached yet.

3.5.4 Yalin Bedload Equation

Based on analyses of the trajectory of the grain motion and Einstein's saltation concept, Yalin (1963) obtained the following bedload equation:

$$q_s = 0.635Du_*[S-(1/a)\ln(1 + a*S)] \quad (45)$$

where $S=u_*/u_{*cr}-1$ is the normalized excess shear velocity and a is equal to $2.45(\rho/\rho_s)^{0.4}(\tau_{cr}/\Delta\rho gD)^{0.5}$. The constant 0.635 was again based on data from unidirectional flume experiments. Since an assumption was made that the bed roughness exceeds the thickness of the viscous sublayer, this equation is generally limited to sediment grains of 0.2 mm or coarser.

3.5.5 Ackers-White Total Load Equation

The Ackers-White total load formula was developed by Ackers (1972) and Ackers and White (1973). Various dimensionless parameters were used by the formula: grain size parameter D_{gr} (described in 3.3), mobility number F_{gr}, critical mobility number A_{gr}, and transport parameter G_{gr}. For pure current cases, sediment transport rate is calculated from:

$$q_s = u_{100}DG_{gr}(u_{100}/u_*)^n \quad (46)$$

in which:

$$G_{gr} = C(F_{gr}/A_{gr} - 1)^M \quad (47)$$

$$F_{gr} = \{u_*^n/[gD(s-1)]^{0.5}\}[u_{100}/5.75\log(10h/D)]^{1-n} \quad (48)$$

In above equations, n is a transition exponent, C and M are the coefficient and exponent in the transport function, respectively. Data from flume experiments were used to determine the values of these coefficients. For $D_{gr} > 60$ ($D > 2.5$ mm):

$$n = 0$$

$$A_{gr} = 0.17 \quad (49)$$

$$M = 1.5$$

$$C = 0.025$$

For $1 < D_{gr} \leq 60$:

$$n = 1.0 - 0.56\log D_{gr}$$

$$A_{gr} = 0.23(D_{gr})^{-0.5} + 0.14 \tag{50}$$

$$M = 9.66D_{gr} + 1.34$$

$$\log C = 2.86\log D_{gr} - (\log D_{gr})^2 - 3.53$$

For combined wave and current flows, SEDTRANS92 uses the modified Ackers and White formula proposed by Swart and Lenoff as given in Swart and Flemming (1980). The instantaneous sediment transport rate is calculated from:

$$q_s = u_a DC(2/f_{cw})^{0.5n}\{|u|/[A_{gr}((s-1)gD)^{0.5}](f_{cw}/2)^{0.5n}$$

$$[5.75\log(10h/D)]^{-(1-n)} - 1\}^M \tag{51}$$

where u_a is the instantaneous combined velocity at the top of the wave-current boundary layer. All the coefficients are the same as those for the steady current case, except that the critical mobility number is as given by equation (25) in section 3.3. Ackers-White method is valid for use over various bedforms and also with suspension and bedload, though the valid grain size is larger than 0.04 mm.

3.5.6 The Smith Method

Smith (1977) derived a different method for computing the boundary shear stress in combined flow conditions where currents are dominant over waves. After the wave and current boundary layer dynamic parameters are determined, the concentration field of suspended sediment is computed based on the conservation of mass. This suspended sediment concentration field is then multiplied by velocity and integrated over the water depth to give the volume flux of suspended sediment. Smith (1977) did not give the expression for the volume flux of sediment and did not provide the appropriate integration method either. These were derived by Martec Ltd. (1987) under certain assumptions. The details of the Smith method can be found in Appendix 2 at the end of this report.

3.5.7 Amos-Greenberg Equation for Cohesive Sediments

Cohesive sediments are different from non-cohesive sediments in two essential ways: aggregation and consolidation. Fine particles of cohesive sediments tend to form large, low density aggregates due to their surface ionic charges. Consequently the settling velocity of muddy sediments is a function of concentration, salinity and flow shearing. After deposition, cohesive sediments will consolidate leading to a progressive increase in density and shear resistance with depth and time. Due to our limited understanding of the erosion, deposition and consolidation processes of cohesive sediments, modelling cohesive sediment transport is still in its early stage. The method used here is that of Amos and Greenberg (1980). Recent advances in this field are summarized by Owen (1976) and Mehta (1991).

The deposition rate of cohesive sediments is given by:

$$r_d = cW_{sc}(1-\tau_b/\tau_d)P_s \tag{52}$$

where c is the mass suspended sediment concentration (SSC), W_{sc} is the settling velocity of cohesive sediments, τ_d is the critical shear stress for deposition, P_s is the probability of resuspension (0.8-1.0) and $(1-\tau_b/\tau_d)$ is defined as the probability of deposition. The erosion rate is defined as:

$$r_e = P(\tau_b - \tau_e) \tag{53}$$

where P is a proportionality coefficient (≈2) and τ_e is the critical shear stress for erosion. Given a long enough time, deposition rate will be equal to the erosion rate for a given flow velocity and a steady state condition will be reached. For this steady state condition, the equilibrium concentration will be zero if $\tau_b<\tau_e$. Otherwise the concentration will be:

$$c = P(\tau_b - \tau_e)/W_{sc}(1-\tau_b/\tau_d)P_s \tag{54}$$

and the horizontal sediment transport rate will be the concentration times the average water volume flux rate per unit width of seafloor:

$$q_s = chu_{100} \tag{55}$$

If steady state is not reached, the concentration must be input by the user either from field measurements or from previous calculation. Deposition rate and erosion rate are computed from equations (52) and (53) respectively. The net erosion rate will be $r_{en} = r_e - r_d$ and can be used to obtain the vertical mass flux rate as:

$$\text{fluxv} = r_{en} \tag{56}$$

The sediment transport rate is then determined as fluxv plus the concentration multiplied by the water volume flux:

$$q_s = \text{fluxv} + chu_{100} \tag{57}$$

All the parameters used in the above method must be input as known values, except the boundary shear stress τ_b. The cohesive sediment settling velocity W_{sc} can not be predicted by the method used for non-cohesive sediments given in section 3.3 because of aggregation and flocculation. W_{sc} is mainly a function of concentration and turbulence, and is less dependent on salinity. Cited settling velocities range from 0.005 mm/s to 3 mm/s. Graphs of W_{sc} can be found in Owen (1970) and Ross (1988). However, field or laboratory measurements are required for each particular site to obtain W_{sc}. Several measurement techniques are described by Amos and Mosher (1985). As is the case for the settling velocity, there is also no known way to predict the critical deposition and erosion stresses, τ_d and τ_e. Measurements have to be done for specific site and mud type. The values of τ_d and τ_e depend on mineralogy, degree of consolidation and salinity. Amos and Greenberg (1980) cite τ_e ranging from 0.1 to 4.52 dynes/cm^2. τ_d=1 dynes/cm^2 and τ_e=2.5 dynes/cm^2 were used by them for the Bay of Fundy muds. Recent in-situ measurements by Gust and Morris (1989) also suggest a τ_e value of 2 dynes/cm^2 for Puget Sound mud. Rheological characteristics have also been found to be related to τ_e. For instance, Mimura (1989) shows that τ_e can be calculated from the yield stress τ_y of cohesive sediments as $\tau_e=0.79\tau_y^{0.94}$. It should be pointed out that laboratory measurements inevitably will disturb the original texture, chemistry and biological conditions of the cohesive sediments. In situ measurements using seaflumes or sea carousels are therefore recommended (Young and Southard, 1978; Amos, et al., 1992).

3.6 Subroutine BEDFORM

Near-bed velocities (u_{100} for currents, u_b for waves) are used in this subroutine to estimate the type of bedforms under various wave-current conditions. For sediments coarser than 2 mm, gravel ripples are the possible bedform. For sediments finer than 0.13 mm, no bedform type is predicted. For fine to very coarse sand ($0.13 \le D \le 2$ mm), bedform type is predicted according to Amos (1990) as given in Table 2. For coarse and very coarse sands, u_b=0 gives pure current ripples and u_a=0 defines wave ripples. If neither u_a nor u_b is zero, then wave dominant bedform will be predicted for $u_{*w}/u_{*c} \ge 1$ and current-dominant bedform for $u_{*w}/u_{*c} < 1$. However, there is no method available for predicting bedform dimensions at these size ranges.

For medium and fine sands, both bedform type and dimension will be predicted. Wave ripple is predicted if u_a=0; current ripple is the bedform type if u_b=0. For combined wave-current flows, if the wave-current angle is equal or less than 45°, bedform types depend on the ratio u_{*w}/u_{*c}. Wave-dominant ripples exist for $u_{*w}/u_{*c} \ge 1$ and current-dominant ripples occur for $u_{*w}/u_{*c} < 1$. When wave-current angle is larger than 45°, orthogonal wave-current bedforms will occur and this is predicted after Amos et al. (1988b):

wave ripples	if $\theta_w>0.15$ and $\theta_c<0.007$
wave-dominant ripples	if $0.007<\theta_c<0.02$ and $\theta_w>0.1$
wave-current ripples	if $0.02<\theta_c<0.04$ and $\theta_w>0.08$
current-dominant ripples	if $0.04<\theta_c<0.06$ and $\theta_w>0.05$
current ripples	if $\theta_c>0.04$ and $\theta_w<0.05$
poorly developed ripples	if $\theta_c<0.04$ and $(\theta_c+\theta_w)<0.15$

Table 2. Near-bed velocities and possible bedform types (after Amos, 1990).

Bedform	Bounds	Sand			
		Fine	Medium	Coarse	V. Coarse
Current	Upper Lower	60 cm/s 13 cm/s	50 cm/s 20 cm/s	35 cm/s 25 cm/s	no ripples
Flat Bed (Lower)	Upper Lower	no flat bed	no flat bed	45 cm/s 35 cm/s	50 cm/s 45 cm/s
2-D Mega-ripples	Upper Lower	no 2-D mega-ripples	60 cm/s 50 cm/s	60 cm/s 40 cm/s	60 cm/s 40 cm/s
Sand Waves	Upper Lower	no sand waves	100 cm/s 60 cm/s	100 cm/s 50 cm/s	100 cm/s 40 cm/s
3-D Mega-ripples	Upper Lower	no 3-D mega-ripples	150 cm/s 60 cm/s	150 cm/s 60 cm/s	no 3-D mega-ripples
Flat Bed (Upper) and Sand Ribbons	Upper Lower	85 cm/s 60 cm/s	170 cm/s 150 cm/s	240 cm/s 150 cm/s	295 cm/s 100 cm/s
Wave Ripples	Upper Lower	70 cm/s 10 cm/s	100 cm/s 13 cm/s	125 cm/s 20 cm/s	200 cm/s 30 cm/s
Wave Induced Flat Bed	Upper Lower	- 70 cm/s	- 80 cm/s	- 90 cm/s	- 100 cm/s

in which θ_w is the wave Shields parameter and θ_c is the current Shields parameter. There are several models for the prediction of ripple height and length under pure currents or pure waves, but none of them has been extended and tested for combined flow conditions. For the application of this model, the predictor of Boyd et al. (1988) is used to predict the ripple length L_r for pure wave, wave-dominant and orthogonal wave-current ripples:

$$L_r = 557A_b(u_bA_b/\nu)^{-0.68} \tag{58}$$

and wavelength of pure current and current-dominant ripples is given according to Yalin (1964):

$$L_r = 1000D \tag{59}$$

Under all conditions, ripple height H_r is predicted as given by Allen (1970):

$$H_r = 0.074L_r^{1.19} \tag{60}$$

4. MODEL CALIBRATION WITH FIELD DATA

Many sediment transport models have been proposed for combined flow conditions, but there is a lack of good quality field measurements of the hydrodynamics and sediment transport rate so that these models can be calibrated. A good step was taken at BIO to reduce this gap. An instrumented tripod (RALPH) was deployed in 23 metre of water on Sable Island Bank, Scotian shelf to measure boundary layer hydrodynamics and sediment responses under combined wave-current conditions. The bottom sediment was composed of well sorted fine sand of a median grain size of 0.23 mm. The deployment site was subject to various tidal currents and waves, thus wave and current ripples prevailed.

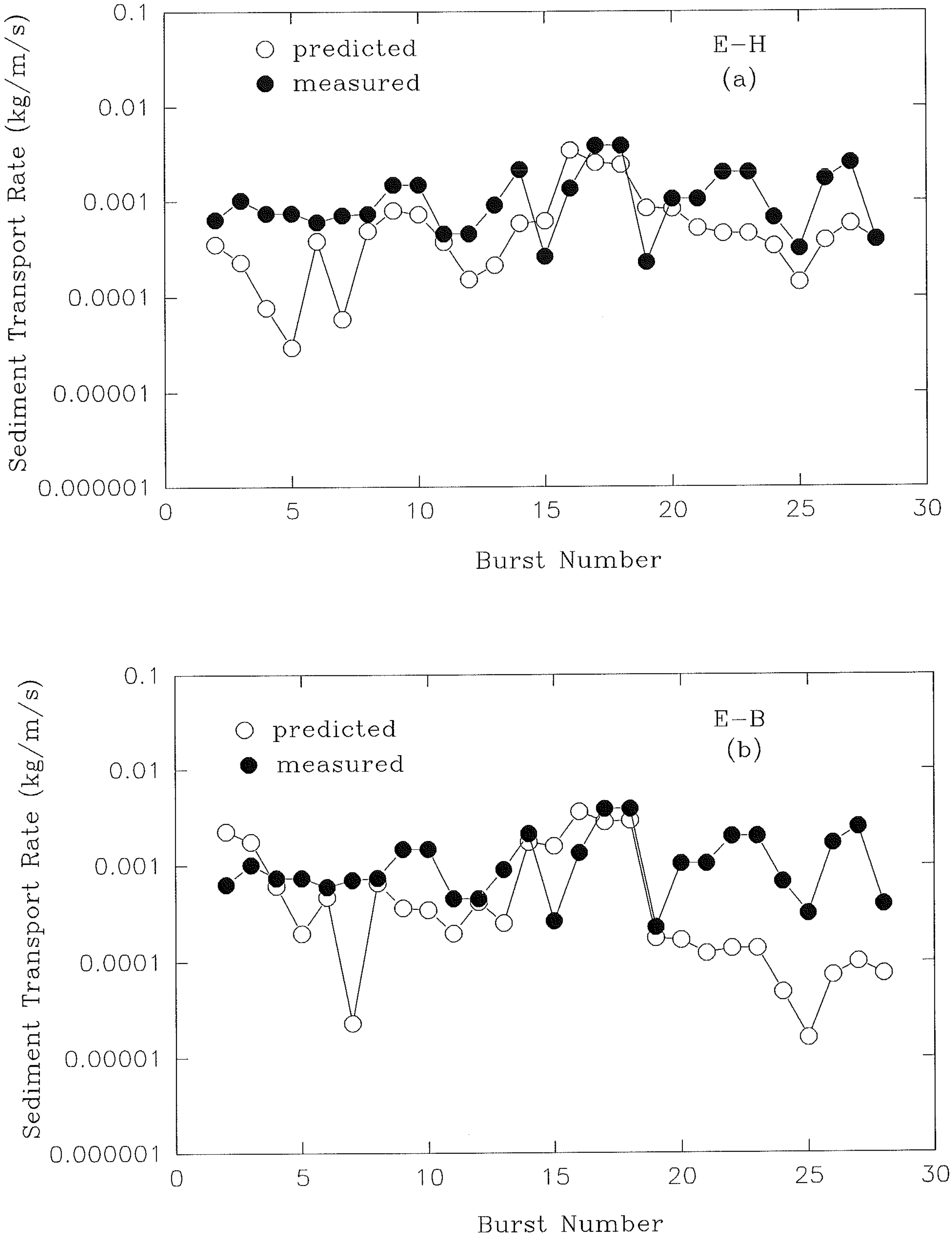
The RALPH package consisted of a Marsh-McBirney electromagnetic current meter 1 metre above the bed, a Sea-Tech transmissometer 1.5 m above the bed and a pressure transducer mounted 2 m above the bottom for wave height measurement. A downward-looking Minolta XL401 super-8 camera and synchronized flash were also mounted on the tripod for ripple wave length and ripple migration rate measurement. All channels were sampled for 512 seconds in each two hours at a 1 Hz frequency. Time-lapse photos of the sea bed were taken each 30 minutes. Significant wave height and mean wave period from zero-crossing analysis were obtained from the pressure transducer data. Ripple height H_r was not measured in the experiment, but is predicted using equation (60) as given in section 3.6. Wave, current and seabed conditions from each burst are brought into our model to predict sediment transport rates under mixed flows. Based on measured ripple geometry and migration rates M_r, the following equation is used to calculate the bedform transport rate in volume:

$$i_s = 0.5\rho_b H_r M_r \tag{61}$$

Time series of sediment transport rates predicted by the upgraded SEDTRANS92 are compared in Figure 5 against the measured bedform transport rates for the same selected bursts as those in Figure 1: (a) Engelund-Hansen, (b) Einstein-Brown, (c) Bagnold and (d) Yalin. Their scatter plots are shown in Figure 6. Ackers-White method is not tested here. A comparison between Fig.1 and Figures 5b and 6b indicates that significant improvement has been obtained and the upgraded model now gives reasonable prediction compared to the measured bedform transport rates. Most of the peaks and troughs correlate well with each other and the scatter falls around the equality line. Also, reasonable predictions are found for all the bursts and no zero transport is predicted for strong current periods as was found with SEDTRANS90.

Figures 5 and 6 show that except Yalin's method, all the models still under-predict sediment transport compared to field measurements. This is especially apparent towards the last few bursts. Bagnold's method uses the combined shear velocity u_{*cw} and does not require integration. Fig. 5c shows that trends of the predicted transport rates agree well with that of the measured transport rates, but the magnitude is smaller. Coefficient m=0.005 in equation (43) was obtained by Sternberg (1972) using flume data of Guy et al. (1966) and thus is valid only when total shear stress is used. This value must be increased if skin friction is used as is the case in this model. Running the model with incremental m has found that m=0.02 gives the best fit to the measured bedform transport rate. Time series and scatter plot of sediment transport rates predicted by this modified Bagnold method are shown in Fig. 7c and Fig. 8c respectively. They give much improved fit to the measured bedform transport rates compared to Figures 5c and 6c. For other equations, u_{*c} and u_{*w} are considered separately in sediment transport prediction. The RALPH site is strongly influenced by tidal currents. Nearly 40% of the selected 26 bursts fall into the situation in which currents are equally or more dominant than waves. The GM model may give inappropriate predictions for current shear stress since it assumes wave dominant conditions. Amos et al. (in review) have used Sternberg-u_{100} Shields parameter and GM wave Shields parameter to successfully define ripple states and threshold values for

Figure 5. Time series of sediment transport rates predicted by SEDTRANS92 and from measured ripple migration rates for selected bursts of the Sable Island data.



Sediment Transport Rate (kg/m/s)
0.1
0.01
0.001
0.0001
0.00001
0.000001
predicted
measured
E−H
(a)
0
5
10
15
20
25
30
Burst Number
Sediment Transport Rate (kg/m/s)
0.1
0.01
0.001
0.0001
0.00001
0.000001
predicted
measured
E−B
(b)
0
5
10
15
20
25
30
Burst Number

Figure 5

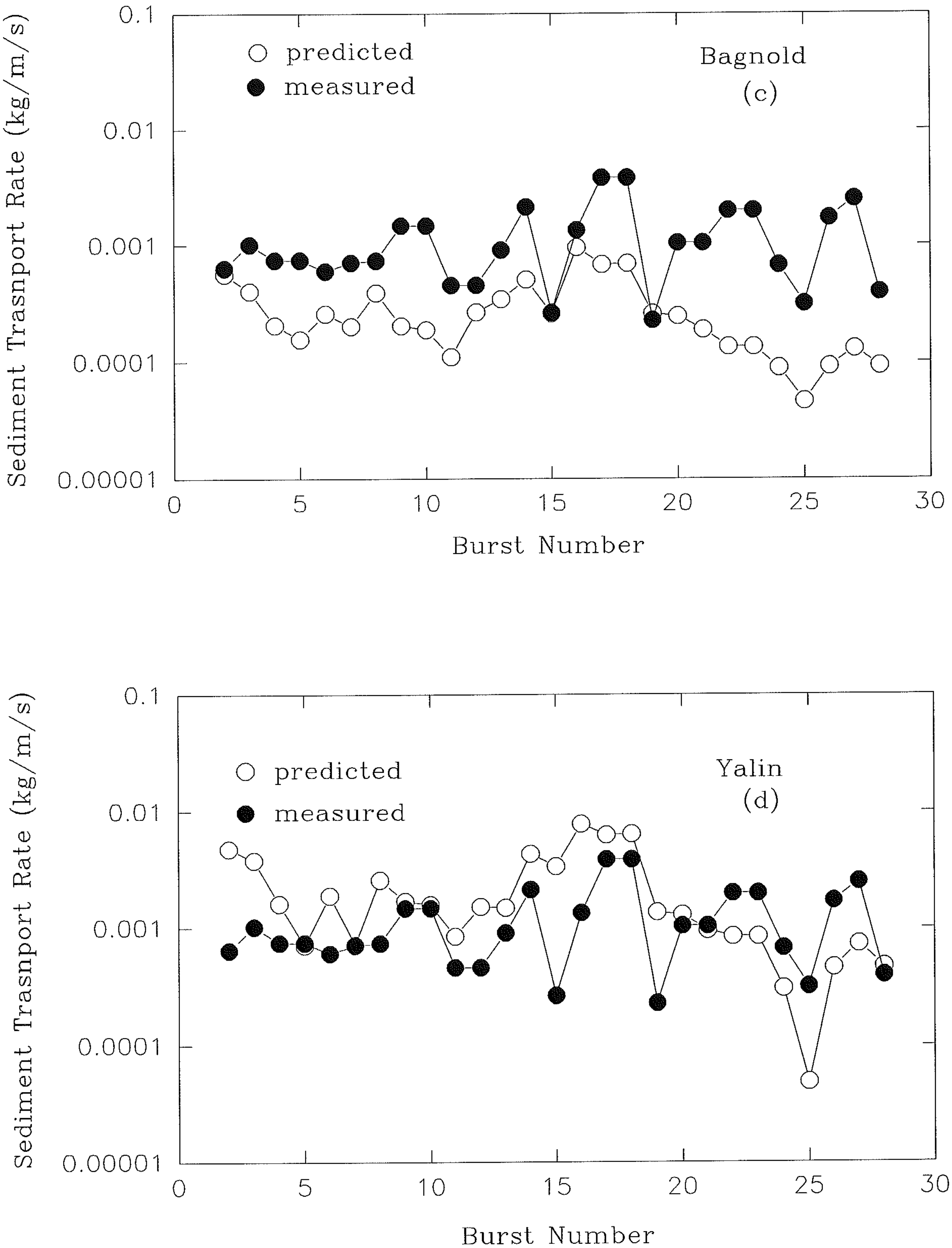


Figure 5 (continued)

Figure 6. Scatter plots of sediment transport rates predicted by SEDTRANS92 versus bedform transport rates for selected bursts of the Sable Island data.

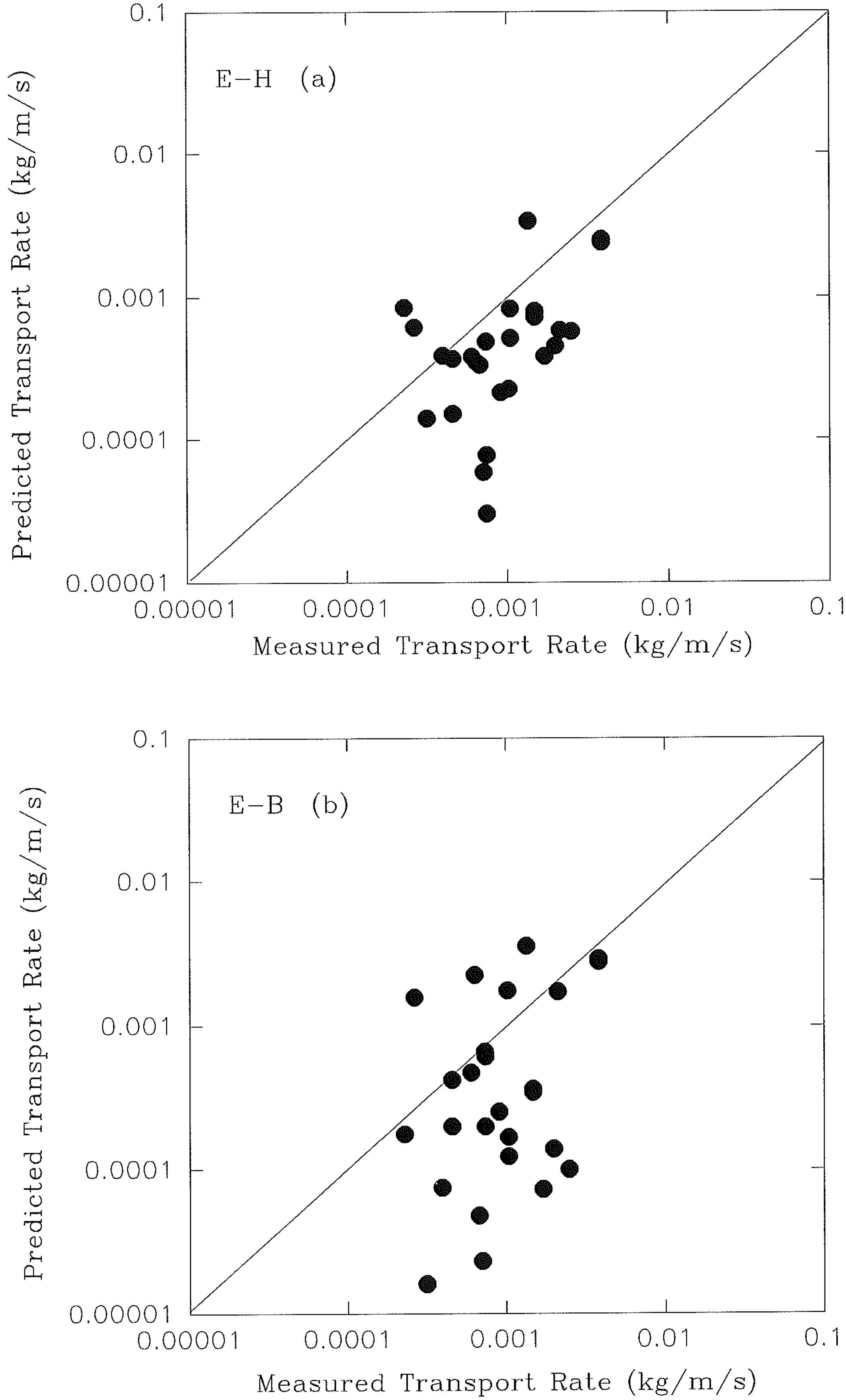

E–H (a)
Predicted Transport Rate (kg/m/s)
Measured Transport Rate (kg/m/s)
0.1
0.01
0.001
0.0001
0.00001
E–B (b)
Predicted Transport Rate (kg/m/s)
Measured Transport Rate (kg/m/s)

Figure 6

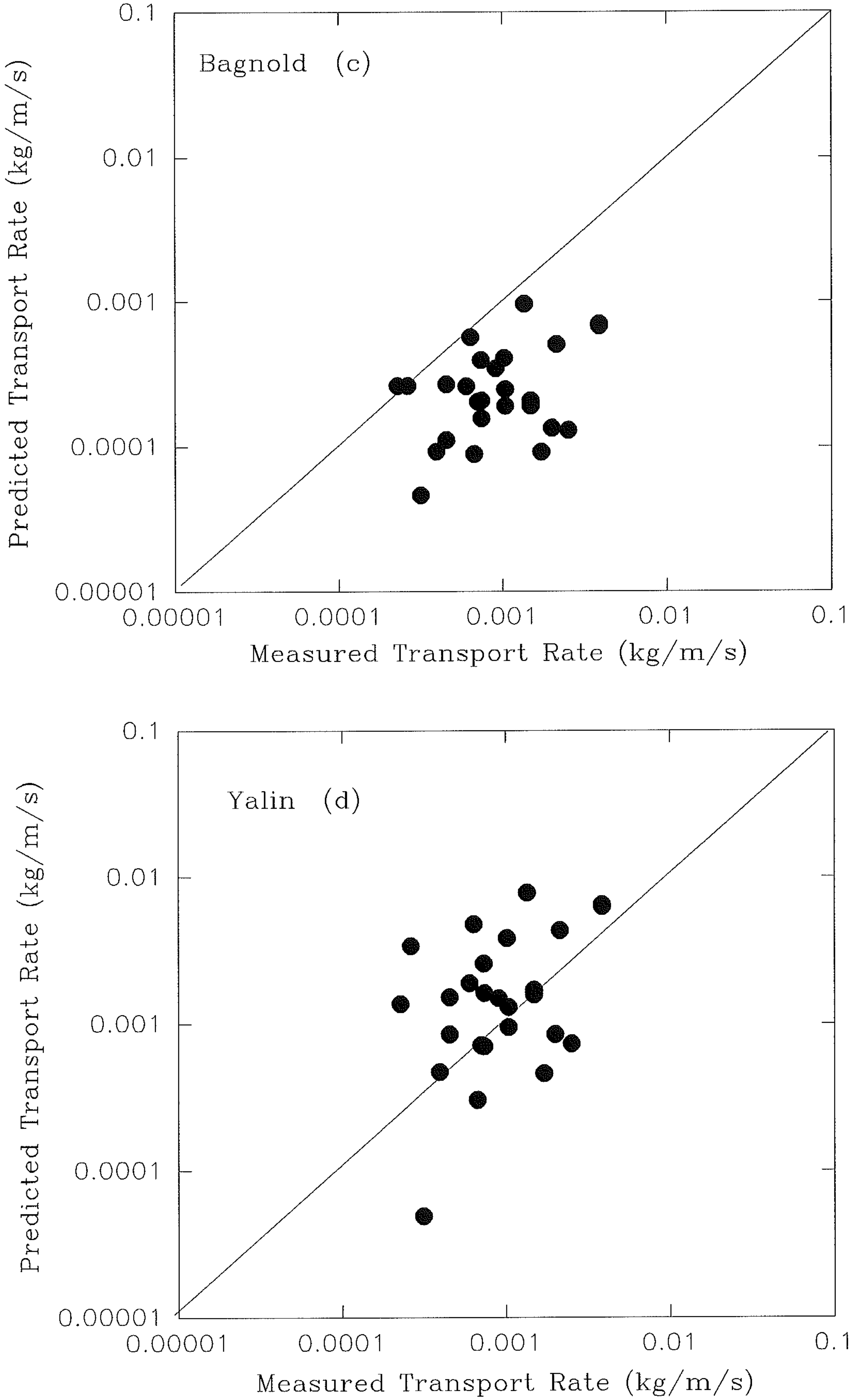
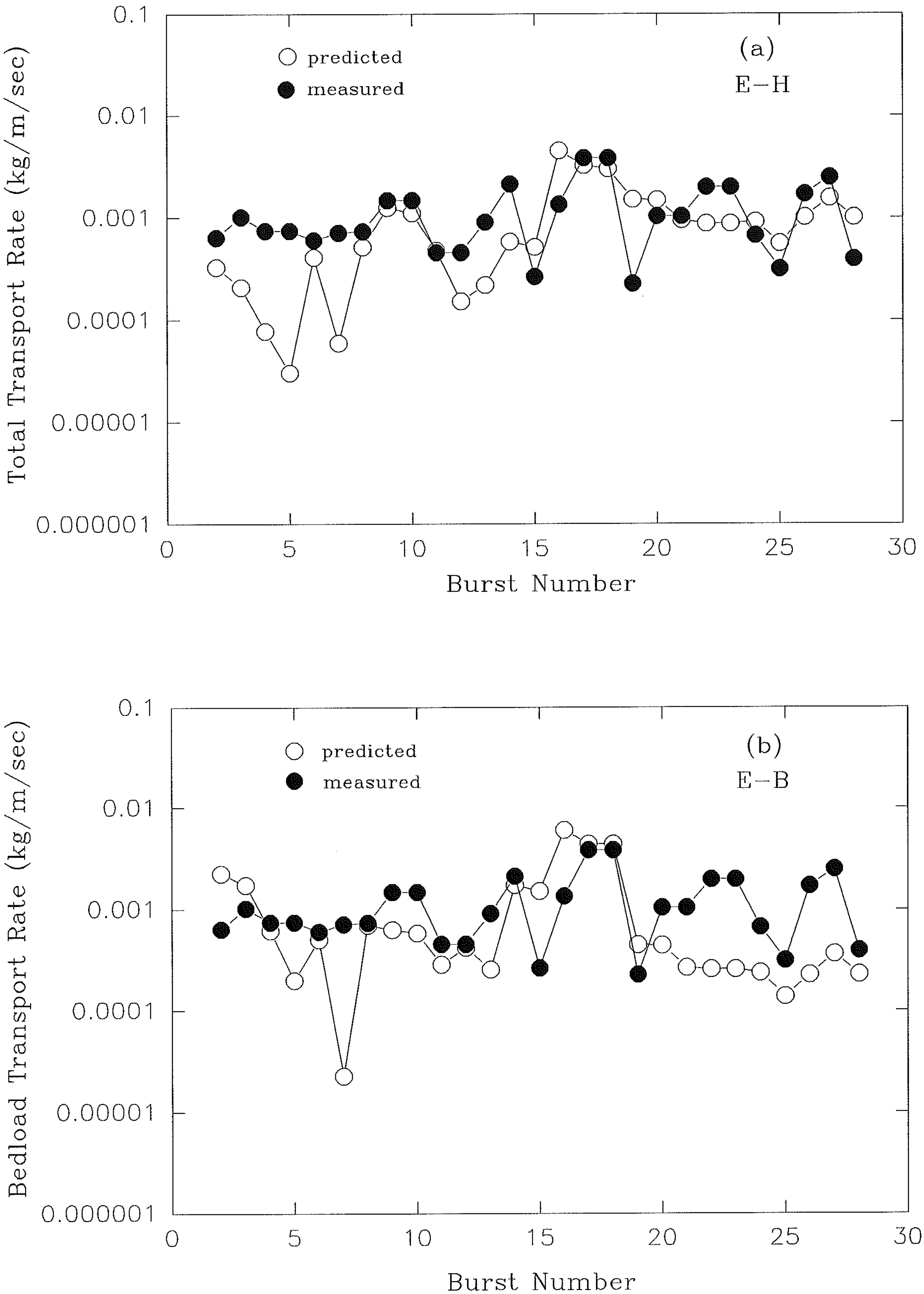


