A Literature Review of the Distribution of Longshore Sediment Transport Across the Surf Zone

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ABSTRACT


Existing models and field and laboratory data which describe the distribution of longshore sediment transport across the surf zone are identified and briefly discussed. Most of the models rely on some formulation of the cross-shore distribution of longshore current. Most models are poorly suited to describe transport above the still-water shoreline in the swash zone, and when evaluated for a planar beach, predict local longshore transport maxima in the outer-mid surf zone. The field and laboratory data suggest that significant transport may occur above the still-water shoreline and indicate a variety of longshore transport distribution profiles.

ADDITIONAL INDEX WORDS: Beach, beach profile, longshore current, shoreline, swash zone, sediment dynamics.

INTRODUCTION

Knowledge of the distribution of longshore sediment transport across the surf zone is fundamentally important to effective modelling of coastal sediment dynamics. Insight to the transport distribution is particularly important to the design of groins, jetties, weirs, pipeline landfalls and outfalls, and aids in understanding the migration of natural or artificially placed shoreline features. Owing to the difficulty of measuring longshore transport (let alone understanding its complexities), most studies have focused upon the total longshore transport rather than upon its distribution across the beach. Consequently, literature reviews and formulations of the total transport are relatively abundant and well-known, while many coastal engineers' and scientists' concept of its distribution is derived from a rather limited base of literature.

Lately, research attention to the longshore transport distribution has increased, in part because it is thought that improved identification of the distribution may enhance understanding of the mechanisms and magnitude of the total transport. Several recent efforts have added significantly to the small, yet diverse, collection of literature which discusses the longshore transport distribution. However, to the author's knowledge, no comprehensive survey of the literature exists. Accordingly, this paper intends to present a summary of those studies and articles pertinent to the description of longshore transport distribution across the surf zone.

A BRIEF NOTE ON TOTAL TRANSPORT

Reviews of the total longshore sediment transport data base are found in SAVAGE (1962), DAS (1971), KING (1972), GREER and MADSEN (1978), WALTON and CHIU (1979), BRUNO, DEAN, and GABLE (1980), and HALLUMERMEIER (1982). SAYAO and KAMPHUIS (1983) offer a review of proposed total transport relationships, several of which are inter-compared in BAKKER (1970), VAN DE GRAAF and VAN OVEREEM (1979), and SWART and FLEMING (1980).

Some models which describe the distribution of longshore transport borrow from fundamental ideas of total transport models; moreover, the results of some total transport studies may illuminate ideas about transport distribution. Therefore, results of several total longshore
transport investigations relevant to this review are described in the following paragraphs.

An expression commonly used for estimating the total longshore transport rate is

$$I_l = K P_{lb},$$

(1)

where $I_l$ is the total immersed-weight longshore sediment transport rate, $P_{lb}$ is the so-called longshore wave energy flux factor evaluated at the wave breakpoint, and $K$ is a dimensionless proportionality coefficient. The total immersed-weight transport rate is related to the total volumetric transport rate $Q_v$ through

$$I_l = \left(p_s - p\right) g \alpha' Q_v,$$

(2)

where $p_s$ and $p$ are the densities of sediment and fluid respectively, $g$ is the acceleration of gravity, and $\alpha'$ is the ratio of sand grain volume without voids to total volume with voids (INMAN and BAGNOLD, 1963). The factor $P_{lb}$ may be written

$$P_{lb} = \frac{1}{2} (E C_o)_b \sin 2\alpha_b,$$

(3)

where $E$ is the wave energy density, $C_o$ is the wave group celerity, $\alpha$ is the wave angle, and the subscript "b" refers to the breakpoint.

Values of the coefficient $K$ suggested for engineering applications have varied by a factor of four since the introduction of Equation 1 (INMAN, 1978; DEAN, 1978). Numerous investigators have attempted to explain the great scatter found for values of $K$. For example, BAJOURNAS (1970), CASTANHO (1970), VAN HIJUM (1976), SWART (1976), and DEAN (1978) have suggested conflicting relationships between longshore sediment transport and sediment size. Probably the most promising empirical descriptions of the coefficient have been reported by KAMPHUIS and READSHAW (1978), VITALE (1981), KAMPHUIS and SAYAO (1982), and OZHAN (1982). From laboratory experiments on sand beaches, each investigator observed a relationship between $K$ (or a similar coefficient) and the surf similarity parameter:

$$\xi_b = \frac{m}{\sqrt{H_b/L_o}},$$

(4)

where $m$ is the beach slope, $L_o$ is the deepwater wavelength, and $H_b$ is the wave height at breaking. Figure 1 compares the approximate surf similarity parameter and $K$ for several laboratory and field studies. In the figure, the KAMPHUIS and READSHAW (1978) and KOMAR and INMAN (1970) data points were determined using average surf zone bottom slope and local breakpoint slope, respectively; $K$ was determined using breaking wave data in the evaluation of Equation 3. The remaining points were estimated using the average bottom slope and wave data reported at the limiting depth for appreciable longshore transport; see HALLERMEIER (1982).

