CHAPTER 306

Field Tests of Suspended-Load Transport Theories Used in Numerical Models

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Abstract

Surfzone optical-backscatter measurements were conducted at a long, straight sandy beach near Colorado River, Texas, in order to test velocity-based theories for predicting suspended-load sediment transport. Statistical methods were applied that provided estimates of theory performances, independent of any calibration or tuning of the model coefficients. The models of Ackers and White, Bowen, and Roelvink and Stive showed trends opposite that of the data (increasing transport estimates as measured transport decreased). The Bailard model performed very well in the cross-shore, explaining both the trends in transport and most of the variance, as determined by correlation coefficients. Bailard's model did not explain most of the variance in the longshore data, but comparison of the model's performance with other datasets show good correlation in the longshore. When the original coefficients in the unidirectional-flow-based Ackers and White model are used, very low transport estimates are produced. This suggests that this empirical model that was calibrated for unidirectional flows should not be used in coastal areas without considerable recalibration of the coefficients using high-quality datasets.

Introduction

A series of tests of sediment-transport theories has been performed with different data sets for different transport types:

- Bedload theories were tested with small-scale tracer experiments (White, 1987).

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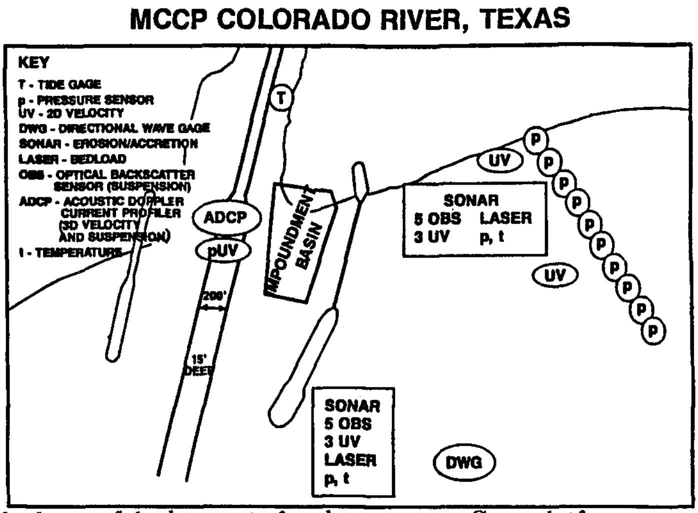

Figure 1: Areas of deployment of each gage type. Gage platforms are not to scale, but for visualization are drawn very large relative to the jetties. The lasers were replaced by micro-OBS gages for bedload.

- The Shore Protection Manual (1984) equation for total longshore transport was tested with large-scale tracer and suspension-trap experiments (White and Inman, 1989).
- Both approximate and exact versions of the SPM longshore-transport formula were tested against each other with surfzone optical-backscatter experiments (White, 1994).
- This paper tests several suspended-load transport equations with optical-backscatter experiments.

Comprehensive arrays of 43 sensors were deployed to measure waves, currents, tides, and sediment transport at a long straight beach with gently-sloping plane parallel contours near a river outlet, Colorado River, Texas (Figure 1).

This project of monitoring the behavior of the jetty system had several objectives. One was to identify and quantify the sediment budgets for the different parts of the system, in order to evaluate the performance of the sediment-management system of jetties, weir, and dredging (King and Prickett, 1997). Another was to evaluate longshore-transport formulas in the Shore Protection Manual (1984) by comparing the measured longshore sediment transport with the transport estimated from the offshore wave data and the SPM formulas (White, 1994). The topic of this paper is testing suspended-load transport theories at a point, in order to find the best ones to use in numerical models. This paper will describe only the results of this final objective.

Tests of sediment-transport theories can be performed in two very different means on two vastly different scales. Whether to test sediment-transport equations used in numerical models by making measurements at one point ("micro-scale") or by comparing the models' predictions of topographic change with measured topography ("macro-scale") is an ongoing debate. Since the main use of a transport theory is in a numerical model to determine changes in beach topography, one approach is to compare measured topographic change with the changes predicted from each numerical model (Schoonees and Theron, 1995). However, this method incorporates **all** error sources (e.g., grid spacing, coefficients' calibration, "skill" of the modeler, etc.) and cannot **separately** evaluate the transport theory used in the numerical model. It is possible in individual tests that these other factors have more effect than the particular theory that is in the model.

