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Longshore current variations, Guyana, South America.

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LONGSHORE CURRENT VARIATIONS, GUYANA, SOUTH AMERICA

by

Lloyd Massimo Prevedel

A Thesis Submitted to the Faculty of Graduate Studies and Research through the Department of Geography in Partial Fulfillment of the Requirements for the Degree of Master of Arts at the University of Windsor

Windsor, Ontario, Canada

1997

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ABSTRACT

Integrated nearshore currents composed of longshore and circulation currents were tested against the continuity of water mass equation (Galvin and Eagleson, 1965), for a dissipative, barred transect of Guyana's Batchelor's Adventure beach. Although there were considerable variations in beach energy conditions during the study period, good agreement ($r^2 = .536$) between observed current velocity and those predicted by the model was established. Considerations of daily wave conditions and especially topographical parameters provided accurate estimates of the flow velocity where currents were being forced alongshore. In addition, the current distribution displayed considerable spatial heterogeneity probably because of varying wave, water and topographical parameters. Bimodal, coast-normal distributions were present, and greatest velocities were observed closest to the breaker zone. Spectral analysis of the current flow indicated that considerable white noise was present in the series. However, the existence of spectral energy peaks at or near the incident wave frequency were satisfactorily demonstrated.
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LIST OF ABBREVIATIONS

\[ g \] - acceleration due to gravity

\[ T \] - wave period

\[ \tan \beta \] - beach slope

\[ \alpha \] - angle of wave approach to the beach

\[ E \] - wave-energy density

\[ n \] - ratio of the wave group and phase velocity

\[ S_{xy} \] - the onshore flux of longshore momentum

\[ U \] - longshore current at the mid-surf position

\[ U_m \] - maximum wave horizontal orbital velocity

\[ H_b \] - wave height at the breaker zone

\[ V_1 \] - estimated longshore current velocity

\[ k \] - a constant (approx = 1)

\[ a_j-b_j \] - orthogonality coefficients

\[ \omega_j \] - radian frequency

\[ d \] - water depth

\[ D \] - distance between stations
LONGSHORE CURRENT VARIATIONS,
GUYANA, SOUTH AMERICA

CHAPTER ONE

INTRODUCTION

Two wave-induced current systems are generally recognized in the
earshore zone in addition to the to-and-fro motions directly produced by wave
orbital motion (Komar, 1975, p 17-18). They include longshore currents driven by
obliquely incident waves, and local cell circulation systems composed of rip and
longshore currents. Wave induced longshore currents flow parallel to the shoreline,
and are either generated by waves breaking at an angle to a coast, or by longshore
variations in wave breaker height. The importance of these currents has been
thoroughly documented (Putnam et al., 1949; Galvin, 1967; Komar and Inman,
1970; Longuet-Higgins, 1970; Thornton, 1970; King, 1972; McDougal and
Hudspeth, 1983; Bowen and Huntley, 1984; Bodge, 1988; Hazen et al., 1990;
Galvin, 1991; Larson and Kraus, 1991). They play an essential role in the
longshore movement of material, and are fundamental to the formation of many
coastal features. Given this, the availability of sediment and the strength of the
current are primary factors in evaluating longshore sediment transport.

Several workers have modelled variations in longshore current strength
across the surf zone (Bowen, 1969a; Longuet-Higgins, 1970; Thornton, 1970;
Komar, 1975), but few measurements have been made in the field (Trenhaile,
1997). Although many studies describe longshore current velocities that are quasi-
parabolically distributed across the surf zone (Inman et al., 1980, Komar and Holman, 1986, Zampol and Inman, 1989), most of this work has been conducted on planar beaches where submarine bars, troughs and other topographical irregularities are absent. Some workers have suggested that longshore current velocities are greatest over the crest of submarine bars (King, 1972; Symonds and Huntley, 1980) but in the field, currents have sometimes been found to be strongest in the intervening troughs (Larson and Kraus, 1991; Smith et al., 1993). In addition, contemporary predictive models rely on averaged results from Lagrangian measurements to establish longshore current velocities. Short period velocity variations in excess of 150 percent over time periods of between three to eighty seconds is not uncommon (Wood and Meadows, 1975) however, and time dependant investigations of longshore current velocity may therefore prove valuable in assessing longshore sediment transport, bed form behaviour, and the siting and performance of coastal structures.

1.2 Study objectives

The objectives of the proposed study are: (1) to measure longshore current velocities across a non-planar beach in Guyana, (2) to determine the relationship between longshore current velocity and wave and topographical parameters for the study beach, and (3) to determine the spatial and temporal composition of these velocities in the surf zone. The proposed study will attempt to clarify how the presence of submarine bars and troughs affect the strength and distribution of longshore currents along the nearshore as well as present time histories of longshore current velocities.
CHAPTER TWO

REGION UNDER STUDY

2.1 The physiography and coastal zone of Guyana

Guyana can be divided into four physiographic regions: the Pakaraima mountains, the Pre-Cambrian lowlands, the sandy, rolling lands, and the coastal plain (Lakhan, 1990)(Figure 1). The elevation of the coastal plain is approximately 1.5 m below sea level at high tide, and extends a distance of about 435 km from Punta Playa in the west to the Corentyne River in the east. Varying in width between 77 km in the west and 26 km in the east, the coastal plain occupies about 8% of the country and contains nearly 90% of its 900 000 inhabitants (Lakhan, 1990). Approximately 50% of the low lying coastal plain is protected by sea walls constructed at the landward limit of the backshore zone.