GALVIN (1968) and BATTJES (1974) reported that the surf similarity parameter $\xi_b$ may describe breaker type; the relationship suggested by the latter is indicated in Figure 1. From the trend shown in the figure, one may conclude that plunging and collapsing breakers lead to greater total longshore transport than spilling breakers for a given level of longshore wave energy flux. Since plunging and collapsing breakers are respectively associated with locally steep slopes (or bars) and the foreshore, one might further conclude that transport can be significant along steep slopes (or bars) and along the foreshore. Much of the existing transport distributed data discussed herein substantiate this idea. A related hypothesis (BODGE, 1986; BODGE and DEAN, 1987), which recognizes that the surf similarity parameter is related to breaker type and that the structure of the surf zone varies for different breaker types, states that if local longshore transport varies with the structure of the surf zone then the distribution of longshore transport across the surf zone should somehow depend upon the breaker type.

**PROPOSED DISTRIBUTED TRANSPORT MODELS**

Virtually all of the models proposed to describe the longshore transport distribution share a central concept: the dual presence of a mechanism which mobilizes beach sediments and a longshore current which transports the sediments downdrift. The models vary widely in the description of this mobilizing mechanism as well as in the degree of independence assumed between the sediment mobilizing and transporting forces.

BAGNOLD (1963) proposed that wave orbital motion mobilizes beach sands and wave power...
is expended maintaining the sand in motion so that any mean local longshore current \( V \) transports the sand. In accordance with this “energetics” approach BAGNOLD suggested a suspended and bedload model which may be written

\[
i(x) = k_B \frac{d}{dx} (E C_x \frac{V}{u_o})
\]

for small angles of wave approach, where \( i(x) \) is the local immersed weight longshore sediment transport rate per unit offshore distance, and where the \( x \)-axis is directed offshore with origin at the still-water shoreline. The proportionally constant \( k_B \) is dimensionless. The term \( u_o \) represents the near-bottom wave orbital velocity.

Assuming linear theory, shallow water conditions, constant proportion \( k \) between water depth \( h \) and wave height \( H \), and further assuming that the longshore current is given by LONGET-HIGGINS (1970) for the case of a planar beach with no lateral mixing, the BAGNOLD expression becomes (where \( h = mx \) for a planar beach):

\[
i(x) = \frac{25\pi}{128} k_s \rho g^{1/2} \frac{m^2 \sin \alpha_h}{C_r} \sqrt{h} h
\]

In 1969, SVASEK (see BAKKER, 1970) proposed a simple distribution model based upon Eq. 1 where the local longshore transport rate is assumed to be proportional to the local loss of wave energy flux; \( i(x) \propto \frac{d}{dh} (E C_x \sin \alpha \cos \alpha) \)
where \( i_t(z) \) is the local immersed weight of longshore sediment transport rate per unit depth. For the same assumptions as described above, the SVASEK model may be written

\[
i_t(x) = \frac{3}{8}K \rho g u \frac{\sin \alpha_r}{\sqrt{h_v}} h^2
\]  

(8)

where use has been made of the relationship \( i_t(x) = m_i i_t(z) \).

THORNTON (1972) proposed a distributed longshore transport model based upon the energetics approach of Bagnold. Specifically,

\[
i_t(x) = \frac{B_v}{(\rho_v - \rho) \delta} E_{C_w} \left[ \frac{V_2}{u_c} \right]^{1/2}
\]  

(9)

For the same assumptions as described above, the THORNTON model becomes

\[
i_t(x) = B_v' \rho g^{1/2} m^{1/4} \sqrt{\sin \alpha_r} h_v^{1/4} h^{1/4}
\]  

(10)

In Eqs. 9 and 10, both \( B_v \) and \( B_v' \) are dimensionless constants.

Figure 2 illustrates the normalized longshore transport distributions from the Bagnold, SVASEK, and THORNTON models for a planar beach (viz., Eqs. 6, 8, and 10). The normalization is \( i_t x_b / I_t \), where \( I_t \) is the total transport and \( x_b \) is the surf zone width, is equivalent to the local longshore transport \( i_t(x) \) compared to uniformly distributed transport across the surf zone, \( I_t / x_b \). It is noted that none of the models predict transport landward of the still-water shoreline. Each model exhibits a maxima and a sharp discontinuity at the breakpoint. The latter is because transport is not predicted seaward of the breakpoint if one assumes no energy losses outside the surf zone.

KOMAR (1971, 1975, and 1977) extended Bagnold’s (1963) model, envisioning that breaking wave induced stress at the bed mobilizes sediment making it available for advection by a longshore current. Therefore, in his popularly-called “stress” model, KOMAR reasoned that the local longshore transport is related to the product of breaking wave related stress and longshore current:

\[
i_t(x) = \frac{\pi k f_w}{8} \rho g h V, \]

(11)

where the wave related stress is taken as a function of the maximum horizontal component of wave orbital motion \( u_c \), in shallow water. The term \( f_w \) is a bed drag coefficient for wave motions and \( k \) is a proportionality constant.