When detailed tests are made of total-load (macro) transport theories, such as the Shore Protection Manual's (1984) well-known longshore-transport formula, the error bars are huge and often larger than the measurements, so that high-confidence objective conclusions can often not be reached (White, 1994; Schoonees and Theron, 1994).

A third problem encountered in testing models with the "macro-scale" method is that individual vertification tests invariably test only one model against one set of data. Schoonees and Theron (1995) point out: "Without direct comparative prototype tests the final conclusion as to which are the better models in practice cannot be given."

In this paper, such a direct comparative prototype test is outlined. This approach is to test each theory against transport measured at a single horizontal location. The theory used in the numerical model, not the model itself, is tested.

Experimental Methods

Several state-of-the-art instruments were deployed: an offshore trawler-resistant Directional Wave Gage (DWG), a puv gage of colocated pressure and current sensors, Optical Backscatter Sensors for suspended-sediment concentrations, electromagnetic current meters for velocities, a new cable with internally imbedded pressure sensors for surfzone waves, and Acoustic Doppler Current Profilers for inlet currents and sediment flux.

The surfzone transport was measured by cross-shore integration of the point measurements from three synoptic multi-sensor platform arrays of Optical Backscatter Sensors (OBSs) (Downing, Sternberg, and Lister, 1981) and Electromagnetic Current Meters (ECMs), sonars, and pressure sensors. Figure 1 shows a plan view of the site with various platforms of gages drawn in the general areas where they were deployed. The sediment concentration was measured with OBS2 optical backscatter sensors, which were each calibrated in a flow tank over a wide range of transport values. The sand from the site was sampled prior to each experiment and generally had a median size of 130 microns, with a size distribution that was always single-peaked. The sand from the site was used in the laboratory to calibrate the sensors over a wide range of transport values (from 1 to 300 grams per liter), both prior to and after each of the three experiments.

The currents were measured with standard 1-inch diameter Marsh-McBirney electromagnetic probes, calibrated just prior to use. Pressure sensors were used to determine the range of vertical integration for each platform, and also times when uppermost sensors were out of the water and thus not to be used.

The sediment transport is the direct integration of the product of these two types of calibrated-sensor outputs, as measured in the surfzone:

$$\vec{i} = (\rho_s - \rho) g N_o \int_0^{\eta} \vec{u}(x, z) c(x, z) dz \tag{1}$$

where $\vec{i}$ is the sediment transport at one horizontal location, ρ_s is the sediment density, ρ the fluid density, g the acceleration of gravity, N_o the solids density (one minus porosity), $\vec{u}$ the fluid velocity, c the sediment concentration, and the integral is taken over the vertical surf depth.

The above integration is first accomplished in the vertical at each platform location by vertically integrating the values of concentration c, longshore velocity v, and vertical range z. See White (1994) for more details. It is important to note that the vertical integration is performed *at each time step of 0.2 seconds*, and is thus unaffected by phenomena with longer time periods, such as bursts of sediment out of the boundary layer. Each sensor measures at one instant, and all the instantaneous products of c, v, and z are vertically summed before moving to the next 0.2s time step.

Theoretical Methods

Theories for computing suspended-sediment transport were obtained via an extensive literature search of several hundred modeling documents (Drake and White, 1995). Five were found to be unique formulas of point transport. Other theories are either variations on these five types, or are not testable with "point" transport measurements. Such other models include (1) diffusion-based theories such as Smith (1977), Grant and Madsen (1979), and Glenn and Grant (1987); (2) the two-layer model of Dally and Dean (1984), and (3) the eddy-viscosity model of Deigaard et al (1986).

The following variables are found in common to many suspended-load theories:
$\vec{i}$ is the local immersed-weight sediment transport,
ρ is fluid density, ρ_s is sediment density,
c_f is a friction coefficient,
e_s is a suspended-load efficiency, e_b is a bedload efficiency,
W is sediment fall speed,
$\vec{u}$ is the fluid velocity,
ϕ is the sand's angle of internal friction (related to grain size),

h is depth, H is wave height, T is wave period,
g is the acceleration of gravity,
β is the beach slope angle,
$\hat{\imath}$ is the unit vector in the offshore direction,
x is the cross-shore spatial coordinate, and y is the longshore coordinate.