The coastal plain is a chenier plain consisting mainly of mangrove swamp vegetation, tropical forest, and cultivated areas in the south (Figure 2). Communities of mangroves periodically occupy the areas in front of the sea wall during beach accretional cycles. Cultivated areas landward of the sea wall mainly consist of pasturage or rice, which are able to survive the high water table and consequently high saline content of the soils. The chenier coast of Guyana varies in size and composition. The cheniers are composed of shell material and coarse sand, but some are made up exclusively of shells. The widest section of the chenier belt (10 km) lies between the Corentyne and Berbice Rivers. Its width shrinks consistently and disappears east of the Pomeroon River. Several surveys (Delft
Figure 1

GUYANA AND ITS NATURAL REGIONS

Guyana's Coastal Plain

Figure 2

Southern boundary of the coastal plain

- Peat (Pegasse) Swamps
- Demerara Formation
- Coropina Formation
- Berbice Formation (White Sands)
- Crystalline Basement
- Shell Beaches
- Cheniers

GUYANA COASTAL PLAIN

Hydraulics Laboratory, 1962; Nedeco, 1972; Abernathy, 1980; Halcrow and Partners, 1984) have stressed the importance of cheniers in protecting the low-lying coastal plain against wave erosion (Daniel, 1989).

2.2 Nearshore processes along the Guyana coast

The northeastern coast of South America (known as the Guiana coast) extends 1600 km between the mouths of the Amazon and the Orinoca Rivers, and forms the coastline of Guyana, Surinam, French Guiana, and parts of Brazil and Venezuela. Nearshore processes along this coast are affected by mud shoals of thixotropic, gel-like fluid muds. Processes of alternating erosion and accretion are controlled by the formation and migration of these mud shoals, which are composed of sediments carried northwestwards by longshore currents from the Amazon Basin. These currents move at a rate of 20 to 50 cm/sec. carrying 1 to 2 hundred million tons of sediment annually (Eisma and van der Marel, 1971). The agitation of the water in this region maintains the sediment in a constant state of flux. It is the suspension of the sediments that imparts a coffee brown colour to the sea 20 to 40 km from the shore (Daniel, 1989). Longshore currents along Guyana's coast coexist with nearshore cell circulation currents (Figure 3).

When the concentration of mud reaches a critical level, it settles on the sea bed in the form of mud shoals which have an average longshore wavelength of 45 km. Their composition varies spatially. Towards their eastern side, the soft mud changes into an immature erodible clay, owing mostly to compaction (Daniel, 1989). Sedimentation on the western sides and erosion on the eastern sides cause the shoals to migrate westwards. The recurrence interval of mud shoals is estimated
Figure 3
Longshore and Nearshore Cell Circulation Currents

Oblique Wave Approach

Longshore Current

Beach

Source: Komar and Inman, 1970
to be approximately 30 years (Nedeco, 1972). Coastal areas shorewards of a mud shoal are protected from wave action by the viscous nature of the mud. In essence, the migration of these shoals directly controls erosion and accretion patterns along the Guyana coast. Aside from being composed of Amazon-borne material, sediment from local rivers (for example, the Corentyne, Berbice, Demerara, Essequibo, Mahaica, and Mahaicony) contribute about 5 to 10% of the nearshore sediment load and almost all the sand. The Guyanese coast is meso-to-microtidal, with a mean spring tidal range of 2.38 meters and a mean neap range of 1.9 meters. The large tidal flows can penetrate 60 to 80 km up the major rivers (Lakhan, 1991).

Two wet and dry seasons exert a significant influence on the nearshore water level and the amount of sediment in the nearshore zone. Most rainfall, 2000-2500 mm/year, occurs during two peak periods April-August and December-January (Potter, 1967). During rainy seasons, excess water is pumped over the sea wall along most of the coastal plain. The region experiences winds which are consistently between northeast and north-northeast.

2.3 The study beach

Guyana is located above the equator on the northern coast of South America between 0° 41' N and 8° 33' N and between 56° 32' W and 61° 22' W. It is bounded by Brazil to the south, Venezuela to the west, Surinam to the east, and the Atlantic Ocean to the north.

The nearshore zone of Guyana has few sand beaches. Most of Guyana's nearshore consists of a churning mass of fluid mud underlain by a thicker more
consolidated body of mud that can not support a person's weight. The study beach is located within the District of Batchelor's Adventure, approximately 16 kilometres east of the capital, Georgetown (Figure 4). This beach was chosen for study because the underlaying sandy bed was firm enough to conduct the nearshore investigation and it was reasonably accessible. Field investigations were conducted along a relatively straight section of the shoreline within the surf zone, the area lying between the breaker and swash zones where bottom turbulence causes waves to dissipate their energy (Figure 5) (Inman and Bagnold, 1963; Carter, 1988). The upper shore consisted of a shell chenier abutting a seawall constructed to protect the low lying coastal plain. The overall beach slope was gentle (between 1 and 3 degrees), although its topography is irregular, consisting of a deep narrow trough running parallel to the shore and lying landward of a large, gently sloping bar, whose crest, at high tide, occupies the midsurf position (Figure 6a).

During field observations in June-July of 1994, the nearshore experienced incident waves with periods of between 5 and 8 seconds and heights of between 0.2 and 0.6 meters. Angles of wave approach were consistently between 331 and 347 degrees. There were integrated longshore and cell circulation current systems on the beach, and rip currents had carved a shallow, narrow channel through the nearshore bar running seawards from the trough to the northwest. Occasionally, waves running upstream were observed in the trough during outward moving tides (Figure 6b).
THE SURF ZONE

Figure 5

**Nearshore Current Patterns at High Tide**

**Figure 6b:** The study beach, consisting of longshore currents driven by longshore variations in wave breaker height and a nearshore cell circulation system driven by longshore forcing. Rip currents had carved a shallow, narrow channel in the nearshore bar that ran seaward from the trough to the northwest. Occassionally, (approximately every 200 seconds) standing waves driven by currents travelling eastward, were detected in the longshore trough. These currents were probably generated by large infragravity wave groups at the end of the bar to the west.

Note: Grey areas indicate water.

**Source:** Author, 1997
CHAPTER THREE

REVIEW OF THE LITERATURE

3.1 Introduction

Despite the effect of refraction, wave crests frequently reach the breaker line at a small angle to the shoreline. Incident angles for swell waves, that begin to feel the bottom a long way from shore, are rarely greater than 10 degrees, but they can be much greater for less well refracted waves of shorter wavelength (Trenhaile, 1997). Oblique waves drive longshore currents parallel to the shoreline, but winds with a substantial longshore vector component also generate shear on the water surface, and they can therefore make a substantial contribution to longshore current forcing (Sherman and Greenwood, 1985; Hubertz, 1986). Longshore currents generated by oblique waves can co-exist with longshore currents in circulation cells that are a result of longshore variations in wave height (Shepard et al., 1941; Shepard and Inman, 1950, 1951).