KOMAR suggested the following expression for the case where stress exerted on the bed by longshore current is also included as a sediment “mobilizing” factor:

\[
i_t(x) = k_v V_s [\rho C_i V_c^2 + \frac{\rho g f_w}{8} k^2 h]
\]  

(12)

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Figure 2. Normalized longshore transport distribution across a planar beach from the Bagnold, Svasek, and Thornton models.
The term $C_r$ is a frictional drag coefficient for the longshore current and $k_c$ is another proportionality constant. Komar assumed that wave-related stress is greatest at the breaker line and decreases to zero near the shoreline. He therefore reasoned that inclusion of the current-related stress will shift the transport distribution seaward for small angles of wave incidence—since the contribution of stress due to waves will dominate that due to longshore current. Large angles of incidence would create stronger longshore current and therefore a transport distribution profile which more closely follows that of the longshore current. Komar also suggested that breaking wave height should not affect the transport distribution since changes in wave height will more or less equally affect the longshore current and wave orbital velocities.

Figure 3 illustrates the longshore transport distributions from the Komar models for the case of a planar beach, lateral mixing, and for wave and longshore current conditions as indicated. The distributions are normalized by their respective maxima. Some transport is predicted seaward of the breakpoint since lateral mixing is considered, but neither model predicts transport above the shoreline in the swash. KOMAR (1971) argues on a theoretical basis that transport across the swash zone can be modelled identically as the surf zone, but swash zone application of any of the existing models is not obvious (save for the approximation obtained by including wave-induced set-up above the still-water shoreline).

BIJKER (1971) was among the first investigators to develop a longshore transport model based upon river-borne sediment transport studies. His expression for the bedload component of longshore transport, taken after FRIJLINK (1952), is of the form of an exponential “stirring parameter” multiplied by a “transporting parameter”. The suspended load component, taken after EINSTEIN’s (1950) work, is expressed in terms of the bedload component through classical, somewhat complicated integrals which depend upon the bed roughness or ripple height, fall velocity, and bed shear velocity. BIJKER’s method is cumbersome to apply, and it is also sensitive to the

![Figure 3](image-url)
value of the thickness assumed for the bedload transport layer.

SWART (1976) discussed the BIJKER method and suggested that a combined bedload and suspended load model is more appropriate. SWART used a modified ACKERS-WHITE (1973) approach and found a lengthy expression for the local longshore transport which is not detailed herein. MADSEN (1978) suggested a distributed longshore transport model which is based upon an experimentally verified expression for sediment transport under oscillatory flow:

\[ \phi(t) = 40 \dot{\phi}(t) \]  

(13)

after BROWN (1950), EINSTEIN (1972), and MADSEN and GRANT (1976), where \( \phi(t) \) and \( \dot{\phi}(t) \) are instantaneous values of the non-dimensional transport function and Shields parameter, respectively. The over-arrow denotes a vector quantity. Specifically,

\[ \dot{\phi}(t) = \frac{q(t)}{w_D} \]  

(14)

\[ \dot{\phi}(t) = \frac{-\tau_s(t)}{g(p_s - \rho)D} \]  

(15)

Here, \( q(t) \) is the instantaneous volumetric sediment transport rate per unit width, and \( w_\sigma \) and \( D \) are the sediment fall velocity and grain size respectively. The instantaneous bottom shear stress \( \tau_s(t) \) is given by

\[ \tau_s(t) = \frac{1}{2} f_{\omega}(u_{\text{ave}}(t) + V \left[ u_{\text{ave}}(t) + V \right] \]  

(16)

where \( u_{\text{ave}} \) and \( V \) are unsteady (wave) and steady (current) velocities, respectively, and \( f_{\omega} \) is a bed friction factor due to combined waves and currents. Time-averaging in the longshore direction and employing linear (shallow water) wave theory, Madsen found the local volumetric longshore transport rate \( q_i(x) \) to be

\[ q_i(x) = 1.7 \frac{w_\sigma}{D^3} \left[ \frac{f_{\omega}}{g(p_s - \rho)} \right] u_o 5V_i \]  

(17)

The normalized (by maxima) longshore transport distribution across a planar beach (for the same conditions shown for the KOMAR models) is illustrated for Eq. 17 in Figure 3. The model does not exhibit a discontinuity in transport at the breaker line if a lateral-mixing model for \( V_i(x) \) is assumed. Like the Komar models, evaluation of the transport landward of the shore-line is not straightforward. It is also noted that the model's dependence upon \( w_\sigma / D^3 \) implies that the longshore transport decreases with increasing sediment size for spherical sand grains.

The laboratory data of SAW ARAGI and DEGUCCI (1978), discussed in the next section, suggests the following empirical description of distributed volumetric longshore transport

\[ q_i(x) \propto V_iD_{50}F_{3.9} \]  

(18)

where

\[ F_{3.9} = \frac{u_o^2 - u_i^2}{g(p_s - \rho)D} \]  

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The friction velocity \( u_o \) = \( \tau_o / \rho \), where the bottom shear stress \( \tau_o \) is due to the combined peak wave orbital velocity and longshore current, and the critical friction velocity \( u_i \) is defined for various diameter sands after IWAGAKI's investigations of sediment transport threshold velocities for open channel flow (see SAWARAGI and DEGUCCI, 1978).