The value always used for the suspension efficiency was the 0.025 best-fit value found from several experiments, as published by Bailard (1981). A consensus in the literature was reached for a friction coefficient c_f value of 0.007, since to one significant figure, this was the value determined by both Thornton (1970) and Bailard's (1981) experiments.

Three of the models we tested are based on Bagnold's (1966) derivation for both bedload and suspended load in streams. Bagnold's basic concept was that the transport uses a fixed fraction of the available stream power. The derivation of Bagnold's transport relation, along with all of the assumptions may be found in Drake and White (1995).

(1) Bowen's (1980) suspended-load model expands Bagnold's basic stream-transport relation using two velocities, an oscillatory and a steady component. Assuming the oscillatory velocity dominates, the formula is expanded in a series and the terms retained yield:

$$\langle \vec{\imath} \rangle = \rho c_f \frac{e_s}{W} \left[\langle |\vec{u}|^3 \vec{u} \rangle + \frac{\beta}{W} \langle |\vec{u}|^5 \rangle \; \hat{\imath} \right] \tag{2}$$

(2) Bailard (1981) worked on this problem at the same time as Bowen and independently derived a similar suspended load model. Again expanding in a series and retaining terms yields:

$$\langle \vec{\imath} \rangle = \rho c_f \frac{e_s}{W} \left[\langle |\vec{u}|^3 \vec{u} \rangle + \frac{e_s \tan\beta}{W} \langle |\vec{u}|^5 \rangle \; \hat{\imath} \right] \tag{3}$$

As opposed to Bowen, the reason for the efficiency e_s appearing again in the second term is based on interpretations of Bagnold's claims regarding whether power is contributed through an efficiency factor. For most applications, there is no practical import as to whether β or $\tan\beta$ is used, since the slope is usually small.

(3) Roelvink and Stive's (1989) transport model contains transport from two different mechanisms. The stream-power based transport follows the work of Bagnold, Bowen, and Bailard. But they also include transport caused by turbulence from breaking waves:

$$\langle \vec{\imath} \rangle = \rho c_f \frac{e_s}{W} \left[\langle |\vec{u}|^3 \vec{u} \rangle + K_1 \hat{\imath} \right] \tag{4}$$

where $K_1 = \beta_d \{ k_t [\exp(h/H_{rms}) - 1]^{-1} \}^{3/2}$

(4) Larson and Kraus' (1989) cross-shore transport model extends the energy-dissipation model of Kriebel and Dean (1985) to predict total cross-shore transport. They add an empirical criterion that determines the **sign** of the transport as either bar growth (offshore transport) or berm growth (onshore transport). Various datasets were used to determine an empirical dividing line between these cases. The resulting model, which forms the basis for CERC's SBEACH cross-shore numerical model is:

$$\langle i \rangle = sgn\left\{ M\left[\frac{\langle H_0 \rangle}{WT}\right]^3 - \frac{2\pi \langle H_0 \rangle}{gT^2} \right\} (\rho_s - \rho) g K \left[E - E_{eq} + \frac{\varepsilon_\beta}{K}\frac{dh}{dx}\right] \qquad (5)$$

when the rate of energy dissipation is greater than that for an equilibrium beach: $E > E_{eq} - \frac{\varepsilon_\beta}{K}\frac{dh}{dx}$, and zero otherwise.

H_0 is the deep wave height, T the period, W the grain fall velocity, and dh/dx is the beach slope. M, K, and ε_β are empirical constants. The quantity in the first set of brackets is used solely to determine the **direction** of transport, with M the empirical constant dividing their cases of onshore and offshore transport.

The energy dissipation is follows the work of Dean. The dissipation in general and the value for the equilibrium beach are:

$$E = \frac{1}{h}\frac{d}{dx}\left[\frac{1}{8}\rho g H_s^2 \sqrt{gh}\right]; \; E_{eq} = \frac{5}{24}\rho g^{3/2}\gamma_b^2 A^{3/2}$$

where γ_b is the ratio between wave height and depth, and A is the profile shape parameter.