Figure 6 (continued)

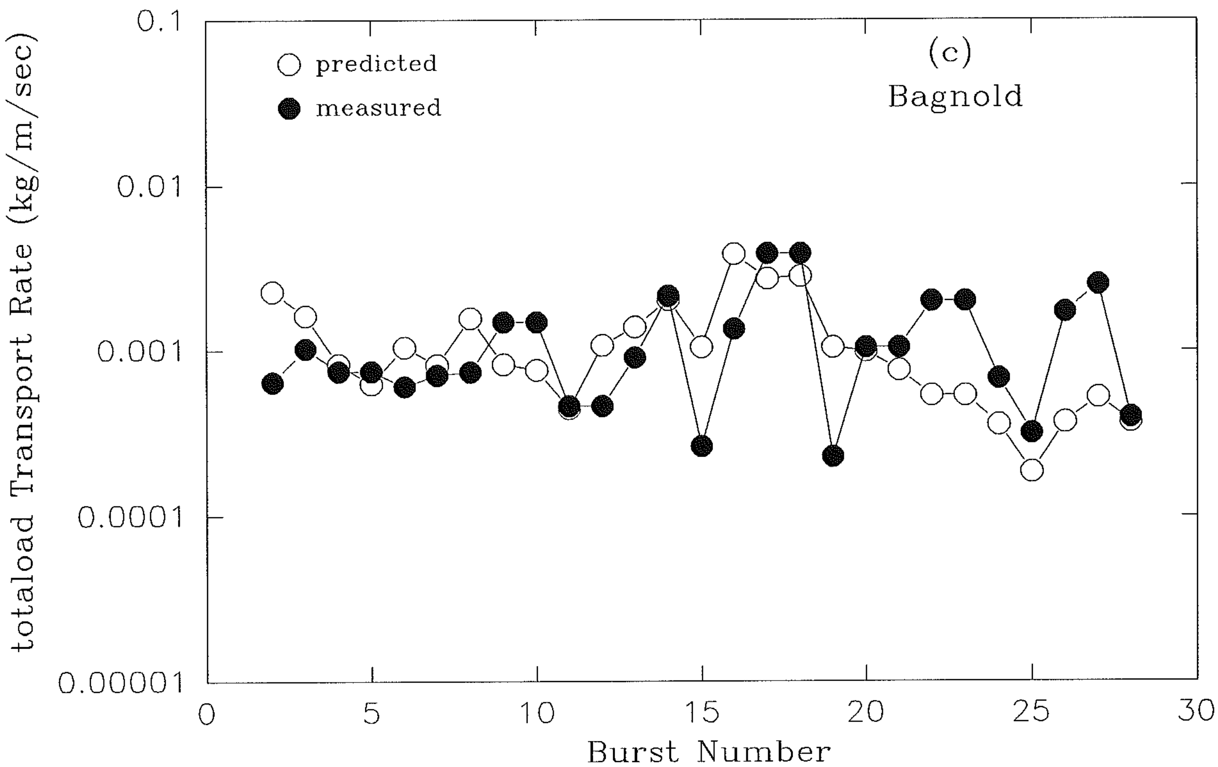
ripple formation and saltation initiation. Model runs using currents only also predict higher sediment transport rates than combined waves and currents for some of the bursts. All these suggest that current shear stress based on u_{100} and f_c=0.006 could be used together with the GM wave shear stress to better predict sediment transport rates for the Sable Island area. Current shear velocity based on f_c=0.006 of Sternberg (1972) thus has been substituted into each of the sediment transport formulae to replace GM u_{*c} for those bursts in which GM u_{*c} is smaller than Sternberg u_{*c}. Sediment transport rates so predicted are plotted in Fig.7 against the measured bedform transport rates as time series, and their scatter plots are shown in Fig.8. Improved fit between the predicted and measured sediment transport rates is found for all the formulae. After the above modification, Yalin method over-predicted sediment transport rates. Since the coefficient 0.635 in equation (45) was based on unidirectional flume experiments, it has been readjusted to 0.318 to obtain the best fit to the measured sediment transport rates under combined flow conditions.

Figure 7. Time series of model-predicted sediment transport rates and ripple migration rates for selected bursts of the Sable Island data, Sternberg (1972) current shear velocity being used to replace the Grant-Madsen current shear velocity in the model.



Total Transport Rate (kg/m/sec)
predicted
measured
(a)
E−H
Burst Number
Bedload Transport Rate (kg/m/sec)
predicted
measured
(b)
E−B
Burst Number

Figure 7



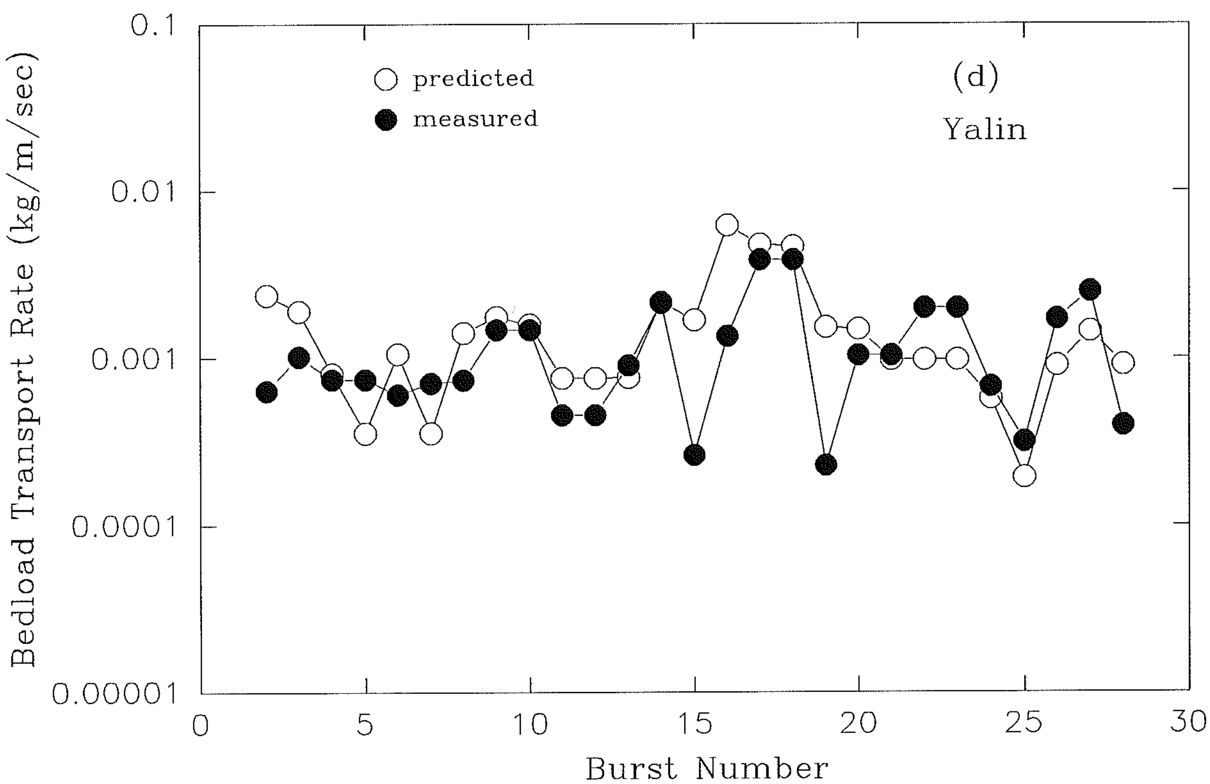


Figure 7 (continued)

Figure 8. Scatter plots of model-predicted sediment transport rates versus ripple migration rates rf selected bursts of the Sable Island data, Sternberg (1972) current shear velocity being used to replace the Grant-Madsen current shear velocity in the model.

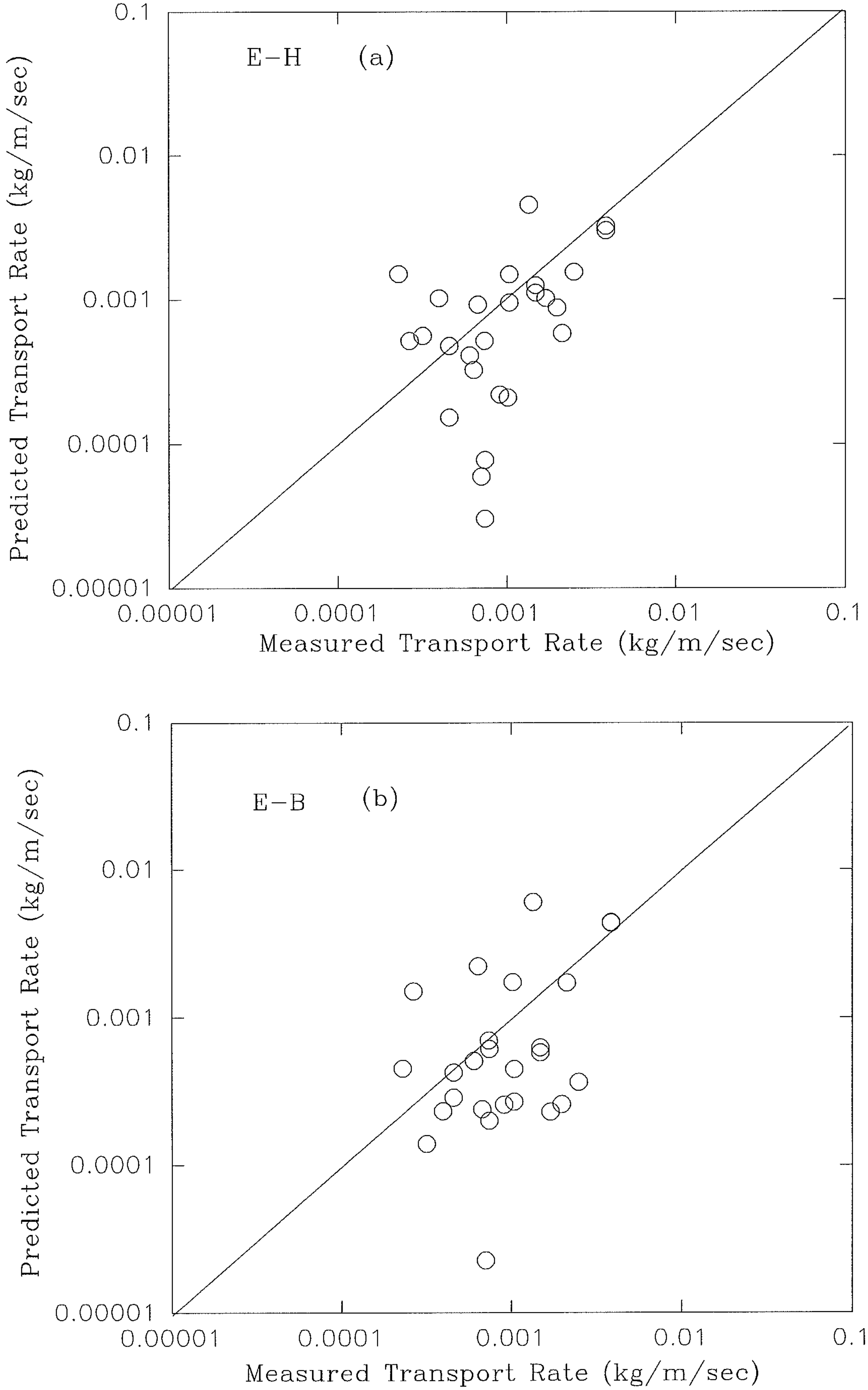
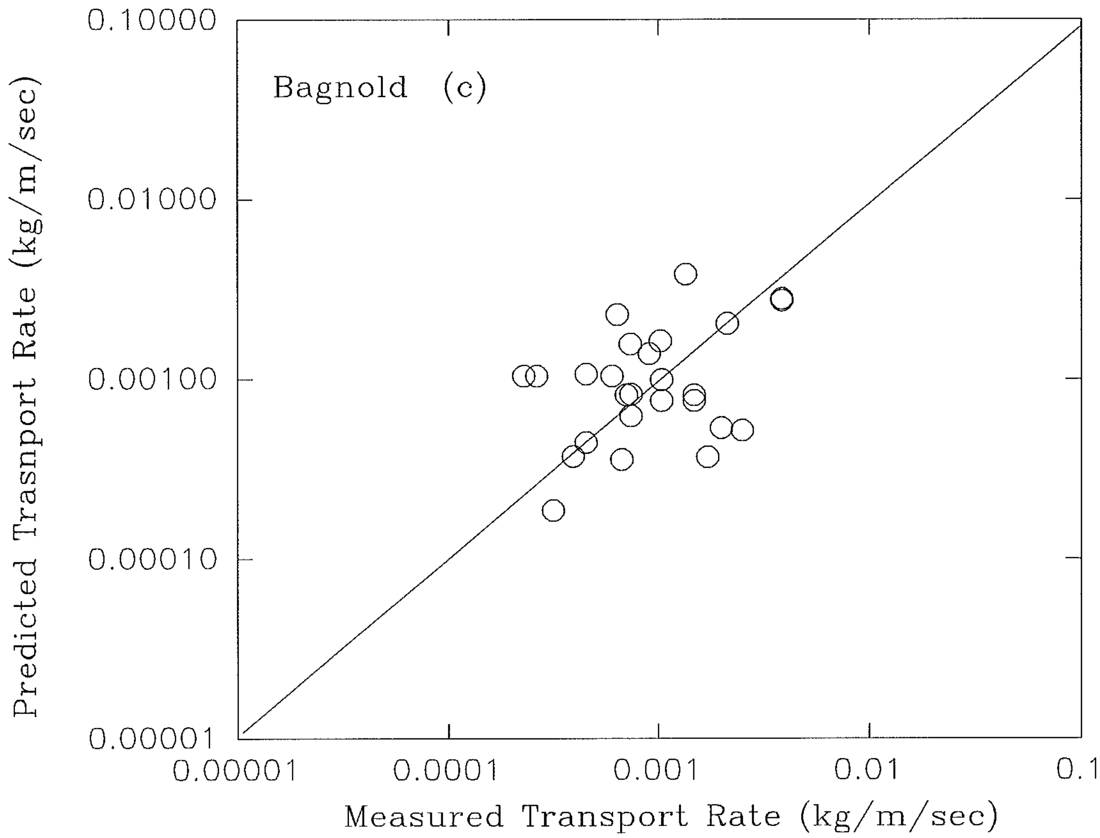

0.1
0.01
0.001
0.0001
0.00001
E-H (a)
Predicted Transport Rate (kg/m/sec)
0.00001 0.0001 0.001 0.01 0.1
Measured Transport Rate (kg/m/sec)
0.1
0.01
0.001
0.0001
0.00001
E-B (b)
Predicted Transport Rate (kg/m/sec)
0.00001 0.0001 0.001 0.01 0.1
Measured Transport Rate (kg/m/sec)

Figure 8



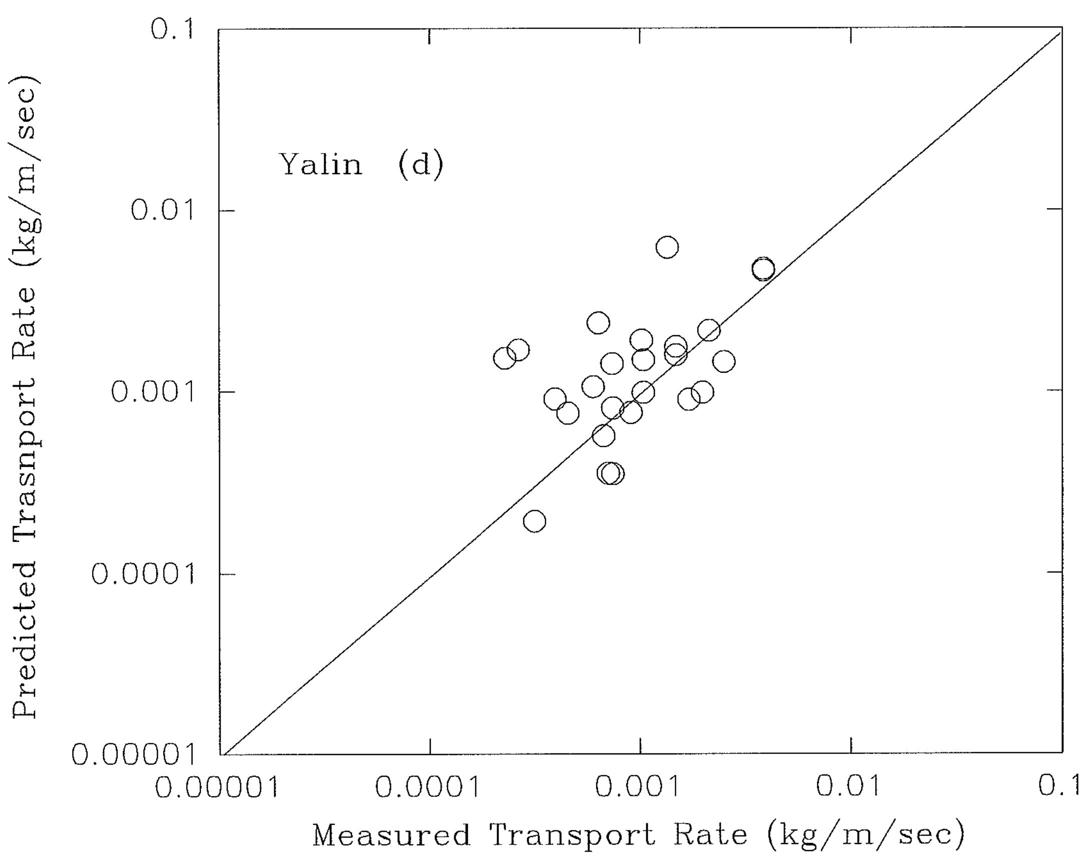


Figure 8 (continued)

5. CONCLUSIONS AND RECOMMENDATIONS

AGC sediment transport model has been thoroughly re-evaluated and upgraded in light of latest advances of the combined wave-current boundary layer theory and recently-available field data measured on Sable Island Bank, the Scotian Shelf. Nearly all of the key subroutines have been modified. Friction factor computation of the old model (SEDTRANS90) not only gives much lower f_{cw}, but also predicts higher f_{cw} with increasing waves, which does not agree with the original Jonsson (1966) theory. This has been corrected in SEDTRANS92 according to GM86. SEDTRANS90 used prevailing shear stress by mistake to directly compute Reynolds number R_e and critical shear stress in subroutine THRESH. The old model also used friction factor to calculate the threshold velocities for bedload and suspended load transport. This leads to significant fluctuations of the threshold criterion for different flow conditions. The upgraded model adopts Yalin's method so that the threshold shear stress can be obtained directly from sediment grain size and fluid viscosity. Critical mean velocity is also replaced by the more conventional critical shear velocity so that the threshold criterion is only a function of grain size and flow viscosity for given fluid and sediment densities.

As has been done in subroutine THRESH, threshold velocities have also been replaced by critical shear velocities in subroutine TIMING of the upgraded model. Martec Ltd. (1984) gave only the equations used for the calculation of sediment transport times. The actual method and procedures are described in this report. Mean velocity is also replaced by shear velocity in the sediment transport calculations under combined flow conditions to achieve better prediction. Detailed descriptions of the Amos-Greenberg cohesive sediment transport model was not given before and this has been included in this report so that the sediment transport model theories are complete. A detailed description of the theory behind subroutine Bedform is also given in this report. Different from SEDTRANS90, ripple length and height are predicted for both fine and medium sand in SEDTRANS92.

Sediment transport rates predicted by the upgraded model are compared to the measured bedform transport rates from the Scotian Shelf. The methods of Engelund-Hansen and Yalin are found to give better prediction, while Bagnold and Einstein-Brown formulae under-predict compared to the field measurements. An improved agreement between predicted and measured transport rates is obtained when the Sternberg (1972) current shear velocity is used together with GM wave shear velocity in subroutine TRANSPO, but the final conclusion and theoretical basis of this substitution needs to be explored and tested by more field data.

It is important to understand that as boundary layer theory is further advanced and more field data become available, sediment transport models have to be continuously revised. Ripple height was not measured in the Sable Island experiment, but is calculated from measured ripple length according to Allen (1970). The prediction of ripple roughness is critical to sediment transport modelling since it controls the partitioning of skin-friction and form drag (Smith and McLean, 1977; Li, in press) and also affects the resuspension of sand from the seabed (Vincent et al., 1991; Li et al., in progress). Several methods have been proposed for predicting ripple geometry under currents or waves (Grant and Madsen, 1982; Nielsen, 1981). However, none of them has been tested by combined flow field data. Thus it is recommended that ripple height as well as ripple wave length should be measured in future field experiments. A tested ripple prediction model should be adopted so that ripple roughness can be predicted for each data burst if field measurements are not available.

When bedforms exist, which is common on continental shelves, skin friction should be separated from the form drag to correctly predict sediment transport rates. Smith and McLean (1977) derived a stress partition model for sand waves and this model has been extended by Li (in press) to current ripples based on flume experiments. Stress partition model for combined wave and current flows is not yet available. The GM model assumes that the average skin friction over rippled bed is equal to that if the bed is flat. This assumption will not be valid for changing flow and ripple conditions (Vincent et al., 1991). Thus it is desired that a stress partition method be included instead of assuming a flat bed. Energy dissipation due to near-bed sediment transport and suspended sediment-induced stratification can significantly affect the calculations of boundary stresses and near-bed velocity profiles, especially when sediment transport rates are high and/or fine-grained sediment is involved. Corrections of these effects should be included in future model improvement.

Figure 6 shows that total sediment transport rates predicted by Engelund-Hansen and Bagnold methods do not significantly differ from the bedload predictions by Einstein-Brown and Yalin formulae. This suggests that the suspended load sediment transport is not properly accounted for in these total-load equations based on unidirectional flume experiment data. For fine-grained sediments and strong waves and currents, it is necessary to predict the suspended sediment concentration from the Rouse equation. This predicted SSC should be multiplied by predicted velocity and integrated over depth to obtain suspended sediment flux. Correspondingly, profiles of suspended sediment concentration should be measured simultaneously in the field to obtain the measured suspended load transport rates. The sum of this measured suspended load transport rate and ripple migration rate may then be compared to the predicted values for a full calibration of the model.

References

Abramowitz, M. and Stegun, I.A., 1964. Handbook of mathematical functions with formulas, graphs and mathematical tables. Dover, New York.

Ackers, P., 1972. Sediment transport in channels: an alternative approach. Report INT 102, Hydraulics Research Station, Wallingford, England.

Ackers, P. and White, W.R., 1973. Sediment transport: new approach and analysis. J. Hydraul. Div., Proc. ASCE, Vol. 99, HY11, pp.2041-2060.

Allen, J.R.L., 1970. Physical processes and sedimentation. Publ. Unwin University Books, London, 248pp.

Amos, C.L., 1990. Modern sedimentary processes. In: Geology of the Continental Margin of Eastern Canada, Geological Survey of Canada, Geology of Canada 2, Ch.11, pp.609-673.

Amos, C.L. and Greenberg, D.A., 1980. The simulation of suspended particulate matter in the Minas Basin, Bay of Fundy - A region of potential tidal power development. Proc. Canadian Coastal Conference, Burlington, Ontario.

Amos, C.L. and Mosher, D.C., 1985. Erosion and deposition of fine-grained sediments from the Bay of Fundy. Sedimentology, 32: 815-832.

Amos, C.L., Gomez, E.A. and Li, M.Z., 1993. Sand transport - measurements and predictions. Proc. Euromech 310, Le Havre, France, 1993.

Amos, C.L., Bowen, A.J., Huntley, D.A. and Judge, J.T., 1988a. Bedform stability under waves and currents. In: Proc. of Workshop on Friction Factors, Toronto, Ontario. Publ. National Research Council of Canada, Ottawa, pp.61-74.

Amos, C.L., Bowen, A.J., Huntley, D.A. and Lewis, C.F.M., 1988b. Ripple generation under the combined influences of waves and currents on the Canadian continental shelf. Cont. Shelf Res., 8: 1129-1153.

Amos, C.L., Grant, J., Daborn, G.R. and Black, K., 1992. Sea carousel - a benthic, annular flume. Estuarine, Coastal and Shelf Science, 34: 557-577.

Amos, C.L., Bowen, A.J., Huntley, D.A., Judge, J.T. and Li, M.Z., Ripple migration and sand transport under combined flows on the Scotian shelf. Cont. Shelf Res., (in review).

Baba, J.P. and Komar, P.D., 1981. Measurements and analysis of settling velocities of natural quartz sand grains. J. Sed. Petrol., 51: 631-640.

Bagnold, R.A., 1963. Mechanics of marine sedimentation. In: M.N. Hill (ed), The Sea, Wiley-Interscience, New York, Vol.3, pp.507-527.

Bagnold, R.A., 1966. An approach to the sediment transport problem from general physics. USGS Prof. Paper, 4421, 37pp.

Boyd, R., Forbes, D.L. and Heffler, D.E., 1988. Time-sequence observations of wave-formed sand ripples on an ocean shoreface. Sedimentology, 35: 449-464.

Brown, C.B., 1950. In: H. Rouse, (ed.), Engineering Hydraulics, John Wiley and Sons, New York, 1039pp.

Cacchione, D.A. and Drake, D.E., 1990. Shelf sediment transport: an overview with applications to the Northern California continental shelf. In: The Sea, John Wiley and Sons, Vol.9, 729-773pp.

Davidson, S. and Amos, C.L., 1985. A re-evaluation of SED1D and SED2D: sediment transport models for the continental shelf. Geological Survey of Canada Open File Report 1705, Section 3, 54pp.

Dyer, K.R., 1986. Coastal and estuarine sediment dynamics. John Wiley and Sons, Chichester, Engl., 342pp.

Engelund, F. and Hansen, E., 1967. A monograph on sediment transport in alluvial streams. Teknisk Vorlag, Copenhagen, Denmark.

Gadd, P.E., Lavelle, J.W. and Swift, D.J.P., 1978. Estimates of sand transport on the New York shelf using near-bottom current-meter observations. J. Sed. Petrol., 48: 239-252.

Gibbs, R.J., Mathews, M.D. and Link, D.A., 1971. The relationship between sphere size and settling velocity. J. Sed. Petrol., 41: 7-18.

Glenn, S.M. and Grant, W.D., 1987. A suspended sediment stratification correction for combined wave and current flows. J. Geophys. Res., 92: 8244-8264.

Grant, W.D. and O.S.Madsen, 1979. Combined wave and current interaction with a rough bottom. J. Geophys. Res., 84: 1797-1808.

Grant, W.D. and O.S.Madsen, 1982. Movable bed roughness in unsteady oscillatory flow. J. Geophys. Res., 87: 469-481.

Grant, W.D. and O.S.Madsen, 1986. The continental shelf bottom boundary layer. Annu. Rev. Fluid Mech., 18: 265-305.

Gust, G. and Morris, M.J., 1989. Erosion threshlods and entrainment rates of undisturbed in-situ sediments. J. Coastal Res., Special Issue 5: 87-100.

Guy, H.P., Simons, D.B. and Richardson, E.V., 1966. Summary of alluvial channel data from flume experiments, 1956-1961. USGS Prof. Paper 462-I, Washington D.C.

Jonsson, I.G., 1966. Wave boundary layers and friction factors. Proc. 10th Int. Conf. Coastal Engrg., Tokyo, pp.127-148.

Li, M.Z., Form drag and stress partitioning of bottom boundary layer flows over sand ripples. J. Geophys. Res. (in press).

Li, M.Z., Wright, L.D. and Amos, C.L. (in progress), Estimating ripple roughness and sand resuspension in a shoreface environment.

Madsen, O.S. and Grant, W.D., 1976. Sediment transport in the coastal environment. MIT, Department of Civil Engineering, Report 209, 105pp.

Martec Ltd., 1984. SED1D: A sediment transport model for the continental shelf. Unpublished report submitted to the Geological Survey of Canada, DSS Contract IOSC. 23420-3-M753, 63pp.

Martec Ltd., 1986. The comparison between observed and predicted sediment transport for the radio-active sand tracer study and SED1D model upgrade. Geological Survey of Canada Open File Report 1705, Section 5-9: F.3p.

Martec Ltd., 1987. Upgrading of AGC sediment transport model. Geological Survey of Canada Open File Report 1705, Section 10: C.14p.

Martec Ltd., 1990. Upgrading and application of the AGC sediment transport model SEDTRANS. Unpublished report submitted to the Geological Survey of Canada, SSC contract No. 23420-0-M166/01-OSC, 56pp.

Mehta, A.J. and Dyer, K.R., 1990. Cohesive sediment transport in estuarine and coastal waters. In: The Sea, John Wiley and Sons, Vol.9, pp.815-839.

Miller,M.C., McCave, I.N. and Komar, P.D., 1977. Threshold of sediment motion under unidirectional currents. Sedimentology, 24: 507-527.

Mimura, N., 1989. Recent Japanese studies on cohesive sediment transport. J. Coastal Res., Special Issue 5: 101-115.

Nielsen, P., 1979. Some basic concepts of wave sediment transport. Inst. Hydrodynamics and Hydraulic Eng., Tech. Univ. of Denmark, Ser. Paper 20, 160pp.

Nielsen, P., 1981. Dynamics and geometry of wave generated ripples. J. Geophys. Res., 86: 6467-6472.

Owen, M.W., 1970. A detailed study of settling velocities of an estuary mud. Hydraulics Research Station, Report INT 78.

Owen, M.W., 1976. Problems in the modelling of transport, erosion, and deposition of cohesive sediments. In: Goldberg, E.D., McCave, I.N., O'Brien, J.J. and Steele, J.H. (Eds.), The

Sea, Wiley-Interscience, New York, Vol.6, pp.515-537.

Ross, M.A., 1988. Vertical structure of estuarine fine sediment suspensions, Ph.D thesis, University of Florida, Gainesville.

Smith, J.D., 1977. Modelling of sediment transport on continental shelves, In: Goldberg, E.D., McCave, I.N., O'Brien, J.J. and Steele, J.H. (Eds.), The Sea, Wiley-Interscience, New York, Vol. 6, pp.539-576.

Smith, J.D. and McLean, S.R., 1977. Spatially averaged flow over a wavy surface. J. Geophys. Res., 82: 1735-1746.

Sternberg, R.W., 1972. Predicting initial motion and bedload transport of sediment particles in the shallow marine environment. In: Shelf sediment transport, process and pattern, Swift, D.J.P., Duane, D.B. and Pilkey, O.H. (eds.), Dowden, Hutchinson & Ross, Inc., pp.61-83.

Swart, D.H. and Fleming, C.A., 1980. Longshore water and sediment movement. Proc. 17th Coastal Engrg. Conf., pp.1275-1294.

Vincent, C.E., Hanes, D.M. and Bowen, A.J., 1991. Acoustic measurements of suspended sand on the shoreface and the control of concentration by bed roughness. Mar. Geol., 96: 1-18.

Yalin, M.S., 1963. An expression for bedload transportation. J. Hydraul. Div., Proc. ASCE, Vol.89, HY3, pp.221-250.

Yalin, M.S., 1964. Geometrical properties of sand waves. J. Hydraul. Div., Proc. ASCE, Vol.90, HY5, pp.105-119.

Yalin, M.S., 1977. Mechanics of sediment transport. Pergamon Press, Oxford, 290pp.

Young, R.N. and Southard, J.B., 1978. Erosion of fine-grained marine sediments: sea-floor and laboratory experiments. Geol. Soc. Amer. Bull., 89: 663-672.