WALTON and CHIU (1979) suggested the following distributed longshore transport model after BROWN (1950), EINSTEIN (1972), and MADSEN (1976), where \( q_i(x) \) and \( w_D \) are instantaneous values of the non-dimensional transport function and Shields parameter, respectively. The over-arrow denotes a vector quantity. Specifically,

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although overall agreement was still rather poor. The terms \( K_F \) and \( K_F' \) are dimensional coefficients.

HALLERMEIER (1982) described the local bedload component of longshore transport using a laboratory-based expression for bedload transport under oscillatory motion. His model functionally appears as

\[
q(x) = \frac{\sigma u^3 \sqrt{D}}{|g(p/p_0 - 1)|^{3/2}} \tan \alpha \tag{22}
\]

where \( \sigma \) is the wave frequency. Hallermeier directly integrated this expression across the surf zone to yield the total longshore bedload transport, but did not discuss the transport distribution outright.

TSUCHIYA (1982) considered the local longshore transport in the form

\[
q(x) = c h \ V(x) \tag{23}
\]

where \( c \) is the average local concentration of sediment expressed as a function of the local applied and critical shear stress. Using a LONGUET-HIGGINS (1970) longshore current profile with lateral mixing, this suspension-dominant model generally predicts the maximum transport at about three-quarters of the distance from the shoreline to the breaker line. Significant amounts of transport are predicted seaward of the breakpoint for decreasing values of the critical shear stress.

BALLARD and INMAN (1981) and BALLARD (1984) proposed an energetics-based expression which independently describes the bedload and suspended load components of the local longshore transport as functions of the local longshore current and water depth. Accordingly, the model is similar in structure to that of WALTON and CHIU (1979) and therefore involves the same difficulty of selecting separate bedload and suspended load transport coefficients. Typical normalized transport curves predicted by the model for a planar beach are shown in Figure 4. Transport maxima is predicted to occur at about nine-tenths of the distance from the shoreline to the breaker line. Transport is described seaward of the breaker line with a slight gradient discontinuity, but is not described above the shoreline.

ABDELRAHMAN (1983) elaborated upon THORNTON’s (1972) model. He described the gradient in energy flux across the surf zone as a function of (1) breaking wave energy dissipation (modelled after a periodic bore), and (2) due to bottom friction (eventually neglected). The local longshore current \( V(x) \) was expressed as a function of breaking wave energy dissipation after LIU and DALRYMPLE (1978). Abdelrahman’s final expression (which appears dimensionally incorrect) predicts the peak longshore transport at the outer-mid surf zone, and predicts transport which decreases to zero at the shoreline. The model was developed and evaluated for random waves.

MCDouGAL and HUDSPETH (1984) evaluated forms of the “energetics” and “stress” models for equilibrium-shape beaches characterized by a planar foreshore intersecting with a concave-up profile of the form

\[
h(x) = A x^{2/3} \tag{24}
\]

where \( A \) is a dimensional “shape factor”. The authors included the effects of static wave-induced set-up across the profile and subsequently developed an appropriate expression for the longshore current. Representative results of their investigation are illustrated in Figure 5 for a single value of the longshore current mixing strength parameter, \( P \), and for various locations of the intersection point between the planar foreshore and concave-up portions of the profile. The models were developed and evaluated assuming constant proportion between the water depth and wave height across the surf zone. It is noted that the non-dimensional shoreline location \( x/x_s = 0 \) refers to the set-up water level. (The approximate still-water shoreline can be shown to be at about \( x/x_s = 0.19 \).)

The transport maxima predicted by the “energetics” model is observed to generally follow the intersection point of the planar and non-planar profiles. Accordingly, the transport maxima might be expected to be centered nearer the shoreline for steeper beaches and nearer the breakpoint for milder-sloping beaches. The “stress” model similarly predicts that the transport maxima follows the point of intersection between the planar and concave-up profiles; however, the effect is not as readily noted. A potentially important result here is that both models as evaluated suggest that the longshore transport distribution shifts shorewards (relative to the planar beach case) as the beach profile assumes more of an “equilibrium” concave-up shape.
Figure 4. Normalized longshore transport distribution across a planar beach from the Bailard model for the conditions shown. (Adapted from Bailard, 1984).

DEIGARD, FREDSSØE, and HEDEGAARD (1986) described a numerical model for the calculation of the local longshore transport rate which utilizes models for the vertical distribution of suspended sediment in combined wave-current motion for non-breaking and breaking wave conditions. These models are combined with detailed descriptions of the wave height and longshore current distributions across the surf zone. Because they neglected the shore-normal momentum equations (which eliminates set-up and set-down descriptions) and because they imposed a zero-velocity boundary condition at the shoreline in the solution of their longshore current equations, their results potentially underestimate longshore current contributions near the shoreline. The authors compared results from their model with field data developed from monitoring of the natural back-filling of a large trench dug across the surf zone (MANGOR, SØRENSEN AND NAVNTOFT, 1974). Agreement was reasonable across the outer surf zone where field results were available. Calculated transport peaks were centered over three bars located across the surf zone. This is in general agreement with other field observations discussed in the next section.