Note that the Larson and Kraus model requires substantially different measured quantities than the other models. Not only are wave heights and periods used, but their variation across the surf zone must be known.

(5) Ackers and White's (1973) river-transport model was not originally developed for or intended for use in an oscillatory flow. However, it has been adapted for use by the Coastal Engineering Research Center for use in modelling the fate of offshore dredge dumps. The fate of these dumps is thought to initially be governed primarily by currents rather than waves. Hence this model was used, and is now being applied to other situations where there is a strong unidirectional (current) component, such as at inlets. Since this model is seeing so many uses in the coastal region, it was included in this testing program.

The unidirectional transport in the original paper is modelled as:

$$\langle i \rangle = 10^{-6}\frac{\rho_s - \rho}{\rho_s} C_g \left(\frac{F_*}{A_g} - 1\right)^m \left(\frac{\rho_s D \bar{u}}{\rho h u_*}\right)(\rho \bar{u} h) \qquad (6)$$

Some of the final parameters, such as depth h and density ρ cancel. What remains are sediment parameters (density ρ_s and size D) and fluid parameters (ρ, a velocity in the direction of transport $\bar{u}$, and a friction velocity $u_* = \sqrt{c_f} u_T$). The velocity u_T is the **total** velocity, and the velocity $\bar{u}$ is the velocity in the direction of transport. So in the cross-shore case, the appropriate instantaneous velocities are the one that appears twice in the numerator, $\bar{u} = u$ (u being the instantaneous cross-shore velocity) and $u_* = \sqrt{c_f}(u^2 + v^2)^{0.5}$ in the denominator.

The remaining parameters are four 'numbers' used in the model. C_g is a function of grain size determined by fitting to Ackers and White's original data set:

$$\log C_g = 2.86 \log D_* - (\log D_*)^2 - 3.53;\ D_* = D \left[\frac{g(\rho_s - \rho)}{\rho \nu^2} \right]^{1/3}$$

where D_* is a dimensionless grain diameter. The exponent m is another empirically fit number $m = 9.66 D_*^{-1} + 1.34$, as is $A_g = 0.23 D_*^{-1/2} + 0.14$. For fine to medium sediments (suspension) the mobility number F_* is the square root of Shields' number:

$$F_* = \sqrt{\theta} = \frac{\sqrt{\rho} u_*}{[gD(\rho_s - \rho)]^{1/2}};\ G_* = C_g \left[\frac{F_*}{A_g} - 1 \right]^m$$

G_* is the so-called transport parameter into which are lumped all the empirical numbers.

Statistical methods

Methods were developed to objectively judge theory performance (White, 1987). The degree of success of the developed theories can be judged by computing correlations between predicted and measured variables by objective statistical techniques. A simple linear regression is performed between measured transport (y) and transport predicted from the models (x):

$$y = mx + b;\ r = m \frac{\sigma_x}{\sigma_y} \tag{7}$$

where r is the correlation coefficient and σ is the standard deviation using N weighting. Negative values represent anti-correlation. The r^2 values are the fraction of the total variance in the data explained by the method.

For a selected level of confidence, say 90%, confidence limits can be computed. Since the correlation r is not a Gaussian function, it must first be translated into a variable that is Gaussian in order to compute confidence limits. The upper confidence limit is: $w^+ = w + Z/\sqrt{N(N-3)}$ where Z comes from the cumulative normal (Gaussian) distribution tables. The lower limit is computed likewise, except there is a + instead of − before the fraction. The quantity w is from a theorem that determined w is a Gaussian function of the correlation r: $w = \tanh^{-1} r$. The confidence limits allow us to state how confident we are that one theory performs better than another theory. Once translated back into r-space via the inverse of the above equation, we obtain a range of correlations for each theory. If the ranges in correlations r for one theory's performance do not overlap the range computed for another theory's performance, then we may conclude at the specified level of confidence that the theory with the higher r values performs better than the one with lower values. The reason for this exercise is to show that random variation in small amounts of experimental data have not, by chance, provided an incorrect conclusion. The percent confidence specifies the probability that such incorrect conclusions have not occurred.