3.2 Theories of longshore current generation

Early research on longshore currents began with an attempt to describe the relationship between current velocity and wave height, wave period, breaker angle, and nearshore topography (Putnam et al., 1949; Inman and Quinn, 1952). Many attempts were later made to account for the presence, and to predict the velocity, of the longshore current (Inman and Bagnold, 1963; Galvin and Eagleson, 1965; Galvin, 1967; Harrison et al., 1965; Harrison, 1968; Bowen, 1969a; Longuet-Higgins, 1970, 1972; Komar and Inman, 1970). Theories of longshore current generation
can generally be classified into three categories, which include: (1) energy flux considerations; (2) considerations of the continuity of water mass and (3) momentum flux considerations.

The effect of longshore currents on landing craft during World War II led to the comprehensive theoretical study by Putnam et al. (1949). They used the solitary wave description of breakers to consider the longshore component of energy flux entering a unit length of the surf zone. A second relation for the mean longshore current velocity was obtained from a conservation of momentum approach. They believed that this momentum, thrown into motion in the direction of wave propagation, provided the driving force for the generation of longshore currents. Although this model proved to be much more successful as a predictor equation, it was reexamined later using the concept of radiation stress (Longuet-Higgins, 1970; Thornton, 1970). The two expressions developed, containing three unknowns: the longshore current velocity; the fraction of incoming energy flux available to drive the longshore current; and a friction factor, provided no means for an independent solution (Meadows, 1977). Furthermore, these expressions were independent of local water depth and distance from the shoreline because they restricted bathymetry to straight and parallel contours with a constant slope, the angle of wave approach was held constant, and no provisions were made for shoaling induced refraction of wave crests. Additional attempts were made at improving these equations by incorporating fluctuations in beach topography and wave parameters (Galvin and Eagleson, 1965; Eagleson, 1965).

Bruun (1963), Inman and Bagnold (1963), Galvin and Eagleson (1965), and
Galvin (1967) developed longshore current models based on the belief that a continuity of water mass exists in the nearshore zone. This approach assumes that water entering the nearshore moves alongshore, progressively increasing in velocity as more and more water advances to the shore until a critical velocity is reached. At that point, the whole current turns seawards in the form of a rip current. Rip channels, which flow perpendicular to the beach, are formed where the waves and the slope of the water set-up are low. Essentially, this theory views the longshore current velocity \((v_r)\) as the product of a balance between the incoming and outward moving water mass and it takes the form:

\[
v_r = 2k_s g T \tan \beta \sin \alpha \cos \alpha
\]

where \(g\) is the acceleration due to gravity \((\text{m/s}^2)\), \(T\) is the wave period \((\text{sec})\), \(\beta\) is the beach slope angle \((\text{deg})\), \(\alpha\) is the angle of wave approach to the beach \((\text{rad})\), and \(k_s\) is a constant.

The radiation stress concept, first introduced by Longuet-Higgins and Stewart (1964) and Longuet-Higgins (1970), has been used by investigators to explain longshore currents (Thornton, 1970). This theory views the momentum flux directed parallel to the shoreline as the driving force of longshore currents, and assumes that currents are steady and constant in the longshore direction. In its simplest form, if \(E\) is the wave-energy density and \(\alpha\) is the angle of wave approach, then the longshore component of the radiation stress is:

\[
S_{xy} = En \sin \alpha \cos \alpha
\]

where \(n\) is the ratio of the wave group and phase velocities \((n = 1/2 \text{ in deep water})\)
and 1 in shallow water) (Bowen, 1969). If x is positive in the onshore direction and y is parallel to the shoreline, then $S_x$ is the onshore flux of longshore momentum due to the presence of waves. Using this relationship, Longuet-Higgins (1970), and Thornton (1970) were able to derive the model:

$$u = 2.7 \, u_m \sin \alpha \cos \alpha$$

where $u$ is the longshore current at the mid-surf position, $u_m$ is the maximum horizontal orbital velocity of the waves (given by linear shallow water theory). This relationship has best predicted available laboratory and field measurements of longshore current velocities on planar beaches (Komar, 1983).

Radiation stress has been used to analyze the change in mean water level or set-up of water at the shore line due to the presence of waves. The momentum brought into the nearshore by waves must be balanced by an opposing force (this effectively was Newton’s definition of a force as a rate of change of momentum), which is manifested as a water slope that forms a pressure gradient on the water surface (Hardisty, 1990). Thus, the difference between the still water level and the mean water level in the presence of waves (known as set-up or set-down), is viewed as the theoretical solution for longshore currents. Of all the equations formulated for the generation of these currents, those based on the concept of radiation stress (momentum flux) concepts have the firmest theoretical basis (Komar 1976, 1983). Expressions utilizing the momentum flux approach demonstrate that longshore current velocity depends upon the angle of wave approach and the orbital velocity at the breaker zone, which largely depends upon breaker height.
3.3 Review of longshore current studies

Much remains to be learned about the distribution of the currents across the width of the surf zone, mainly owing to the almost total lack of quality field data (Komar, 1983). While measuring longshore current variability, Guza and Thornton (1979) found that there was considerable spatial variability across the surf zone. Initial attempts at understanding this distribution have concentrated on modelling variations in longshore current strength across the surf zone of planar beaches (Bowen, 1969a; Longuet-Higgins, 1970; Thornton, 1970; Komar, 1975). Results indicated that the longshore current velocity was parabolically distributed, and was at a maximum at the midsurf position. Most recent studies suggest that velocities are quasi-parabolically distributed across the surf zone (Inman et al., 1980; Komar and Holman, 1986; Zampol and Inman, 1989). It has been found that velocity increases seawards from the shoreline, reaching a maximum at or just beyond the midsurf position before rapidly declining to zero outside the breaker zone. Larson and Kraus (1991) however, found that velocity increased quickly seawards from the shoreline to a maximum shoreward of the midsurf position, before slowly declining to zero beyond the breaker zone.