Finally, BODGE (1986) and BODGE and DEAN (1987) tested forms of the “energetics” and “stress” models, as well as several alternate models, against longshore transport distributions found from field and laboratory investigations using short-term impoundment techniques. The model which resulted in best agreement with the data is based upon the assumption that sediment is mobilized in proportion to the local rate of wave energy dissipation per unit volume and is transported alongshore by an existing current, i.e.,

$$i(x) = k_m \frac{1}{h} \frac{\delta}{\delta x} (E C_e) V \left[ \frac{dh}{dx} \right]^r$$

(25)

where $k_m$ is a constant of proportionality with units of time, and the factor of local bottom slope has been semi-empirically introduced. The exponent $r$ was found to be between 0 and 0.5. Scaling effects in their movable-bed laboratory tests may have resulted in exaggerated apparent relationship between local transport and bottom slope. Accordingly, the exponent $r$ is probably best taken as 0 although a value of 0.5 yielded best agreement with their data.

In order to avoid a singularity and ensure continuity at the shoreline, it was assumed in the evaluation of Eq. 25 that the height of the water column which defines the local surf zone volume is given by $H + d$, where $d$ is the still water depth plus wave-induced set-up. Assum-
Longshore Sediment Transport

The earliest published prototype observations of the longshore transport distribution were by the BEACH EROSION BOARD (1933). Sediment concentrations measured from water samples collected beneath a pier were used to indicate the relative magnitude of the suspended component of longshore drift across the surf zone. The results suggested maximum transport at the breaker line and in the swash zone. Transport decreased with increasing depth seaward of the breaker line.

From experiments on a moveable-bed laboratory model, SAVILLE (1950) noted a relationship between the beach profile/wave conditions and longshore transport. Although he did not discuss the transport distribution outright, he observed that the bulk of the longshore transport occurred within the surf zone and on the foreshore.

Saville emphasized that locations of significant longshore transport might correspond to those of concentrated cross-shore processes; that is, greater amounts of sediment are mobilized for transport as the profile adjusts to the wave climate. Saville suggested that this not only increases the total longshore transport (substantiated by laboratory measurements of KAMPHUIS and READSHAW, 1978), but may affect where the transport occurs. He observed that on equilibrium storm beach profiles, the longshore drift was primarily due to advection of sediment by the longshore current within the surf zone. On equilibrium summer beach pro-

by intersecting concave-up and planar foreshore profiles. As with the former investigators’ findings, the transport maxima was predicted to follow the intersection point of the two profile shapes. With the inclusion of wave-induced setup, considerable transport was predicted above the still-water shoreline.

Upon integration of the distribution models across the surf zone, the Bagnold, Thornton, Komar, Walton and Chui, and Svasek models yield expressions for the total longshore transport rate which are similar to the fairly traditional total transport expressions. This is true (for all but the latter two) if the longshore current is assumed uniform across the surf zone and proportional to the wave orbital velocity and \( \sin 2\alpha \) (see, for example, KOMAR, 1971).

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The earliest published prototype observations of the longshore transport distribution were by the BEACH EROSION BOARD (1933). Sediment concentrations measured from water samples collected beneath a pier were used to indicate the relative magnitude of the suspended component of longshore drift across the surf zone. The results suggested maximum transport at the breaker line and in the swash zone. Transport decreased with increasing depth seaward of the breaker line.

From experiments on a moveable-bed laboratory model, SAVILLE (1950) noted a relationship between the beach profile/wave conditions and longshore transport. Although he did not discuss the transport distribution outright, he observed that the bulk of the longshore transport occurred within the surf zone and on the foreshore.

Saville emphasized that locations of significant longshore transport might correspond to those of concentrated cross-shore processes; that is, greater amounts of sediment are mobilized for transport as the profile adjusts to the wave climate. Saville suggested that this not only increases the total longshore transport (substantiated by laboratory measurements of KAMPHUIS and READSHAW, 1978), but may affect where the transport occurs. He observed that on equilibrium storm beach profiles, the longshore drift was primarily due to advection of sediment by the longshore current within the surf zone. On equilibrium summer beach pro-
files, the transport was almost entirely due to beach “drifting” along the foreshore. The transition between these two cases occurred abruptly at $H_o/L_m = 0.03$ (which corresponds to the transition between spilling and plunging waves for his laboratory beach slope of 1:10). The total transport along summer beach profiles (i.e., those with the more plunging-type waves) was much greater than that along storm beach profiles for the same wave energy levels. This suggests that longshore drift along the foreshore is associated with plunging waves and is at least as significant in magnitude as transport associated with longshore currents seaward of the shoreline.