The statistical methods separate the issues of calibration and testing. Correlation coefficients determine the degree of success of each theory **without calibrating** to the data; confidence intervals determine which theories are better than which other theories; regression slopes determine appropriate coefficients for each of the theories, independently of the quality or goodness-of-fit issue.

Results

Experiments were performed over a two-week period in January 1992 over greatly varying wave conditions. Each experiment consisted of measurements taken each fifth of a second. The vertically integrated transports were then averaged over the recording time for the experiment, typically one to three hours. This dataset consisted of 81 such cross-shore transport and 36 longshore transport experiments.

Unfortunately, we encountered practical problems when using two of the five theories. The **Larson and Kraus** theory requires somewhat different data than the others: considerable information about wave height and period, and also cross-shore variation in these quantities. The original project had the purpose of measuring transport rates and of testing velocity-based theories. Thus such detailed wave information was not computed in the original dataset. Future work is planned to compute these quantities in order to test this theory.

The **Ackers and White** formula was used but produced extremely small values of transport, by several orders of magnitude. Numerous independent checks of the testing program failed to reveal any programming errors. Another possibile explanation is that we are incorrectly surmising how to compute the different velocities required by this unidirectional-flow theory. Of course, it is also quite possible that the results are correct and suggest that such a unidirectional-flow theory was not intended for and should not be used in oscillatory flow. Since we encountered such low values in these cross-shore computations, we did not continue testing this theory with longshore data. Thus their theory does not appear in Table 3.

Correlations between theories and measurements were computed over each time period and are listed in Tables 1 and 2 for cross-shore transport and Table 3 for longshore transport. Confidence limits were also computed in order to determine how confident one can be of conclusions that one theory performs better than another.

Modifications to the theoretical transport equations may be extracted from Tables 1, 2, and 3. The slope m could be used to modify the theory's empirical coefficient or the friction coefficient c_f, *provided* a y-intercept were also added to the equation. So one might compute i from the original formula, and then $i_{new} = m i_{old} + b$.

Table 1: Correlation of Theoretical and Measured CROSS-SHORE Transports for the OUTER Surf Zone

Method being correlated with measured transport:	Measured Transport	Bowen (1980)	Bailard (1981)	Roelvink and Stive (1989)	Ackers and White (1973)
	Outer surf, top water column (number of experiments, N = 15)				
μ Mean, dynes/(cm-s)	-3833.	6178.4	-291.9	2062.5	.00003096
σ Standard Deviation, dynes/(cm-s)	8388.	16373.6	776.2	3395.1	.00008103
m, Regression Slope		-.4612	10.2	-2.2	-93015000.
b, Intercept, dynes/(cm-s)		-983.7	-854.1	778.9	-953.7
r, Correlation Coefficient		-0.900	0.945	-0.905	-0.899
r^2		0.810	0.893	0.819	0.808
Lower 90% Confidence Limit for r		-0.921	0.930	-0.925	-0.920
Upper 90% Confidence Limit for r		-0.874	0.957	-0.880	-0.873
	Outer surf, mid water column (number of experiments, N = 15)				
μ Mean, dynes/(cm-s)	-3833.	181.5	-83.5	303.9	.000000982
σ Standard Deviation, dynes/(cm-s)	8388.	221.1	162.7	301.2	.000001599
m, Regression Slope		-19.9	50.7	-12.7	4192780000.
b, Intercept, dynes/(cm-s)		-219.3	397.8	13.8	1008.9
r, Correlation Coefficient		-0.525	0.983	-0.455	-0.799
r^2		0.276	0.966	0.207	0.638
Lower 90% Confidence Limit for r		-0.608	0.978	-0.547	-0.352
Upper 90% Confidence Limit for r		-0.430	0.987	-0.352	-0.750
	Outer surf, bottom water column (number of experiments, N = 15)				
μ Mean, dynes/(cm-s)	-3833.	40.4	-21.8	151.0	.000000219
σ Standard Deviation, dynes/(cm-s)	8388.	55.2	40.5	157.9	.000000289
m, Regression Slope		-129.7	203.4	-45.3	27350800000.
b, Intercept, dynes/(cm-s)		1411.8	595.5	3005.1	1168.6
r, Correlation Coefficient		-0.854	0.982	-0.852	-0.942
r^2		0.729	0.964	0.726	0.887
Lower 90% Confidence Limit for r		-0.884	0.977	-0.882	-0.954
Upper 90% Confidence Limit for r		-0.817	0.986	-0.814	-0.926

The computed statistics are reported with far more significant digits than the method justifies, in order to retain digits until the rounding of the final result.