The need to recognize topography as an important interacting variable was emphasized by Sonu et al. (1967) and Komar (1983). Longshore current velocity distributions across the surf zone of nonplanar beaches differ from those of planar beaches (McDougal and Hudspeth, 1983; Bodge, 1988). McDougal and Hudspeth (1983) obtained analytical solutions for concave-up beach profiles (which approximates the profiles of many beaches). Their results indicated that maximum
longshore currents are slower and closer to the shoreline than those on planar beaches. Similar results were obtained by Bodge (1988), thus indicating that as beaches become more concave in shape, the longshore current maximum tends to move closer to the shoreline.

The presence of submarine bars and other topographical irregularities can also have a significant effect on the strength and distribution of longshore currents (King, 1972; Symonds and Huntley, 1980; Larson and Kraus, 1991). In Saville's (1950) wave tank experiment, it was found that the maximum current velocity was always greatest along a bar located in the breaker zone (King, 1972). Very rapid reductions in velocity were noted seaward of the bar, while velocities decreased more slowly landwards. These results were later supported by the theoretical models of Symonds and Huntley (1980). Maximum longshore current velocities in the field however, are more commonly found over troughs (Komar, 1983). The mathematical model of Larson and Kraus (1991) and Smith et al. (1993) also suggested that current velocities are greatest in troughs. This model greatly improved the level of agreement with measured velocity distributions along the North Carolina coast, and produced a persistent broad peak in current velocity in the trough between the nearshore bar and the shoreline.

Contemporary predictive models rely on substituting averaged current velocity values for the distribution of values observed in the field and laboratory. However, several investigators have suggested that longshore currents have significant temporally unsteady components (Putnam et al., 1949; Inman and Quinn, 1952; Harrison, 1968; Dette, 1974; Wood and Meadows, 1975; Meadows, 1977).
Putnam et al. (1949) observed longshore velocity variations as large as 25 percent of the mean during their Lagrangian field measurements. Inman and Quinn (1952) noted longshore current variability as large as 300 to 500 percent in successive thirty-second time-averaged Lagrangian measurements. Variability of wave height and nearshore cell circulation was considered to be the cause of these variations and thus, five successive thirty-second observations were made in order to obtain a mean longshore current with an average coefficient of variation comparable to the standard error. Similarly, Harrison (1968) determined that variations in longshore current velocity between two adjacent stations could be assumed to be within 10 percent of the "true" velocity. Wood and Meadows (1975) stated that the general conclusion of these studies is that temporal variations are viewed as unimportant to the determination of longshore current velocity. However, Dette (1974) observed temporal variations in longshore current strength of as much 100 percent, with as much as nine fluctuations per wave period. In addition, changes in the instantaneous longshore velocity were from 0 to 2 m/sec within a fraction of a wave period.

Wood and Meadows (1975) found that at a fixed point in the surf zone, variations in excess of 150 percent occurred over time periods from three to eighty seconds. They attributed these variations to infragravity fluctuations in wave height. Using spectral analysis, Meadows (1977) found that along the eastern shore of Lake Michigan, periodic variations in longshore current velocity were directly associated with the mean period of the incident breaking waves. Long, infragravity waves can be generated by low-frequency periodic and aperiodic events. Although
they are of considerable importance to coastal processes, they are often difficult to
detect because of their low heights and long periods. Beaches facing long wave
fetches sometimes experience the effects of swell waves originating from different
storm sources, with frequencies that are slightly out of phase. The addition of two
such waves produces regular alternations of groups of high and low waves. The
interval between two groups of high waves is typically between two and four
minutes, and it is often the 6th, 7th, or 8th wave that is the highest. This
phenomenon (surf beat) creates rhythmic, infragravity vibrations in the nearshore
zone, which have profound effects on surf zone processes, and important
morphological implications (Trenhaile, 1997).

3.4 Limitations of previous longshore current studies

These field measurements strongly support the concept that significant
unsteady motion does occur in longshore currents over relatively short time spans,
and that time-averaging is a physically inappropriate procedure (Wood and
Meadows, 1975). Two principal unknowns are responsible for uncertainty in field
data: the effect of variations in nearshore hydrography and the effect of substituting
a mean value for the distribution of values for each measured variable (Galvin,
1967). Since 1968, the effect of variations in nearshore hydrography has been
investigated in some detail. However, modern predictive models continue to rely on
verification based on Lagrangian averaging rather than on the spectrum of values
found in the field, and as a consequence, they have reinforced the development of
steady and quasi-steady longshore current theory. This steady state approach is
applied to all existing longshore current theories. Thus, the mean velocity of the
flow field is assumed to be an adequate representation of the flow at any instant in
time (Meadows, 1977). Few studies have investigated temporal variations of
longshore current velocities across the surf zone (Dette, 1974; Wood and Meadows,
1975; Meadows, 1977). Suggestions have been made that a reexamination of
longshore current theory using time dependant studies should be conducted in
order to establish physically appropriate predictive equations.

There are no satisfactory field measurements of the velocity distribution
across the surf zone (Komar, 1976, 1983; Galvin, 1991). In fact, the main constraint
to further progress is certainly our almost total lack of quality field data on longshore
currents, especially of the complete velocity profile (Komar, 1983). Many attempts
have been made to extend the original radiation stress theory to improve prediction
of longshore current velocity (Liu and Dalrymple, 1978; Madsen et al., 1978; Komar,
1979; Komar and Oltman-Shay, 1989; Losada et al., 1987). Of particular concern
is the fact that 75% of all laboratory experiments for which breaker angle and height
are required use the remarkably old data of either Putnam et al (1949) or Galvin
(1967). These data sets contain values for breaker heights and angles that were
computed rather than measured. Thus, studies which have used the data to
validate theories cannot be supported (Galvin 1991). For example, although Liu
and Dalrymple (1978) found very good agreement between their equation (which
accounted for large breaker angles and bottom friction) and the 1949 data, this
agreement does not validate the theory and may in fact refute it. Recent work has
concentrated on establishing accurate predictive models of longshore current
distributions (Liu and Dalrymple, 1978; Madsen et al., 1978; Komar, 1979; Komar
and Oltman-Shay, 1989; Losada et al., 1987). However, considerable uncertainty and disagreement still exists on how longshore current velocities react to irregular topography (King, 1972; Symonds and Huntley, 1980; Larson and Kraus, 1991).
CHAPTER FOUR