ZENKOVITCH (1960) evaluated fluorescent tracer movements as an indicator of longshore drift across beaches in the Soviet Union. Figure 6 illustrates typical measurements from his studies of the distribution profiles of longshore current, longshore sediment (tracer) advection velocity, and suspended sediment concentration. Peak longshore drift was observed at the breaker location(s) and at the shoreline and swash zone. Generally, the transport rate was found to increase in areas of observed high turbulence (bar breaks and the shoreline) and to decrease in areas of lower turbulence (troughs).

INGLE (1966) described several fluorescent tracer experiments on prototype beaches which yielded longshore transport distribution profiles similar to those found by Zenkovitch.

THORNTON (1968) used numerous 20-cm high traps operated from a pier at Fernandina Beach, Florida, to collect the longshore component of sand transport. In general, he found that longshore transport increased shoreward and was associated with bars rather than troughs. Thornton rationalized (and substantiated through measurement) that kinetic energy increases shoreward and therefore bed shear and associated mobilization of sediments increases shoreward. Thornton's measurements were limited to the outer portion of the surf zone in water depths of one-half meter or more.

BRUNN (1969) utilized the same technique as Thornton but caught fluorescent sand tracer in the traps. He found several dissimilar transport distributions and, unlike the previous investigators, observed greater drift in the beach troughs than over the bars. Brunn suggested that this was likely due to an absence of
wave breaking over the bars and/or strong tidally-driven longshore currents which were present in the troughs.

BIJKER (1971) conducted laboratory experiments where sand transported along a model beach spilled over a weir and into a cross-shore series of deposition bins located at the extreme downdrift end of the beach. Figure 7 illustrates the transport profile derived from the distribution of material deposited in the bins after about 10 hours of testing in comparison to Bijker's predictive model. The measured distribution is suspect because of transport disturbances caused by the weir over which the sand flowed. The longshore current, wave height, and beach profiles 2 m updrift of the bins are also shown in the figure. Bijker reported that the bulk of the longshore transport (or deposition in the bins) initially occurred seaward of the bar and gradually moved shoreward as the bar became more pronounced. He suggests that this may be attributed to increasingly greater concentration of the longshore current between the shoreline and the bar as the bar grew in relief.

SAWARAGI and DEGUCHI (1978) placed round traps divided into pie-shaped sections into the bed to collect sediment transport from several directions simultaneously. Four different longshore transport distribution profiles were apparent from their four field studies: (1) maximum in the swash zone, (2) maximum towards the shoreline, (3) maximum at the breaker line, and (4) bimodal with maxima at the shoreline and at the breaker line. In each case, significant longshore transport was observed above the shoreline with about 10% to 30% of the total transport collected seaward of the breaker line. Possible correlation between the cross-shore and longshore transport distributions was also apparent.

SAWARAGI and DEGUCHI (1978) subsequently used their trapping technique on a movable bed laboratory beach and also measured the cross-shore and longshore components of bed shear stress on a similar fixed bed labo-

![Figure 7](https://example.com/figure7.jpg)
Figure 8. Laboratory measurements of Sawaragi and Deguchi of longshore transport distribution for median sand diameter of (a) 0.34 mm, (b) 0.68 mm. Corresponding wave height and longshore current distributions shown in (c) for 0.34 mm (solid line) and 0.68 mm (broken line) sand sizes. (Adapted from Sawaragi and Deguchi, 1978.)

The laboratory data of Sawaragi and Deguchi indicate peak transport at $x/x_b = 0.6$ to 0.8. Ten to twenty percent of the total transport is seen seaward of the breaker line. For the finer sediment, transport at the shoreline increases with decreasing wave steepness; however, transport above the shoreline is not quantified. As with the field results, the measured cross-shore transport distributions (not shown) were found to be similar to those of the longshore transport.

TSUCHIYA (1982) presents one result from an experimental investigation of the transport distribution; details of his study were not available to the author. His data indicates a primary transport peak at about $x/x_b = 0.8$. Secondary peaks are noted in the swash zone and just outside of the breaker line.

BEREK and DEAN (1982) hypothesized that the longshore transport distribution can be inferred from the relative amount of rotation of depth contours in a pocket beach after a change in wave direction—so long as on/offshore transport does not appreciably contribute to the contour changes. Using survey data collected in two-month intervals at Leadbetter Beach (Santa Barbara, California), BEREK and DEAN calculated the local longshore transport at particular depth contours of interest through consideration of hourly fluctuations in tide and longshore wave energy flux and through the measured contour changes. Their results are shown in Figure 9 where the local transport rate has been normalized by the value calculated at the mean shoreline. Less confidence is expressed in the October to December evaluation because of presumed “leaks” in the pocket beach. Distribution models of three other investigators discussed previously are shown for comparison (as presented by Berek and Dean). These models were evaluated over the temporally fluctuating tide; accordingly, their predicted distributions moved across the mean water depths so that the local transport calculated at the mean shoreline is non-zero. Berek and Dean’s results suggest that longshore transport increases towards the mean shoreline or at least is greatest across the inner surf zone.