APPENDIX 1

PROGRAM LISTINGS FOR SEDTRANS92

Appendix 1

```
      PROGRAM SEDTRANS92
C*****************************************************************************************************
C*****************************************************************************************************
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      CHARACTER*15 NAME
C
C  THIS IS THE INTERACTIVE VERSION
C
C              SEDTRANS92:  A SEDIMENT TRANSPORT MODEL
C              FOR CONTINENTAL SHELF CONDITIONS
C
C              ATLANTIC GEOSCIENCE CENTER-GSC
C              BEDFORD INSTITUTE OF OCEANOGRAPHY
C              SEPTEMBER, 1992
C              LAST MODIFIED: JANUARY, 1993
C
C  THIS PROGRAM CALCULATES SEDIMENT TRANSPORT FOR HORIZONTAL BEDS UNDER COMBINED
C  WAVE AND CURRENT CONDITIONS.  A CHOICE OF TRANSPORT FORMULAE IS AVAILABLE TO THE
C  USER. HOWEVER, NONE OF THESE FORMULAE HAVE BEEN CALIBRATED FOR COMBINED
C  WAVE-CURRENT FLOWS.
C
C  THE AVAILABLE OPTIONS ARE:
C
C  IOPT1 = 1 - ENGELUND-HANSEN (1967) TOTAL LOAD EQUATION
C          2 - EINSTEIN-BROWN (1950) BEDLOAD EQUATION
C          3 - BAGNOLD (1963) TOTAL LOAD EQUATION
C          4 - YALIN (1963) BEDLOAD EQUATION
C          5 - ACKERS-WHITE (1973) TOTAL LOAD EQUATION
C          6 - SMITH (1977) SUSPENDED LOAD (WAVES AND CURRENTS)
C          7 - AMOS AND GREENBERG (1980) COHESIVE SEDIMENTS
C
C  THE USER SHOULD BE FAMILIAR WITH THE EQUATIONS USED AND THEIR LIMITATIONS.
C  ALL DIMENSIONAL VARIABLES ARE IN SI UNITS.
C  OUTPUT DATA WILL BE SENT TO A FILE YOU CHOOSE AND THE TERMINAL (LOGICAL UNIT # 7 IS USED)
C  ALL WARNINGS, MESSAGES, ETC. ARE DIRECTED TO THE TERMINAL
C
C*****************************************************************************************************
C  VARIABLES
C
C     AB = EXCERSION LENGTH OF BOTTOM WAVE ORBIT (M) (1/2 OF THE ORBITAL DIAMETER)
C     AGR = CRITICAL MOBILITY NUMBER USED IN ACKERS-WHITE FORMULA
C     CDIR = DIRECTION OF AMBIENT CURRENT (DEGREES TRUE)
C     CONC = CALCULATED SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     D = WATER DEPTH (M)
C     DGR = DIMENSIONLESS GRAIN DIAMETER IN ACKERS-WHITE FORMULA
C     FCW = BOTTOM (SKIN) FRICTION FACTOR
C     FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GD
C     GD = SEDIMENT GRAIN DIAMETER (M)
C     HT = WAVE HEIGHT (M)
C     IBRK = WAVE-BREAKING CRITERION
C     IOPT1 = SEDIMENT TRANSPORT FORMULA OPTION NUMBER
C     IOPT2 = FRICTION FACTOR PREDICTOR OPTION NUMBER (1 = GRANT & MADSEN; 2 = SMITH)
C     IRUN = RUN OR CYCLE NUMBER
C     PER = WAVE PERIOD (S)
```

```
C     PERBED = PERCENTAGE OF TIME SPENT IN ONLY BEDLOAD TRANSPORT PHASE
C     PERSUSP = PERCENTAGE OF TIME SPENT IN SUSPENDED LOAD TRANSPORT PHASE
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY
C           LAYER (RADIANS)
C     PHI100 = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS AT 1 M ABOVE SEABED (RADIANS)
C           NOTE:  PHI100 = PHIZ AS LONG AS PHIZ IS MEASURED OUTSIDE THE WAVE BOUNDARY LAYER.
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RGR = REYNOLDS NUMBER AS A FUNCTION OF DGR, AS GIVEN BY SWART AND FLEMING (1980)
C     RHOS = DENSITY OF SEDIMENT GRAIN  (KG/M**3)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     RK = EFFICIENCY FACTOR OF THE MODIFIED BAGNOLD BEDLOAD EQUATION
C     RKB = BOTTOM ROUGHNESS HEIGHT (M)
C     RKBC = APPARENT BOTTOM ROUGHNESS (M)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C     SED = TIME-AVERAGED NET SEDIMENT TRANSPORT AS VOLUME OF SEDIMENT SOLIDS
C            TRANSPORTED PER UNIT BED WIDTH PER UNIT TIME (M**3/S/M)
C     SEDDIR = DIRECTION OF NET SEDIMENT TRANSPORT (AZIMUTH, DEGREES)
C     SEDM = TIME-AVERAGED NET SEDIMENT TRANSPORT AS MASS OF SEDIMENT SOLIDS
C              TRANSPORTED PER UNIT BED WIDTH PER UNIT TIME (KG/S/M)
C     TB1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT CEASES (S)
C     TB2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT
C            RECOMMENCES (S)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     TS1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C            CEASES (S)
C     TS2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C            RECOMMENCES (S)
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC. (M/S)
C     UB = MAXIMUM WAVE INDUCED ORBITAL VELOCITY AT THE BOTTOM (M/S)
C     USTC = TOTAL CURRENT SHEAR VELOCITY OF GM (M/S)
C     USTCRB = CRITICAL SHEAR VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/S)
C     USTCRS = CRITICAL SHEAR VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/S)
C     USTCS = FINAL CURRENT SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTCSGM = CURRENT SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     USTCS1 = STERNBERG CURRENT SHEAR VELOCITY (M/S)
C     USTCW = COMBINED TOTAL SHEAR VELOCITY OF GM (M/S)
C     USTCWS = FINAL COMBINED SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTCWSGM = COMBINED SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     USTW = TOTAL WAVE SHEAR VELOCITY OF GM (M/S)
C     USTWS = FINAL WAVE SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTWSGM = WAVE SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     UZ = AMBIENT CURRENT AT HEIGHT Z ABOVE THE SEAFLOOR (M/S)
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     VCB = CRITICAL FLOW VELOCITY FOR INITIATION OF BEDLOAD (M/S)
C     VCS = CRITICAL FLOW VELOCITY FOR INITIATION OF SUSPENDED DLOAD (M/S)
C     WDIR = WAVE PROPOGATION DIRECTION (DEGREES TRUE)
C     WS = SETTLING VELOCITY (M/S)
C     WL = WAVE LENGTH (M)
C     Z = HEIGHT OF UZ ABOVE SEAFLOOR (M)
C
C*****************************************************************************************************
C  SET UP INPUT AND OUTPUT FILES
C
      WRITE (*,3)
 3    FORMAT(/,' ENTER FILE NAME IN WHICH OUTPUT WILL BE STORED: ')
      READ (*,4) NAME
 4    FORMAT (A15)
      OPEN (7,FILE=NAME,STATUS='UNKNOWN',FORM='FORMATTED')
```

```
C  OPEN SEDOUTI TO STORE TABULAR OUTPUTS OF THE MODEL
      OPEN (8, FILE= 'SEDOUTI',STATUS = 'UNKNOWN',FORM='FORMATTED')
C  WRITE THE HEADERS TO THE TABULAR OUTPUT FILE SEDOUTI
      WRITE (8,118)
 118  FORMAT(' FCW   USTCS1   USTCSGM   USTWS   USTCWS   USTCW   SEDM')
C
C*****************************************************************************************
C  READ IN THE INPUT PARAMETERS
C
 5    CALL READIN(IRUN,D,UZ,Z,CDIR,HT,PER,WDIR,GD,RKB,RHOS,RHOW,QI,IOPT1,IOPT2,FRACT,CONC0,
     @     TOWCE,TOWCD,WS,PRS,RKERO)
C
C*****************************************************************************************
C  QI = THE INPUT DATA QUIT INDEX (RE-ENTER INPUT OR NO MORE RUNS REQUIRED)
      IF (QI .EQ. 1.0) GO TO 10
C
C*****************************************************************************************
C  WRITE OUT THE INPUT PARAMETERS TO DISK AND THE TERMINAL
C
      CALL INOUT(IRUN,D,UZ,CDIR,Z,HT,PER,WDIR,GD,RKB,RHOS,RHOW,FRACT,CONC0,TOWCE,TOWCD,Ws,
     @     PRS,RKERO,IOPT1)
C
C*****************************************************************************************
C  CALCULATE WAVE INDUCED BOTTOM VELOCITY AND ORBITAL DIAMETER
C
      CALL OSCIL(HT,PER,D,UB,AB,WL,IBRK)
C
C*****************************************************************************************
C  CALCULATE FRICTION FACTOR, AMBIENT CURRENT AND BOTTOM STRESSES
C
      CALL FRICFAC(UZ,Z,CDIR,UB,AB,PER,WDIR,GD,RKB,RHOW,IOPT2,RKBC,FCW,UA,PHIB,U100,PHI100,
     @     USTCSGM,USTWSGM,USTCWSGM,USTC,USTW,USTCW)
C
C*****************************************************************************************
C  CALCULATE THRESHHOLD CRITERIA FOR SEDIMENT TRANSPORT
C  NOT APPLICABLE FOR COHSEIVE SEDIMENTS THEREFORE SKIP IF NECESSARY
      IF (IOPT1.EQ.7) GOTO 1100
C
      CALL THRESH(D,UB,GD,RHOS,RHOW,IOPT1,FCW,USTCRB,USTCRS,VCB,VCS,DGR,AGR,RGR)
C
C*****************************************************************************************
C  CALCULATE THE DURATION OF THE DIFFERENT SEDIMENT TRANSPORT PHASES
C
      CALL TIMING(UA,PHIB,UB,PER,U100,USTCRB,USTCRS,USTCSGM,USTWSGM,USTCWSGM,TB1,TB2,TS1,
     @     TS2,PERBED,PERSUSP,USTCS,USTWS,USTCWS)
C
 1100 CONTINUE
C
C*****************************************************************************************
C  CALCULATE SEDIMENT TRANSPORT RATE AND DIRECTION
C
      CALL TRANSPO(D,UA,UB,U100,PHIB,PHI100,FCW,PER,GD,RKB,FRACT,RHOS,RHOW,VCB,VCS,USTCRB,
     @     USTCS,USTWS,USTCWS,AGR,DGR,CDIR,WDIR,TB1,TB2,TS1,TS2,PERBED,PERSUSP,IOPT1,IOPT2,
     @     CONC0,TOWCD,TOWCE,WS,PRS,RKERO,SED,SEDM,SEDDIR,CONC)
C
C*****************************************************************************************
C  FINAL OUTPUTS OF THE MODEL
C
      CALL OUTOUT(UB,AB,WL,FCW,UA,U100,PHIB,USTCSGM,USTWS,USTCWS,USTCW,
```

```
     @    USTCRB,USTCRS,TS1,TB1,TS2,TB2,PERBED,PERSUSP,IOPT1,IOPT2,RK,SED,SEDM,SEDDIR,CONC)
C
C*****************************************************************************************************
C  PREDICT THE POTENTIAL BEDFORMS
C
      CALL BEDFORM(U100,UA,UB,GD,FCW,PHIB,RHOW,RHOS,AB,IOPT1)
C
C*****************************************************************************************************
C  GIVE USER THE OPTION OF DOING ANOTHER RUN
C
 10   CONTINUE
C
      WRITE (*,15)
 15   FORMAT(///,' ENTER 1 TO DO ANOTHER RUN, 0 TO STOP: ')
C
C  IND IS A TEMPORARY INDICATOR OF CHOICE
C
      READ (*,*) IND
      IF (IND .EQ. 0) GOTO 999
C
      GO TO 5
C
C*****************************************************************************************************
C*****************************************************************************************************
C
 999  STOP
C
C  END OF THE MAIN PROGRAM
      END
```

```
 PROGRAM SEDTRANS92
C*****************************************************************************************************
C*****************************************************************************************************
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      CHARACTER*80 CHR
C
C     THIS IS THE BATCH VERSION
C
C                   SEDTRANS92: A SEDIMENT TRANSPORT MODEL
C                   FOR CONTINENTAL SHELF CONDITIONS
C
C                   ATLANTIC GEOSCIENCE CENTER-GSC
C                   BEDFORD INSTITUTE OF OCEANOGRAPHY
C                   SEPTEMBER, 1992
C                   Last Modified: January, 1993
C
C     THIS PROGRAM CALCULATES SEDIMENT TRANSPORT FOR HORIZONTAL BEDS UNDER COMBINED WAVE
C     AND CURRENT CONDITIONS.  A CHOICE OF TRANSPORT FORMULAE IS AVAILABLE TO THE USER.
C     HOWEVER, NONE OF THESE FORMULAE HAVE BEEN CALIBRATED FOR COMBINED WAVE AND CURRENT
C     FLOWS.
C
C     THE AVAILABLE OPTIONS ARE:
C
C     IOPT1 = 1 - ENGELUND-HANSEN (1967) TOTAL LOAD EQUATION
C             2 - EINSTEIN-BROWN (1950) BEDLOAD EQUATION
C             3 - BAGNOLD (1963) TOTAL LOAD EQUATION
C             4 - YALIN (1963) BEDLOAD EQUATION
C             5 - ACKERS-WHITE (1973) TOTAL LOAD EQUATION
C             6 - SMITH (1977) SUSPENDED LOAD (WAVES AND CURRENTS)
C             7 - AMOS and GREENBERG (1980) COHESIVE SEDIMENTS
C
C     THE USER SHOULD BE FAMILIAR WITH THE EQUATIONS USED AND THEIR LIMITATIONS.
C     ALL DIMENSIONAL VARIABLES ARE IN SI UNITS
C     INPUT DATA SHOULD BE STORED IN FILE 'INDATA' (LOGICAL UNIT #3).
C     DETAILED OUTPUT DATA WILL BE SENT TO FILE "OUTDATA" AND THE TABULATED OUTPUT SENT TO
C     FILE "SEDOUT" (LOGICAL UNITS #7 AND #8)
C     ALL WARNINGS, MESSAGES, ETC. ARE DIRECTED TO THE TERMINAL
C
C*****************************************************************************************************
C   VARIABLES
C
C       AB = EXCERSION LENGTH OF BOTTOM WAVE ORBIT (M) (1/2 OF THE ORBITAL DIAMETER)
C       AGR = CRITICAL MOBILITY NUMBER USED IN ACKERS-WHITE FORMULA
C       CDIR = DIRECTION OF AMBIENT CURRENT (DEGREES TRUE)
C       CONC = CALCULATED SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C       CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C       D = WATER DEPTH (M)
C       DGR = DIMENSIONLESS GRAIN DIAMETER IN ACKERS-WHITE FORMULA
C       FCW = BOTTOM (SKIN) FRICTION FACTOR
C       FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GDC
C       GD = SEDIMENT GRAIN DIAMETER (M)
C       HT = WAVE HEIGHT (M)
C       IBRK = WAVE-BREAKING CRITERION
C       IOPT1 = SEDIMENT TRANSPORT FORMULA OPTION NUMBER
C       IOPT2 = FRICTION FACTOR PREDICTOR OPTION NUMBER (1 = GRANT & MADSEN; 2 = SMITH)
C       IRUN = RUN OR CYCLE NUMBER
C       PER = WAVE PERIOD (S)
C       PERBED = PERCENTAGE OF TIME SPENT IN ONLY BEDLOAD TRANSPORT PHASE
C       PERSUSP = PERCENTAGE OF TIME SPENT IN SUSPENDED LOAD TRANSPORT PHASE
```

```
C  READ THE HEADER LINE OF THE INPUT FILE INDATA
      READ (3,'(A80)')
C
C****************************************************************************************************
C  READ IN THE INPUT PARAMETERS
C
 1    CALL READBCH(IRUN,D,UZ,Z,CDIR,HT,PER,WDIR,GD,RKB,FRACT,RHOS,RHOW,IOPT1,IOPT2,IND)
     @     CONC0,TOWCE,TOWCD,WS,PRS,RKERO)
C
C****************************************************************************************************
C  WRITE OUT THE INPUT PARAMETERS TO DISK AND TERMINAL
C
      CALLINOUT(IRUN,D,UZ,CDIR,Z,HT,PER,WDIR,GD,RKB,RHOS,RHOW,FRACT,CONC0,TOWCE,TOWCD,Ws,PRS,
     @     RKERO,IOPT1)
C
C****************************************************************************************************
C  CALCULATE WAVE INDUCED BOTTOM VELOCITY AND ORBIT SIZE
C
      CALL OSCIL(HT,PER,D,UB,AB,WL,IBRK)
C
C****************************************************************************************************
C  CALCULATE FRICTION FACTOR, AMBIENT CURRENT AND BOTTOM STRESSES.
C
      CALL FRICFAC(UZ,Z,CDIR,UB,AB,PER,WDIR,GD,RKB,RHOW,IOPT2,RKBC,FCW,UA,PHIB,U100,PHI100,
     @     USTCSGM,USTWSGM,USTCWSGM,USTC,USTW,USTCW)
C
C****************************************************************************************************
C  CALCULATE THRESHOLD CRITERIA FOR SEDIMENT TRANSPORT
C  NOT APPLICABLE FOR COHESIVE SEDIMENTS THEREFORE SKIP IF NECESSARY
      IF (IOPT1.EQ.7) GOTO 1100
C
      CALL THRESH(D,UB,GD,RHOS,RHOW,IOPT1,FCW,USTCRB,USTCRS,CB,VCS,DGR,AGR,RGR)
C
C****************************************************************************************************
C  CALCULATE THE DURATION OF THE DIFFERENT SEDIMENT TRANSPORT PHASES
C
      CALL TIMING(UA,PHIB,UB,PER,U100,USTCRB,USTCRS,USTCSGM,USTWSGM,USTCWSGM,TB1,TB2,
     @     TS1,TS2,PERBED,PERSUSP,USTCS,USTWS,USTCWS)
C
1100  CONTINUE
C
C****************************************************************************************************
C  CALCULATE SEDIMENT TRANSPORT RATE AND DIRECTION
C
      CALL TRANSPO(D,UA,UB,U100,PHIB,PHI100,FCW,PER,GD,RKB,FRACT,RHOS,RHOW,VCB,VCS,USTCRB,USTCS,
     @     USTWS,USTCWS,AGR,DGR,CDIR,WDIR,TB1,TB2,TS1,TS2,PERBED,PERSUSP,IOPT1,IOPT2,CONC0,
     @     TOWCD,TOWCE,WS,PRS,RKERO,SED,SEDM,SEDDIR,CONC)
C
C****************************************************************************************************
C  FINAL OUTPUTS OF THE MODEL
C
      CALL OUTOUT(UB,AB,WL,FCW,UA,U100,PHIB,USTCSGM,USTWS,USTCWS,USTCW,
     @     USTCRB,USTCRS,TS1,TB1,TS2,TB2,PERBED,PERSUSP,IOPT1,IOPT2,RK,SED,SEDM,CONC)
C
C****************************************************************************************************
C  PREDICT POTENTIAL BEDFORMS
C
      CALL BEDFORM(U100,UA,UB,GD,FCW,PHIB,RHOW,RHOS,AB,IOPT1)
C
```

```
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY
C            LAYER (RADIANS)
C     PHI100 = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS AT 1 M ABOVE SEABED (RADIANS)
C            NOTE:  PHI100 = PHIZ AS LONG AS PHIZ IS MEASURED OUTSIDE THE WAVE BOUNDARY LAYER.
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RGR = REYNOLDS NUMBER AS A FUNCTION OF DGR, AS GIVEN BY SWART AND FLEMING (1980)
C     RHOS = DENSITY OF SEDIMENT MINERAL(S)   (KG/M**3)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     RK = EFFICIENCY FACTOR OF THE MODIFIED BAGNOLD BEDLOAD EQUATION
C     RKB = BOTTOM ROUGHNESS HEIGHT (M)
C     RKBC = APPARENT BOTTOM ROUGHNESS (M)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C     SED = TIME-AVERAGED NET SEDIMENT TRANSPORT AS VOLUME OF SEDIMENT SOLIDS
C             TRANSPORTED PER UNIT BED WIDTH PER UNIT TIME (M**3/S/M)
C     SEDDIR = DIRECTION OF NET SEDIMENT TRANSPORT (AZIMUTH,DEGREES)
C     SEDM = TIME-AVERAGED NET SEDIMENT TRANSPORT AS MASS OF SEDIMENT SOLIDS
C              TRANSPORTED PER UNIT BED WIDTH PER UNIT TIME (KG/S/M)
C     TB1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT CEASES (SEC)
C     TB2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT
C            RECOMMENCES (SEC)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     TS1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C            CEASES (SEC)
C     TS2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C            RECOMMENCES (SEC)
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC. (M/SEC)
C     UB = MAXIMUM WAVE INDUCED ORBITAL VELOCITY AT THE BOTTOM (M/S)
C     USTC = TOTAL CURRENT SHEAR VELOCITY OF GM (M/S)
C     USTCRB = CRITICAL SHEAR VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/SEC)
C     USTCRS = CRITICAL SHEAR VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/SEC)
C     USTCS = FINAL CURRENT SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTCSGM = CURRENT SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     USTCS1 = STERNBERG CURRENT SHEAR VELOCITY (M/S)
C     USTCW = COMBINED TOTAL SHEAR VELOCITY OF GM (M/S)
C     USTCWS = FINAL COMBINED SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTCWSGM = COMBINED SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     USTW = TOTAL WAVE SHEAR VELOCITY OF GM (M/S)
C     USTWS = FINAL WAVE SKIN-FRICTION SHEAR VELOCITY (M/S)
C     USTWSGM = WAVE SKIN-FRICTION SHEAR VELOCITY OF GM (M/S)
C     UZ = AMBIENT CURRENT AT HEIGHT Z ABOVE THE SEAFLOOR (M/S)
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     VCB = CRITICAL FLOW VELOCITY FOR INITIATION OF BEDLOAD (M/S)
C     VCS = CRITICAL FLOW VELOCITY FOR INITIATION OF SUSPENDED DLOAD (M/S)
C     WDIR = WAVE PROPOGATION DIRECTION (DEGREES TRUE)
C     WS = SETTLING VELOCITY (M/S)
C     WL = WAVE LENGTH (M)
C     Z = HEIGHT OF UZ ABOVE SEAFLOOR (M)
C
C*****************************************************************************************************
C  SET UP INPUT AND OUTPUT FILES
C
      OPEN (3, FILE='INDATA',STATUS='UNKNOWN',FORM='FORMATTED')
C
      OPEN (7, FILE='OUTDATA',STATUS='UNKNOWN',FORM='FORMATTED')
      OPEN (8, FILE='SEDOUT',STATUS ='UNKNOWN',FORM='FORMATTED')
C  WRITE THE HEADERS TO THE TABULER OUTPUT FILE SEDOUT
      WRITE (8,777)
 777  FORMAT(' FCW   USTCS1  USTCSGM  USTWS  USTCWS  USTCWSM   USTCW   SEDM')
```

```
C  IF END OF THE INPUT FILE, TERMINATE THE PROGRAM
C
      IF (IND .EQ. 1) THEN
         GOTO 999
      ELSE
         GO TO 1
      ENDIF
C
C****************************************************************************************************
C****************************************************************************************************
C
 999  CONTINUE
      STOP
C
C  END OF THE MAIN PROGRAM
      END
```

```
C**********************************************************************************************
      SUBROUTINE  READIN(IRUN,D,UZ,Z,CDIR,HT,PER,WDIR,GD,RKB,RHOS,RHOW,QI,IOPT1,IOPT2,FRACT,CONC0,
     @TOWCE,TOWCD,Ws,PRS,RKERO)
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      CHARACTER*1 IYN
      COMMON /CHECK/ICHK
C
C     THIS SUBROUTINE CONTROLS USER INPUT OF THE DATA REQUIRED FOR RUNNING SEDTRANS92.
C
      PI = ACOS(-1.)
C
C---------------------------------------------------------------------------------------------
C VARIABLES
C     IRUN = RUN OR CYCLE NUMBER
C     D = WATER DEPTH (M)
C     UZ = AMBIENT CURRENT AT HEIGHT Z ABOVE THE SEAFLOOR (M/S)
C     Z = HEIGHT OF UZ ABOVE SEAFLOOR
C     CDIR = DIRECTION OF AMBIENT CURRENT (DEGREES TRUE)
C     HT = WAVE HEIGHT (M)
C     PER = WAVE PERIOD (S)
C     WDIR = WAVE PROPOGATION DIRECTION (DEGREES TRUE)
C     GD = SEDIMENT GRAIN DIAMETER (M)
C     RHOS = DENSITY OF SEDIMENT MINERAL(S)   (KG/M**3)
C     FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GD
C     RKB = BOTTOM ROUGHNESS HEIGHT (M)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     QI = QUIT INDEX
C     CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     Ws = SETTLING VELOCITY (m/s)
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C
C---------------------------------------------------------------------------------------------
C INTERACTIVE DATA ENTRY
C
 1    WRITE (*,15)
 15   FORMAT(' IF YOU WISH TO ABORT A RUN, ENTER -99 AS RESPONSE',/,
     @T11,'TO ANY OF THE FOLLOWING QUESTIONS')
C
C INITIALIZE QUIT INDEX TO 0
C
      QI=0.0
C
C ENTER DATA
C
      WRITE (*,25)
 25   FORMAT(//,' ENTER RUN NUMBER (1 - 9999): ')
      READ (*,*) IRUN
C
      WRITE (*,35)
 35   FORMAT(//,' ENTER WATER DEPTH (m): ')
      READ (*,*) D
      IF ( D .EQ. -99.) GO TO 998
C
      WRITE (*,45)
 45   FORMAT(//,' ENTER CURRENT SPEED,DIRECTION AND HEIGHT ABOVE SEABED (m/s, DEGREES, m): ')
```

```
      READ (*,*)  UZ,CDIR,Z
      IF (UZ .EQ. -99. .OR. CDIR .EQ. -99. .OR. Z .EQ. -99.) GO TO 998
C
      WRITE (*,55)
 55   FORMAT(//,' ENTER WAVE HEIGHT, PERIOD AND DIRECTION (METRES,SECONDS,DEGREES TRUE): ')
      READ (*,*) HT,PER,WDIR
      IF (HT .EQ. -99. .OR. PER .EQ. -99. .OR. WDIR .EQ. -99.) GO TO 998
C
      WRITE (*,65)
 65   FORMAT(//,' ENTER SEDIMENT GRAIN SIZE, BED ROUGHNESS (m)')
      READ (*,*) GD,RKB
      RHOS=2650.
      RHOW=1025
      FRACT=1.0
      IF (GD .EQ. -99. .OR. RHOS .EQ. -99.) GO TO 998
C
 90   WRITE (*,95)
 95   FORMAT (//,' CHOOSE BETWEEN:',/,
     @  '  1 - ENGELUND-HANSEN (1967) TOTAL LOAD EQUATION',/,
     @  '  2 - EINSTEIN-BROWN (1950) BEDLOAD EQUATION',/,
     @  '  3 - BAGNOLD (1963) TOTAL LOAD EQUATION',/,
     @  '  4 - YALIN (1963) BEDLOAD EQUATION',/,
     @  '  5 - ACKERS-WHITE TOTAL LOAD EQUATION',/,
     @  '  6 - SMITH (1977) SUSPENDED LOAD (WAVES AND CURRENTS)',/,
     &  '  7 - AMOS AND GREENBERG (1980) COHESIVE SEDIMENTS',/,
     @  ' ENTER 1,2,3,4,5,6 OR 7: ')
      READ (*,*) IOPT1
      IF (IOPT1 .EQ. -99) GO TO 998
      IF (IOPT1 .LT. 1 .OR. IOPT1 .GT. 7) GO TO 90
C
 100  WRITE (*,105)
 105  FORMAT (//,' FOR FRICTION FACTOR CALCULATION,CHOOSE BETWEEN: '/
     @  '  1 - GRANT AND MADSEN(1977) THEORY (WAVE-DOMINATED FLOWS)'/
     @  '  2 - SMITH(1977) THEORY (CURRENT-DOMINATED FLOWS)'/
     @  ' ENTER 1 OR 2: ')
      READ (*,*) IOPT2
      IF (IOPT2.EQ.-99) GO TO 998
      IF (IOPT2.LT.1 .OR. IOPT2.GT.2) GO TO 100
C
C-----------------------------------------------------------------------------------------------------------------
C CHECK THAT SMITH METHOD IS NOT USED IN A "CURRENT ONLY" SCENARIO.
      IF ((IOPT1.EQ.6 .OR. IOPT2.EQ.2) .AND. HT.EQ.0.) THEN
          WRITE(*,106)
 106      FORMAT (//,' THE SMITH METHOD CANNOT BE USED WITH ONLY CURRENTS AND NO WAVES')
          GOTO 1
      ENDIF
      GO TO 999
 998  QI=1.0
C
C-----------------------------------------------------------------------------------------------------------------
C CHECK THE GRAIN SIZE LIMITS FOR EACH THEORY
 999  CONTINUE
      IFLAG = 0
      GOTO (204,214,224,234,244,1005,254) IOPT1
 204  IF (GD.LT.0.00015) THEN
          WRITE (*,205)
 205      FORMAT (//' ***WARNING*** - ENGELUND-HANSEN FORMULA NOT RECOMMENDED',
     @  /T18,'FOR USE WITH SEDIMENTS FINER THAN 0.15 MM')
          IFLAG=1
```

```
      ENDIF
      GOTO 1000
 214  IF (GD.LT.0.0003 .OR. GD.GT..0286) THEN
          WRITE (*,215)
          PRINT*,' CHECK INPUT DATA FOR RUN # ',IRUN
 215      FORMAT (//' ***WARNING*** - EINSTEIN-BROWN FORMULA IS BASED ON LABORATORY',
     @    /T18,'EXPERIMENTS USING SEDIMENTS WITH GRAIN SIZES OF 0.3 TO 28.6 MM')
          IFLAG=1
      ENDIF
      GOTO 1000
 224  IF (GD.LT.0.00018 .OR. GD.GT.0.00045) THEN
          WRITE (*,225)
          PRINT*,' CHECK INPUT DATA FOR RUN # ',IRUN
 225      FORMAT (//' ***WARNING*** - BAGNOLD FORMULA IS BASED ON LABORATORY TESTS',
     @    /T18,'WITH GRAIN SIZES BETWEEN 0.18 AND 0.45 MM')
          IFLAG=1
      ENDIF
      GOTO 1000
 234  IF (GD.LT.0.0002) THEN
          WRITE (*,235)
          PRINT*,' CHECK INPUT DATA FOR RUN # ',IRUN
 235      FORMAT (//' ***WARNING*** - YALIN FORMULA IS NOT RECOMMENDED FOR USE WITH SEDIMENTS',
     @    /T18,'SMALLER THAN 0.2MM, BASED ON THE RESULTS OF SENSITIVITY ANALYSES')
          IFLAG=1
      ENDIF
      GOTO 1000
 244  IF (GD.LT.0.00005 .OR. GD.GT..0291) THEN
          WRITE (*,245)
          PRINT*,' CHECK INPUT DATA FOR RUN # ',IRUN
 245      FORMAT (//' ***WARNING*** - ACKERS-WHITE FORMULA IS BASED ON LABORATORY',
     @      /T18,'EXPERIMENTS USING SEDIMENTS WITH GRAIN SIZES OF 0.05 TO 29.1 MM')
          IFLAG=1
      ENDIF
      GOTO 1000
 254  IF (GD.GT.0.00001) THEN
          WRITE (*,255)
          WRITE (7,255)
          PRINT*,' CHECK INPUT DATA FOR RUN # ',IRUN
 255      FORMAT (//' ***WARNING*** - AMOS-GREENBERG METHOD IS NOT INTENDED ',
     @    'FOR NON-COHESIVE SEDIMENTS')
          IFLAG=1
      ENDIF
C
 1000 CONTINUE
C
C IF THE GRAIN SIZE IS NOT WITHIN THE LIMITS FOR THE SEDIMENT TRANSPORT FORMULA, THEN GIVE THE
C USER THE OPTION OF ENTERING A DIFFERENT GRAIN SIZE FOR THE RUN.
      IF (IFLAG.EQ.1) THEN
          WRITE (*,256)
 256      FORMAT (//' SELECT NEW VALUE FOR SEDIMENT GRAIN SIZE?'/' (ENTER Y/N): ')
          READ (*,'(A1)') IYN
          IF (IYN.EQ.'Y') THEN
            WRITE (*,265)
 265        FORMAT (//' ENTER SEDIMENT GRAIN SIZE (M): ')
            READ (*,*) GD
            GO TO 999
          ENDIF
      ENDIF
C
```

```
C-----------------------------------------------------------------------------------------------------------------
C IF AMOS-GREENBERG METHOD IS USED, INPUT THE REQUIRED PARAMETERS
      IF(IOPT1 .EQ. 7)THEN
          PRINT*,'INPUT THE INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie. mg/l) '
          PRINT*,'(ZERO IF STEADY STATE (EROSION=DEPOSTION) IS ASSUMED)'
          READ (*,*)CONC0
          PRINT*,'INPUT THE CRITICAL STRESS FOR EROSION (Pa) '
          READ (*,*)TOWCE
          PRINT*,'INPUT THE CRITICAL STRESS FOR DEPOSITION (Pa) '
          READ (*,*)TOWCD
          PRINT*,'INPUT THE SETTLING VELOCITY (m/s) '
          READ (*,*)Ws
          PRINT*,'INPUT THE PROBABILITY OF RESUSPENSION'
          PRINT*,' (NORMALLY ASSUMED = 1.0) '
          READ (*,*)PRS
          PRINT*,'INPUT THE PROPORTIONALITY COEFFICIENT FOR EROSION RATE'
          PRINT*,' (IF UNKNOWN USE A DEFAULT VALUE OF 2.0) '
          READ (*,*)RKERO