METHODOLOGY

4.1 Theoretical structure

Classically, longshore currents have been assumed to be steady flows parallel to the shoreline. Longshore current theory has subsequently been developed in an attempt to predict the one-dimensional, steady state distribution of the current velocity across the surf zone (Meadows, 1977). Subsequently, this has resulted in the conclusion that the general flow distribution is non-uniform across the surf zone. Theoretical formulations assume that longshore current velocities are confined within the surf zone and disappear at its onshore and offshore limits, giving rise to the expectation that a single velocity maximum exists. Given that the location of this maximum is dependant on several variables (eg., location at which wave height and wave particle velocity reach their maximum), it is not surprising to find discrepancies in the location of longshore current maxima from study to study.

Application of the temporal dependancy of longshore current velocities has received little theoretical attention or experimental verification. Presently, the mean velocity of the current flow is assumed to adequately represent the current at any instant in time. This approach is employed in an attempt to devise an analytically tractable formula. Wood and Meadows (1975) and Meadows (1977), however, have found that the total longshore current flow field is composed of both a steady and a time-dependant component. Fluctuations in the steady component
were attributed to wave orbital velocities, however, much larger, unsteady, time-dependant components were attributed to low frequency edge waves. Examination of both the spatial and temporal variation of longshore currents necessitates the formulation of an "a priori model".

4.2 The a priori model

An a priori model, based on the theory of current generation, demonstrates the relationship between waves, topography, and the spatial and temporal distribution of longshore currents (Figure 7). An a priori model is a formal representation of a real world image, which provides an initial, theoretical basis for an investigation.

The model which will be employed for the purposes of this investigation suggests that longshore currents along Guyana's coast constitute an integration of: longshore currents driven by an oblique wave approach and the wave breaker height (Inman and Bagnold, 1963; Longuet-Higgins, 1970; Thornton, 1970) and local cell circulation composed of rip and longshore currents driven by longshore variations in wave height (Figure 3)(Shepard et al., 1941; Shepard and Inman, 1950, 1951). Combining the two mechanisms produces a resultant system characterized by spatial disparities and temporal unsteadiness (Dette, 1974; Wood and Meadows, 1975; Meadows, 1977). It has been suggested that variations in time and space are a direct result of varying wave and topographical parameters (Sonu et al., 1967; Komar, 1983). According to Sonu et al. (1967), field experience indicates that the longshore current is a velocity field consisting of a multitude of velocity vectors.
whose basic pattern varies according to wave-current-topography interactions. Rip currents and their longshore feeder systems can be strengthened by water draining from the beach during ebb tides. This is particularly significant when the water flows alongshore in troughs, before turning seawards (Sonu, 1973). In turn, regularly spaced rip currents affect topography by cutting channels through nearshore bars as they turn seawards. Beach topography can have a profound effect on wave energy parameters (Komar, 1979; Larson and Kraus, 1991; McDougal and Hudspeth, 1983) by providing varying substrate conditions that influence wave height and direction (Hardisty, 1990). Thus, the model describes interrelationships between the subsystems and the overall process-response system by the various feedback mechanisms.

The lack of research on the spatial and temporal distribution of longshore currents justifies this investigation. Although a significant body of work has been conducted utilizing models to describe longshore currents in the surf zone, considerable disagreement remains as to the accuracy of these models given varying topographical parameters.

4.3 Hypothesized relations

Based on the review of the literature, the objectives of the study, and the conceptual framework, it is hypothesized that:

(1) A functional relationship exists between longshore current velocity and wave period, beach slope, and angle of wave approach.

(2) Observed breaking wave periods will be exhibited within the range of short period longshore current velocity fluctuations.

These hypotheses are based on general inferences forwarded by several
investigators. The first hypothesis, for example, is well recognized but has been the subject of considerable debate (Komar, 1979). As previously discussed, theories of longshore current generation can generally be classified into three categories, including: (1) energy flux considerations; (2) considerations of the continuity of water mass; and (3) momentum flux considerations. More recent current predictor models utilize the momentum flux approach. However, these models do not account for currents being generated over submarine bars and troughs (Komar and Inman, 1970, Komar 1979). Given this, and the prominent bar occupying the study beach, analysis of this hypothesis will attempt to determine if the continuity of water mass approach is appropriate as a predictor of longshore currents.

The second hypothesis draws on inferences forwarded by Dette (1974), Wood and Meadows (1975), and Meadows (1977), which suggest that the assumption of steady or slowly varying longshore current flow is inappropriate in the presence of an oscillatory, breaking wave field. For example, Meadows (1977) found that periodic fluctuations in the longshore current could be directly associated with the mean period of the incident breaking waves. In addition, longer period fluctuations were identified and attributed to infragravity variations in wave height.

4.4 Research methodology

Given the proposed model, the study objectives, and the review of the literature, investigating the spatial and temporal distribution of longshore currents required field measurements of longshore current velocities and the topography of the nearshore zone. In order to test the hypotheses, a study was designed to obtain adequate samples from a beach along the nearshore zone.
In order to select a beach meeting the above criteria, the period between June 10 and June 16, 1994 was spent in investigating the conditions along Guyana's coastal zone. Once a suitable site was chosen, and with the use of appropriate letters of introduction, the researcher was able to meet with the Minister of Science and Technology to obtain permission for the proposed study.