Table 2: Correlation of Theoretical and Measured CROSS-SHORE Transports for the MIDDLE and INNER Surf Zone

Method being correlated with measured transport:	Measured Transport	Bowen (1980)	Bailard (1981)	Roelvink and Stive (1989)	Ackers and White (1973)
	Mid surf, top water column (number of experiments, N = 8)				
μ Mean, dynes/(cm-s)	-24000.	3229.4	-2456.2	1173.7	
σ Standard Deviation, dynes/(cm-s)	12177.	4172.0	3252.4	1303.7	
m, Regression Slope		-1.674	2.038	0.525	
b, Intercept, dynes/(cm-s)		-18595.2	-18994.6	-24616.5	
r, Correlation Coefficient		-0.573	0.544	0.056	
r^2		0.328	0.296	0.003	
Lower 90% Confidence Limit for r		-0.723	0.335	-0.202	
Upper 90% Confidence Limit for r		-0.372	0.702	0.307	
	Mid surf, bottom water column (number of experiments, N = 8)				
μ Mean, dynes/(cm-s)	-24000.	3220.2	-2092.6	1498.7	
σ Standard Deviation, dynes/(cm-s)	12177.	3521.5	2986.0	1072.3	
m, Regression Slope		-2.208	2.096	0.932	
b, Intercept, dynes/(cm-s)		-16890.8	-19614.5	-25397.4	
r, Correlation Coefficient		-0.638	0.514	0.284	
r^2		0.407	0.264	0.081	
Lower 90% Confidence Limit for r		-0.768	0.298	0.680	
Upper 90% Confidence Limit for r		-0.457	0.680	0.503	
	Inner surf, mid water column (number of experiments, N = 20)				
μ Mean, dynes/(cm-s)	1275.	1024.4	44.9	1188.4	
σ Standard Deviation, dynes/(cm-s)	8076.	1212.8	532.1	1235.5	
m, Regression Slope		2.775	13.800	3.575	
b, Intercept, dynes/(cm-s)		-1567.7	655.9	-2973.4	
r, Correlation Coefficient		0.417	0.909	0.547	
r^2		0.174	0.826	0.299	
Lower 90% Confidence Limit for r		0.341	0.892	0.482	
Upper 90% Confidence Limit for r		0.488	0.923	0.606	

The computed statistics are reported with far more significant digits than the method justifies, in order to retain digits until the rounding of the final result.

Table 3: Correlation of Theoretical and Measured LONG-SHORE Transports

Method being correlated with measured transport:	Measured Transport	Bowen and Bailard (same model in the longshore)
	Mid surf, top water column (number of experiments, N = 8)	
μ Mean, dynes/(cm-s)	-48350.	-3810.0
σ Standard Deviation, dynes/(cm-s)	18563.3	3714.2
m, Regression Slope		2.205
b, Intercept, dynes/(cm-s)		-39950.3
r, Correlation Coefficient		0.441
r^2		0.194
Lower 90% Confidence Limit for r		0.209
Upper 90% Confidence Limit for r		0.626
	Mid surf, bottom water column (number of experiments, N = 8)	
μ Mean, dynes/(cm-s)	-48350.	-3796.4
σ Standard Deviation, dynes/(cm-s)	18563.	3370.2
m, Regression Slope		2.549
b, Intercept, dynes/(cm-s)		-38674.7
r, Correlation Coefficient		0.463
r^2		0.214
Lower 90% Confidence Limit for r		0.235
Upper 90% Confidence Limit for r		0.642
	Inner surf, mid water column (number of experiments, N = 20)	
μ Mean, dynes/(cm-s)	11,505.	736.9
σ Standard Deviation, dynes/(cm-s)	10,792.	761.7
m, Regression Slope		9.417
b, Intercept, dynes/(cm-s)		4564.8
r, Correlation Coefficient		0.665
r^2		0.442
Lower 90% Confidence Limit for r		0.613
Upper 90% Confidence Limit for r		0.712

The computed statistics are reported with far more significant digits than the method justifies, in order to retain digits until the rounding of the final result.