      ENDIF
C
C-----------------------------------------------------------------------------------------------------------------
C IF SMITH METHOD IS USED, CHECK FOR CODIRECTIONAL FLOW
C
 1005 IF((IOPT2.EQ.2 .OR. IOPT1.EQ.6) .AND. TAN(CDIR*PI/180.)
     &.NE.TAN(WDIR*PI/180.)) THEN
          WRITE (*,275) IRUN,WDIR
 275      FORMAT (' ***WARNING*** - SMITH METHOD ASSUMES WAVES AND CURRENTS ARE IN SAME',
     @    ' DIRECTION'/' FOR IRUN = ',I3,' WAVE DIRECTION IS ',F12.7,' DEGREES TRUE'/
     @    ' ENTER NEW VALUE OF CDIR (DEGREES TRUE): ')
          READ (*,*) CDIR
          GO TO 1005
      ENDIF
    RETURN
    END
```

```
C*************************************************************************************************************
      SUBROUTINE READBCH(IRUN,D,UZ,Z,CDIR,HT,PER,WDIR,GD,RKB,FRACT,RHOS,RHOW,IOPT1,IOPT2,IND,
     @CONC0,TOWCE,TOWCD,WS,PRS,RKERO)
C
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON /CHECK/ICHK
C
C     THIS SUBROUTINE CONTROLS USER INPUT OF THE DATA REQUIRED FOR RUNNING THE BATCH-MODE
C     SEDTRANS92.
C
      IND = 0
      PI = ACOS(-1.)
C
C-------------------------------------------------------------------------------------------------------------
C VARIABLES
C     IRUN = RUN OR CYCLE NUMBER
C     D = WATER DEPTH (M)
C     UZ = AMBIENT CURRENT AT HEIGHT Z ABOVE THE SEAFLOOR (M/S)
C     Z = HEIGHT OF UZ ABOVE SEAFLOOR
C     CDIR = DIRECTION OF AMBIENT CURRENT (DEGREES TRUE)
C     HT = WAVE HEIGHT (M)
C     PER = WAVE PERIOD (S)
C     WDIR = WAVE PROPOGATION DIRECTION (DEGREES TRUE)
C     GD = SEDIMENT GRAIN DIAMETER (M)
C     RHOS = DENSITY OF SEDIMENT MINERAL(S)   (KG/M**3)
C     FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GD
C     RKB = BOTTOM ROUGHNESS HEIGHT (M)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     QI = QUIT INDEX
C     CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     Ws = SETTLING VELOCITY (m/s)
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C
C-------------------------------------------------------------------------------------------------------------
C BATCH DATA ENTRY
200   CONTINUE
      READ (3,*,ERR=200,END=1001) IRUN,D,UZ,Z,CDIR,HT,PER,WDIR,GD,RKB,FRACT,RHOS,RHOW,IOPT1,IOPT2
     @CONC0,TOWCE,TOWCD,Ws,PRS,RKERO
C
C-------------------------------------------------------------------------------------------------------------
C CHECK THAT SMITH IS NOT USED IN A "CURRENT ONLY" SCENARIO.
      IF ((IOPT1.EQ.6 .OR. IOPT2.EQ.2) .AND. HT.EQ.0.) THEN
            WRITE(*,106)
            WRITE(7,106)
106         FORMAT (//,' THE SMITH METHOD CANNOT BE USED WITH ONLY CURRENTS AND NO WAVES')
            GOTO 200
      ENDIF
C
C-------------------------------------------------------------------------------------------------------------
C CHECK THE GRAIN SIZE LIMITS FOR EACH THEORY
999   CONTINUE
      GOTO (204,214,224,234,244,1005,254) IOPT1
204   IF (GD.LT.0.00015) THEN
            WRITE (7,205)
205         FORMAT (//' ***WARNING*** - ENGELUND-HANSEN FORMULA NOT RECOMMENDED',
     @      /T18,'FOR USE WITH SEDIMENTS SMALLER THAN 0.15 MM')
```

```
      ENDIF
      GOTO 1000
214   IF (GD.LT.0.0003 .OR. GD.GT..0286) THEN
         WRITE (7,215)
215      FORMAT (//' ***WARNING*** - EINSTEIN-BROWN FORMULA IS BASED ON LABORTORY',
     @   '/T18,'EXPERIMENTS USING SEDIMENTS WITH GRAIN SIZES'/T18,'OF 0.3 TO 28.6 MM')
      ENDIF
      GOTO 1000
224   IF (GD.LT.0.00018 .OR. GD.GT.0.00045) THEN
         WRITE (7,225)
225      FORMAT (//' ***WARNING*** - BAGNOLD FORMULA IS BASED ON LABORATORY TESTS',
     @   /T18,'WITH GRAIN SIZES BETWEEN 0.18 AND 0.45 MM')
      ENDIF
      GOTO 1000
234   IF (GD.LT.0.0002) THEN
         WRITE (7,235)
235      FORMAT (//' ***WARNING*** - YALIN FORMULA IS NOT RECOMMENDED FOR USE',
     @   /T18,'WITH SEDIMENTS SMALLER THAN 0.2MM, BASED ON THE RESULTS OF',
         /T18,'SENSITIVITY ANALYSES')
      ENDIF
      GOTO 1000
244   IF (GD.LT.0.00005 .OR. GD.GT..0291) THEN
         WRITE (7,245)
245      FORMAT (//' ***WARNING*** - ACKERS-WHITE FORMULA IS BASED ON LABORATORY',
     @   /T18,'EXPERIMENTS USING SEDIMENTS WITH GRAIN SIZES'/T18,'OF 0.05 TO 29.1 MM')
      ENDIF
      GOTO 1000
254   IF (GD.GT.0.00001) THEN
         WRITE (7,255)
255      FORMAT (//' ***WARNING*** - AMOS-GREENBERG METHOD IS NOT INTENDED
     @   FOR NON-COHESIVE SEDIMENTS')
      ENDIF
C
1000  CONTINUE
C-----------------------------------------------------------------------------------------------------------
C IF SMITH METHOD IS USED, CHECK FOR CODIRECTIONAL FLOW
1005  IF((IOPT2.EQ.2 .OR. IOPT1.EQ.6).AND. TAN(CDIR*PI/180.)
      &.NE.TAN(WDIR*PI/180.)) THEN
         WRITE (7,275) IRUN,WDIR
275      FORMAT (' ***WARNING*** - SMITH METHOD ASSUMES WAVES AND CURRENTS ARE IN ',
     @   'SAME DIRECTION'/' FOR IRUN = ',I3,', WAVE DIRECTION IS ',F12.7,' DEGREES TRUE')
      ENDIF
      RETURN
1001  CONTINUE
      IND = 1
C IND IS A TEMPORARY INDICATOR OF END OF FILE
      PRINT
      PRINT*,'ALL DONE, THANK YOU FOR USING SEDTRANS92.'
      STOP
      END
```

```
C*****************************************************************************************************
      SUBROUTINE INOUT(IRUN,D,UZ,CDIR,Z,HT,PER,WDIR,GD,RKB,RHOS,RHOW,FRACT,CONC0,TOWCE,TOWCD,
     @WS,PRS,RKERO,IOPT1)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C     THIS SUBROUTINE PRINTS THE VALUES OF THE INPUT PARAMETERS FROM SUBROUTINE READIN
C
      IF (IRUN.EQ.1) THEN
         WRITE (*,5)
         WRITE (7,5)
5        FORMAT(/,T11,'SED92:  A SEDIMENT TRANSPORT MODEL ',/,
         @T11,'FOR CONTINENTAL SHELF CONDITIONS',//,
         @T11,'ATLANTIC GEOSCIENCE CENTER       SEPTEMBER, 1992',//,
         @T11,'THE USER SHOULD BE FAMILIAR WITH THE EQUATIONS USED',/,
         @T11,'AND THEIR LIMITATIONS',//,
         @T11,'ALL DIMENSIONAL VARIABLES ARE IN SI UNITS',/)
      ENDIF
C
C-----------------------------------------------------------------------------------------------------
C VARIABLES
C     IRUN = RUN OR CYCLE NUMBER
C     D = WATER DEPTH (M)
C     UZ = AMBIENT CURRENT AT HEIGHT Z ABOVE THE SEAFLOOR (M/S)
C     Z = HEIGHT OF UZ ABOVE SEAFLOOR
C     CDIR = DIRECTION OF AMBIENT CURRENT (DEGREES TRUE)
C     HT = WAVE HEIGHT (M)
C     PER = WAVE PERIOD (S)
C     WDIR = WAVE PROPOGATION DIRECTION (DEGREES TRUE)
C     GD = SEDIMENT GRAIN DIAMETER (M)
C     RHOS = DENSITY OF SEDIMENT MINERAL(S)   (KG/M**3)
C     FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GD
C     RKB = BOTTOM ROUGHNESS HEIGHT (M)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     VISC = DYNAMIC FLUID VISCOSITY (KG/M*SEC)
C     CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     CONC = CALCULATED SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     WS = SETTLING VELOCITY (m/s)
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C
C-----------------------------------------------------------------------------------------------------
C
      WRITE (*,15) IRUN
      WRITE (7,15) IRUN
15    FORMAT(//,T21,'RUN NUMBER ',I9,/,T4,'INPUT DATA:',/)
C
      WRITE (*,25) D,UZ,CDIR,Z
      WRITE (7,25) D,UZ,CDIR,Z
25    FORMAT(T11,'WATER DEPTH =',F7.2,' M',/,T11,'CURRENT SPEED =',F7.2,
      @' M/SEC',/,T11,'CURRENT DIRECTION =',F7.2,' DEGREES TRUE',/,
      @T11,'HEIGHT ABOVE BED =',F7.2,'  M')
C
      WRITE (*,35) HT,PER,WDIR
      WRITE (7,35) HT,PER,WDIR
35    FORMAT(T11,'WAVE HEIGHT =',F7.2,' M',/,T11,'WAVE PERIOD =',F6.2,
      @' SEC',/,T11,'WAVE DIRECTION =',F7.2,' DEGREES TRUE',/)
C
```

```
      WRITE (*,45) GD,RHOS,FRACT
      WRITE (7,45) GD,RHOS,FRACT
45    FORMAT(T11,'SEDIMENT GRAIN SIZE =',F6.5,' M ',/,T11,
     @'SEDIMENT DENSITY =',F7.1,' KG/CUBIC M',/T11,
     @'FRACTION OF SEABED MATERIAL = ',F5.2)
C
      WRITE (*,55) RKB,RHOW
      WRITE (7,55) RKB,RHOW
55    FORMAT(T11,'BOTTOM ROUGHNESS HEIGHT =',F7.4,' M',/,T11,
     @'FLUID DENSITY =',F7.1,' KG/CUBIC M')
C ------------------------------------------------------------------------
C IF AMOS-GREENBERG METHOD IS USED, INPUT THE REQUIRED PARAMETERS
      IF (IOPT1 .EQ. 7) THEN
         WRITE (*,65) CONC0,TOWCE,TOWCD,Ws,PRS,RKERO
         WRITE (7,65) CONC0,TOWCE,TOWCD,Ws,PRS,RKERO
65       FORMAT(T11,'THE INITIAL ESTIMATE OF SEDIMENT CONCENTR. ='
     @,F7.2,' (ppm) (ie. mg/l)',/,T11,
     @'THE CRITICAL STRESS FOR EROSION = ',F7.3,' (Pa)',/,T11,
     @'THE CRITICAL STRESS FOR DEPOSITION  = ',F7.3,' (Pa)',/,T11,
     @'THE SETTLING VELOCITY  = ',F7.5,' (m/s)',/,T11,
     @'THE PROBABILITY OF RESUSPENSION = ',F7.1,/,T11,
     @'THE PROPORTIONALITY COEFFICIENT FOR EROSION RATE = ',F7.1)
      ENDIF
      RETURN
      END
```

```
C*****************************************************************************************************
      SUBROUTINE OSCIL(HT,PER,D,UB,AB,WL,IBRK)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES WAVE-INDUCED BOTTOM PARTICLE VELOCITY AND DISPLACEMENT
C AMPLITUDE USING LINEAR WAVE THEORY.  A CHECK IS ALSO MADE FOR WAVE BREAKING.
C
C-----------------------------------------------------------------------------------------------------
C INPUT VARIABLES:
C     HT = WAVE HEIGHT (M)
C     PER = WAVE PERIOD (SEC)
C     D = WATER DEPTH (M)
C
C OUTPUT VARIABLES:
C     UB = MAX. WAVE-INDUCED BOTTOM HORIZ. PARTICLE VELOCITY (M/SEC)
C     AB = MAX. WAVE-INDUCED BOTTOM HORIZ. PARTICLE DISPLACEMENT(M) (1/2 OF THE ORBIT SIZE)
C     WL = WAVELENGTH FROM LWT DISPERSION EQUATION (M)
C
C INTERMEDIATE VARIABLES:
C     G = ACCELERATION DUE TO GRAVITY (M/SEC**2)
C     C = CONVERSION FACTOR TO CGS UNITS
C     W = WAVE ANGULAR FREQUENCY (RAD/SEC)
C     K = WAVE NUMBER (RAD/M)
C     KD = K*D
C     HB = BREAKING WAVE HT. FOR GIVEN WAVE PERIOD, WATER DEPTH (M)
C
      G=9.81
      PI=2.*ASIN(1.)
C
C-----------------------------------------------------------------------------------------------------
C CHECK FOR CURRENT ONLY CASE (INCLUDING 'DEEP WATER' WAVE CONDITIONS)
C
C FOR DEEP WATER WAVE CONDITIONS THE NORMAL CRITERION IS D/WL GREATER THAN 0.5. TO ENSURE
C NO APPRECIABLE WAVE INDUCED BOTTOM STRESS, THIS CODE USES THE CRITERION OF D/WL GREATER
C THAN 2.0
C
C     WL0 = DEEP WATER WAVE LENGTH (M)
      WL0 = G*PER*PER/(2*PI)
C
      IF (HT.EQ.0.0 .OR. (D/WL0).GT.2.) THEN
        UB=0.0
        AB=0.0
        WL=0.0
        RETURN
      ENDIF
C
C-----------------------------------------------------------------------------------------------------
C CALCULATE WAVELENGTH BY NEWTON-RAPHSON SOLUTION OF LWT DISPERSION EQUATION.
C
      W=2.*PI/PER
      RKD0=W**2*D/G
      RKD=RKD0
20    CONTINUE
      DKD=(1./TANH(RKD)-RKD/RKD0)/(1./RKD0+1./SINH(RKD)**2)
      RKD=RKD+DKD
      IF (ABS(DKD) .GE. 1.0E-4) GO TO 20
      WL=WL0*TANH(RKD)
C
C-----------------------------------------------------------------------------------------------------
```

```
C NEXT CHECK FOR BREAKING WAVES USING THE MICHE (1944) CRITERION
C
      IBRK=0
      HB=0.142*WL*TANH(RKD)
      IF (HT .GE. HB) THEN
         WRITE (*,25)
         WRITE (7,25)
         IBRK=1
      ENDIF
25    FORMAT(///,' ***WARNING***',/,' THIS CASE CORRESPONDS TO BREAKING',
     @' WAVE CONDITIONS WHERE',/,' LINEAR WAVE THEORY IS NOT VALID')
C
C-------------------------------------------------------------------------------------------------------------------------------------
C CALCULATE WAVE-INDUCED BOTTOM PARTICLE VELOCITY AND ORBIT SIZE
C
C CONVENTIONALLY:
C     UB=HT*G*PER/(2*WL*COSH(2*PI*D/WL))
C THE MORE EFFICIENT ALGORITH IS:
      UB=PI*HT/(PER*SINH(RKD))
C CONVENTIONALLY:
C     AB=HT/(2*SINH(2*PI*D/WL))
C THE MORE EFFICIENT ALGORITH IS:
      AB=UB/W
C
      RETURN
      END
```

```
C*****************************************************************************************************
      SUBROUTINE FRICFAC(UZ,Z,CDIR,UB,AB,PER,WDIR,GD,RKB,RHOW,IOPT2,RKBC,FCW,UA,PHIB,U100,
     &PHI100,USTCSGM,USTWSGM,USTCWSGM,USTC,USTW,USTCW)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE USES THE UPDATED GM METHOD TO CALCULATE THE FRICTION FACTOR FOR VARIOUS
C WAVE AND CURRENT CONDITIONS.
C
C-----------------------------------------------------------------------------------------------------
C INPUT VARIABLES:
C
C     UZ = CURRENT SPEED AT HEIGHT Z (M) ABOVE SEABED (M/SEC)
C     Z = HEIGHT ABOVE SEABED AT WHICH CURRENT IS MEASURED (M)
C     CDIR = CURRENT DIRECTION AT 1 M. ABOVE SEABED (AZIMUTH)
C     UB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE VELOCITY (M/SEC)
C     AB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE DISPLACEMENT (M)
C     PER = WAVE PERIOD (SEC)
C     WDIR = WAVE DIRECTION (AZIMUTH)
C     GD = SEDIMENT GRAIN SIZE (M)
C     RKB = BOTTOM ROUGHNESS (M)
C     RHOW = DENSITY OF FLUID (WATER)  (KG/M**3)
C     IOPT2 = FRICTION FACTOR PREDICTOR OPTION NUMBER (1 = GRANT&MADSEN)
C
C OUTPUT VARIABLES:
C
C     RKBC = APPARENT BOTTOM ROUGHNESS (M)
C     FCW = BOTTOM FRICTION FACTOR
C     UA = CURRENT SPEED AT THE TOP OF THE WAVE-CURRENT BONDARY LAYER TO BE USED IN BOTTOM
C           STRESS CALC. (M/SEC)
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY LAYER
C           (RADIANS)
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     PHI100 = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS AT 1 M ABOVE SEABED (RADIANS)
C           NOTE:  PHI100 = PHIZ AS LONG AS PHIZ IS MEASURED OUTSIDE THE WAVE BOUNDARY LAYER.
C     USTCSGM = CURRENT SKIN-FRICTION SHEAR VELOCITY OF GM
C     USTWSGM = WAVE SKIN-FRICTION SHEAR VELOCITY OF GM
C     USTCWSGM = COMBINED SKIN-FRICTION SHEAR VELOCITY OF GM
C     USTC = TOTAL CURRENT SHEAR VELOCITY OF GM
C     USTW = TOTAL WAVE SHEAR VELOCITY OF GM
C     USTCW = TOTAL COMBINED SHEAR VELOCITY OF GM
C
C INTERMEDIATE VARIABLES:
C
C     FBAD = TOTAL FRICTION FACTOR INCLUDING FORM DRAG
C     UBAD = CURRENT SPEED NEGLECTING FORM DRAG (M/SEC)
C     PHIBAD = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS, WITHIN WAVE B.L. AND NEGLECTING
C        FORM DRAG (RADIANS)
C     RATIO = UA/UB;  DETERMINES VALIDITY OF EQUATION OF MOTION USED BY GRANT AND MADSEN (1979)
C
C-----------------------------------------------------------------------------------------------------
C INITIALIZE PARAMETERS
      USTC=0.0
      USTW=0.0
      USTCW=0.0
C
C-----------------------------------------------------------------------------------------------------
C PURE CURRENT CASE
C
      IF (UB .EQ. 0.0) THEN
```

```
         CALL FRIC1(UZ,Z,GD,RKB,FCW,UA,U100)
         PHIB=0.0
         PHI100=0.0
         RKBC=RKB
         RETURN
      ENDIF
C-----------------------------------------------------------------------------------------------------------------------------------------------
C WAVES AND CURRENT CASE (CHECK FOR VALIDITY OF METHOD)
C
      IF (UZ .NE. 0.0) THEN
C CHOOSE GM OR SMITH METHOD, 1 AS GM METHOD AND 2 AS SMITH METHOD
         GO TO (1,2) IOPT2
C-----------------------------------------------
C GRANT AND MADSEN (1986) THEORY
C-----------------------------------------------
1     PHI100=DMIN1(ABS(CDIR-WDIR),ABS(180.-ABS(CDIR-WDIR)),
      @360.-ABS(CDIR-WDIR))*ASIN(1.)/90.
      PHIB=PHI100
C COMPUTE FCW BASED ON GRAIN ROUGHNESS HEIGHT GRKB=2.5*GD
      IF (RKB .EQ. 0.0) THEN
         GRKB = 2.5*GD
         CALL FRIC2(UZ,Z,PHI100,UB,PER,GRKB,RKBC,FCW,UA,PHIB,U100,USTCSGM,USTWSGM,USTCWSGM)
      ELSE
C COMPUTE FCW AS WELL AS FCWBAD BASED ON TOTAL ROUGHNESS TRKB. HERE
C 27.7*RKB*0.1 IS THE RIPPLE ROUGHNESS & 0.1 IS THE RIPPLE STEEPNESS
         TRKB=2.5*GD+27.7*RKB*0.1
         CALL FRIC2(UZ,Z,PHI100,UB,PER,TRKB,RKBC,FBAD,UA,PHIB,U100,USTC,USTW,USTCW)
         GRKB=2.5*GD
         CALL FRIC2(UZ,Z,PHI100,UB,PER,GRKB,RKBCBAD,FCW,UBAD,PHIBAD,UBAD100,USTCSGM,
         @USTWSGM,USTCWSGM)
      ENDIF
      GO TO 3
C-----------------------------------------------
C SMITH (1977) THEORY
C-----------------------------------------------
2     CONTINUE
      PHI100=DMIN1(ABS(CDIR-WDIR),ABS(180.-ABS(CDIR-WDIR)),
      @360.-ABS(CDIR-WDIR))*ASIN(1.)/90.
      PHIB=PHI100
C
C SMITH ONLY CONSIDERS CO-DIRECTIONAL WAVES AND CURRENTS, THEREFORE A WARNING IS PRINTED
C FOR NON-ZERO PHI100 (IE PHI100> 10 DEGREES).
C
      IF (ABS(PHI100).GE. 0.2) THEN
         WRITE(*,11)
         WRITE(7,11)
11       FORMAT (///,' ***WARNING*** ',/,' PHI100 > 10 DEGREES',5X,
         @'SMITH (1977) METHOD MAY NOT BE APPROPRIATE')
      ENDIF
C
C SHEAR VELOCITIES PREDICTED BY SMITH METHOD ARE ASSIGNED TO USTCSGM,USTWSGM AND
C USTCWSGM RESPECTIVELY FOR RUNING SUBROUTINE TIMING.
      CALL FRIC4 (UZ,Z,UB,PER,GD,RHOW,FCW,UA,RKB,U100,USTCSGM,USTWSGM,USTCWSGM)
C
C TOTAL SHEAR VELOCITIES ARE NOT PREDICTED IN SMITH METHOFD. SO ZERO VALUES ARE ASSIGNED
C TO THEM:
      USTC = 0
      USTW = 0
      USTCW = 0
```

```
      RKBC = RKB
C
C PREVENT FRICTION FACTOR FROM FALLING BELOW THE 'CURRENT ONLY' VALUE
C FROM STERNBERG (1972)
      IF (FCW.LT.0.006D0) FCW=0.006D0
C
C---------------------------------------------
C CHECK RATIO OF UA/UB
C---------------------------------------------
3     RATIO=UA/UB
      IF (IOPT2.EQ.1 .AND. RATIO.GT.1.) WRITE (*,15)
      IF (IOPT2.EQ.1 .AND. RATIO.GT.1.) WRITE (7,15)
15    FORMAT(//,' ***WARNING*** ',/,' UA/UB > 1.0',5X,'GRANT AND',
     @' MADSEN (1979) METHOD MAY NOT BE APPROPRIATE')
      IF (IOPT2.EQ.2 .AND. RATIO.LE.1.) WRITE (*,25)
      IF (IOPT2.EQ.2 .AND. RATIO.LE.1.) WRITE (7,25)
25    FORMAT (//,' ***WARNING*** ',/,' UA/UB < 1.0',5X,
     @'SMITH (1977) METHOD MAY NOT BE APPROPRIATE')
C
      RETURN
      ENDIF
C
C------------------------------------------------------------------------------------------------------------------------------------
C PURE WAVES CASE
      CALL FRIC3(AB,GD,FCW)
      UA=0.0
      U100=0.0
      PHIB=0.0
      PHI100=0.0
      RKBC=RKB
      RETURN
      END
C
C*************************************************************************************
      SUBROUTINE FRIC1(UZ,Z,GD,RKB,FCW,UA,U100)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES THE BOTTOM FRICTION FACTOR FOR THE PURE CURRENT CASE.
C A CONSTANT FRICTION FACTOR IS ASSUMED, BASED ON THE WORK OF STERNBERG (1971).
C
C INPUT VARIABLES:
C
C     UZ = CURRENT SPEED AT HEIGHT Z (M) ABOVE SEABED (M/SEC)
C     GD = SEDIMENT GRAIN SIZE (M)
C     RKB = BOTTOM ROUGHNESS (M)
C
C OUTPUT VARIABLES:
C
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     FCW = BOTTOM FRICTION FACTOR FOR THE PURE CURRENT CASE
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC. (M/SEC)
C
      FCW=6.0E-3
      IF (RKB .EQ. 0.0) RKB=GD
      U100=UZ*LOG(30.0/RKB)/LOG(30.*Z/RKB)
      UA=U100
      RETURN
      END
C
```

```
C***************************************************************************************
      SUBROUTINE FRIC2(UZ,Z,PHI100,UB,PER,RKB,RKBC,FCW,UA,PHIB,U100,USTC,USTW,USTCW)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES THE FRICTION FACTOR FOR COMBINED WAVE AND CURRENT CONDITIONS
C USING THE METHOD OF GRANT AND MADSEN (1986). THIS METHOD IS NOT VALID FOR UA/UB > 1.0
C (APPROXIMATELY) DUE TO THE REL-ATIVE IMPORTANCE OF THE CONVECTIVE ACCELERATION TERMS IN
C THE EQUATION OF MOTION.
C
C INPUT VARIABLES:
C
C     UZ = CURRENT SPEED AT HEIGHT Z (M) ABOVE SEABED (M/SEC)
C     PHI100 = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS AT 1 M ABOVE SEABED (RADIANS)
C        (NB:  PHI100 = PHIZ)
C     UB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE VELOCITY (M/SEC)
C     PER = WAVE PERIOD (SEC)
C     RKB = BOTTOM ROUGHNESS HEIGHT (RIPPLE HEIGHT HERE, M)
C
C OUTPUT VARIABLES:
C
C     FCW = BOTTOM FRICTION FACTOR FOR THE COMBINED CASE
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC. (M/SEC)
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY
C        LAYER (RADIANS)
C     RKBC = APPARENT BOTTOM ROUGHNESS (M)
C     USTC = CURRENT SHEAR VELOCITY OF GM (M/SEC)
C     USTW = WAVE SHEAR VELOCITY OF GM (M/SEC)
C     USTCW = COMBINED SHEAR VELOCITY OF GM (M/SEC)
C
C INTERMEDIATE VARIABLES:
C     ZO = DYNAMIC BOTTOM ROUGHNESS LENGTH
C     CR = FACTOR DESCRIBING RELATIVE RATIO OF USTC/USTW
C     DELTCW = THICKNESS OF THE WAVE-CURRENT BOUNDARY LAYER
C     DELTA = ITERATION CRITERION FOR UST CALCULATION
C
C INITIALIZE ITERATION PARAMETERS
C
      PI=2.*ASIN(1.)
      W=2.*PI/PER
      PHIB=PHI100
      DELTA=1.0
      CR=1.0
      FCW=0.01
C
C CALCULATE UST'S BY ITERATION (GM,1986)
10    IF (DELTA .LT. 0.00001) GO TO 200
      ZO=RKB/30.
      TEMP=CR*UB/(ZO*W)
C INITIALIZE THE ITERATION CRITERION EPSILON
      EPSILON=1.0
50    IF (EPSILON .LT. 0.00001) GO TO 100
C
C CALCULATE FCW ACCORDING TO GM (1986). NEWTON-RAPHSON SOLUTION IS USED IN ITERATION.
      X=4*SQRT(FCW)
      A=0.24*X-1.65+DLOG10(TEMP*X)-1/X
      B=0.24+1/X**2+1/(X*DLOG(10.))
      DX=A/B
      XNEW=X-DX
```

```
      FCWNEW=(XNEW/4)**2
      EPSILON=DABS(FCWNEW/FCW-1)
      FCW=FCWNEW
      GO TO 50
100   CONTINUE
C
C CALCULATE USTW, USTCW AND DELTCW (BOUNDARY LAYER THICKNESS)
      USTW=SQRT(0.5*CR*FCW*UB**2)
      USTCW=SQRT(CR)*USTW
      DELTCW=2.*0.4*USTCW/W
C
C CALCULATE CURRENT SHEAR VELOCITY USTC
      AA=DLOG(DELTCW/ZO)/USTCW
      BB=DLOG(Z/DELTCW)
      CC=-0.4*UZ
      DD=SQRT(BB**2-4*AA*CC)
      USTC=0.5*(-BB+DD)/AA
      RKBC=DELTCW*EXP(-AA*USTC)
      CRNEW=SQRT(1.0+2*(USTC/USTW)**2*COS(PHIB)+(USTC/USTW)**4)
      DELTA=DABS(CRNEW/CR-1)
      CR=CRNEW
      GO TO 10
200   CONTINUE
C
C CALCULATE VELOCITY AT THE TOP OF THE WAVE-CURRENT BOUNDARY LAYER
      UA=(USTC/0.4)*DLOG(DELTCW/RKBC)
      IF (DELTCW .GT. Z) THEN
         WRITE (*,55)
         WRITE (7,55)
55       FORMAT(///,' ***WARNING***',/,' DELTCW > Z',5X,'GRANT AND',
         @'MADSEN (1979) METHOD MAY NOT BE APPROPRIATE')
      ENDIF
C
C CALCULATE VELOCITY AT 1M ABOVE THE BOTTOM
      IF (DELTCW .GT. 1.) THEN
      U100=(USTC/USTCW)*(USTC/0.4)*DLOG(1./ZO)
      ELSE
      U100=(USTC/0.4)*DLOG(1./RKBC)
      ENDIF
      RETURN
      END
C
C**************************************************************************************
      SUBROUTINE FRIC3(AB,GD,FCW)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES THE BOTTOM FRICTION FACTOR FOR THE PURE WAVE CONDITION USING
C THE METHOD OF JONSSON (1966) AS MODIFIED BY NIELSEN (1979).  THE BOTTOM ROUGHNESS IS TAKEN AS
C THE GRAIN DIAMETER AS IN GRANT AND MADSEN (1976).
C
C INPUT VARIABLES:
C
C     AB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE DISPLACEMENT(CM)
C     GD = SEDIMENT GRAIN SIZE(CM)
C
C OUTPUT VARIABLES:
C
C     FCW = BOTTOM FRICTION FACTOR FOR THE PURE WAVE CASE
C
```

```
      FCW=DMIN1(EXP(5.213*(GD/AB)**0.194-5.977),0.28D0)
      RETURN
      END
C
C*****************************************************************************************
      SUBROUTINE FRIC4 (UZ,Z,U0,PER,GD,RHOW,FCW,UA,RKB,U100,USTCSGM,USTWSGM,USTCWSGM)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      COMMON /CHECK/ ICHK
      COMMON /VF9Z/ USTAR1,VKK,USTARM,Z0,ZA
      COMMON /VEVK0/ EVK0
      DIMENSION AB1(28),OR1(28),AB2(14),OR2(14),U(1),S(1),BPAR(4),C1(27,3),C2(13,3)
      DATA BPAR /0.,0.,0.,0./
      DATA AB1 /1.D-10,2.D-10,6.D-10,1.D-9,2.D-9,6.D-9,1.D-8,2.D-8,
     @6.D-8,1.D-7,2.D-7,6.D-7,1.D-6,2.D-6,6.D-6,1.D-5,
     @2.D-5,6.D-5,1.D-4,2.D-4,6.D-4,1.D-3,2.D-3,6.D-3,
     @1.D-2,2.D-2,6.D-2,1.D-1/
      DATA OR1 /0.0097,0.0100,0.0103,0.0106,0.0109,0.0116,0.0123,
     @0.0130,0.0138,0.0147,0.0156,0.0170,0.0180,0.0191,
     @0.0209,0.0229,0.0250,0.0289,0.0316,0.0356,0.0438,
     @0.0478,0.0554,0.0723,0.0813,0.1000,0.1304,0.1557/
      DATA AB2 /3.,4.,5.,6.,8.,10.,13.,15.,20.,30.,40.,60.,80.,100./
      DATA OR2 /0.037037037,0.0290,0.0253,0.0230,0.0217,0.0214,
     @0.0218,0.0223,0.0236,0.0265,0.0290,0.0310,0.0323,0.033333333/
C
C THIS SUBROUTINE CALCULATES THE FRICTION FACTOR FOR COMBINED WAVE AND CURRENT CONDITIONS
C USING THE METHOD OF SMITH (1977).  THIS METHOD IS APPLIED TO COMBINED WAVE/CURRENT FLOWS
C WHEN CURRENTS DOMINATE.
C
C FRIC4 WORKS IN CGS UNITS.
C DUE TO ITS COMPLEXITY, THE INPUT IS CONVERTED FROM SI TO CGS AND THE OUTPUT IS CONVERTED
C BACK FROM CGS TO SI RATHER THAN CONVERT ALL OF FRIC4 TO SI.
C
      UZ = UZ*100.
      Z = Z*100.
      U0 = U0*100.
      GD = GD*100.
      RHOW = RHOW/1000.
C
C----------------------------------------------
C COMPUTE USTARM FOR WAVES
C----------------------------------------------
      PI = ACOS(-1.)
      MCOUNT = 50
      USU0SV = 0.
      VKK = 0.4
      UNDFLW = 1.D-30
      ICOUNT = 0
      VISC = 13.D-3
      VISK = VISC/RHOW
      TOLR = 1.D-6
C INITIAL ESTIMATE FOR Z0(CM)
      Z0 = 1.D-3
C CUBIC SPLINE INTERPOLATION OF FIG. 5, SMITH,1977 TO FIND (K0/U0)
      W = 2.*PI/PER
      IF (ICHK.EQ.1) WRITE (7,1000) U0
1000  FORMAT (' INTERMEDIATE RESULTS FOR MANUAL CHECKING: '//' U0 = ',F9.4/)
10    U(1) = W*Z0/U0
      ICOUNT = ICOUNT + 1
```

```
      IF (ICHK.EQ.1) WRITE (7,1001) ICOUNT
1001 FORMAT (' ITERATION = ',I3)
      CALL ICSICU (AB1,OR1,28,BPAR,C1,27,IER)
      CALL ICSEVU (AB1,OR1,28,C1,27,U,S,1,IER)
      RK0U0 = S(1)
C COMPUTE MAXIMUM VALUE OF USTAR AND REYNOLDS NUMBER
      USU0 = RK0U0/VKK
C CHECK FOR CONVERGENCE
      DIFF = ABS((USU0 - USU0SV)/USU0)
      IF (ICHK.EQ.1) WRITE (7,1002) U(1),S(1),USU0,DIFF
1002 FORMAT (' W*Z0/U0 = ',E11.4,T25,'RK0U0 = ',F7.4,T45,'USU0 = ',
     @F7.4,T63,'DIFF = ',F7.4)
      IF (ICOUNT.GT.MCOUNT .OR. DIFF.LT.TOLR) GO TO 20
      USTARM = U0*USU0
      RSTAR = USTARM*GD/VISK
C COMPUTE NEW ESTIMATE OF Z0 FOR HYDRAULICALLY SMOOTH,ROUGH OR TRANSITIONAL FLOWS AND
C ITERATE UNTIL USU0 CONVERGES
      IF (RSTAR.LT.3.) THEN
C SMOOTH FLOWS
         ZFKS = 1./(9.*RSTAR)
      ELSE IF (RSTAR.GT.100) THEN
C ROUGH FLOWS
         ZFKS = 1./30.
      ELSE
C TRANSITIONAL FLOWS: CUBIC SPLINE INTERPOLATION OF FIG. 1, SMITH,1977 TO FIND (ZF/KS)
         U(1) = RSTAR
         CALL ICSICU (AB2,OR2,14,BPAR,C2,13,IER)
         CALL ICSEVU (AB2,OR2,14,C2,13,U,S,1,IER)
         ZFKS = S(1)
      ENDIF
      Z0 = ZFKS*GD
      USU0SV = USU0
      IF (ICHK.EQ.1) WRITE (7,1003) USTARM,RSTAR,ZFKS,Z0,USU0SV
1003 FORMAT (' USTARM = ',F7.4,T25,'RSTAR = ',F9.4,T45,'ZFKS = ',
     @F7.4,T63,'Z0 = ',E11.4/' USU0SV = ',F7.4)
      GO TO 10
20    CONTINUE
      USTARM = USU0*U0
      IF (ICHK.EQ.1) WRITE (7,1004) Z0,ZFKS,USU0,USTARM
1004 FORMAT (/' ITERATION CONVERGED: '/' Z0 = ',E11.4,T25,'ZFKS = ',
     @F7.4,T45,'USU0 = ',F7.4,T63,'USTARM = ',F7.4/)
C
C-----------------------------------------------
C COMPUTE USTAR1 FOR CURRENT
C-----------------------------------------------
C ASSUME CONSTANT FRICTION FACTOR BASED ON STERNBERG (1971)
      FC = 6.D-3
      RKB = Z0/ZFKS
      U100 = UZ*LOG(3000./RKB)/LOG(30.*Z/RKB)
      UA = U100
      USTAR1 = SQRT(FC/2.)*UA
      IF (ICHK.EQ.1) WRITE (7,1005) RKB,U100,UA,USTAR1