From a field study using fluorescent tracers, KRAUS et al. (1982) identified four basically different longshore transport distributions across the surf zone: (1) generally uniform, (2)
bimodal with swash zone and breakpoint peaks, (3) maximum towards the breaker line, and (4) maximum towards the shoreline. The surf similarity parameter (as calculated by the author) for each of the six experiments from which these distributions were derived are, respectively, (1) $\xi_b = 0.12$, (2) $\xi_b = 0.11$ to 0.15, (3) $\xi_b = 0.11$ to 0.23, (4) $\xi_b = 0.18$ to 0.35. The reported wave conditions for the experiments considered were mixed spilling and plunging (SUNAMURA and KRAUS, 1985). KRAUS et al. suggested that there is no reason to expect a "standard" distribution profile for longshore sediment transport in the prototype given the variability of longshore current distribution across real beaches and the variability of the dominant mode of sediment transport (i.e., suspended load vs. bedload).

FULFORD (1982, 1987) examined contour changes updrift of a high-relief groyne after ten hours of oblique wave attack on a laboratory beach (SAVAGE, 1959). The beach was in only approximate equilibrium with the wave conditions before the test was begun. Fulford used an "impoundment technique" analysis approach where the local longshore transport is calculated through integration of measured profile changes updrift of a shore-perpendicular barrier. His results are illustrated in Figure 10. The zero-hour still water shoreline corresponds to $x/x_o = 0$. Peak transport is calculated at $x/x_o = 0.35$. Of the total transport, about 18% is
observed above the still-water shoreline location with another 18% seaward of the average breaker location. Using rms wave parameters calculated by Fulford, the surf similarity parameter for SAVAGE’s experiment was approximately $\xi_b \approx 0.23$ to $0.28$. The nearshore peak in transport agrees roughly with the SAWARAGI and DEGUCHI (1978) and KRAUS et al. (1982) field data for this range of the surf similarity parameter.

It is noted that Fulford’s distribution does not close to zero seaward of the breaker line. This is partly because the groyne did not extend significantly seaward of the breaker line and partly because FULFORD did not account for cross-shore transport effects. Specifically, the contours outside of the breaker line shifted considerably seaward during the ten-hour test (out to a depth $h \approx 2.5h_b$). This shift, interpreted by FULFORD as a longshore transport signal, was relatively constant across the entire length of the beach and was therefore mostly unrelated to impoundment of longshore drift by the barrier.

ABDELRAHMAN (1983) evaluated beach profile changes out to wading depths over several stormy days along Leadbetter Beach, Santa Barbara, California, in order to approximate the longshore transport distribution. He assumed that cross-shore transport was negligible during the survey period because of the absence of pronounced berms or bars in the profiles. His data analysis technique was based upon that of an impoundment approach; however, this requires that a gradient of longshore transport exists along the beach. It appears that ABDELRAHMAN calculated the mean alongshore gradient in longshore transport and assumed that its distribution was similar to that of the longshore transport. His results indicate considerable shoreline/swash zone transport (or alongshore gradient thereof).

DOWNING (1984) and STERNBERG et al. (1984) measured vertical sediment concentration profiles simultaneously with the longshore current across the surf zone on natural beaches. Each developed local longshore suspended sediment transport values using

$$ q(x) = V_{x,z,t} \int_{h}^{0} c(x,z,t) \, dz $$

(27)

where $c(x,z,t)$ is the local instantaneous sediment concentration profile and the over-bar denotes time averaging. Downing’s findings for a wide, relatively planar-bed surf zone (with spilling breakers) at Twin Harbor Beach, Washington, are shown in normalized form in Figure 11. His measurements excluded water depths less than about half a meter. Sternberg’s

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Figure 10. Longshore transport distribution from Fulford inferred from impoundment updrift of a barrier on a laboratory beach (Savage, 1959). (Adapted from Fulford, 1982.)
findings from Leadbetter Beach, (Santa Barbara, California), are shown in Figure 12. The mean shoreline position is $x/x_b = 0$.

The results from both of these investigations indicate maximum transport at about mid-surf. The authors report that considerable longshore drift was observed in the swash zone but measurements could not be taken in this area. It is also noted that the studies neglect bedload transport and that the use of Eq. 27 implies that the longshore current is uniform through the water column.

MANGOR, SØRENSEN, and NAVNTOFT (1984) monitored the natural re-filling of a large trench dug across the Danish North Sea Coast and attempted to correlate the volumetric accretion in the trench with total longshore transport predictions. Some distributed transport information may be developed from their data; however, the data are somewhat smeared by hydrodynamic forces and the temporal intervals between surveys of the trench.

BODGE (1986), (see also BODGE and DEAN, 1987), used a “short-term impoundment technique” to estimate the longshore transport distribution. Single, low-profile groynes were rapidly deployed in field and laboratory environments, and profile changes updrift of the groynes were subsequently measured and analyzed to extract the local longshore transport across the surf zone. The data were treated to remove potential contributions and/or smearing due to tidal and cross-shore transport processes. The latter were reported to be relatively small for the laboratory data as the model beach was pre-equilibrated with the wave conditions before each impoundment experiment was begun. Representative results from their investigation are illustrated in Figure 13. The distributions predicted for each data set from their suggested model (Eqs. 25 and 26) are also shown.