4.5 Sampling design

Data were obtained by field measurement along a randomly selected, single profile of the study beach (Figure 8) for the period June 17 to July 6, 1994. This profile extended from the swash zone to the breaker zone and was surveyed using the horizontal and vertical measurements based upon standard levelling techniques with readings taken at the shoreline and at all significant breaks of slope. Research along the Bachelor's Adventure beach was limited by several factors owing mainly to time and cost constraints. In order to acquire longshore current velocity readings, and still maintain appropriate water levels while the tide was ebbing, a selection sampling method was determined through examination of the literature and consideration of the study hypotheses. Classically, field measurements of longshore currents have concentrated on obtaining values near the breaker and swash zones, and the midsurf position (Wood and Meadows, 1975; Meadows, 1977; Inman et al., 1980; Komar and Holman, 1986; Zampol and Inman, 1989). Readings at major topographical inflections were also taken where topography was considered to be a significant factor (Larson and Kraus, 1991; Smith et al., 1993). The decision was made to sample one transect at four stations distributed across the surf zone.
Source: Author, 1997

Figure 8
4.6 Data Collection

An electromagnetic portable water flowmeter was used to determine longshore current velocities. This device operates under the Faraday Principle, in which a conductor (such as water) moves through the device's sensor and cuts the lines of magnetic flux. This disruption produces a voltage directly proportional to the velocity at which the conductor moves through the magnetic field (Marsh-McBirney Inc., 1990). Its accuracy is considered to be ± 2 percent of the recorded reading.

The device was oriented parallel to the shoreline and sequential measurements were compiled at four stations along the beach transect (Figure 9). The outermost current monitoring station was located shorewards of the active breaking zone. Another station was located at the crest of the submarine bar which occupied the midsurf position during high tide.

The innermost stations were located in the shore-parallel trough and just seawards of the swash zone. To evaluate the spatial distribution of longshore currents, five, ten second interval, fixed point averages of velocities were recorded at all four stations at 20 and 80 percent of the water depth, as recommended by the instrument manufacturers (Marsh-McBirney Inc, 1990), and averaged so that five, ten second readings were obtained for each station per day. To evaluate the temporal distribution of longshore currents, between 150 and 300 continuous, two
second interval measurements were recorded daily at the outermost station and the station occupying the shore-parallel trough. These data were recorded at sixty percent of the water depth. To determine daily nearshore conditions, supplementary data on wave heights and water depth were determined using a standard calibrated wave staff. Similarly, measurements were made of wave period and the angle of wave approach using stopwatch and compass procedures respectively.

To evaluate the first hypothesis, that a direct relationship exists between longshore current velocity and wave period, beach slope, and angle of wave approach, an analysis procedure which incorporates the daily fluctuations of oceanic conditions is necessary. Komar’s (1979) momentum flux model takes the form:

\[ v_1 = 1.17(gH_s)^{1/2} \sin \alpha \cos \alpha \]

where,
- \( v_1 \) is the estimated longshore current (m/s)
- \( g \) is the acceleration due to gravity = 9.8 m/s²
- \( H_s \) is the wave height at the breaker zone (m)
- \( \alpha \) is the angle of wave approach to the beach in radians

Given the beach bathymetry, which includes a distinctive bar, it was decided that a model utilizing the continuity of water mass approach would be tested. Galvin and Eagleson’s (1965) model assumes that a mass transfer of water in the form of solitary waves enters the nearshore and eventually moves alongshore. This longshore movement accelerates as more and more water is added until a critical velocity is reached, at which point the current turns seawards in the form of a rip current (Komar, 1976). Although rip currents are known to be formed by longshore
variations in breaker height, this model has been deemed appropriate when a water mass is trapped in the nearshore region by waves entering over a bar (Komar, 1977, p 184). The trapped water flows alongshore until a gap or gully is reached where the stream then turns seawards. The model that was used in this study was:

\[ v_1 = 2k_g T \tan \beta \sin \alpha \cos \alpha \]

where,
- \( v_1 \) is the estimated longshore current velocity (m/s)
- \( k \) is a constant = approx 1
- \( g \) is the acceleration due to gravity = 9.8 m/s²
- \( T \) is the wave period (sec)
- \( \beta \) is the beach slope angle (deg)
- \( \alpha \) is the angle of wave approach (rad)

Since the model incorporates the daily variability of nearshore conditions, it enables the investigator to determine if (1) changes in daily morphology (especially beach slope) and wave conditions determine the longshore current velocity magnitudes, and (2) the continuity of water mass approach is an appropriate assessor of longshore current velocities in the study area.

An independent Pearson Correlation and Regression test was employed to evaluate the hypothesis that a functional relationship exists between longshore current velocity and wave period, beach slope, and angle of wave approach. The correlation test was performed to assess whether some dependant variable (observed longshore current velocity) is functionally related to the independent variable (estimated longshore current velocity). Regression analysis was conducted so that the form of this relationship could be obtained. Four assumptions associated with this test are as follows: (1) the regression analysis fits a straight line trend through the scatter of data points; (2) for every value of the independent
variable (x), the distribution of residual values (Y-Yi) should be normal, and their means zero. Meeting these requirements makes it virtually certain that the dependant variable (observed longshore current velocity) and independant variable (predicted longshore current velocity) are themselves normally distributed; (3) for every value of the independant variable, the variance of residual error is assumed to be equal. This is known as the homoscedasticity requirement; and finally (4) the value of each residual is independent of all other residual values so that no autocorrelation exists.

Although we know that there is considerable variation in longshore current velocity across the surf zone, attempts at understanding and describing this distribution have lead to a variety of opinions. Quasi-parabolic distributions are generally identified, but the location of velocity maxima has not been adequately determined. Thornton (1970) found that a longshore current velocity maximum existed over a bar which occupied the breaker zone. Velocities decreased landward and seaward of this maximum, providing a distribution that was generally parabolic in shape. Observations by Komar (1983) and inferences forwarded by Larson and Kraus (1991) and Smith et al. (1993), suggest that longshore current velocities are greater over troughs because of marked decreases in bottom friction. Given the station locations and the conclusions drawn by the above investigators, two dimensional graphs were produced describing velocity changes with distance across the surf zone for each of the twelve days. This was done in an attempt to identify the shape of the longshore current velocity distribution.