1005 FORMAT (' RKB = ',F7.4,T25,'U100 = ',F9.4,T45,'UA = ',F9.4,T63,'USTAR1 = ',F7.4)
C
C--------------------------------------------------------------------------------------------
C COMPUTE MAXIMUM SHEAR STRESS FOR COMBINED FLOW
C--------------------------------------------------------------------------------------------
      EVK0 = VKK*(USTAR1 + USTARM)
      XI0 = 2.*SQRT(W*Z0/EVK0)
```

```
      IF (ICHK.EQ.1) WRITE (7,1006) EVK0,XI0
 1006 FORMAT (' EVK0 = ',F7.4,T25,'XI0 = ',F7.4)
      CALL KELVIN (1,0,0.,XI0,XI0KER,XI0KEI)
      VR00 = XI0KER
      VI00 = XI0KEI
      VRSQ = VR00**2.
      IF (ABS(VI00).LT.UNDFLW) THEN
         VI00 = 0.
         VISQ = 0.
         ELSE
         VISQ = VI00**2.
      ENDIF
      IF (ICHK.EQ.1) WRITE (7,1007) VR00,VI00
 1007 FORMAT (' VR00 = ',F13.7,T25,'VI00 = ',F13.7)
      CALL KELVIN (1,1,0.,XI0,XI0KER1,XI0KEI1)
      VR10 = XI0KER1
      VI10 = XI0KEI1
      IF (ICHK.EQ.1) WRITE (7,1008) VR10,VI10
 1008 FORMAT (' VR10 = ',F13.7,T25,'VI10 = ',F13.7)
      DF1 = ((VR10+VI10)*VR00 + (VI10-VR10)*VI00)/(SQRT(2.)*(VRSQ+VISQ))
      DF2 = (-(VR10+VI10)*VI00 + (VI10-VR10)*VR00)/(SQRT(2.)*(VRSQ+VISQ))
      TAUM = RHOW*((USTAR1*EVK0/VKK)/(1.+(USTARM/USTAR1))
      @+(U0*XI0*EVK0/2.)*SQRT(DF1**2.+DF2**2.))
      IF (ICHK.EQ.1) WRITE (7,1009) DF1,DF2,TAUM
 1009 FORMAT (' DF1 = ',F7.4,T25,'DF2 = ',F7.4,T45,'TAUM = ',F7.4)
C
C-----------------------------------------------------------------------------------------------
C COMPUTE MAXIMUM VELOCITY FOR COMBINED FLOW
C------------------------------------------- ------------------------------------------------
C MAXIMUM VELOCITY COMPUTED AT TOP OF WAVE BOUNDARY LAYER DELW
      DELW = 0.03*U0/W
      ZW = DELW
      XI = 2.*SQRT(W*ZW/EVK0)
      IF (ICHK.EQ.1) WRITE (7,1010) DELW,ZW,XI
 1010 FORMAT (' DELW = ',F7.4,T25,'ZW = ',F7.4,T45,'XI = ',F7.4)
      CALL KELVIN (1,0,0.,XI,XIKER,XIKEI)
      VR0Z = XIKER
      VI0Z = XIKEI
      F1 = (VR0Z*VR00+VI0Z*VI00)/(VRSQ+VISQ)
      F2 = -(VR0Z*VI00-VI0Z*VR00)/(VRSQ+VISQ)
      IF (ICHK.EQ.1) WRITE (7,1011) VR0Z,VI0Z,F1,F2
 1011 FORMAT (' VR0Z = ',F13.7,T25,'VI0Z = ',F13.7,T45,'F1 = ',F7.4,
      @T63,'F2 = ',F7.4)
C
C COMPUTE TIME TM WHEN MAXIMUM VELOCITY OCCURS
      TM = RTAN3(F2,(1.-F1))/W
      UM = (USTAR1/VKK)*LOG(ZW/Z0)/(1.+(USTARM/USTAR1))
      @+ U0*(COS(W*TM) - F1*COS(W*TM) + F2*SIN(W*TM))
      IF (ICHK.EQ.1) WRITE (7,1012) TM,UM
 1012 FORMAT (' TM = ',F8.4,T25,'UM = ',F9.4)
C
C COMPUTE WAVE-CURRENT FRICTION FACTOR
      IF (1./UM.LT.UNDFLW) THEN
         FCW = 0.
      ELSE
         FCW = 2.*TAUM/(RHOW*UM**2.)
      ENDIF
      IF (ICHK.EQ.1) WRITE (7,1013) FCW
 1013 FORMAT (' FCW = ',F6.4)
```

```
C
C-----------------------------------------------
C CONVERT OUTPUT TO SI UNITS
C-----------------------------------------------
      UZ = UZ/100.
      Z = Z/100.
      U0 = U0/100.
      GD = GD/100.
      RHOW = RHOW*1000.
      UA=UA/100.
      RKB=RKB/100.
      U100=U100/100.
      USTCSGM=USTAR1/100
      USTWSGM=USTARM/100
      USTCWSGM=SQRT(TAUM/(10*RHOW))
C
      RETURN
      END
C
C*******************************************************************************************
      FUNCTION RTAN3 (Y,X)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C A FUNCTION CALLED IN FRIC4
      PI = ACOS(-1.)
      IF (X .EQ. 0. .AND. Y .GT. 0.) THEN
         RTAN3 = PI/2.
      ELSE IF (X .LT. 0. .AND. Y .EQ. 0.) THEN
         RTAN3 = PI
      ELSE IF (X .EQ. 0. .AND. Y .LT. 0.) THEN
         RTAN3 = 3.*PI/2.
      ELSE IF (X .LT. 0. .AND. Y .GE. 0.) THEN
         RTAN3 = PI - ATAN2(Y,-X)
      ELSE IF (X .LT. 0. .AND. Y .LT. 0.) THEN
         RTAN3 = PI + ATAN2(-Y,-X)
      ELSE IF (X .GT. 0. .AND. Y .LT. 0.) THEN
         RTAN3 = 2.*PI - ATAN2(-Y,X)
      ELSE IF (X .GT. 0. .AND. Y .GE. 0.) THEN
         RTAN3 = ATAN2(Y,X)
      ENDIF
      RETURN
      END
```

```
C*****************************************************************************************************
      SUBROUTINE THRESH(D,UB,GD,RHOS,RHOW,IOPT1,FCW,USTCRB,USTCRS,VCB,VCS,DGR,AGR,RGR)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES THE THRESHOLD SHEAR VELOCITY FOR BOTH BEDLOAD AND SUSPENDED
C LOAD SEDIMENT TRANSPORT. THE CRITICAL STRESS FOR BEDLOAD TRANSPORT IS BASED ON THE YALIN
C METHOD MODIFIED FROM MILLER ET AL. (1977). THE CRITICAL STRESS FOR SUSPENDED LOAD IS BASED
C ON THE WORK OF BAGNOLD (1966), WHERE THE PARTICLE FALL VELOCITY IS AS GIVEN BY GIBBS
C ET AL. (1971).
C
C INPUT VARIABLES:
C
C     D = WATER DEPTH (M)
C     UB = MAXIMUM WAVE INDUCED ORBITAL VELOCITY AT THE BOTTOM (M/S)
C     GD = SEDIMENT GRAIN SIZE (M)
C     RHOS = SEDIMENT DENSITY (KG/M**3)
C     RHOW = FLUID DENSITY (KG/M**3)
C     IOPT1 = OPTION SELECTED FOR SEDIMENT TRANSPORT FORMULA
C     FCW = BOTTOM FRICTION FACTOR
C
C OUTPUT VARIABLES:
C
C     USTCRB = CRITICAL SHEAR VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/SEC)
C     USTCRS = CRITICAL SHEAR VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/SEC)
C     AGR = CRITICAL MOBILITY NUMBER USED IN ACKERS-WHITE FORMULA
C     DGR = DIMENSIONLESS GRAIN DIAMETER IN ACKERS-WHITE FORMULA
C     RGR = REYNOLDS NUMBER AS A FUNCTION OF DGR, AS GIVEN BY SWART AND FLEMMING (1980)
C     VCB = CRITICAL FLUID VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/SEC)
C     VCS = CRITICAL FLUID VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/SEC)
C
C INTERMEDIATE VARIABLES:
C
C     ALPHA = FACTOR RELATING MAX. SHEAR STRESS TO RHO*UB**2*FCW/2.
C     DRHO = SEDIMENT DENSITY - FLUID DENSITY (KG/M**3)
C     VISC = DYNAMIC VISCOSITY OF THE FLUID (KG/M*SEC (OR N.S/M**2))
C     G = ACCELERATION DUE TO GRAVITY (M/SEC**2)
C     FALL = FALL VELOCITY OF SEDIMENT GRAINS AS GIVEN BY GIBBS ET AL. (1971) (M/SEC)
C     TCB = CRITICAL SHEAR STRESS FOR INITIATION OF BEDLOAD TRANSPORT (NEWTONS/M**2)
C     TCS = CRITICAL SHEAR STRESS FOR INITIATION OF SUSPENDED LOAD TRANSPORT (NEWTONS/M**2)
C     DS = DIFFERENCE BETWEEN SPECIFIC GRAVITY OF SEDIMENT AND WATER
C     VISK = KINEMATIC VISCOSITY OF FLUID (M**2/SEC)
C     YALIN = YALIN PARAMETER
C     LGYALIN = LOG OF THE YALIN PARAMETER
C
C INITIALIZE CONSTANTS
C
      G= 9.81
      VISC=1.3D-3
      VISK=VISC/RHOW
      DRHO=RHOS-RHOW
      YALIN=0
      LGYALIN=0
C
C----------------------------------------------------------------------
C Dynamic Viscosity of Sea Water (SI units)

C Temp. S=Salinity
C (C)    S=5     S=10    S=20    S=30    S=40
C 0      0.00180 0.00180 0.00184 0.00189 0.00190
```

```
C 5      0.00153  0.00154  0.00157  0.00159  0.00162
C 10     0.00132  0.00133  0.00140  0.00138  0.00140
C 15     0.00115  0.00116  0.00118  0.00121  0.00123
C 20     0.00102  0.00103  0.00105  0.00107  0.00109
C 25     0.00090  0.00091  0.00093  0.00095  0.00097
C 30     0.00081  0.00082  0.00084  0.00086  0.00088
C ** From Handbook of Marine Science
C
C-----------------------------------------------------------------------
C CALCULATE THRESHOLD SHEAR VELOCITY FOR BEDLOAD TRANSPORT, USTCRB
C-----------------------------------------------------------------------
C FOR ACKERS-WHITE OPTION, GOTO 500
      IF (IOPT1 .EQ. 5) GOTO 500
C
C YALIN METHOD MODIFIED FROM MILLER ET AL. (1977).
C
      YALIN=SQRT((DRHO*G*GD**3)/(RHOW*VISK**2))
C
      LGYALIN=DLOG10(YALIN)
      IF (YALIN .GE. 3000) THEN
         TCB=0.045*DRHO*G*GD
      ELSE IF (YALIN .LE. 100) THEN
         TCB=DRHO*G*GD*10.**((0.041*LGYALIN**2)-0.356*LGYALIN-0.977)
      ELSE
         TCB=DRHO*G*GD*10.**(0.132*LGYALIN-1.804)
      ENDIF
C
C CALCULATE BEDLOAD THRESHOLD SHEAR VELOCITY USTCRB
      USTCRB=SQRT(TCB/RHOW)
C CALCULATE BEDLOAD THRESHOLD FLOW VELOCITY VCB
      VCB=SQRT(2.*TCB/(RHOW*FCW))
      GOTO 510

500   CONTINUE
C
C ACKERS-WHITE CRITERIA
C
      DS = DRHO/RHOW
      DGR = GD*(G*DS/VISK**2)**(1./3.)
      IF (DGR .LE. 1.) THEN
         WRITE (*,5)
         STOP
5        FORMAT (' FINE SEDIMENT - THEORY NOT APPLICABLE')
      ENDIF
      IF (UB .EQ. 0.) THEN
C CURRENTS ONLY (ACKERS AND WHITE,1973)
         IF (DGR .GT. 60.) THEN
            AGR = 0.17
            GO TO 10
         ELSE IF (DGR .GT. 1. .AND. DGR .LE. 60.) THEN
            AGR = (0.23/SQRT(DGR)) + 0.14
            GO TO 10
         ENDIF
      ELSE
C WAVES AND CURRENTS (SWART AND FLEMING,1980)
         RGR = 10.**(0.092*(DLOG10(DGR))**2+1.158*DLOG10(DGR)-0.367)
         AGR = RGR*(DGR)**(-1.5)
         GO TO 10
      ENDIF
```

```
10    CONTINUE
      TCB = RHOW*G*GD*DS*AGR**2
      IF (DGR .GT. 60.) THEN
         RN = 0.
      ELSE IF (DGR .GT. 1. .AND. DGR .LE. 60.) THEN
         RN = 1.0 - 0.56*DLOG10(DGR)
      ELSE
         WRITE (*,15)
         WRITE (7,15)
15       FORMAT (' FINE SEDIMENT - THEORY NOT APPLICABLE')
         STOP
      ENDIF
C
      USTCRB = SQRT(TCB/RHOW)
      VCB = USTCRB/SQRT(FCW/2.)
C
510   CONTINUE
C
C-----------------------------------------------------------------------------------------------------------------------
C CALCULATE THRESHOLD SHEAR VELOCITY FOR SUSPENDED LOAD TRANSPORT, USTCRS
C-----------------------------------------------------------------------------------------------------------------------
C VCS AND VCB ARE EQUAL FOR ACKERS AND WHITE EQUATION
      IF (IOPT1 .EQ. 5) THEN
         VCS = VCB
         USTCRS = USTCRB
      ELSE
C CALCULATE FALL VELOCITY FROM GIBBS ET AL. (1971)
         FALL=(-3.*VISC+SQRT(9.*VISC**2+G*(GD/2.)**2*RHOW*DRHO*
     &  (.00015476+0.099205*GD)))/(RHOW*(.00011607+0.074405*GD))
C CALCULATE USTCRS BASED ON BAGNOLD (1966)
         TCS=0.64*RHOW*FALL**2
         USTCRS=SQRT(TCS/RHOW)
         VCS=SQRT(2.*TCS/(RHOW*FCW))
      ENDIF
C
      RETURN
      END
```

```
C*****************************************************************************************************
      SUBROUTINE TIMING(UA,PHIB,UB,PER,U100,USTCRB,USTCRS,USTCSGM,USTWSGM,USTCWSGM,TB1,TB2,
     @TS1,TS2,PERBED,PERSUSP,USTCS,USTWS,USTCWS)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES THE DURATION OF SEDIMENT TRANSPORT PHASES (NO TRANSPORT,
C BEDLOAD TRANSPORT, SUSPENDED LOAD TRANSPORT) BY CALCULATING WHEN THE RESPECTIVE
C CRITICAL SHEAR VELOCITIES ARE EXCEEDED.
C
C INPUT VARIABLES:
C
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC. (M/SEC)
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY LAYER
C     UB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE VELOCITY (M/SEC)
C     PER = WAVE PERIOD (SEC)
C     U100 = CURRENT VELOCITY AT 1M OF HEIGHT
C     USTCRB = CRITICAL FLUID VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/SEC)
C     USTCRS = CRITICAL FLUID VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/SEC)
C
C OUTPUT VARIABLES:
C
C     TS1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT CEASES (SEC)
C     TB1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT CEASES (SEC)
C     TS2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C        RECOMMENCES (SEC)
C     TB2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT RECOMMENCES (SEC)
C     PERBED = PERCENTAGE OF TIME SPENT IN ONLY BEDLOAD TRANSPORT PHASE.
C     PERSUSP = PERCENTAGE OF TIME SPENT IN SUSPENDED LOAD TRANSPORT PHASE.
C     USTCS = GM CURRENT SKIN-FRICTION SHEAR VELOCITY
C     USTWS = GM WAVE SKIN-FRICTION SHEAR VELOCITY
C     USTCWS = GM COMBINED SKIN-FRICTION SHEAR VELOCITY
C
C INTERMEDIATE VARIABLES:
C
C     XS1 = B+SQRT(B24ACS) USED IN SUSPENDED TIME CALCULATION UNDER CREST
C     XB1 = B+SQRT(B24ACB) USED IN BEDLOAD TIME CALCULATION UNDER CREST
C     XS2 = B-SQRT(B24ACS) USED IN SUSPENDED TIME CALCULATION UNDER TROUGH
C     XB2 = B-SQRT(B24ACB) USED IN BEDLOAD TIME CALCULATION UNDER TROUGH
C     B = -B/2A, AS IN EQ'N. FOR ROOTS OF A QUADRATIC EQUATION
C     B24AC = (B**2-4*A*C)/(2*A)**2, AS IN QUADRATIC EQ'N. SOLUTION
C
C SET DEFAULT VALUES TO ZERO
C
      PI=2.*ASIN(1.)
      TS1=0.0
      TB1=0.0
      TS2=0.0
      TB2=0.0
      PERSUSP=0.0
      PERBED=0.0
C
C--------------------------------------------------------------------------------------------
C CONSIDER PURE CURRENT CASE
C--------------------------------------------------------------------------------------------
C
      USTCS=USTCSGM
      IF (UB .EQ. 0.0) THEN
         IF (USTCS .GE. USTCRS) PERSUSP=100
         IF (USTCS .GE. USTCRB .AND. USTCS .LT. USTCRS) PERBED=100
```

```
         RETURN
      ENDIF
C
C--------------------------------------------------------------------------------------
C WAVE PRESENT CASE
C--------------------------------------------------------------------------------------
C COMPUTE SKIN-FRICTION SHEAR VELOCITY DUE TO WAVE
      IF (UB .NE. 0.0) USTWS=USTWSGM
C
C COMPUTE THE COMBINED MAXIMUM SKIN-FRICTION SHEAR VELOCITY OF GM
      USTCWS=USTCWSGM
C
C COMPUTE VECTORIALLY THE MAXIMUM COMBINED SKIN-FRICTION SHEAR VELOCITY
      USTCWS=SQRT((USTCS*SIN(PHIB))**2+(USTCS*COS(PHIB)+USTWS)**2)
C
C--------------------------------------------------------------------------------------
C CONSIDER PURE WAVE CASE
C--------------------------------------------------------------------------------------
      IF (UA .EQ. 0.0) THEN
C COMPUTE TIME IN SUSPENDED LOAD TRANSPORT
         IF (USTCRS .LT. USTWS) THEN
            TS1=PER/(2.*PI)*ACOS(USTCRS/USTWS)
            TS2=PER/2.-TS1
            PERSUSP=400.*TS1/PER
         ENDIF
C COMPUTE TIME IN ONLY BEDLOAD TRANSPORT
         IF (USTCRB .LT. USTCRS .AND. USTCRB .LT. USTWS) THEN
            TB1=PER/(2.*PI)*ACOS(USTCRB/USTWS)
            TB2=PER/2.-TB1
            PERBED=400.*(TB1-TS1)/PER
         ENDIF
         RETURN
      ENDIF
C--------------------------------------------------------------------------------------
C  CONSIDER COMBINED WAVE-CURRENT CASE
C--------------------------------------------------------------------------------------
C FIRST CALCULATE TIMES FOR SUSPENDED LOAD TRANSPORT
C
      IF (USTCWS .LT. USTCRS) THEN
         PERSUSP=0
         GO TO 50
      ENDIF
      B24ACS=(USTCRS**2.0-(USTCS*SIN(PHIB))**2.0)/(USTWS**2.0)
      IF (B24ACS .LE. 0.0) THEN
C CRITICAL STRESS FOR SUSPENSION OF SEDIMENT ALWAYS EXCEEDED
         TS1=PER/2.
         PERSUSP=100.0
         PERBED=0.0
         RETURN
      ENDIF
      B=-USTCS*COS(PHIB)/USTWS
      XS1=B+SQRT(B24ACS)
      IF (XS1 .GE. 1.0) THEN
C CRITICAL STRESS FOR SUSPENSION OF SEDIMENT NEVER EXCEEDED
         PERSUSP=0.0
         GO TO 50
      ENDIF
      IF (XS1 .LE. -1.0) THEN
C SECOND CASE WHERE CRITICAL STRESS FOR SUSPENSION OF SEDIMENT IS ALWAYS EXCEEDED.
```

```
         TS1=PER/2.
         PERSUSP=100.0
         PERBED=0.0
         RETURN
      ELSE
C CRITICAL STRESS FOR SUSPENSION OF SEDIMENT SOMETIMES EXCEEDED
         TS1=PER/(2.*PI)*ACOS(XS1)
      ENDIF
C
      XS2=B-SQRT(B24ACS)
      IF (XS2 .LE. -1.0) THEN
C CRITICAL STRESS FOR SUSPENSION OF SEDIMENT NOT EXCEEDED DURING TROUGH
         PERSUSP=200.*TS1/PER
      ELSE
C CRITICAL STRESS FOR SUSPENSION OF SEDIMENT EXCEEDED DURING TROUGH
         TS2=PER/(2.*PI)*ACOS(XS2)
         PERSUSP=(2.*(TS1-TS2)+PER)/PER*100.
      ENDIF
C
C CALCULATE TIMES FOR BEDLOAD TRANSPORT
C CALCULATE TIMES FOR BEDLOAD ONLY IF USTCRB < USTCRS
C
50    IF (USTCRB .GE. USTCRS ) RETURN
C IF MAXIMUM SHEAR VELOCITY IS < USTCRB, THEN NO BEDLOAD TRANSPORT
      IF (USTCWSM .LT. USTCRB) THEN
         PERBED=0
         RETURN
      ENDIF
55    B24ACB=(USTCRB**2-(USTCS*SIN(PHIB))**2)/(USTWS**2)
      IF (B24ACB .LE. 0.0) THEN
C CRITICAL STRESS FOR BEDLOAD TRANSPORT ALWAYS EXCEEDED
         TB1=PER/2.
         PERBED=100.-PERSUSP
         RETURN
      ENDIF
      B=-USTCS*COS(PHIB)/USTWS
      XB1=B+SQRT(B24ACB)
      IF (XB1 .GE. 1.0) THEN
C CRITICAL STRESS FOR BEDLOAD TRANSPORT NEVER EXCEEDED
         PERBED=0.0
         RETURN
      ENDIF
      IF (XB1 .LE. -1.0) THEN
C SECOND CASE WHERE CRITICAL STRESS FOR BEDLOAD TRANSPORT IS ALWAYS EXCEEDED.
         TB1=PER/2.
         PERBED=100.-PERSUSP
         RETURN
      ENDIF
C
C CRITICAL STRESS FOR BEDLOAD TRANSPORT EXCEEDED DURING CREST
      TB1=PER/(2.*PI)*ACOS(XB1)
      XB2=B-SQRT(B24ACB)
      IF (XB2 .LE. -1.0) THEN
C CRITICAL STRESS FOR BEDLOAD TRANSPORT NOT EXCEEDED DURING TROUGH
         PERBED=200.*TB1/PER-PERSUSP
      ELSE
C CRITICAL STRESS FOR BEDLOAD TRANSPORT EXCEEDED DURING TROUGH
         TB2=PER/(2.*PI)*ACOS(XB2)
         PERBED=(2.*(TB1-TB2)+PER)/PER*100.-PERSUSP
```

```
      ENDIF
C
      RETURN
      END
```

```
C*****************************************************************************************************
      SUBROUTINE TRANSPO(D,UA,UB,U100,PHIB,PHI100,FCW,PER,GD,RKB,FRACT,RHOS,RHOW,VCB,VCS,USTCRB,
     @USTCS,USTWS,USTCWS,AGR,DGR,CDIR,WDIR,TB1,TB2,TS1,TS2,PERBED,PERSUSP,IOPT1,IOPT2,
     @CONC0,TOWCD,TOWCE,WS,PRS,RKERO,SED,SEDM,SEDDIR,CONC)
C
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON UAX,UAY,UBB,W,A,VCBB,COEFF,RM
C
C THIS SUBROUTINE CALCULATES THE TIME-AVERAGED NET SEDIMENT TRANSPORT BY A CHOICE OF
C METHODS.  FOR THE PURE WAVE CASE THERE IS NO NET TRANSPORT SINCE TRANSPORT DURING THE
C WAVE CREST IS EQUAL AND OPPOSITE TO THAT DURING THE WAVE TROUGH (DUE TO THE USE OF LINEAR
C WAVE THEORY). FOR THE PURE CURRENT AND MIXED CONDITIONS, THE USER MAKES A CHOICE BETWEEN
C TRANSPORT FORMULAE, HOWEVER IF SUSPENDED LOAD TRANSPORT IS SIGNIFICANT IT IS RECOMMENDED
C THAT A TOTAL LOAD FORMULA BE USED.
C
C THE OPTIONS AVAILABLE ARE:
C
C          1 - ENGELUND-HANSEN (1967) TOTAL LOAD EQUATION,
C          2 - EINSTEIN-BROWN (1950) BEDLOAD EQUATION,
C          3 - BAGNOLD (1963) TOTAL LOAD EQUATION,
C          4 - YALIN (1963) BEDLOAD EQUATION,
C          5 - ACKERS-WHITE (1973) TOTAL LOAD EQUATION,
C          6 - SMITH (1977) SUSPENDED LOAD (WAVES AND CURRENTS),
C          7 - AMOS AND GREENBERG (1980) COHESIVE SEDIMENTS.
C
C THE CHOICE IS CONTROLLED BE THE VALUE OF "IOPT1" (1 TO 7) WHICH IS READ IN IN SUBROUTINE READIN
C (READBCH FOR THE BATCH PROGRAM)
C
C INPUT VARIABLES:
C
C     D = WATER DEPTH (M)
C     UA = CURRENT SPEED TO BE USED IN BOTTOM STRESS CALC (M/SEC)
C     UB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE VELOCITY (M/SEC)
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED (M/SEC)
C     PHIB = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS WITHIN THE WAVE BOUNDARY
C        LAYER (RADIANS)
C     PHI100 = ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS AT 1 M ABOVE SEABED (RADIANS)
C     FCW = BOTTOM FRICTION FACTOR
C     PER = WAVE PERIOD (SEC)
C     GD = SEDIMENT GRAIN SIZE (M)
C     RKB = BOTTOM ROUGHNESS (M)
C     FRACT = FRACTION OF THE TOTAL SEDIMENT WITH GRAIN SIZE GD
C     RHOS = SEDIMENT DENSITY (KG/M**3)
C     RHOW = FLUID DENSITY (KG/M**3)
C     VCB = CRITICAL FLUID VELOCITY FOR INITIATION OF BEDLOAD TRANSPORT (M/SEC)
C     VCS = CRITICAL FLUID VELOCITY FOR INITIATION OF SUSPENDED LOAD TRANSPORT (M/SEC)
C     USTCRB = CRITICAL SHEAR VELOCITY FOR BEDLOAD TRANSPORT
C     USTCS = MAXIMUM CURRENT SKIN-FRICTION SHEAR VELOCITY
C     USTWS = GM WAVE SKIN-FRICTION SHEAR VELOCITY
C     USTCWS = GM COMBINED WAVE-CURRENT SKIN-FRICTION SHEAR VELOCITY
C     AGR = CRITICAL MOBILITY NUMBER IN ACKERS-WHITE FORMULA
C     DGR = DIMENSIONLESS GRAIN DIAMETER IN ACKERS-WHITE FORMULA
C     CDIR = CURRENT DIRECTION (AZIMUTH,DEGREES)
C     WDIR = WAVE DIRECTION (AZIMUTH,DEGREES)
C     TB1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT CEASES (SEC)
C     TB2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH BEDLOAD TRANSPORT RECOMMENCES (SEC)
C     TS1 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT CEASES (SEC)
C     TS2 = TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH SUSPENDED LOAD TRANSPORT
C        RECOMMENCES (SEC)
```

```
C     PERBED = PERCENTAGE OF TIME SPENT IN BEDLOAD TRANSPORT PHASE
C     PERSUSP = PERCENTAGE OF TIME SPENT IN SUSPENDED LOAD TRANSPORT PHASE
C     IOPT1 = OPTION SELECTED FOR SEDIMENT TRANSPORT FORMULA
C     IOPT2 = OPTION SELECTED FOR FRICTION-FACTOR PREDICTOR
C
C VARIABLES USED FOR COHESIVE SEDIMENT TRANSPORT CALCULATIONS
C
C     CONC0 = INITIAL ESTIMATE OF SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C     TOWCD = CRITICAL STRESS FOR DEPOSITION (Pa)
C     TOWCE = CRITICAL STRESS FOR EROSION (Pa)
C     WS = SETTLING VELOCITY (m/s)
C     PRS = PROBABILITY OF RESUSPENSION (NORMALLY ASSUMED = 1.0)
C     RKERO = PROPORTIONALITY COEFFICIENT FOR EROSION RATE (DEFAULT = 2.0)
C
C OUTPUT VARIABLES:
C
C     SED = TIME-AVERAGED NET SEDIMENT TRANSPORT AS VOLUME TRANSPORTED PER UNIT BED
C        WIDTH PER UNIT TIME (M**3/M/S)
C     SEDM = TIME-AVERAGED NET SEDIMENT TRANSPORT AS MASS OF SEDIMENT SOLIDS TRANSPORTED PER
C        UNIT BED WIDTH PER UNIT TIME (KG/M/S)
C     SEDDIR = DIRECTION OF NET SEDIMENT TRANSPORT (AZIMUTH,DEGREES)
C     CONC = CALCULATED SEDIMENT CONCENTRATION (ppm) (ie mg/l)
C
C INTERMEDIATE VARIABLES:
C
C     C = COEFFICIENT IN ACKERS-WHITE FORMULA
C     DS = DIFFERENCE BETWEEN SPECIFIC GRAVITY OF SEDIMENT AND WATER
C     FGR = SEDIMENT MOBITITY NUMBER OF ACKERS AND WHITE (1973)
C     GGR = DIMENSIONLESS SEDIMENT RANSPORT RATE OF ACKERS AND WHITE (1973)
C     M = EXPONENT IN ACKERS-WHITE FORMULA
C     N = TRANSITION EXPONENT IN ACKERS-WHITE FORMULA BY STUART AND FLEMMING (1980)
C     RLWRT = LOWER LIMIT OF TRANSPORT INTEGRATION UNDER TROUGH
C     S = SPECIFIC GRAVITY OF WATER
C     STEPC = INTEGRATION STEP OF SEDIMENT TRANSPORT UNDER CREST
C     STEPT = INTEGRATION STEP OF SEDIMENT TRANSPORT UNDER TROUGH
C     TAU0 = CURRENT SHEAR STRESS
C     TIMEC = SEDIMENT TRANSPORT TIME UNDER CREST
C     TIMET = SEDIMENT TRANSPORT TIME UNDER TROUGH
C     VST = SHEAR VELOCITY (M/SEC)
C     X = SEDIMENT LOAD, EXPRESSED AS CONCENTRATION BY WEIGHT
C
C INITIALIZE CONSTANTS AND VARIABLES
      G=9.81
      VISC=1.3D-3
      PI=2.*ASIN(1.)
      DRHO=RHOS-RHOW
      DGAMMA=G*DRHO
      FALL=(-3.*VISC+SQRT(9.*VISC**2+G*(GD/2.)**2*RHOW*DRHO*(0.00015476+
     @0.099205*GD)))/(RHOW*(0.00011607+0.074405*GD))
      TAUCRB=RHOW*USTCRB**2
      UAX=UA*COS(PHIB)
      UAY=UA*SIN(PHIB)
      IF (PER .NE. 0.0) W=2.*PI/PER
      VCBB=VCB
      UBB=UB
      SED=0.0
      SEDM=0.0
      SEDDIR=0.0
C-----------------------------------------------------------------------------------------------------------------
```

```
C WAVES ONLY (NO NET CURRENT)
C
C FOR THE PURE WAVE CASE NO NET TRANSPORT OCCURS
      IF (UA .EQ. 0.0) RETURN
C
C-----------------------------------------------------------------------------------------------------------------------
C  CURRENT ONLY (NO WAVES)
C
C  NO INTEGRATION IS REQUIRED FOR THE PURE CURRENT CASE.
C
C WHEN TRANSPORT IS AS SUSPENDED LOAD, THE TOTAL TRANSPORT FORMULA OF ENGELUND AND
C HANSEN (1967) WAS THE DEFAULT OPTION IN OLDER VERSIONS OF THIS SOFTWARE.  THIS IS NOT THE CASE
C WITH THE PRESENT VERSION.
C HOWEVER, WHEN THERE IS NO "PURE" BEDLOAD PHASE THEN A WARNING MESSAGE IS PRINTED
C CONCERNING THE USE OF "BEDLOAD" TRANSPORT PREDICTORS
C
C SKIP THIS SECTION IF THERE ARE BOTH WAVES AND CURRENTS
      IF (UB .NE. 0.0) GOTO 888
C
C CHECK IF THERE IS ANY TRANSPORT FOR NON-COHESIVE SEDIMENTS,IF NOT THEN EXIT.
      IF (IOPT1.NE.7) THEN
         IF (PERBED .EQ. 0.0 .AND. PERSUSP .EQ. 0.0) RETURN
      ENDIF
C
C PRINT WARNING MESSAGE IF PREDICTOR CHOICE MAY BE INAPPROPRIATE BECAUSE THERE IS NOT A TIME
C DURING THE WAVE CYCLE WHEN THERE IS ONLY BEDLOAD TRANSPORT. (NON-COHESIVE ONLY!)
C
      IF (IOPT1.NE.7) THEN
C
         IF (PERBED .EQ. 0.0 .AND. IOPT1 .EQ. 2) THEN
            WRITE (*,25)
            WRITE (7,25)
25          FORMAT(/,' NO "PURE" BEDLOAD TRANSPORT PHASE THEREFORE THE',/,
            @'EINSTEIN-BROWN EQUATION MAY BE INAPPROPRIATE')
         ENDIF
         IF (PERBED .EQ. 0.0 .AND. IOPT1 .EQ. 4) THEN
            WRITE (*,26)
            WRITE (7,26)
26          FORMAT(/,' NO "PURE" BEDLOAD TRANSPORT PHASE THEREFORE THE',/,
            @'YALIN EQUATION MAY BE INAPPROPRIATE')
         ENDIF
      ENDIF
C
      TAU0=RHOW*FCW/2.*UA**2
C
      GOTO (1,2,3,4,5,6,7) IOPT1
1     CALL ENGHAN(U100,TAU0,RHOW,GD,DGAMMA,SED)
      SEDDIR=CDIR
      GOTO 999
2     CALL EINBWN(FALL,GD,TAU0,DGAMMA,SED)
      SEDDIR=CDIR
      GOTO 999
3     CALL BAGNLD(RHOS,U100,VCB,SED)
      SEDDIR=CDIR
      GOTO 999
4     CALL YALIN(FCW,UA,VCB,RHOW,RHOS,TAUCRB,G,DRHO,GD,SED)
      SEDDIR=CDIR
      GOTO 999
5     CALL ACKWHT(RHOW,DGAMMA,G,DGR,FCW,UA,GD,D,AGR,CDIR,SED)
```

```
      SEDDIR=CDIR
6     GOTO 999
7     CALL AMOSGB(RHOW,CONC0,TOWCE,TOWCD,TAU0,WS,PRS,RKERO,UA,D,SEDM,CONC)
C CONVERT SEDM FROM MASS FLUX TO VOLUME FLUX
      SED = SEDM/RHOS
      SEDDIR=CDIR
      GOTO 999
C
C NOTE: THE PURE CURRENT SMITH CASE IS NOT ALLOWED IN READIN.
C
888   CONTINUE
C
C--------------------------------------------------------------------------------------------------------------------
C CURRENTS AND WAVES
C
C THE COMBINED WAVE AND CURRENT CASE REQUIRES INTEGRATION OF THE INSTANTANEOUS TRANSPORT
C OVER THE WAVE PERIOD. THE USE OF LWT ALLOWS INTEGRATION TO BE DONE OVER ONLY HALF A WAVE
C CYCLE. BAGNOLD'S METHOD DOES NOT REQUIRE INTEGRATION. THE X- AND Y- COMPONENTS OF
C TRANSPORT ARE CONSIDERED SEPARATELY, WHERE THE X-COMPONENT IS PARALLEL TO THE WAVE
C DIRECTION AND THE Y-COMPONENT IS NORMAL TO THE WAVE DIRECTION.
C
C CHECK IF CRITICAL STRESS IS EVER EXCEEDED, IF NOT THEN EXIT.
      IF (TB1 .EQ. 0.0 .AND. TS1 .EQ. 0.0) RETURN
      IF (IOPT1.NE.7) THEN
         IF (PERBED .EQ. 0.0 .AND. PERSUSP .EQ. 0.0) RETURN
      ENDIF
C
C INITIALIZE CONSTANTS AND VARIABLES
C
      SEDXC=0.0
      SEDXT=0.0
      SEDYC=0.0
      SEDYT=0.0
      RLWRC = 0.0
      RLWRT = 0.0
      UPPERC = 0.0
      UPPERT = 0.0
      NMAX = 6
      JMAX = 5
C
C COMPUTE THE TRANSPORT TIMES UNDER WAVE CREST AND TROUGH RESPECTIVELY
      IF (TB1 .EQ. PER/2 .OR. TS1 .EQ. PER/2) THEN
         TIMEC = PER/4
         TIMET = PER/4
         RLWRT = PER/4
      ELSE IF (TB1 .GT. 0 .AND. TB2 .GT. 0) THEN
         TIMEC = TB1
         TIMET = PER/2 - TB2
         RLWRT = TB2
      ELSE
         TIMEC=TB1
         TIMET=0.
      ENDIF
C
C COMPUTE THE INTEGRATION TIME STEPS
      IF (TIMEC .GE. 10.) THEN
         M = 20
      ELSE
         M=10
```

```
      ENDIF
      IF (TIMET .GE. 10.) THEN
         N = 20
      ELSE
         N = 10
      ENDIF
      STEPC = TIMEC/M
      STEPT = TIMET/N
C
C DECIDE FORMULA TO USE ACCORDING TO IOPT1
      GOTO (11,12,13,14,15,16,17) IOPT1
C
11    CALL ENGHANB(RHOW,U100,DGAMMA,GD,USTCS,PHIB,USTWS,W,M,N,TIMEC,TIMET,STEPC,STEPT,
     @RLWRT,SEDXC,SEDXT,SEDYC,SEDYT)
      GOTO 998
C
12    CALL EINBWNB(FALL,GD,RHOW,DGAMMA,M,N,TIMEC,TIMET,STEPC,STEPT,RLWRT,PHIB,USTCS,USTWS,W,
     @SEDXC,SEDXT,SEDYC,SEDYT)