Table 4: Correlations between Model Predictions and Measured Transport

	Bowen (1980)	Bailard (1981)	Roelvink & Stive (1989)	Ackers & White (1973)
January 1992: 81 Experiments for Cross-Shore Transport				
r for outer surf, upper water column	-0.900	0.945	-0.905	-0.899
r for outer surf, mid water column	-0.525	0.983	-0.455	-0.799
r for outer surf, bottom water column	-0.854	0.982	-0.852	-0.942
r for mid surf, upper water column	-0.573	0.544	0.056	
r for mid surf, lower water column	-0.638	0.514	0.284	
r for inner surf	0.417	0.909	0.547	
January 1992: 36 Experiments for Long-Shore Transport				
r for mid surf, upper water column	0.441	0.441		
r for mid surf, lower water column	0.463	0.463		
r for inner surf	0.665	0.665		

All the correlations between models and data are summarized in Table 4. Note that many correlations are negative. This means that the **trend** in the theoretical predictions are opposite the trend in the data. (As measured transport increases, predicted transport decreases.) It does **not** mean that the direction of the predicted transport is opposite that of measured transport.

Conclusions

Conclusions about model performances can be made from the correlations in Table 4. For the 6 groups of 81 surfzone experiments of 1 to 3 hours length each:

1. The Bailard model performs very well in the cross-shore, predicting most of the variation in cross-shore transport.

   Mean r = 0.81 and mean $r^2 = 0.70$ (Explains **70% of the variance**)

2. The Bowen model and the Roelvink & Stive model do not predict most of the variation in cross-shore transport, and frequently predict the wrong trend (e.g., predicted transport increases as measured transport decreases). The only significant difference between the Bowen and Bailard models is a appearance of the suspended-load efficiency coefficient in the second term, caused by different interpretations of Bagnold's original work on this point by Bowen and Bailard. The results of this study are strong evidence that Bailard's interpretation is correct.

   Bowen: mean r = - 0.52 and mean $r^2 = 0.45$ (**45% of the variance**)

Roelvink & Stive: mean r = - 0.22 and $r^2 = 0.36$ (**36% of the variance**)

3. The Ackers and White model performs strangely. Using the coefficients provided in their original publication and making our stated assumptions about how to compute the velocities, results in extremely low values of transport. Results show strong **anti**-correlation with the data. The most likely explanation of the anti-correlation is some local circulation pattern at the outer surf platform, since some of the other models also exhibit this anti-correlation result at that site.

   Mean r = 0.88 and mean $r^2 = 0.77$ (Explains **77% of the variance**)

4. The Bowen model and the Bailard model (identical in the longshore) model do not predict most of the variation in longshore transport.

   Mean r = 0.52 and mean $r^2 = 0.28$ (Explains **28% of the variance**)

   Knowledge of the performance of this model in the longshore is by no means conclusive. Thornton reports in meetings for the Delilah/Duck94 surfzone experiments, that performance levels are similar to what we found here. But we have also tested this model in the longshore against numerous other Shore Protection Manual-type formulas and also other velocity-based formulas in another study using Nearshore Sediment Transport Study sand-tracer data at Santa Barbara, California (White and Grandon, draft). In that study this model performed excellently, with correlations around 0.9.

In another study, the main factor not included in these equations that was found to improve *local* estimates of transport, was inclusion of a sediment threshold-of-motion criterion (White, 1987; White, 1989). In comparing predictions of different local **bedload** transport theories with transport measured by sand tracer, it was found that agreement on direction of transport improved from 70% to 100% of the experiments, once a threshold criterion was added to the theory. We have included threshold subroutines in our testing program and plan to apply such criteria to these suspension models and report the results in a followup paper.

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