To evaluate the second hypothesis, that observed breaking wave periods
will be exhibited within the range of short period longshore current velocity fluctuations, time histories of the two second interval data were constructed. Spectral analysis was then performed in order to isolate the periodic components of these time histories. Spectral analysis requires a roughly Gaussian probability density function and must be stationary (exhibiting no long-term trend). A discussion of spectral analysis is provided in the next chapter.
CHAPTER FIVE
SPECTRAL ANALYSIS

5.1 Introduction

In its simplest form, a time series is no more than a set of data \( \{y_t: t = 1, \ldots, N\} \) in which \( t \) indicates the time at which the datum \( y_t \) was observed. If a time series can be predicted exactly (tidal motion for example), then the series is said to be deterministic. If the time series can only be partially predicted (nearshore surface elevation for example), then the series is stochastic (Hegge and Masselink, 1996). Unlike most statistical methods, when a sequence of observations is obtained from an experimental unit, the assumption of mutual independence of sample units is seldom sustainable (Diggle, 1990). The implicit nature of time series analysis requires, and is concerned with the character of the dependence amongst the members of a sequence of values. Time series analysis is often referred to as analysis in the time domain. However, a different approach, one which examines sequences of data in the frequency domain, can also be utilized.

Spectral analysis may be considered the scale breakdown of a phenomenon in space or time (Rayner, 1971). This method differs from other time series methods in that the order and separation time of events are just as important as the number of events occurring in a particular time interval. Attention focuses on the interval between occurrences or groups of occurrences. The purpose of spectrum analysis is to identify the seasonal fluctuations of different lengths, whereas in ARIMA (autoregressive moving average) models or exponential smoothing, the
length of the seasonal component is usually known and then included in some theoretical model of moving averages or autocorrelations. Given this, no a priori constraints are placed on the analysis and the examination is purely mathematical: it is not based on any theory about a process underlying the series. Thus, spectral analysis lends itself to the study of time series where no obvious cyclical variation can be observed.

5.2 Fourier Analysis

A time series \( \{y_t\}, t = 1...N \) is regarded as being discrete when it is derived from the continuous series \( y(t) \) of duration \( T \) by sampling current values at time spacing \( D \) with \( N = T/D \). The aim of spectrum analysis is to fit a set of sine and cosine functions of different frequencies to the data series so that these component frequencies can be examined to evaluate their contribution to the original function. The exact fit of the discrete series \( \{y_t\} \) may be obtained after expanding it in terms of a finite sum of periodic functions also called a finite Fourier series (Chatfield, 1989, p 105):

\[
y_t = a_0 + \sum_{j=1}^{M_1} a_j \cos(\omega_j t) + \sum_{j=1}^{M_2} b_j \sin(\omega_j t)
\]  

(1)

where,

\( \omega_j \) is the radian frequency \( = 2\pi j/N \)

\( M_1 = N/2 \) and \( M_2 = M_1 - 1 \); \( N \) is the oscillation period

The coefficients \( a_j \) and \( b_j \) are directly obtained, with the use of relations of orthogonality between sine and cosine functions, by the following equations:

\[
a_0 = 1/N \sum_{t=1}^{N} y_t
\]

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\[ a_j = \frac{2}{N} \sum_{t=1}^{N} y_t \cos\left[j(t-1)2\pi/N\right] \]
\[ b_j = \frac{2}{N} \sum_{t=1}^{N} y_t \sin\left[j(t-1)2\pi/N\right] \]

where, \( j = 1 \ldots M_2 \).

The periodogram is a summary description of the componentized sinusoidal waves at different frequencies. Specifically, the periodogram values are computed as:

\[ P_k = \text{sine coefficient}_k^2 \cdot \text{cosine coefficient}_k^2 \cdot \frac{N}{2} \quad (2) \]

where \( P_k \) is the periodogram value at frequency \( k \) and \( N \) is the overall length of the series. The periodogram values or density estimates can be interpreted in terms of the variance of the data at the respective period or frequency. The importance of any frequency may then be gauged as its percentage contribution to the total variance in the whole spectrum of frequencies present in the series. The lowest Fourier frequency is one with zero cycles. Basically, this represents a "cycle" that in effect, does not vary. The highest frequency is one with half as many cycles as the number of observations. Since it takes two samples (a high and a low) to complete a waveform, the highest frequency observable is one with half as many cycles as the number of observations and therefore only the first half of the Fourier series is used in the calculation of the periodogram.

### 5.3 Data Transformations

Many time series display a trend as well as a mean component. The trend component describes the net influence of "long-term" factors whose effects on the series tend to change gradually. In most cases, these effects operate in one
direction over time, and can be modelled (for long-term forecasting) by a smooth, continuous curve spanning the entire time series. However, trend is of little interest when attempting to uncover periodicities in the data series. In fact, spectral analysis requires stationarity of the series so that the first cosine coefficient that is fitted (for frequency 0.0), does not overwhelm the variance (density estimates). Similarly, the mean is a cycle of frequency zero per unit time; that is, it is a constant. Both of these potentially strong effects may mask the more interesting periodicities in the data. In addition, if trends in the mean are not removed, the resulting spectrum will be dominated by energy at the low end of the frequency scale (Hegge and Masselink, 1996). Thus, both the mean and the trend should be removed from the series prior to analysis. To accomplish this a polynomial curve is fitted to the data and subtracted. Each value in the series is transformed in the following simplified manner (Statsoft, 1995):

\[ y_t = (y_t - M); \]  

Mean subtract

where,

\[ M \] is the overall mean for the untransformed series.

\[ y_t = y_t - (a + b \cdot T); \]  

Trend Subtract

where,

\[ T \] refers to the case number

\[ a \] and \[ b \] are the intercept and slope constants derived from least squares methods.