      GOTO 998
C
13    CALL BAGNLDB(RHOW,USTCWS,USTCRB,U100,DGAMMA,CDIR,SED,SEDDIR)
      GOTO 998
C
14    CALLYALINB(RHOW,RHOS,USTCRB,DGAMMA,GD,PHIB,USTCS,USTWS,M,N,W,STEPC,STEPT,RLWRT,SEDXC,
     @SEDXT,SEDYC,SEDYT)
      GOTO 998
C
15    CALL ACKWHTB(DGR,AGR,DS,G,GD,FCW,DGAMMA,RHOW,D,TB1,TB2,TS1,TS2,UPPERC,UPPERT,RLWRC,
     @RLWRT,PER,NMAX,JMAX,SEDXC,SEDYC,SEDXT,SEDYT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      GOTO 998
C
16    CALL SMITH(TS1,RHOS,RHOW,FRACT,GD,IOPT2,PER,VCS,FCW,UB,UA,RKB,PHI100,SED)
      SEDDIR=CDIR
      GO TO 998
C
17    CALL AMOSGBB(RHOW,CONC0,TOWCE,TOWCD,WS,PRS,RKERO,FCW,UBB,UAX,UAY,PER,D,SEDM,CONC)
      SEDDIR=CDIR
C CONVERT SEDM FROM MASS FLUX TO VOLUME FLUX
      SED = SEDM/RHOS
C
998   CONTINUE
C
C AMOS, BAGNOLD AND SMITH ALL OUTPUT SED AND SEDDIR DIRECTLY. OTHER PREDICTORS REQUIRE THAT
C THE X-Y COMPONENTS BE RESOLVED.
C
      IF (IOPT1 .NE. 3 .AND. IOPT1 .NE. 6 .AND. IOPT1 .NE. 7) THEN
         SEDX=(SEDXC+SEDXT)/PER
         SEDY=(SEDYC+SEDYT)/PER
         SED=SQRT(SEDX**2+SEDY**2)
         IF (SEDY .EQ. 0. .AND. SEDX .EQ. 0.) THEN
            SEDDIR = 0.
         ELSE
            PHIS=ATAN2(SEDY,SEDX)
            DIF=SIGN((PHI100-PHIS)*180./PI,CDIR-WDIR)
            CWDIF=ABS(CDIR-WDIR)
            IF(CWDIF .LE. 90.0) SEDDIR=CDIR-DIF
            IF (CWDIF .LE. 180.0 .AND. CWDIF .GT. 90.0) SEDDIR=CDIR+DIF
            IF (CWDIF .LE. 270.0 .AND. CWDIF .GT. 180.0) SEDDIR=CDIR-DIF
            IF (CWDIF .LE. 360.0 .AND. CWDIF .GT. 270.0) SEDDIR=CDIR+DIF
```

```
            IF (SEDDIR .LT. 0.0) SEDDIR=SEDDIR+360.0
            IF (SEDDIR .GE. 360.0) SEDDIR=SEDDIR-360.0
          ENDIF
      ENDIF
C
C CONVERT SED FROM VOLUME FLUX TO MASS FLUX (KG/SEC/M)
999   SEDM = RHOS*SED
      RETURN
      END
C
C***********************************************************************************************
      SUBROUTINE ENGHAN(U100,TAU0,RHOW,GD,DGAMMA,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE ENGELUND AND
C HANSEN (1967) TOTAL LOAD EQUATION FOR CURRENTS ONLY.
C
      V=U100
      SED=0.05*V**2*SQRT(TAU0**3*RHOW)/(GD*DGAMMA**2)
      RETURN
      END
C
C***********************************************************************************************
      SUBROUTINE EINBWN(FALL,GD,TAU0,DGAMMA,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE EINSTEIN AND BROWN
C (1950) BEDLOAD EQUATION FOR CURRENTS ONLY.
C

      SED = 40.0*FALL*GD*(TAU0/(DGAMMA*GD))**3
      RETURN
      END
C
C***********************************************************************************************
      SUBROUTINE BAGNLD(RHOS,U100,VCB,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE BAGNOLD (1963) TOTAL
C LOAD EQUATION FOR CURRENTS ONLY.
C
      BETA=1.73D0
      IF (GD .LE. 0.00031) BETA=7.22D0
      SED=BETA/RHOS*(U100-VCB)**3
      RETURN
      END
C
C***********************************************************************************************
      SUBROUTINE YALIN(FCW,UA,VCB,RHOW,RHOS,TAUCRB,G,DRHO,GD,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE YALIN (1963) BEDLOAD
C EQUATION FOR CURRENTS ONLY.
C
      USTAR=SQRT(FCW/2.)*UA
      S=(UA/VCB)**2-1.0
      A=2.45*(RHOW/RHOS)**0.4*SQRT(TAUCRB/(G*DRHO*GD))
      SED=0.635*GD*USTAR*S*(1.0-DLOG(1.0+A*S)/(A*S))
      RETURN
```

```
      END
C
C*******************************************************************************************
      SUBROUTINE ACKWHT(RHOW,DGAMMA,G,DGR,U100,FCW,UA,GD,D,AGR,CDIR,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE ACKERS-WHITE TOTAL
C LOAD EQUATION FOR CURRENTS ONLY.
C
      S = RHOS/RHOW
      DS = DGAMMA/(RHOW*G)
      CALL INTVAL(DGR,C,RM,RN)
      VST = SQRT(FCW/2.)*UA
      FGR = (VST**RN/SQRT(G*GD*DS))*(UA/(5.75*DLOG10(10.*D/GD)))**(1.-RN)
      IF (FGR .LT. AGR) THEN
         WRITE (*,36)
         WRITE (7,36)
36       FORMAT (' ACKERS-WHITE MOBILITY NUMBER "FGR" IS LESS',
         @' THAN "AGR",',/,' WHERE AGR IS THE CRITICAL MOBILITY',
         @' NUMBER',/,' CALCULATED USING THE ACKERS-WHITE METHOD')
         CDIR = 0.
         GGR = 0
         SED = 0.
      ELSE
         GGR = C*((FGR/AGR)-1.)**RM
         SED = U100*GD*GGR*(U100/VST)**RN
      ENDIF
      RETURN
      END
C
C*******************************************************************************************
      SUBROUTINE ENGHANB(RHOW,U100,DGAMMA,GD,USTCS,PHIB,USTWS,W,M,N,TIMEC,TIMET,STEPC,STEPT,
      @RLWRT,SEDXC,SEDXT,SEDYC,SEDYT)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO ENGELUND AND HANSEN
C (1967) TOTAL LOAD EQUATION FOR COMBINED CURRENTS AND WAVES.
C
      CONST=0.05*(RHOW*U100/DGAMMA)**2/GD
      GSXC = 0
      SEDXC = 0
      GSXT = 0
      SEDXT = 0
C
C COMPUTE TRANSPORT VOLUME-X FOR THE CREST
      DO 111 I = 0, (M-1)
      USTCWX=USTCS*COS(PHIB)+0.5*USTWS*(COS(W*I*STEPC)+COS(W*(I+1)*STEPC))
      GSXC=CONST*STEPC*USTCWX**3
      SEDXC=SEDXC+GSXC
111   CONTINUE
      SEDXC=2*SEDXC
      IF (TIMET .EQ. 0.) GO TO 333
C COMPUTE TRANSPORT VOLUME-X FOR THE TROUGH
      DO 222 I = 0, (N-1)
      USTCWX=USTCS*COS(PHIB)+0.5*USTWS*
      @(COS(W*(RLWRT+I*STEPT))+COS(W*(RLWRT+(I+1)*STEPT)))
      GSXT=CONST*STEPT*USTCWX**3
      SEDXT=SEDXT+GSXT
222   CONTINUE
```

```
      SEDXT=2*SEDXT
C COMPUTE SEDIMENT TRANSPORT VOLUME IN THE Y DIRECTION
333   SEDYC=2*CONST*TIMEC*(USTCS*SIN(PHIB))**3
      SEDYT=2*CONST*TIMET*(USTCS*SIN(PHIB))**3
C
      RETURN
      END
C
C*****************************************************************************************************
      SUBROUTINE EINBWNB(FALL,GD,RHOW,DGAMMA,M,N,TIMEC,TIMET,STEPC,STEPT,RLWRT,PHIB,USTCS,
     @USTWS,W,SEDXC,SEDXT,SEDYC,SEDYT)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE EINSTEIN AND BROWN
C (1950) BEDLOAD EQUATION FOR COMBINED CURRENTS AND WAVES.
C
      CONST=40*FALL*GD*(RHOW/(GD*DGAMMA))**3
      GSXC = 0
      SEDXC = 0
      GSXT = 0
      SEDXT = 0
C
C COMPUTE TRANSPORT VOLUME-X FOR THE CREST
      DO 111 I = 0, (M-1)
      USTCWX=USTCS*COS(PHIB)+0.5*USTWS*(COS(W*I*STEPC)+COS(W*(I+1)*STEPC))
      GSXC=CONST*STEPC*USTCWX**6
      SEDXC=SEDXC+GSXC
111   CONTINUE
      SEDXC=2*SEDXC
      IF (TIMET .EQ. 0.) GO TO 333
C COMPUTE TRANSPORT VOLUME-X FOR THE TROUGH
      DO 222 I = 0, (N-1)
      USTCWX=USTCS*COS(PHIB)+0.5*USTWS*
     @(COS(W*(RLWRT+I*STEPT))+COS(W*(RLWRT+(I+1)*STEPT)))
      GSXT=CONST*STEPT*(USTCWX)*DABS(USTCWX**5)
      SEDXT=SEDXT+GSXT
222   CONTINUE
      SEDXT=2*SEDXT
C COMPUTE SEDIMENT TRANSPORT VOLUME IN THE Y DIRECTION
333   SEDYC=2*CONST*TIMEC*(USTCS*SIN(PHIB))**6
      SEDYT=2*CONST*TIMET*(USTCS*SIN(PHIB))**6
C
      RETURN
      END
C
C*****************************************************************************************************
      SUBROUTINE BAGNLDB(RHOW,USTCWS,USTCRB,U100,DGAMMA,CDIR,SED,SEDDIR)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE MODIFIED BAGNOLD
C (1963) TOTAL LOAD EQUATION FOR COMBINED CURRENTS AND WAVES. IT DOES NOT REQUIRE
C INTEGRATION.
C
C EST = NORMALIZED EXCESS SHEAR STRESS ABOVE TAU-CRITICAL (BEDLOAD)
C
      TAUCRB = RHOW*USTCRB**2.
      TAUMAX = RHOW*USTCWS**2
      EST = (TAUMAX - TAUCRB)/TAUCRB
C
```

```
C RK AFTER STERNBERG (1972). STERNBERG USED TAU-TOTAL DUE TO RIPPLE AND GRAIN SIZE IN OBTAINING
C THE K COEFFICIENT FOR CURRENT. USING USTCWS OF GM TO CALCULATE K WILL UNDERESTIMATE K AND
C THUS COEFFICIENT 0.005 OF STERNBERG HAS BEEN MODIFIED TO 0.02 TO GIVE THE BEST FIT TO THE
C MEASURED TRANSPORT RATES.
C
      IF (EST .LT. 0) THEN
         SED = 0
      ELSE
         RK = 0.02*EXP(0.7*EST)
         SED=RK*TAUMAX*U100/DGAMMA
      ENDIF
      SEDDIR=CDIR
      RETURN
      END
C
C*********************************************************************************************
      SUBROUTINE YALINB(RHOW,RHOS,USTCRB,DGAMMA,GD,PHIB,USTCS,USTWS,M,N,W,STEPC,STEPT,RLWRT,
     @SEDXC,SEDXT,SEDYC,SEDYT)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES FOR COMBINED WAVES AND
C CURRENTS ACCORDING TO THE MODIFIED YALIN (1963) BEDLOAD EQUATION.
C
      A=2.45*SQRT((RHOW*USTCRB**2)/(DGAMMA*GD))*(RHOW/RHOS)**0.4
      CONST=0.635*GD
      GSXC = 0
      GSYC = 0
      SEDXC = 0
      SEDYC = 0
      GSXT = 0
      GSYT = 0
      SEDXT = 0
      SEDYT = 0

C COMPUTE TRANSPORT VOLUME UNDER THE CREST
      DO 111 I = 0, (M-1)
         USTCWX1=USTCS*COS(PHIB)+USTWS*COS(W*I*STEPC)
         USTCWX2=USTCS*COS(PHIB)+USTWS*COS(W*(I+1)*STEPC)
         USTCWM1=SQRT((USTCS*SIN(PHIB))**2+USTCWX1**2)
         USTCWM2=SQRT((USTCS*SIN(PHIB))**2+USTCWX2**2)
         S1=USTCWM1**2/USTCRB**2-1
C NO TRANSPORT WHEN S1 OR S2 IS < 0 (USTCWM < USTCRB)
         IF (S1 .LT. 0) S1 = 0.0
         S2=USTCWM2**2/USTCRB**2-1
         IF (S2 .LT. 0) S2 = 0.0
         FACTOR1=DABS(S1-LOG(1+A*S1)/A)
         FACTOR2=DABS(S2-LOG(1+A*S2)/A)
         GSXC=CONST*0.5*(USTCWX1+USTCWX2)*STEPC*0.5*(FACTOR1+FACTOR2)
         GSYC=CONST*USTCS*SIN(PHIB)*STEPC*0.5*(FACTOR1+FACTOR2)
         SEDXC=SEDXC+GSXC
         SEDYC=SEDYC+GSYC
111   CONTINUE
      SEDXC=2*SEDXC
      SEDYC=2*SEDYC
C COMPUTE TRANSPORT VOLUME UNDER THE TROUGH
      DO 222 I = 0, (N-1)
         USTCWX1=USTCS*COS(PHIB)+USTWS*COS(W*(RLWRT+I*STEPT))
         USTCWX2=USTCS*COS(PHIB)+USTWS*COS(W*(RLWRT+(I+1)*STEPT))
         USTCWM1=SQRT((USTCS*SIN(PHIB))**2+USTCWX1**2)
```

```
        USTCWM2=SQRT((USTCS*SIN(PHIB))**2+USTCWX2**2)
        S1=USTCWM1**2/USTCRB**2-1
        IF (S1 .LT. 0) S1=0.0
        S2=USTCWM2**2/USTCRB**2-1
        IF (S2 .LT. 0) S2=0.0
        FACTOR1=DABS(S1-LOG(1+A*S1)/A)
        FACTOR2=DABS(S2-LOG(1+A*S2)/A)
        GSXT=CONST*0.5*(USTCWX1+USTCWX2)*STEPT*0.5*(FACTOR1+FACTOR2)
        GSYT=CONST*USTCS*SIN(PHIB)*STEPT*0.5*(FACTOR1+FACTOR2)
        SEDXT=SEDXT+GSXT
        SEDYT=SEDYT+GSYT
222   CONTINUE
      SEDXT=2*SEDXT
      SEDYT=2*SEDYT
C
      RETURN
      END
C
C*******************************************************************************************************
      SUBROUTINE ACKWHTB(DGR,AGR,DS,G,GD,FCW,DGAMMA,RHOW,D,TB1,TB2,TS1,TS2,UPPERC,UPPERT,
     @RLWRC,RLWRT,PER,NMAX,JMAX,SEDXC,SEDYC,SEDXT,SEDYT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE ACKERS-WHITE TOTAL
C LOAD EQUATION FOR COMBINED CURRENTS AND WAVES.
C
      DS = DGAMMA/(RHOW*G)
      CALL INTVAL(DGR,C,RM,RN)
      COEFF = (1./(AGR*SQRT(DS*G*GD)))*(SQRT(FCW/2.))**RN*
     @(1./(5.75*DLOG10(10.*D/GD)))**(1.-RN)
      CONST = GD*C*(SQRT(2./FCW))**RN
      CALL FNDVAL(7,8,TB1,TB2,TB1,TB2,TS1,TS2,UPPERC,UPPERT,RLWRC,RLWRT,PER,NMAX,JMAX,CONST,
     @SEDXC,SEDYC,SEDXT,SEDYT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      RETURN
      END
C
C*******************************************************************************************************
      SUBROUTINE SMITH(TS1,RHOS,RHOW,FRACT,GD,IOPT2,PER,VCS,FCW,UB,UA,RKB,PHI100,SED)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      COMMON /VT1T2/ T1,T2
C
C THIS SUBROUTINE CALCULATES SEDIMENT TRANSPORT RATES ACCORDING TO THE SMITH (1977)
C SUSPENDED LOAD METHOD FOR COMBINED CURRENTS AND WAVES.
C
C THE SMITH ROUTINES WORK IN CGS UNITS. DUE TO THE OVERALL COMPLEXITY, THE INPUT IS CONVERTED
C FROM SI TO CGS AND THE OUTPUT IS CONVERTED BACK FROM CGS TO SI RATHER THAN CONVERT ALL
C OF THE INDIVIDUAL ROUTINES TO SI UNITS.
C
      RHOS = RHOS/1000.
      RHOW = RHOW/1000.
      GD = GD*100.
      VCS = VCS*100.
      UB = UB*100.
      UA = UA*100.
      RKB = RKB*100.
C
C SMITH ONLY CONSIDERS CO-DIRECTIONAL WAVES AND CURRENTS, THEREFORE A WARNING IS PRINTED
C FOR NON-ZERO PHI100 (IE PHI100> 10 DEGREES).
C
```

```
      IF (ABS(PHI100).GE. 0.2) THEN
         WRITE(*,11)
         WRITE(7,11)
11       FORMAT (///,' ***WARNING*** ',/,' PHI100 > 10 DEGREES',5X,
         @'SMITH (1977) METHOD MAY NOT BE APPROPRIATE')
      ENDIF
C
C IF THE FRICTION FACTOR FCW WAS NOT CALCULATED ACCORDING TO SMITH IN FRICFAC (IN FRIC4) THEN
C CERTAIN VARIABLES MUST BE INITIALIZED BY CALLING USTARS.
C
      IF (IOPT2.NE.2) CALL USTARS (UB,GD,RHOW,FCW,UA)
C
      T1 = 0.
      T2 = TS1
      CALL CONCN (GD,RHOS,RHOW,FRACT,PER,VCS,FCW,UB,SED)
C
C CONVERT OUTPUT BACK TO SI UNITS
C
      RHOS = RHOS*1000.
      RHOW = RHOW*1000.
      GD = GD/100.
      VCS = VCS/100.
      UB = UB/100.
      UA = UA/100.
      RKB = RKB/100.
      SED = SED/10000.
C
      RETURN
      END
C
C*******************************************************************************************
      SUBROUTINE FNDVAL(INDA,INDB,TB1,TB2,EXT1,EXT2,TS1,TS2,UPPERC,UPPERT,RLWRC,RLWRT,PER,NMAX,
      @JMAX,CONST,SEDXC,SEDYC,SEDXT,SEDYT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      IF (TB1 .NE. 0.) THEN
         RLWRC = 0.0
         UPPERC = EXT1
      ELSE
         RLWRC = 0.0
         UPPERC = TS1
      ENDIF
      CALL ROMB2(NMAX,RLWRC,UPPERC,INDA,JMAX,RSLTXC,ERRC,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      CALL ROMB2(NMAX,RLWRC,UPPERC,INDB,JMAX,RSLTYC,ERRC,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      SEDXC = 2.*CONST*RSLTXC
      SEDYC = 2.*CONST*RSLTYC
C
      IF (TB2 .NE. 0.0) THEN
         RLWRT = EXT2
         UPPERT = PER/2.
      ELSE IF (TS2 .NE. 0.) THEN
         RLWRT = TS2
         UPPERT = PER/2.
      ENDIF
      CALL ROMB2(NMAX,RLWRT,UPPERT,INDA,JMAX,RSLTXT,ERRT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      CALL ROMB2(NMAX,RLWRT,UPPERT,INDB,JMAX,RSLTYT,ERRT,UAX,UAY,UBB,W,A,VCBB,COEFF,RM)
      SEDXT = 2.*CONST*RSLTXT
      SEDYT = 2.*CONST*RSLTYT
      RETURN
```

```
      END
C
C*********************************************************************************************
      SUBROUTINE INTVAL(DGR,C,RM,RN)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      IF (DGR .GT. 60.) THEN
         RN = 0.
         RM = 1.50
         C = 0.025
      ELSE IF (DGR .GT. 1. .AND. DGR .LE. 60.) THEN
         RN = 1.00 - 0.56*DLOG10(DGR)
         RM = (9.66/DGR) + 1.34
         C = 10.**(2.86*DLOG10(DGR)-(DLOG10(DGR))**2-3.53)
      ELSE
         WRITE (*,35)
35       FORMAT (' FINE SEDIMENT - THEORY NOT APPLICABLE')
         STOP
      ENDIF
      RETURN
      END
C
C*********************************************************************************************
      SUBROUTINE USTARS (U0,GD,RHOW,FCW,UA)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      COMMON /CHECK/ ICHK
      COMMON /VF9Z/ USTAR1,VKK,USTARM,Z0,ZA
      COMMON /VEVK0/ EVK0
      DIMENSION AB2(14),OR2(14),U(1),S(1),BPAR(4),C2(13,3)
      DATA BPAR /0.,0.,0.,0./
      DATA AB2 /3.,4.,5.,6.,8.,10.,13.,15.,20.,30.,40.,60.,80.,100./
      DATA OR2 /0.037037037,0.0290,0.0253,0.0230,0.0217,0.0214,
     @0.0218,0.0223,0.0236,0.0265,0.0290,0.0310,0.0323,
     @0.033333333/
C
C THIS SUBROUTINE CALCULATES THE VALUES OF VARIABLES USED IN THE SMITH CALCULATIONS WHICH
C WOULD HAVE BEEN DETERMINED IF THE SMITH FRICTION FACTOR WAS SELECTED RATHER THAN THE
C GRANT&MADSEN METHOD.
C
      VISC = 13.D-3
      VISK = VISC/RHOW
      VKK = 0.4
C VKK = VON KARMANS CONSTANT
C
C COMPUTE USTARM FOR WAVES
C
      TAUWV = 0.5*FCW*RHOW*U0*U0
      USTARM = SQRT(TAUWV/RHOW)
C
C COMPUTE USTAR1 FOR CURRENT
      USTAR1 = SQRT(FCW/2.)*UA
C
C COMPUTE EVK0
C
      EVK0 = VKK*(USTAR1 + USTARM)
C
C COMPUTE Z0
C
```

```
      RSTAR = USTARM*GD/VISK
C
C COMPUTE ESTIMATE OF Z0 FOR HYDRAULICALLY SMOOTH,ROUGH OR TRANSITIONAL FLOWS AND ITERATE
C UNTIL USU0 CONVERGES
      IF (RSTAR.LT.3.) THEN
C SMOOTH FLOWS
        ZFKS = 1./(9.*RSTAR)
      ELSE IF (RSTAR.GT.100) THEN
C ROUGH FLOWS
        ZFKS = 1./30.
      ELSE
C TRANSITIONAL FLOWS: CUBIC SPLINE INTERPOLATION OF FIG. 1, SMITH,1977 TO FIND (ZF/KS)
        U(1) = RSTAR
        CALL ICSICU (AB2,OR2,14,BPAR,C2,13,IER)
        CALL ICSEVU (AB2,OR2,14,C2,13,U,S,1,IER)
        ZFKS = S(1)
      ENDIF
      Z0 = ZFKS*GD
C
     RETURN
     END
C
C*********************************************************************************************
      SUBROUTINE CONCN (GD,RHOS,RHOW,FRACT,PER,VCS,FCW,UB,SEDX)
      PARAMETER (MTIME=100,MTERM=100)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      COMMON /VAB/ AM,BM
      COMMON /VNTERM/ W,NTERM
      COMMON /VEVK0/ EVK0
      COMMON /VF9Z/ USTAR1,VKK,USTARM,Z0,ZA
      COMMON /VU0/ U0
      COMMON /VF9T2/ XI0KER,XI0KEI
      COMMON /VF9T1/ XIAKER,XIAKEI
      COMMON /VT1T2/ T1,T2
      COMMON /VPN/ PN
      COMMON /CHECK/ICHK
      DIMENSION CNZA(MTIME),AM(MTERM),BM(MTERM)
      PI = ACOS(-1.)
      DO 4 I=1,MTIME
      CNZA(I) = 0.
4     CONTINUE
      DO 5 I=1,MTERM
      AM(I) = 0.
      BM(I) = 0.
5     CONTINUE
      U0 = UB
      NTIME = 50
      G = 981.
      VKK = 0.4
      VISC = 13.D-3
      DRHO = RHOS - RHOW
      W = 2.*PI/PER
      GAMY = 0.635
      GAMN = FRACT*GAMY
      TAUCS = (FCW/2.)*RHOW*VCS**2
      FALL=(-3.*VISC+SQRT(9.*VISC**2+G*(GD/2.)**2*RHOW*DRHO*(0.015476+
     @0.099205*GD)))/(RHOW*(0.011607+0.074405*GD))
      IF (ICHK.EQ.1) WRITE (7,1000) EVK0,GAMN,TAUCS,FALL
```

```
1000 FORMAT (' INTERMEDIATE VALUES FOR MANUAL CHECKING: '/.' EVK0 = ',F7.4,T25,'GAMN =
     ',F7.4,T45,'TAUCS = ',.F7.4,T63,'FALL = ',F7.4)
C
C COMPUTE CONCENTRATION AT Z = ZA
C
     PN = FALL/EVK0
     ZA = 2.*GD
     XIA = 2.*SQRT(W*ZA/EVK0)
     CALL KELVIN (2,0.,PN,XIA,XIAKER,XIAKEI)
     IF (ICHK.EQ.1) WRITE (7,1001) PN,XIA,XIAKER,XIAKEI
1001 FORMAT (' PN = ',F7.4,T25,'XIA = ',F7.4,T45,'XIAKER = ',.F8.3,T63,'XIAKEI = ',F8.3)
     XI0 = 2.*SQRT(W*Z0/EVK0)
     CALL KELVIN (1,0,0.,XI0,XI0KER,XI0KEI)
     VR00 = XI0KER
     VI00 = XI0KEI
     IF (ICHK.EQ.1) WRITE (7,1002) Z0,XI0,XI0KER,XI0KEI
1002 FORMAT (' Z0 = ',F7.4,T25,'XI0 = ',F7.4,T45,'XI0KER = ',F7.3,T63,'XI0KEI = ',F7.3)
     CALL KELVIN (1,1,0.,XI0,XI0KER1,XI0KEI1)
     VR10 = XI0KER1
     VI10 = XI0KEI1
     VRSQ = VR00**2.
     VISQ = VI00**2.
     DF1 = ((VR10+VI10)*VR00 + (VI10-VR10)*VI00)/(SQRT(2.)*(VRSQ+VISQ))
     DF2 = (-(VR10+VI10)*VI00 + (VI10-VR10)*VR00)/(SQRT(2.)*(VRSQ+VISQ))
     IF (ICHK.EQ.1) WRITE (7,1003) XI0KER1,XI0KEI1,DF1,DF2
1003 FORMAT (' XI0KER1 = ',F7.3,T25,'XI0KEI1 = ',F7.3,T45,'DF1 = ',F7.4,T63,'DF2 = ',F7.4)
     IF (ICHK.EQ.1) WRITE (7,1004) U0,USTAR1,USTARM
1004 FORMAT (' U0 = ',F7.4,T25,'USTAR1 = ',F7.4,T45,'USTARM = ',F7.4)
     C1 = -GAMN + (GAMN*RHOW/TAUCS)*(EVK0*USTAR1/VKK)/(1. + USTARM/USTAR1)
     C2 = (GAMN*RHOW/TAUCS)*(EVK0*U0*XI0/2.)*SQRT(DF1**2 + DF2**2)
     PHASE = ATAN2(DF2,DF1)
     IF (ICHK.EQ.1) WRITE (7,1005) C1,C2,PHASE
1005 FORMAT (' C1 = ',F7.4,T25,'C2 = ',F7.4,T45,'PHASE = ',F7.4)
     T = 0.
     DT = PER/FLOAT(NTIME-1)
     DO 10 IT=1,NTIME
     T = FLOAT(IT-1)*DT
     CNZA(IT) = C1 + C2*COS(W*T + PHASE)
     IF (ICHK.EQ.1) WRITE (7,1006) IT,T,CNZA(IT)
     IF (ICHK.EQ.1) WRITE (*,1006) IT,T,CNZA(IT)
1006 FORMAT (' IT = ',I2,5X,'T = ',F7.4,5X,'CNZA = ',F7.4)
10   CONTINUE
C
C COMPUTE FOURIER COEFFICIENTS
C
     CALL FFT (CNZA,BM,NTIME,NTIME,NTIME,1,IERR)
     CALL REALTR(CNZA,BM,NTIME,1)
     DO 20 IK=1,NTIME
     AM(IK) = (0.5/FLOAT(NTIME))*CNZA(IK)
     BM(IK) = (0.5/FLOAT(NTIME))*BM(IK)
     IF (ICHK.EQ.1) WRITE (7,1007) IK,AM(IK),BM(IK)
1007 FORMAT (' IK = ',I2,5X,'AM = ',E10.3,5X,'BM = ',E10.3)
20   CONTINUE
C
C INTEGRATE OVER WATER DEPTH USING SUBROUTINE ROMBZ (INTEGRATION OVER TIME IN ROMBZ IS
C PERFORMED IN FUNCTION F9Z)
C
     NMAX = 6
     JMAX = 5
```

```
      A = Z0
      B = ZA
      NTERM = NTIME
      WRITE (*,1008)
      IF (ICHK.EQ.1) WRITE (7,1008)
 1008 FORMAT (' BEGIN INTEGRATION OVER WATER DEPTH')
      CALL ROMBZ (NMAX,A,B,JMAX,RSLT,ERR)
      WRITE (*,1009)
      IF (ICHK.EQ.1) WRITE (7,1009)
 1009 FORMAT (' END INTEGRATION OVER WATER DEPTH')
      SEDX = 2.*RSLT
      SEDY = 0.
      WRITE (*,1010) SEDX,SEDY
      IF (ICHK.EQ.1) WRITE (7,1010) SEDX,SEDY
 1010 FORMAT (' SEDX = ',E11.4,/' SEDY = ',E11.4)
      RETURN
      END
C
C*******************************************************************************************
      SUBROUTINE AMOSGB(RHOW,CONC0,TOWCE,TOWCD,TAU0,Ws,PRS,RKERO,UA,D,SED,CONC)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE CALCULATES COHESIVE SEDIMENT TRANSPORT RATES FOR PURE CURRENTS ACCORDING
C TO THE AMOS AND GREENBERG (1980) METHOD.
C
C NOTE: STEADY STATE CONDITIONS ARE ASSUMED FOR THIS 1-D MODEL IF CONC0 WAS SELECTED AS 0.0.
C     IN A 2-D MODEL THERE MAY BE SUFFICIENT SOURCE OR SINK IN LIGHT OF THE VELOCITIES AND GRID
C     CELL SIZE TO ALLOW THE MASS FLUX TO DIFFER FROM THE MASS EROSION RATE!
C
C THE PROBABILITY OF DEPOSITION = (1.0 - TAU0/TOWCD) (ALWAYS >0.)
      PDEP=(1.0 - TAU0/TOWCD)
      IF (PDEP.LT.0.) PDEP=0.
C
      IF (CONC0.EQ.0.0) THEN
         IF (TAU0.GT.TOWCE) THEN
            CONC= RKERO*(TAU0 - TOWCE) * 1000000.0/( WS*PDEP*PRS )
         ELSE
            CONC=0.0
         ENDIF
C
C SED IS THE HORIZONTAL MASS FLUX RATE IN KG/S PER M WIDTH OF SEAFLOOR
         SED=CONC/1000000.0*D*UA
         RETURN
      ELSE
C
C CALCULATE THE EROSION RATE
C
         IF (TAU0.GT.TOWCE) THEN
            ERATE=RKERO*(TAU0 - TOWCE)
         ELSE
            ERATE=0.0
         ENDIF
C

C CALCULATE THE DEPOSITION RATE
C
         DRATE=CONC0/1000000.0*WS*PDEP*PRS
C
C CALCULATE THE NET EROSION RATE [kg/s/m^2 of soil]
```

```
        RNET=ERATE-DRATE
C
C CHECK THE FLUX RATE ASSUMING A BULK DENSITY OF 1800 KG/M^3 AND ASSUMING THAT THE
C CONCENTRATION OF SPM DECAYS IN PROPORTION TO THE INCREASE IN WATER VELOCITY ABOVE THE
C SEAFLOOR (ie THE FLUX OF SEDIMENT IS CONSTANT THROUGHOUT THE WATER COLUMN).
C
C VFLUX IS THE VERTICAL MASS FLUX RATE IN kg/s PER m^2 OF SEAFLOOR

        VFLUX=RNET
C
C IF THE CALCULATED NET VERTICAL MASS RATE OF EROSION IS LESS THAN THE HORIZONTAL FLUX
C CALCULATED FROM:
C       CONCENTRATION*D*UA,
C THEN THE INITIAL ESTIMATE OF THE CONCENTRATION OF SEDIMENT MAY HAVE BEEN TOO HIGH.
C HOWEVER, ASSUMING THAT SHORT TERM INEQUALITIES IN THE DEPOSITION AND EROSION REATES DO
C NOT AFFECT THE CONCENTRATION ENOUGH TO AFFECT THE DEPOSITION RATE, THEN THE HORIZONTAL
C FLUX WILL BE EQUAL TO THE VERTICAL FLUX PLUS SSC X VOLUME FLUX OF WATER.  UNDER THESE
C CONDITIONS:
C
C SED IS THE VERTICAL MASS FLUX RATE IN kg/s PER m WIDTH OF SEAFLOOR PLUS THE INITIAL
C CONCENTRATION x THE VOLUME FLUX OF WATER PER UNIT WIDTH OF SEAFLOOR.
C
        SED=VFLUX+CONC0/1000000.0*D*UA
C
C OTHERWISE:
C
C SED IS THE HORIZONTAL MASS FLUX RATE IN kg/s PER m^2 OF SEAFLOOR.
C      SED = HFLUX=CONC/1000000.0*RHOW*D*UA
C WHICH MUST BE FOUND BY FINE TUNING THE CONCENTRATION WHICH CAN ONLY BE DONE BY KNOWING
C HOW TAUCRIT FOR EROSION CHANGES OVER TIME.
C
C CALCULATE THE NEW RESULTING SUSPENDED SEDIMENT CONCENTRATION
C SINCE SED=CONC/1000000.0*D*UA
        CONC=SED*1000000.0/(D*UA)
      RETURN
      ENDIF
      END
C
C*************************************************************************************************
      SUBROUTINE AMOSGBB(RHOW,CONC0,TOWCE,TOWCD,WS,PRS,RKERO,FCW,UBB,UAX,UAY,PER,D,SED,
     @CONC)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
      PI = ACOS(-1.)
C
C THIS SUBROUTINE CALCULATES COHESIVE SEDIMENT TRANSPORT RATES FOR COMBINED CURRENTS AND
C WAVES ACCORDING TO THE METHOD OF AMOS and GREENBERG (1980?)
C
C IT IS THE SAME AS SUBROUTINE AMOSGB EXCEPT THAT THE EXCESS SHEAR STRESSES ARE TEMPORALLY
C AVERAGED OVER A WAVE CYCLE.
C
C THE PROBABILITY OF DEPOSITION = (1.0 - TAU/TOWCD) (ALWAYS >0.)
C
      AVGDIFT=0.0
      AVGPDEP=0.0
      IF (CONC0.EQ.0.0) THEN
C
C INTEGRATE OVER A WAVE PERIOD IN 20 TIME STEPS
        DO 10 IT=1,20
```

```
        DT=PER/20
        T=DT*(IT-1)
C
C AVGDIFT = AVERAGE OVER ONE WAVE CYCLE OF (TAU - TOWCE)
C AVGPDEP = AVERAGE OVER ONE WAVE CYCLE OF (1.0 - TAU/TOWCD)
C
        UX=UAX+UBB*COS(T*2.0*PI/PER)
        UY=UAY
        SPD=SQRT(UX*UX+UY*UY)
        TAU=RHOW*FCW/2.*SPD**2
        IF(TAU.GT.TOWCE)AVGDIFT=AVGDIFT+(TAU-TOWCE)*DT/PER
        PDEP=(1.0 - TAU/TOWCD)
        IF(PDEP.LT.0.)PDEP=0.
        AVGPDEP=AVGPDEP+PDEP*DT/PER
10    CONTINUE
        CONC= RKERO*(AVGDIFT) * 1000000.0/( WS*AVGPDEP*PRS )
C
C SED IS THE HORIZONTAL MASS FLUX RATE IN kg/s PER m WIDTH OF SEAFLOOR
        UA=SQRT(UAX*UAX+UAY*UAY)
        SED=CONC/1000000.0*D*UA
        RETURN
      ELSE
C
C CALCULATE THE EROSION AND DEPOSITION RATES
C
        AVGDIFT=0.0
        AVGPDEP=0.0
        DO 100 IT=1,20
        DT=PER/20
        T=DT*(IT-1)
C
C AVGDIFT = AVERAGE OVER ONE WAVE CYCLE OF (TAU - TOWCE)
C
        UX=UAX+UBB*COS(T*2.0*PI/PER)
        UY=UAY
        SPD=SQRT(UX*UX+UY*UY)
        TAU=RHOW*FCW/2.*SPD**2
        IF(TAU.GT.TOWCE)AVGDIFT=AVGDIFT+(TAU-TOWCE)*DT/PER
        DEP=(1.0 - TAU/TOWCD)
        IF(PDEP.LT.0.)PDEP=0.
        AVGPDEP=AVGPDEP+PDEP*DT/PER
100   CONTINUE

        ERATE=RKERO*AVGDIFT
        DRATE=CONC0/1000000.0*WS*AVGPDEP*PRS
C
C CALCULATE THE NET EROSION RATE [(kg/s/m^2) of soil]
C
        RNET=ERATE-DRATE
C
C CHECK THE FLUX RATE ASSUMING A BULK DENSITY OF 1800 KG/M^3 AND ASSUMING THAT THE
C CONCENTRATION OF SPM DECAYS IN PROPORTION TO THE INCREASE IN WATER VELOCITY ABOVE THE
C SEAFLOOR (ie THE FLUX OF SEDIMENT IS CONSTANT THROUGHOUT THE WATER COLUMN).
C
C VFLUX IS THE VERTICAL MASS FLUX RATE IN kg/s PER m^2 OF SEAFLOOR
C

        VFLUX=RNET
C
```

```
C IF THE CALCULATED NET VERTICAL MASS RATE OF EROSION IS LESS THAN THE HORIZONTAL FLUX
C CALCULATED FROM:
C       CONCENTRATION*D*UA,
C THEN THE INITIAL ESTIMATE OF THE CONCENTRATION OF SEDIMENT MAY HAVE BEEN TOO HIGH.
C HOWEVER, ASSUMING THAT SHORT TERM INEQUALITIES IN THE DEPOSITION AND EROSION REATES DO
C NOT AFFECT THE CONCENTRATION ENOUGH TO AFFECT THE DEPOSITION RATE, THEN THE HORIZONTAL
C FLUX WILL BE EQUAL TO THE VERTICAL FLUX PLUS SSC X VOLUME FLUX OF WATER.  UNDER THESE
C CONDITIONS:
C
C SED IS THE VERTICAL MASS FLUX RATE IN kg/s PER m WIDTH OF SEAFLOOR PLUS THE INITIAL
C CONCENTRATION x THE VOLUME FLUX OF WATER PER UNIT WIDTH OF SEAFLOOR.
C
        UA=SQRT(UAX*UAX+UAY*UAY)
        SED=VFLUX+CONC0/1000000.0*D*UA
C
C OTHERWISE:
C
C SED IS THE HORIZONTAL MASS FLUX RATE IN kg/s PER m^2 OF SEAFLOOR.
C       SED = HFLUX=CONC/1000000.0*D*UA
C WHICH MUST BE FOUND BY FINE TUNING THE CONCENTRATION WHICH CAN ONLY BE DONE BY KNOWING
C HOW TAUCRIT FOR EROSION CHANGES OVER TIME.
C
C CALCULATE THE NEW RESULTING SUSPENDED SEDIMENT CONCENTRATION
C SINCE SED=CONC/1000000.0*D*UA
        CONC=SED*1000000.0/(D*UA)
        RETURN
      ENDIF
      END
```

```
C*****************************************************************************************************
      SUBROUTINE OUTOUT(UB,AB,WL,FCW,UA,U100,PHIB,USTCSGM,USTWS,USTCWS,USTCW,
     @USTCRB,USTCRS,TS1,TB1,TS2,TB2,PERBED,PERSUSP,IOPT1,IOPT2,RK,SED,SEDM,SEDDIR,CONC)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE WRITES THE VALUES OF THE OUTPUT PARAMETERS FROM ALL
C SUBROUTINES
C
      WRITE (*,15)
      WRITE (7,15)