Based upon their measurements, Bodge and Dean suggest that the transport distribution is generally bimodal with peaks at the shoreline and at the mid-outer surf zone. The relative significance of the peaks shifts from the near-breakpoint peak to the near-shoreline peak as the breaking wave condition varies from spilling to collapsing. Longshore transport seaward of the breakpoint represents about 10% to 20% of the total. Swash zone transport accounts for...
at least 5% to 60% of the total for spilling to collapsing conditions, respectively. It was also suggested that smaller levels of swash contributions for spilling wave cases may be due to the high phase difference of the swash in a spilling surf zone (i.e., where the swash is not completed before the arrival of the next wave).

KRAUS and DEAN (1987) offer initial results of investigations of longshore transport using "streamer traps" (see also KRAUS, 1987). These traps are positioned vertically and laterally across the surf zone and are directed into the longshore flow to collect the longshore component of transport. From the results of ten separate field measurements, Kraus and Dean identified four distribution profiles similar to the four reported earlier by KRAUS et al. (1982). A portion of their findings is illustrated in Figure 14.

**SUMMARY**

At least fifteen expressions have been suggested to date for the distribution of longshore sediment transport across the surf zone. In general, most of the models assume that sediment is locally mobilized (1) as a function of energy dissipation from the breaking waves, or (2) by the bed shear stress induced by the peak horizontal wave orbital velocities alone or (3) by the combined peak orbital velocities and longshore current. The mobilized sediment is then assumed to be advected downdrift by the local longshore current. Accordingly, knowledge of
Figure 13. Longshore transport distribution from Bodge and Dean inferred from impoundment updrift of a barrier (bold lines) and from Eq. 26 (light lines). Results for various surf zone types from (a-e) laboratory tests and (f) field measurement. (Adapted from Bodge, 1986).
the distribution of longshore current across the surf zone is important to the prediction of local transport for most models. Many investigators have relied upon the expression for longshore current across a planar beach suggested by Longuet-Higgins (1970).

Almost all of the existing models suggest that the longshore sediment transport is greatest between the mid-surf zone and the breaker line for a planar beach, and that the longshore transport tends to zero at the shoreline and outside the breaker line. Models which do not include bottom stress due to longshore current or non-breaking wave orbital motion exhibit discontinuities in transport at the breaker line with no transport seaward of the breaker line. Few models explicitly describe nor are well-conditioned to treat longshore transport in the swash zone.

Data from field and laboratory studies of longshore transport indicate that (1) significant levels of transport may occur above the shoreline, i.e., in the swash zone, (2) contribution of the swash zone transport increases as waves break near or upon the foreshore, (3) about 10% to 30% of the total transport occurs seaward of the breaker line, (4) maximum local transport is at least as likely to occur within the shoreward half of the surf zone as within the seaward half, (5) greater transport is often associated with shallower depths, i.e., breakpoint bars and the shoreline, and (6) field measurements demonstrate great variability in the shape of the transport distribution profile.

It would appear that our abilities to understand and successfully predict the longshore transport distribution across the surf zone are impeded primarily by a lack of reliable and complete field and laboratory data. Unfortunately, the difficulty of accurately modelling...
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avoided, as the present database suggests that these areas may be very active in littoral drift. Consequently, imaginative efforts must be directed at developing instrumentation and monitoring equipment for shallow water as well as three-dimensional hydrodynamic/transport models which describe swash processes. A complete study might ideally include measurements across the swash and surf zones of local sediment transport, wave height, longshore current, bed profile, vertical suspended sediment distribution, and grain size, as appropriate. Also, the time scale of each study should be commensurate with that of the duration of the directional wave event which drives the transport. Lastly, emphasis should be placed on modelling the transport distribution across non-planar beaches as the results developed using planar beach assumptions appear to be at odds with those developed from non-planar models and from field and laboratory studies.

**LITERATURE CITED**


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RESUMEN
Se analiza y estudia los modelos existentes y los datos de campo y naturaleza que describen la distribución de transporte de sedimentos a lo largo de la costa en la zona de rota. La mayoría de los modelos se apoyan en cierta formulación sobre la distribución transversal de la corriente longitudinal. Muchos de ellos no están bien preparados para describir el transporte sobre el nivel medio en la zona de flujo-reflujo y cuando se aplican a una playa plana, predicen el máximo transporte en la mitad exterior de la zona de remolinos. Los datos de laboratorio y campo sugieren que una parte significativa del transporte puede ocurrir sobre el nivel medio del mar y pueden de manifestar la variedad de perfiles transversales de distribución de transporte.—Department of Water Sciences, University of Cantabria, Santander, Spain.

ZUSAMMENFASSUNG
Eine Literaturübersicht über die Verteilung der strandparallel transportierten Sedimente innerhalb der Brandungzone Bestehende Modelle sowie Feld- und Laborergebnisse, welche die Verteilung der strandparallel transportierten Sedimente innerhalb der Brandungszone beschreiben, werden aufgeführt und kurz diskutiert. Die meisten Modelle füllen auf Überlegungen über