15    FORMAT(/,T4,'RESULTS:',/)
C
      WRITE (*,25) UB,AB,WL
      WRITE (7,25) UB,AB,WL
25    FORMAT(T11,'MAX. WAVE-INDUCED BOTTOM HORIZONTAL PARTICLE',/,T11,
     @'VELOCITY, FROM LINEAR WAVE THEORY',T56,'=',F7.2,' M/SEC',/,T11,
     @'MAX. WAVE-INDUCED BOTTOM HORIZONTAL PARTICLE',/,T11,
     @'DISPLACEMENT, FROM LINEAR WAVE THEORY',T56,'=',F8.2,' M',/,T11,
     @'WAVELENGTH, FROM LWT DISPERSION EQUATION =',F7.2,' M',/)
C
      WRITE (*,35) FCW
      WRITE (7,35) FCW
 35   FORMAT(T11,'BOTTOM FRICTION FACTOR =',F7.4)
      IF (UB .EQ. 0.0) THEN
        WRITE (*,45)
        WRITE (7,45)
45      FORMAT(T11,'(STERNBERG, 1971)')
      ELSE IF (UA .EQ. 0.0) THEN
        WRITE (*,55)
        WRITE (7,55)
55      FORMAT(T11,'(JONSSON, 1966)')
      ELSE IF (IOPT2.EQ.1) THEN
        WRITE (*,65)
        WRITE (7,65)
65      FORMAT(T11,'(GRANT AND MADSEN, 1979)')
      ELSE IF (IOPT2.EQ.2) THEN
        WRITE(*,66)
        WRITE (7,66)
66      FORMAT (T11,'(SMITH, 1977)')
        ENDIF
      ENDIF
C
      WRITE (*,75) U100,UA,PHIB*90./ASIN(1.)
      WRITE (7,75) U100,UA,PHIB*90./ASIN(1.)
75    FORMAT(T11,'CURRENT SPEED 1 M. ABOVE SEABED',T53,'=',F7.2,
     @' M/SEC',/,T11,'CURRENT SPEED TO BE USED IN BOTTOM STRESS',/,T11,
     @'CALCULATIONS',T53,'=',F7.2,' M/SEC',/,T11,
     @'ANGLE BETWEEN WAVE AND CURRENT DIRECTIONS',/,T11,
     @'WITHIN WAVE BOUNDARY LAYER',T53,'=',F7.2,' DEGREES',/,T11,
     @'NOTE:  THIS APPLIES TO MIXED FLOW CONDITIONS ONLY',/T11)
C
C FOR COHESIVE SEDIMENTS SKIP CALCULATED CRITICAL SHEAR STRESSES
      IF(IOPT1.EQ.7)GOTO 110
C
      WRITE (*,85) USTCRB,USTCRS
      WRITE (7,85) USTCRB,USTCRS
85    FORMAT(T11,'CRITICAL SHEAR VELOCITY FOR INITIATION OF',/,T11,
     @'BEDLOAD TRANSPORT',T53,'=',F7.4,' M/SEC',/,T11,
     @'CRITICAL SHEAR VELOCITY FOR INITIATION OF',/,T11,
```

```
      @'SUSPENDED LOAD TRANSPORT',T53,'=',F7.4,' M/SEC',/)
      IF (IOPT1 .EQ. 5) THEN
         WRITE (*,86)
         WRITE (7,86)
86       FORMAT(T11,'NOTE:  CRITICAL VELOCITY FOR BEDLOAD TRANSPORT ',
         @/,T17,'IS CALCULATED USING THE ACKERS-WHITE METHOD RATHER THAN',/,
         @T17,'THE SHIELDS CURVE.  THE CRITICAL VELOCITY FOR SUSPENDED',
         @/,T17,'LOAD TRANSPORT IS NOT USED AND HAS BEEN SET EQUAL TO THE'
         @,/,T17,'CRITICAL VELOCITY FOR BEDLOAD TRANSPORT',/)
      ENDIF
C
      WRITE (*,95) TS1,TB1,TS2,TB2
      WRITE (7,95) TS1,TB1,TS2,TB2
95    FORMAT(T11,'TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH',/,T11,
      @'SUSPENDED LOAD TRANSPORT CEASES',T54,'=',F6.2,' SEC',/,T11,
      @'TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH',/,T11,
      @'BEDLOAD TRANSPORT CEASES',T54,'=',F6.2,' SEC',/,T11,
      @'TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH',/,T11,
      @'SUSPENDED LOAD TRANSPORT RECOMMENCES       =',F6.2,' SEC',/,T11,
      @'TIME, AFTER PASSAGE OF WAVE CREST, AT WHICH',/,T11,
      @'BEDLOAD TRANSPORT RECOMMENCES              =',F6.2,' SEC',/)
C
      WRITE (*,105) PERBED,PERSUSP
      WRITE (7,105) PERBED,PERSUSP
105   FORMAT(T11,'PERCENT OF TIME IN ONLY BEDLOAD TRANSPORT PHASE =',F7.2,/,
      @T11,'PERCENT OF TIME IN SUSPENDED LOAD TRANSPORT PHASE =',F7.2,/)
C
110   CONTINUE
C
      WRITE (*,115) SEDDIR,SED,SEDM
      WRITE (7,115) SEDDIR,SED,SEDM
      WRITE (8,120) FCW,USTCS1,USTCSGM,USTWS,USTCWS,USTCW,SEDM
115   FORMAT(T11,'DIRECTION OF NET SEDIMENT TRANSPORT =',F7.2,
      @' DEGREES TRUE',/,T6,'TIME-AVERAGED NET SEDIMENT TRANSPORT =',
      @G12.4,' M**3/SEC/M '/T44,G12.4,' KG/SEC/M',/,T6)
120   FORMAT(F8.5,5F8.4,F10.6)
C
      IF (UA .NE. 0.0) THEN
         GOTO(123,133,143,153,163,173,183)IOPT1
C IOPT = 1
123   WRITE (*,125)
      WRITE (7,125)
125   FORMAT(T11,'(ENGELUND-HANSEN (1967) TOTAL LOAD EQUATION)')
      GOTO 190
C IOPT1 = 2
133   WRITE (*,135)
      WRITE (7,135)
135   FORMAT(T11,'(EINSTEIN-BROWN (1950) BEDLOAD EQUATION)')
      GOTO 190
C IOPT1 = 3
143   IF (UB .EQ. 0.0) THEN
         WRITE (*,145) RK
         WRITE (7,145) RK
145      FORMAT(T11,'(MODIFIED BAGNOLD (GADD, 1978) BEDLOAD EQUATION'/
      @ T11,' EFFICIENCY FACTOR, K = ',F4.2)
      ELSE
         WRITE (*,146) RK
         WRITE (7,146) RK
146      FORMAT(T11,'(BAGNOLD (1963) TOTAL LOAD EQUATION)'/
```

```
     @ T11,' EFFICIENCY FACTOR, K = ',F4.2)
     ENDIF
     GOTO 190
C IOPT1 = 4
153  WRITE (*,155)
     WRITE (7,155)
155  FORMAT(T11,'(YALIN (1963) BEDLOAD EQUATION)')
     GOTO 190
C IOPT1 = 5
163  WRITE (*,165)
     WRITE (7,165)
165  FORMAT (T11,'(ACKERS-WHITE TOTAL LOAD EQUATION)')
     GOTO 190
C IOPT1 = 6
173  WRITE (*,175)
     WRITE (7,175)
175  FORMAT (T11,'(SMITH (1977) SUSPENDED LOAD EQUATION)')
     GOTO 190
C IOPT1 = 7
183  WRITE (*,185)
     WRITE (7,185)
185  FORMAT (T11,'AMOS and GREENBERG (1980) COHESIVE SEDIMENT SUSPENDED LOAD')
     WRITE (*,186)CONC
     WRITE (7,186)CONC
186  FORMAT (T11,'CALCULATED SEDIMENT CONCENTRATION (ppm) (ie mg/l) = ',1P,E8.2) C
190  CONTINUE
C
     IF (IOPT2.EQ.1) THEN
        WRITE (*,195)
        WRITE (7,195)
195     FORMAT (T11,' FRICTION FACTOR FROM GRANT & MADSEN (1979) ',
     @ ' '/T11,' (FOR WAVE-DOMINATED FLOWS)')
     ELSE IF (IOPT2.EQ.2) THEN
        WRITE (*,196)
        WRITE (7,196)
196     FORMAT (T11,' FRICTION FACTOR FROM SMITH (1977) ',
     @ ' '/T11,' (FOR CURRENT-DOMINATED FLOWS)')
        ENDIF
     ENDIF
C
     RETURN
     END
```

```
C****************************************************************************************************
      SUBROUTINE BEDFORM(U100,UA,UB,GD,FCW,PHIB,RHOW,RHOS,AB,IOPT1)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C
C THIS SUBROUTINE PREDICTS THE EXPECTED TYPE OF BEDFORM FOR THE GIVEN FLOW CONDITIONS. THE
C BEDFORM TYPE IS ONLY APPROXIMATE SINCE IT IS BASED ON A VELOCITY MEASUREMENT ONLY. THE
C LIMITS ARE FROM AMOS (1990). RIPPLE DIMENSION IS ALSO PREDICTED FOR FINE AND MEDIUM SANDS.
C
      PI   = 2.*ASIN(1.)
      G    = 9.81
      VISK = 1.3D-3/RHOW
C
C INPUT VARIABLES:
C
C     U100 = CURRENT SPEED AT 1 M. ABOVE SEABED ( M/SEC)
C     UA = MEAN VELOCITY AT TOP OF THE WAVE BOUNDARY LAYER (M/SEC)
C     UB = MAXIMUM WAVE-INDUCED BOTTOM PARTICLE VELOCITY (M/SEC)
C     AB = EXCURSION LENGTH OF BOTTOM WAVE ORBIT (M)
C     FCW = BOTTOM (SKIN) FRICTION FACTOR
C     GD = SEDIMENT GRAIN SIZE (M)
C
C SKIP THE BEDFORM SECTION IF SEDIMENTS ARE COHESIVE
      IF (IOPT1.EQ.7) GOTO 1000
C
C SET UP FORMAT STATEMENTS
C
      WRITE (*,15)
      WRITE (7,15)
15    FORMAT(//,T11,'EXPECTED BEDFORMS ARE (C. L. AMOS):',/)
C
C WAVES ONLY
20    FORMAT(T21,'WAVE INDUCED BEDFORMS:')
25    FORMAT(T21,'WAVE RIPPLES')
30    FORMAT(T21,'WAVE RIPPLES OR WAVE-INDUCED (UPPER) FLAT BED')
35    FORMAT(T21,'WAVE-INDUCED (UPPER) FLAT BED')
C
C CURRENTS ONLY
40    FORMAT(T21,'CURRENT INDUCED BEDFORMS:')
45    FORMAT(T21,'CURRENT RIPPLES')
55    FORMAT(T21,'FLAT BED (LOWER)')
65    FORMAT(T21,'FLAT BED (LOWER) OR 2-D MEGARIPPLES')
75    FORMAT(T21,'FLAT BED (LOWER) OR 2-D MEGARIPPLES OR SAND WAVES')
85    FORMAT(T21,'2-D MEGARIPPLES')
95    FORMAT(T21,'2-D MEGARIPPLES OR SAND WAVES')
105   FORMAT(T21,'SAND WAVES')
115   FORMAT(T21,'SAND WAVES OR 3-D MEGARIPPLES')
125   FORMAT(T21,'3-D MEGARIPPLES')
135   FORMAT(T21,'FLAT BED (UPPER) AND SAND RIBBONS')
145   FORMAT(T21,'SEDIMENT IN SUSPENSION')
C
C CURRENTS AND WAVES
155   FORMAT(T21,'NO TRANSPORT')
156   FORMAT(T21,'NO TRANSPORT  FLAT BED')
165   FORMAT(T21,'BEDFORMS UNKNOWN FOR CO-DIRECTIONAL MIXED FLOW CONDITIONS BUT:')
166   FORMAT(T21,'WORK BY AMOS ET AL (1987) SHOWS THAT INDEPENDENT',/,
     &T21,'WAVE AND CURRENT BEDFORMS MAY EXIST WHICH WOULD BE:',/)
175   FORMAT(T21,'POSSIBLE GRAVEL RIPPLES (E.G. .2 M HIGH & 2 M LONG)'
     &,/,T21,'(SEE D.L. FORBES OF AGC FOR FURTHER DETAIL)')
185   FORMAT(T21,'BEDFORM DIMENSIONS NOT YET AVAILABLE')
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```
265  FORMAT(T21,'BEDFORMS UNKNOWN FOR ORTHOGONAL MIXED FLOW CONDITIONS
     &',/,T21,'FOR OTHER THAN FINE-MEDIUM SAND BUT:')
266  FORMAT(T21,'WORK BY AMOS ET AL (1987) SHOWS THAT INDEPENDENT',/,
     &T21,'WAVE AND CURRENT BEDFORMS EXIST WHICH ARE:',/)
405  FORMAT(T21,'VERY COARSE SAND (WENTWORTH SCALE)')
415  FORMAT(T21,'COARSE SAND (WENTWORTH SCALE)')
425  FORMAT(T21,'MEDIUM SAND (WENTWORTH SCALE)')
435  FORMAT(T21,'FINE SAND (WENTWORTH SCALE)')
445  FORMAT(T21,'VERY FINE SAND OR CLAY OR SILT (WENTWORTH SCALE)'
     &,/,T21,'NO BEDFORM DATA AVAILABLE')
C
C GRANULE AND GRAVEL SIZES (WENTWORTH SCALE) ANY FLOW CONDITIONS
C
     IF (GD .GT. 0.002) THEN
        WRITE(7,175)
        WRITE(*,175)
        RETURN
     ENDIF
C
C VERY FINE SAND OR CLAY OR SILT (WENTWORTH SCALE)
C
     IF (GD .LE. 0.000125) THEN
        WRITE(7,445)
        WRITE(*,445)
        RETURN
     ENDIF
C
C SINCE THE GRAIN SIZE CLASSIFICATION IS BASED ON THE WENTWORTH SCALE WHICH IS BASED ON PHI
C SIZES, THE PHI UNITS CAN BE USED TO DIRECT THIS COMPUTER CODE.
C
     CONV=4.D0/DLOG(0.0625D0)
C PHI IS THE NEXT HIGHEST PHI UNIT (IE FINE SAND =3, MEDIUM SAND =2, COARSE SAND =1,
C VERY COARSE SAND =0)
C
C WSP = WAVE SKIN-FRICTION SHIELD'S PARAMETER
C CSP = CURRENT SKIN-FRICTION SHIELD'S PARAMETER
C
     WSP=RHOW*FCW*UB*UB/(2.*(RHOS-RHOW)*G*GD)
     CSP=RHOW*0.006*UA*UA/(2.*(RHOS-RHOW)*G*GD)
     PHI=CONV*DLOG(1000.D0*GD/2.D0)
     GOTO (1,2,3,4)INT(PHI+1)
1    CONTINUE
C
C VERY COARSE SAND (WENTWORTH SCALE)
C
     WRITE(7,405)
     WRITE(*,405)
     WRITE(7,185)
     WRITE(*,185)
C FIRST, CHECK FOR COMBINED FLOW CONDITIONS
     IF (UB.NE.0. .AND. UA.NE.0.) THEN
C MIXED FLOWS
        IF (PHIB*180/PI .LE. 45.) THEN
C CO-DIRECTIONAL WAVES AND CURRENTS
           WRITE (*,165)
           WRITE (7,165)
           WRITE (*,166)
           WRITE (7,166)
        ELSE
```

```
C ORTHOGONAL WAVES AND CURRENTS
          WRITE (*,265)
          WRITE (7,265)
          WRITE (*,166)
          WRITE (7,166)
        ENDIF
C PREDICT BEDFORM TYPES BASED ON THE RATIO OF WSP/CSP
        IF (WSP/CSP .GE. 1) THEN
C WAVE-DOMINANT BEDFORMS
          WRITE (*,512)
          WRITE (7,512)
          IF (UB .LT. 0.3) WRITE (*,155)
          IF (UB .LT. 0.3) WRITE (7,155)
          IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (*,25)
          IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (7,25)
          IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (*,30)
          IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (7,30)
          IF (UB .GE. 2.0) WRITE (*,35)
          IF (UB .GE. 2.0) WRITE (7,35)
        ELSE
C CURRENT-DOMINANT BEDFORMS
          WRITE (*,505)
          WRITE (7,505)
          IF (U100 .LT. 0.4) WRITE (*,155)
          IF (U100 .LT. 0.4) WRITE (7,155)
          IF (U100 .GE. 0.4 .AND. U100 .LE. 0.45) WRITE (*,95)
          IF (U100 .GE. 0.4 .AND. U100 .LE. 0.45) WRITE (7,95)
          IF (U100 .GE. 0.45 .AND. U100 .LE. 0.5) WRITE (*,75)
          IF (U100 .GE. 0.45 .AND. U100 .LE. 0.5) WRITE (7,75)
          IF (U100 .GE. 0.5 .AND. U100 .LE. 0.6) WRITE (*,95)
          IF (U100 .GE. 0.5 .AND. U100 .LE. 0.6) WRITE (7,95)
          IF (U100 .GE. 0.6 .AND. U100 .LE. 1.0) WRITE (*,105)
          IF (U100 .GE. 0.6 .AND. U100 .LE. 1.0) WRITE (7,105)
          IF (U100 .GE. 1.0 .AND. U100 .LE. 2.95) WRITE (*,135)
          IF (U100 .GE. 1.0 .AND. U100 .LE. 2.95) WRITE (7,135)
          IF (U100 .GE. 2.95) WRITE (*,145)
          IF (U100 .GE. 2.95) WRITE (7,145)
        ENDIF
      ENDIF
C
C PURE WAVE CASE
      IF (UB .NE. 0.0) THEN
        WRITE (*,20)
        WRITE (7,20)
        IF (UB .LT. 0.3) WRITE (*,155)
        IF (UB .LT. 0.3) WRITE (7,155)
        IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (*,25)
        IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (7,25)
        IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (*,30)
        IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (7,30)
        IF (UB .GE. 2.0) WRITE (*,35)
        IF (UB .GE. 2.0) WRITE (7,35)
      ENDIF
C
C PURE CURRENT CASE
      IF (UA .NE. 0.0) THEN
        WRITE (*,40)
        WRITE (7,40)
        IF (U100 .LT. 0.4) WRITE (*,155)
```

```
        IF (U100 .LT. 0.4) WRITE (7,155)
        IF (U100 .GE. 0.4 .AND. U100 .LE. 0.45) WRITE (*,95)
        IF (U100 .GE. 0.4 .AND. U100 .LE. 0.45) WRITE (7,95)
        IF (U100 .GE. 0.45 .AND. U100 .LE. 0.5) WRITE (*,75)
        IF (U100 .GE. 0.45 .AND. U100 .LE. 0.5) WRITE (7,75)
        IF (U100 .GE. 0.5 .AND. U100 .LE. 0.6) WRITE (*,95)
        IF (U100 .GE. 0.5 .AND. U100 .LE. 0.6) WRITE (7,95)
        IF (U100 .GE. 0.6 .AND. U100 .LE. 1.0) WRITE (*,105)
        IF (U100 .GE. 0.6 .AND. U100 .LE. 1.0) WRITE (7,105)
        IF (U100 .GE. 1.0 .AND. U100 .LE. 2.95) WRITE (*,135)
        IF (U100 .GE. 1.0 .AND. U100 .LE. 2.95) WRITE (7,135)
        IF (U100 .GE. 2.95) WRITE (*,145)
        IF (U100 .GE. 2.95) WRITE (7,145)
      ENDIF
      RETURN
C
2     CONTINUE
C
C COARSE SAND (WENTWORTH SCALE)
C
      WRITE(7,415)
      WRITE(*,415)
      WRITE(7,185)
      WRITE(*,185)
C FIRST, CHECK FOR COMBINED FLOW CONDITIONS
      IF (UB.NE.0. .AND. UA.NE.0.) THEN
C MIXED FLOWS
        IF (PHIB*180/PI .LE. 45.) THEN
C CO-DIRECTIONAL WAVES AND CURRENTS
          WRITE (*,165)
          WRITE (7,165)
          WRITE (*,166)
          WRITE (7,166)
        ELSE
C ORTHOGONAL WAVES AND CURRENTS
          WRITE (*,265)
          WRITE (7,265)
          WRITE (*,166)
          WRITE (7,166)
        ENDIF
C PREDICT BEDFORM TYPES BASED ON THE RATIO OF WSP/CSP
        IF (WSP/CSP .GE. 1) THEN
C WAVE-DOMINANT BEDFORMS
          WRITE (*,512)
          WRITE (7,512)
          IF (UB .LT. 0.3) WRITE (*,155)
          IF (UB .LT. 0.3) WRITE (7,155)
          IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (*,25)
          IF (UB .GE. 0.3 .AND. UB .LT. 1.0) WRITE (7,25)
          IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (*,30)
          IF (UB .GE. 1.0 .AND. UB .LT. 2.0) WRITE (7,30)
          IF (UB .GE. 2.0) WRITE (*,35)
          IF (UB .GE. 2.0) WRITE (7,35)
        ELSE
C CURRENT-DOMINANT BEDFORMS
          WRITE (*,505)
          WRITE (7,505)
          IF (U100 .LT. 0.25) WRITE (*,155)
          IF (U100 .LT. 0.25) WRITE (7,155)
```

```
          IF (U100 .GE. 0.25 .AND. U100 .LT. 0.35) WRITE (*,45)
          IF (U100 .GE. 0.25 .AND. U100 .LT. 0.35) WRITE (7,45)
          IF (U100 .GE. 0.35 .AND. U100 .LT. 0.4) WRITE (*,55)
          IF (U100 .GE. 0.35 .AND. U100 .LT. 0.4) WRITE (7,55)
          IF (U100 .GE. 0.4 .AND. U100 .LT. 0.45) WRITE (*,65)
          IF (U100 .GE. 0.4 .AND. U100 .LT. 0.45) WRITE (7,65)
          IF (U100 .GE. 0.45 .AND. U100 .LT. 0.5) WRITE (*,85)
          IF (U100 .GE. 0.45 .AND. U100 .LT. 0.5) WRITE (7,85)
          IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (*,95)
          IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (7,95)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (*,115)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (7,115)
          IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (*,125)
          IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (7,125)
          IF (U100 .GE. 1.5 .AND. U100 .LT. 2.4) WRITE (*,135)
          IF (U100 .GE. 1.5 .AND. U100 .LT. 2.4) WRITE (7,135)
          IF (U100 .GE. 2.4) WRITE (*,145)
          IF (U100 .GE. 2.4) WRITE (7,145)
        ENDIF
      ENDIF
C
C  PURE WAVE CASE
      IF (UB .NE. 0.0) THEN
        WRITE (*,20)
        WRITE (7,20)
        IF (UB .LT. 0.2) WRITE (*,155)
        IF (UB .LT. 0.2) WRITE (7,155)
        IF (UB .GE. 0.2 .AND. UB .LT. 0.9) WRITE (*,25)
        IF (UB .GE. 0.2 .AND. UB .LT. 0.9) WRITE (7,25)
        IF (UB .GE. 0.9 .AND. UB .LT. 1.25) WRITE (*,30)
        IF (UB .GE. 0.9 .AND. UB .LT. 1.25) WRITE (7,30)
        IF (UB .GE. 1.25) WRITE (*,35)
        IF (UB .GE. 1.25) WRITE (7,35)
      ENDIF
C
C  PURE CURRENT CASE
      IF (UA .NE. 0.0) THEN
        WRITE (*,40)
        WRITE (7,40)
        IF (U100 .LT. 0.25) WRITE (*,155)
        IF (U100 .LT. 0.25) WRITE (7,155)
        IF (U100 .GE. 0.25 .AND. U100 .LT. 0.35) WRITE (*,45)
        IF (U100 .GE. 0.25 .AND. U100 .LT. 0.35) WRITE (7,45)
        IF (U100 .GE. 0.35 .AND. U100 .LT. 0.4) WRITE (*,55)
        IF (U100 .GE. 0.35 .AND. U100 .LT. 0.4) WRITE (7,55)
        IF (U100 .GE. 0.4 .AND. U100 .LT. 0.45) WRITE (*,65)
        IF (U100 .GE. 0.4 .AND. U100 .LT. 0.45) WRITE (7,65)
        IF (U100 .GE. 0.45 .AND. U100 .LT. 0.5) WRITE (*,85)
        IF (U100 .GE. 0.45 .AND. U100 .LT. 0.5) WRITE (7,85)
        IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (*,95)
        IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (7,95)
        IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (*,115)
        IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (7,115)
        IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (*,125)
        IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (7,125)
        IF (U100 .GE. 1.5 .AND. U100 .LT. 2.4) WRITE (*,135)
        IF (U100 .GE. 1.5 .AND. U100 .LT. 2.4) WRITE (7,135)
        IF (U100 .GE. 2.4) WRITE (*,145)
        IF (U100 .GE. 2.4) WRITE (7,145)
```

```
      ENDIF
      RETURN
C
3     CONTINUE
C
C MEDIUM SAND (WENTWORTH SCALE)
C
      WRITE(7,425)
      WRITE(*,425)
C
C FIRST, CHECK FOR COMBINED FLOW CONDITIONS. IF NOT, GO TO 31
      IF(UB.EQ.0. .OR. UA.EQ.0.) GOTO 31
C ORTHOGONAL WAVES AND CURRENTS
      IF (PHIB*180/PI .GT. 45.) GOTO 42
C CO-DIRECTIONAL WAVES AND CURRENTS
      WRITE (*,165)
      WRITE (7,165)
      WRITE (*,166)
      WRITE (7,166)
C PREDICT BEDFORM TYPES BASED ON THE RATIO OF WSP/CSP
      IF (WSP/CSP .GE. 1) THEN
C WAVE-DOMINANT BEDFORMS
         WRITE (*,512)
         WRITE (7,512)
         IF (UB .LT. 0.13) WRITE (*,155)
         IF (UB .LT. 0.13) WRITE (7,155)
         IF (UB .GE. 0.13 .AND. UB .LT. 0.8) WRITE (*,25)
         IF (UB .GE. 0.13 .AND. UB .LT. 0.8) WRITE (7,25)
         IF (UB .GE. 0.8 .AND. UB .LT. 1.0) WRITE (*,30)
         IF (UB .GE. 0.8 .AND. UB .LT. 1.0) WRITE (7,30)
         IF (UB .GE. 1.0) WRITE (*,35)
         IF (UB .GE. 1.0) WRITE (7,35)
C FOR WAVE RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
         GOTO 43
      ELSE
C CURRENT-DOMINANT BEDFORMS
         WRITE (*,505)
         WRITE (7,505)
         IF (U100 .LT. 0.2) WRITE (*,155)
         IF (U100 .LT. 0.2) WRITE (7,155)
         IF (U100 .GE. 0.2 .AND. U100 .LT. 0.5) WRITE (*,45)
         IF (U100 .GE. 0.2 .AND. U100 .LT. 0.5) WRITE (7,45)
         IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (*,85)
         IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (7,85)
         IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (*,115)
         IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (7,115)
         IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (*,125)
         IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (7,125)
         IF (U100 .GE. 1.5 .AND. U100 .LT. 1.7) WRITE (*,135)
         IF (U100 .GE. 1.5 .AND. U100 .LT. 1.7) WRITE (7,135)
         IF (U100 .GE. 1.7) WRITE (*,145)
         IF (U100 .GE. 1.7) WRITE (7,145)
C FOR CURRENT RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 44
         GOTO 44
      ENDIF
C
C PURE WAVE CASE
31    CONTINUE
      IF (UB .NE. 0.0) THEN
```

```
          WRITE (*,20)
          WRITE (7,20)
          IF (UB .LT. 0.13) WRITE (*,155)
          IF (UB .LT. 0.13) WRITE (7,155)
          IF (UB .GE. 0.13 .AND. UB .LT. 0.8) WRITE (*,25)
          IF (UB .GE. 0.13 .AND. UB .LT. 0.8) WRITE (7,25)
          IF (UB .GE. 0.8 .AND. UB .LT. 1.0) WRITE (*,30)
          IF (UB .GE. 0.8 .AND. UB .LT. 1.0) WRITE (7,30)
          IF (UB .GE. 1.0) WRITE (*,35)
          IF (UB .GE. 1.0) WRITE (7,35)
C FOR WAVE RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
      ENDIF
C
C PURE CURRENT CASE
      IF (UA .NE. 0.0) THEN
          WRITE (*,40)
          WRITE (7,40)
          IF (U100 .LT. 0.2) WRITE (*,155)
          IF (U100 .LT. 0.2) WRITE (7,155)
          IF (U100 .GE. 0.2 .AND. U100 .LT. 0.5) WRITE (*,45)
          IF (U100 .GE. 0.2 .AND. U100 .LT. 0.5) WRITE (7,45)
          IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (*,85)
          IF (U100 .GE. 0.5 .AND. U100 .LT. 0.6) WRITE (7,85)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (*,115)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 1.0) WRITE (7,115)
          IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (*,125)
          IF (U100 .GE. 1.0 .AND. U100 .LT. 1.5) WRITE (7,125)
          IF (U100 .GE. 1.5 .AND. U100 .LT. 1.7) WRITE (*,135)
          IF (U100 .GE. 1.5 .AND. U100 .LT. 1.7) WRITE (7,135)
          IF (U100 .GE. 1.7) WRITE (*,145)
          IF (U100 .GE. 1.7) WRITE (7,145)
C FOR CURRENT RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 44
          GOTO 44
      ENDIF
      RETURN
C
4     CONTINUE
C
C FINE SAND (WENTWORTH SCALE)
C
      WRITE(7,435)
      WRITE(*,435)
C
C FIRST, CHECK FOR COMBINED FLOW CONDITIONS. IF NOT, GO TO 41.
      IF (UB.EQ.0. .OR. UA.EQ.0.) GOTO 41
C ORTHOGONAL WAVES AND CURRENTS
      IF (PHIB*180/PI .GT. 45.) GOTO 42
C CO-DIRECTIONAL WAVES AND CURRENTS
      WRITE (*,165)
      WRITE (7,165)
      WRITE (*,166)
      WRITE (7,166)
C PREDICT BEDFORM TYPES BASED ON THE RATIO OF WSP/CSP
      IF (WSP/CSP .GE. 1) THEN
C WAVE-DOMINANT BEDFORMS
          WRITE (*,512)
          WRITE (7,512)
          IF (UB .LT. 0.1) WRITE (*,155)
```

```
          IF (UB .LT. 0.1) WRITE (7,155)
          IF (UB .GE. 0.1 .AND. UB .LT. 0.7) WRITE (*,25)
          IF (UB .GE. 0.1 .AND. UB .LT. 0.7) WRITE (7,25)
          IF (UB .GE. 0.7) WRITE (*,35)
          IF (UB .GE. 0.7) WRITE (7,35)
C FOR WAVE RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
      ELSE
C CURRENT-DOMINANT BEDFORMS
          WRITE (*,505)
          WRITE (7,505)
          IF (U100 .LT. 0.13) WRITE (*,155)
          IF (U100 .LT. 0.13) WRITE (7,155)
          IF (U100 .GE. 0.13 .AND. U100 .LT. 0.6) WRITE (*,45)
          IF (U100 .GE. 0.13 .AND. U100 .LT. 0.6) WRITE (7,45)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 0.85) WRITE (*,135)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 0.85) WRITE (7,135)
          IF (U100 .GE. 0.85) WRITE (*,145)
          IF (U100 .GE. 0.85) WRITE (7,145)
C FOR CURRENT RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 44
          GOTO 44
      ENDIF
C
C PURE WAVE CASE
41    IF (UB .NE. 0.0) THEN
          IF (UB .LT. 0.1) WRITE (*,155)
          IF (UB .LT. 0.1) WRITE (7,155)
          IF (UB .GE. 0.1 .AND. UB .LT. 0.7) WRITE (*,25)
          IF (UB .GE. 0.1 .AND. UB .LT. 0.7) WRITE (7,25)
          IF (UB .GE. 0.7) WRITE (*,35)
          IF (UB .GE. 0.7) WRITE (7,35)
C FOR WAVE RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
      ENDIF
C
C PURE CURRENT CASE
      IF (UB .EQ. 0.0) THEN
          IF (U100 .LT. 0.13) WRITE (*,155)
          IF (U100 .LT. 0.13) WRITE (7,155)
          IF (U100 .GE. 0.13 .AND. U100 .LT. 0.6) WRITE (*,45)
          IF (U100 .GE. 0.13 .AND. U100 .LT. 0.6) WRITE (7,45)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 0.85) WRITE (*,135)
          IF (U100 .GE. 0.6 .AND. U100 .LT. 0.85) WRITE (7,135)
          IF (U100 .GE. 0.85) WRITE (*,145)
          IF (U100 .GE. 0.85) WRITE (7,145)
C FOR CURRENT RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 44
          GOTO 44
      ENDIF
C
42    CONTINUE
C
C ORTHOGONAL WAVES AND CURRENTS
      WRITE (*,266)
      WRITE (7,266)
      IF ((WSP+CSP).GT.1.0) THEN
C BEYOND DATA RANGE, UPPER FLAT BED IS POSSIBLE.
          WRITE(*,508)
          WRITE(7,508)
          RETURN
```

```
      ENDIF
      IF ((WSP+CSP).LT.0.04) THEN
C NO TRANSPORT, LOWER FLAT BED.
        WRITE(*,156)
        WRITE(7,156)
      ELSE
        IF (WSP/CSP.LT.1.) THEN
C CURRENT-DOMINANT RIPPLES
          WRITE(*,505)
          WRITE(7,505)
          IF ((WSP+CSP).GT.0.08) THEN
          WRITE(*,506)
          WRITE(7,506)
          ELSE
          WRITE(*,507)
          WRITE(7,507)
          ENDIF
C FOR RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
        ENDIF
        WSPP=DEXP(1.314D0*DLOG(CSP)+1.8212D0)
        IF (WSP.LT.WSPP) THEN
C CURRENT RIPPLES WITH SUBORDINATE WAVE RIPPLES
          WRITE(*,509)
          WRITE(7,509)
C FOR RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
        ENDIF
        WSPP=DEXP(1.52D0*DLOG(CSP)+3.49D0)
        IF (WSP.LT.WSPP) THEN
C WAVE AND CURRENT RIPPLES
          WRITE(*,510)
          WRITE(7,510)
C FOR RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
        ENDIF
        WSPP=DEXP(3.322D0*DLOG(CSP)+15.3D0)
        IF (WSP.LT.WSPP) THEN
C WAVE RIPPLES WITH SUBORDINATE CURRENT RIPPLES
          WRITE(*,511)
          WRITE(7,511)
C FOR RIPPLE HEIGHT AND LENGTH PREDICTION, GO TO 43
          GOTO 43
        ENDIF
C WAVE-DOMINANT RIPPLES
        WRITE(*,512)
        WRITE(7,512)
      ENDIF
C
C CHECK FOR POORLY-DEVELOPED RIPPLES
43    IF (CSP.LT.0.04 .AND. (WSP+CSP).GE.0.04 .AND. (WSP+CSP).LT.0.18 ) THEN
        WRITE(*,513)
        WRITE(7,513)
      ENDIF
C ESTIMATE RIPPLE DIMENSIONS (RIPPLE LENGTH, RL, FROM BOYD ET AL, 1988 AND RIPPLE HEIGHT, RH,
C FROM ALLEN, 1970).
      RL=AB*557*(UB*AB/VISK)**(-0.68)
      RH=0.00074*(100.*RL)**1.19
      WRITE(*,605)RL,RH
```

```
      WRITE(7,605)RL,RH
      GOTO 1010
C
C ESTIMEAT DIMENSIONS OF CURRENT OR CURRENT-DOMINANT RIPPLES AFTER YALIN (1964) AND
C ALLEN (1970)
C
44    RL=1000*GD
      RH=0.00074*(100.*RL)**1.19
      WRITE(*,610)RL,RH
      WRITE(7,610)RL,RH
      GOTO 1010
C
505   FORMAT(T21,'CURRENT RIPPLES DOMINATE')
506   FORMAT(T21,'LINGUOID FORMS DOMINATE')
507   FORMAT(T21,'STRAIGHT CRESTED AND LINGUOID FORMS PRESENT')
508   FORMAT(T21,'BEYOND DATA RANGE.',/,T21,'POSSIBLE WAVE/CURRENT INDUC
     &ED FLAT BED',/,T21,'AND/OR SEDIMENT IN SUSPENSION')
509   FORMAT(T21,'CURRENT RIPPLES WITH SUBORDINATE WAVE RIPPLES')
510   FORMAT(T21,'WAVE AND CURRENT RIPPLES')
511   FORMAT(T21,'WAVE RIPPLES WITH SUBORDINATE CURRENT RIPPLES')
512   FORMAT(T21,'WAVE RIPPLES DOMINATE')
513   FORMAT(T21,'POORLY DEVELOPED RIPPLES MAY EXIST DEPENDING ON',/,T21
     &,'LOCAL BIOTURBATION RATES AND BROADNESS OF WAVE SPECTRUM')
605   FORMAT(T21,'WAVE RIPPLE LENGTH FROM BOYD ET AL (1988) = ',F7.3,' M',
     &/,T21,'WAVE RIPPLE HEIGHT FROM ALLEN (1970)        = ',F7.3,' M')
610   FORMAT(T21,'CURRENT RIPPLE LENGTH FROM YALIN (1964) = ',F7.3,' M',
     &/,T21,' RIPPLE HEIGHT FROM ALLEN (1970)        = ',F7.3,'M')
1000  WRITE (*,1005)
      WRITE (7,1005)
1005  FORMAT(//,T11,'NO BEDFORMS ESTIMATES FOR COHESIVE SEDIMENTS ')
1010  RETURN
      END
```

APPENDIX 2

THE SMITH METHOD

APPENDIX 2. THE SMITH METHOD

The Smith (1977) method is for computing boundary shear stress and suspended sediment transport rates under current-dominant combined flow conditions. This appendix gives general expressions and computation procedures of the method. Detailed theory and equation derivations can be found in Smith (1977) and Martec (1987).

Friction Factor and Shear Stress Computation

The equation governing uniform flow near the seabed due to combined waves and currents is:

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\partial}{\partial z}\left(k_z\frac{\partial u}{\partial z}\right) \qquad (1)$$

The boundary conditions are:

$$u \rightarrow u_\infty(t) \qquad \text{as } z \rightarrow \infty \qquad (2a)$$

$$u \rightarrow 0 \qquad \text{as } z \rightarrow z_o \qquad (2b)$$

where u is the velocity, p is the pressure, t is the time, z_o is the bottom roughness length and k_z is the kinematic eddy viscosity as a function of depth z. The momentum equation can be separated into two parts, the steady components and the unsteady components:

$$0 = \frac{\partial}{\partial z} k_z \frac{\partial u_c}{\partial z} \qquad (3)$$

$$\frac{\partial u_w}{\partial t} = \frac{\partial u_\infty}{\partial t} + \frac{\partial}{\partial z} k_z \frac{\partial u_w}{\partial z} \qquad (4)$$

where u_c is the current velocity, u_w is the wave velocity and u_∞ is the wave velocity outside of the boundary layer.

For pure current case, the kinematic eddy viscosity is assumed to be $k_z = \kappa z u_{*c}$, where κ is the von Karman constant and u_{*c} is the current shear velocity. With this assumption, the solution to equation (3) is given as:

$$u_c = \frac{u_{*c}}{\kappa} \ln \frac{z}{z_o} \qquad (5)$$

For pure wave case, the eddy viscosity is described by $k_z = \kappa z u_{*w}$, where u_{*w} is the wave shear velocity. With this, the solution to equation (4) is given in terms of zero order Kelvin functions ker and kei:

$$u_w = u_b[\cos\omega t - \frac{(\text{ker}\xi)(\text{ker}\xi_o) + (\text{kei}\xi)(\text{kei}\xi_o)}{\text{ker}^2\xi_o + \text{kei}^2\xi_o}\cos\omega t$$

$$- \frac{(\text{ker}\xi)(\text{kei}\xi_o) - (\text{kei}\xi)(\text{ker}\xi_o)}{\text{ker}^2\xi_o + \text{kei}^2\xi_o}\sin\omega t] \qquad (6)$$

where u_b is the maximum bottom wave orbital velocity, ω is the wave frequency, $\xi = 2(\omega z/k_o)^{1/2}$, $\xi_o = 2(\omega z_o/k_o)^{1/2}$ and $k_o = \kappa u_{*w}$. Tabulated zero order Kelvin functions ker and kei can be found in Abramowitz and Stegun (1964).

When waves and currents co-exist, the eddy viscosity is assumed to be due to the sum of the current and wave shear velocities:

$$k_z = \kappa(u_{*c} + u_{*w})z \qquad (7)$$

With this eddy viscosity, the steady component solution to equation (3) is:

$$u_c = \frac{u_{*c}}{\kappa}(1 + \frac{u_{*w}}{u_{*c}})^{-1}\ln\frac{z}{z_o} \qquad (8)$$

and the unsteady component solution to equation (4) is:

$$u_w = u_b[\cos\omega t - \frac{(\text{ker}\xi)(\text{ker}\xi_o) + (\text{kei}\xi)(\text{kei}\xi_o)}{\text{ker}^2\xi_o + \text{kei}^2\xi_o}\cos\omega t$$

$$- \frac{(\text{ker}\xi)(\text{kei}\xi_o) - (\text{kei}\xi)(\text{ker}\xi_o)}{\text{ker}^2\xi_o + \text{kei}^2\xi_o}\sin\omega t] \qquad (9)$$

where ξ and ξ_o are the same as given above, but a new k_o is given $k_o = \kappa(u_{*c}+u_{*w})$. The combined velocity near the seabed is:

$$u = u_c + u_w \qquad (10)$$

This combined velocity reaches a maximum when $\partial u/\partial t=0$ or:

$$t_m = \frac{1}{\omega}\tan^{-1}\frac{F_2(\xi,\xi_o)}{1-F_1(\xi,\xi_o)} \qquad (11)$$

and the maximum velocity is given as:

$$u_m = \frac{u_{*c}}{\kappa}(1 + \frac{u_{*w}}{u_{*c}})^{-1}\ln\frac{z}{z_o} + u_b[\cos\omega t_m$$

$$- F_1(\xi,\xi_o)\cos\omega t_m + F_2(\xi,\xi_o)\sin\omega t_m] \quad (12)$$

where:

$$F_1(\xi,\xi_o) = \frac{(\ker\xi)(\ker\xi_o) + (\mathrm{kei}\,\xi)(\mathrm{kei}\,\xi_o)}{\ker^2\xi_o + \mathrm{kei}^2\xi_o} \quad (13a)$$

$$F_2(\xi,\xi_o) = \frac{(\ker\xi)(\mathrm{kei}\,\xi_o) - (\mathrm{kei}\,\xi)(\ker\xi_o)}{\ker^2\xi_o + \mathrm{kei}^2\xi_o} \quad (13b)$$

Since boundary shear stress is

$$\tau_b = \rho k_o z \frac{\partial u}{\partial z}\Big|_{zo} = \rho u_*^2 \quad (14)$$

Differentiating u and setting $z=z_o$ gives us the shear velocity:

$$u_* = \{\frac{k_o\, u_{*c}}{\kappa}(1+\frac{u_{*w}}{u_{*c}})^{-1} + \frac{k_o u_b \xi_o}{2}\{[F_1'(\xi_o)]^2 + [F_2'(\xi_o)]^2\}^{1/2}$$

$$\cos[\omega t + \tan^{-1}(\frac{F_2'(\xi_o)}{F_1'(\xi_o)})]\}^{1/2} \quad (15)$$

where

$$F_1'(\xi_o) = \frac{(\ker_1\xi_o+\mathrm{kei}_1\xi_o)\ker\xi_o + (\mathrm{kei}_1\xi_o-\ker_1\xi_o)\mathrm{kei}\,\xi_o}{\sqrt{2}\,(\ker^2\xi_o + \mathrm{kei}^2\xi_o)} \quad (16a)$$

$$F_2'(\xi_o) = \frac{-(\ker_1\xi_o+\mathrm{kei}_1\xi_o)\mathrm{kei}\,\xi_o + (\mathrm{kei}_1\xi_o-\ker_1\xi_o)\ker\xi_o}{\sqrt{2}\,(\ker^2\xi_o + \mathrm{kei}^2\xi_o)} \quad (16b)$$

where ker1 and kei1 are first-order Kelvin functions. The maximum shear velocity occurs when

$$\cos[\omega t + \tan^{-1}(\frac{F_2'(\xi_o)}{F_1'(\xi_o)})] = 1 \quad (17)$$

This maximum shear velocity is:

$$u_{*m} = \{\frac{k_o u_{*c}}{\kappa}(1+\frac{u_{*w}}{u_{*c}})^{-1}+\frac{k_o u_b \xi_o}{2}\{[F_1'(\xi_o)]^2 + [F_2'(\xi_o)]^2\}^{1/2} \quad (18)$$

Assuming a quadratic law, the friction factor can be obtained from:

$$f_{cw} = 2(u_{*w}/u_m)^2 \quad (19)$$

Suspended Sediment Transport Computation

Smith (1977) adopted Yalin method for bedload calculation. This method has been described in section 3.5.4 of this report. For suspended load, the concentration profile of suspended sediment is computed fro each size class and this is added for all the classes to get the total concentration. This total concentration field is then multiplied by the velocity field and integrated over water depth to give the volume flux of suspended sediment.

The conservation of mass yields N equations of the form:

$$\frac{\partial c_n}{\partial t} + \nabla(u_n c_n) = 0 \quad (20)$$

where c_n is the instantaneous volume concentration of sediment in class n and u_n is its instantaneous velocity. ∇ represents the partial differentiation with respect to x, y, and z. Averaging each of these equations over time, approximating the turbulent mass fluxes by gradient type diffusion and assuming the flow to be horizontally uniform yield N equations of the form:

$$\frac{\partial \bar{c}_n}{\partial t} = \frac{\partial}{\partial z}\left[-w_n \bar{c}_n + k_n \frac{\partial \bar{c}_n}{\partial z}\right] \quad (21)$$

where k_n is the eddy diffusion coefficient and w_n is sediment settling velocity. Assuming sediment velocity equal to the fluid vertical velocity u_w minus the sediment settling velocity and that k_n is equal to eddy viscosity k_z should yield a set of equations of the form

$$\frac{\partial \bar{c}_n}{\partial t} = \frac{\partial}{\partial z}\left[\bar{w}_n \bar{c}_n + k_z \frac{\partial \bar{c}_n}{\partial z}\right] \quad (22)$$

Taking $k_z = k_o z$ as required in the law of wall region and writing $dv = k_o dt$ and $p_n = w_n/k_o$ gives

$$\frac{\partial \bar{c}_n}{\partial v} = \frac{\partial}{\partial z}\left(p_n \bar{c}_n + z \frac{\partial \bar{c}_n}{\partial z}\right) \quad (23)$$

A separable solution with a sinusoidal time variation can be found in terms of Kelvin functions of order n. When sediment concentration at a reference level $z=z_a$ oscillates sinusoidally with time around a mean value and the boundary layer is of infinite depth, the concentration field is:

$$\bar{c}_n = \bar{c}_{cn}\left(\frac{\xi_a}{\xi}\right)^{2pn} + \left(\bar{c}_{cn}\frac{\xi_a}{\xi}\right)^{pn}\left[\frac{(ker_{pn}\xi)(ker_{pn}\xi_a)+(ker_{pn}\xi)(ker_{pn}\xi_a)}{(ker^2_{pn}\xi_a + kei^2_{pn}\xi_a)}\cos\omega t + \frac{(ker_{pn}\xi)(kei_{pn}\xi_a)-(kei_{pn}\xi)(ker_{pn}\xi_a)}{(ker^2_{pn}\xi_a + kei^2_{pn}\xi_a)}\sin\omega t\right]$$

$$= \bar{c}_{cn}\left(\frac{z_a}{z}\right)^{pn} + \bar{c}_{wn}\left(\frac{z_a}{z}\right)^{pn/2}[F_1(\xi;\xi_a,p_n)\cos\omega t + F_2(\xi;\xi_a,p_n)\sin\omega t] \qquad (24)$$

where $\bar{c}_{cn}$ is the mean value of concentration at $z=z_a$, $\bar{c}_{wn}$ is the amplitude of the sinusoidal variation, $\xi = 2(\omega z/k_o)^{1/2}$, $\xi_a = 2(\omega z_a/k_o)^{1/2}$ and $k_o = \kappa(u_{*c} + u_{*w})$.

The result of equation (24) can be generalized for any size or specific gravity class as long as p_n is constant with time. To accomplish this, the concentration of sediment in class n at $z = z_a$ must be expressible in terms of a Fourier series. Generalizing the concentration field given in equation (24) to:

$$\bar{c}_n(z,t) = \left(\frac{z_a}{z}\right)^{pn} A_o + \left(\frac{z_a}{z}\right)^{pn/2} \{\sum_{m=1}^{\infty} A_m[F_1(\xi;\xi_a,p_n)_m\cos\omega_m t + F_2(\xi;\xi_a,p_n)_m\sin\omega_m t] + \sum_{m=1}^{\infty} B_m[F_1(\xi;\xi_a,p_n)_m\sin\omega_m t+F_2(\xi;\xi_a,p_n)_m\cos\omega_m t]\} \qquad (25)$$

yields

$$\bar{c}_n(z_a,t) = A_o + \{\sum_{m=1}^{\infty}(A_m\cos\omega_m t + B_m\sin\omega_m t) \qquad (26)$$

at $z = z_a$ as required. $\bar{c}_n(z_a,t)$ is a function of the normalized excess shear stress $(\tau_b/\tau_c - 1)$, where τ_c is the critical shear stress. Thus equation (26) can be written as:

$$\gamma_n(\tau_b/\tau_c - 1) = A_o + \{\sum_{m=1}^{\infty}(A_m\cos\omega_m t + B_m\sin\omega_m t) \qquad (27)$$

where $\gamma_n = 0.635f_n$ and f_n is the fraction of sediment in class n. A fast Fourier transform is first applied to equation (27) to compute the Fourier coefficients A_o, A_m and B_m, which are then used in equation (25) to compute the suspended sediment concentration field. The concentration field $c_n(z,t)$ is multiplied by the velocity field $u(z,t)$ and the volume flux of suspended sediment is then determined by averaging over time and integrating from z_o to the water surface.