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One problem associated with fitting a sine function to the time series is that of leakage. Leakage refers to the distortion produced when the value of a spectral estimate (spectral density value) is reduced through leakage of spectral energy into neighbouring frequency groups. Variation at one frequency "leaks" into periodogram terms at frequencies different from the true frequency of the variation and thus, strong periodicities at one frequency results in large spectral density estimates in several adjacent frequencies. According to Hegge and Masselink (1996), there are three ways of dealing with the problem of leakage and they are as follows: (1) by padding the series with a constant to introduce smaller increments within the frequency group and greater increments between frequency groups; (2) by tapering a proportion of the data at the beginning and end of the series via multiplication of weights and; (3) by smoothing the entire periodogram via a weighted moving average transformation. A clearer picture of underlying periodicities emerges when smoothing is used. The exact frequency of periodogram peaks is lost but distinct frequency regions are created so that random fluctuations are minimized and chaotic behaviour is better controlled. Since smoothing de-emphasizes minor fluctuations, it is often applied in conjunction with tapering so that leakage and random noise are downplayed. The widely used split-cosine-bell taper is defined as (Statsoft, 1995):

\[
\begin{align*}
    w(t) &= 0.5 \{1 - \cos [\pi *(t-0.5)/m]\} \quad t = 0 \text{ to } m-1 \\
    w(t) &= 0.5 \{1 - \cos [\pi *(n-t-0.5)/m]\} \quad t = n -m \text{ to } n-1
\end{align*}
\]

where \(m\) is chosen so that \(2^*m/n\) is equal to the proportion of data to be tapered. Smoothing can be performed so that for each frequency, the weights for the
weighted moving average of the periodogram values are computed as:

\[ w(j) = 0.5 + 0.5 \cos(\pi j/p) \quad j=\text{freq 0 to freq p}, \]  

(6)

and that a span or window (number of values to be weighted together) is chosen (Blackman and Tukey, 1958). This window refers to the pattern of the weights applied in constructing the moving average and indicates the number of points included in the moving average. Another transformation involves the concept of serial dependancy. It is defined as correlational dependancy of order \( k \) (lag) between each \( i \)th element of the series and the \( (i - k) \)th element (Statsoft, 1995). This relationship is measured using the autocorrelation correlogram which displays the autocorrelation function (ACF). Highly significant autocorrelations at the first, second, third, and fourth lag can overwhelm all other, more obscure autocorrelations that are of interest (for example, the autocorrelation that occurs at lag \( k \), corresponding to the incident wave period). This is removed by differencing the series using the formula (Statsoft, 1995):

\[ x = x - \{a + b \times x(\text{lag})\}, \]  

(7)

where,

- \( x \) is each value in the series
- \( a \) and \( b \) are the intercept and slope constants derived from least squares methods
CHAPTER SIX

RESULTS AND DISCUSSIONS

6.1 Assessment of the Continuity of Water Mass Approach

The supplementary data on wave and topographical parameters (Table 1) were employed to determine the estimated longshore current velocity from the model (Galvin and Eagleson, 1965):

\[ v_1 = 2k_1gT \tan \beta \sin \alpha \cos \alpha \]  (8)

where,

- \( v_1 \) is the estimated longshore current velocity
- \( k_1 \) is the wave number = wave length = approx 1
- \( g \) is the acceleration due to gravity = 9.8 m/s²
- \( T \) is the wave period
- \( \beta \) is the beach slope angle
- \( \alpha \) is the angle of wave approach

In order to obtain the daily assessments of station-to-station beach slopes (\( \beta \)), water depth (d) and the distance between successive stations (D) were taken at all four stations and utilized in the following equation:

\[ \tan \beta = \frac{(d1-d2)}{D} \]  (9)

Once the estimated longshore current velocity was calculated from equation (8), an Independent Pearson Correlation and Regression test was employed to evaluate the hypothesis that a functional relationship exists between the observed longshore current velocities and the predicted longshore current velocities. Note, station one of day 9 was removed from the analysis because very low water depths undermined the accuracy of the measured velocity. A square root function was applied to the observed and predicted longshore current values in order to
Table 1: Wave, Water, and Topographical Parameters collected off Batchelor's Adventure Beach, 1994. The observed and estimated longshore current velocities have been transformed via a square root function. Estimated longshore current was obtained using equation (8)(Galvin and Eagleson, 1965).

<table>
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<th>Day</th>
<th>Station</th>
<th>T (sec)</th>
<th>H2O dep (m)</th>
<th>Tan β</th>
<th>ω (deg)</th>
<th>ω (Rads)</th>
<th>Vel Obs (m/s)</th>
<th>Vel Pred (m/s)</th>
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normalize the data sets (Statsoft, 1995). This was performed so that for each value of the observed longshore current velocity, the distribution of the residuals would be normally distributed and their means would be equal to zero, and so that the predicted longshore current velocity values would themselves be normally distributed. The correlation and regression test was conducted after satisfying the test assumptions. Results have been plotted in Figure 10 (Statsoft, 1995).

![Graph showing observed versus predicted longshore current velocity with regression line and 95% confidence interval](image)

**FIGURE 10.** Predicted versus observed longshore current velocity. Predicted values were calculated using the model of Galvin and Eagleson (1965)(Equation8). Data values are shown in Table 1 and a squareroot function was applied to the velocity values. Source: Author, 1997

The mathematical form of the relationship determined by the regression analysis was in the form $y = .005 + .91x$ and it has a correlation coefficient of 0.7534. There is therefore a direct, strong, and sensitive relationship between the observed longshore current velocity and that predicted by the model of Galvin and Eagleson.
(1965). A summary of the correlation and regression results are presented in Table 2 and a complete report is given in Appendix I.

**TABLE 2: Summary of the correlation and regression results**

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<th>Mult R</th>
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<th>Adjusted R²</th>
<th>S.E.</th>
<th>B Est Vel</th>
<th>B Constant</th>
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In addition to the model's (equation 8) agreement with the observed velocities in the field, the analysis confirms Galvin and Eagleson's recognition of the dependence of longshore current on beach slope, wave period, and breaker angle. Thus, fluctuations in these factors during the study period contributed considerably to the heterogeneity of the current distribution. As well, the continuity of water mass approach is justified as a method of prediction where nearshore bars and troughs act in a manner that in essence, forces the movement of currents in the longshore direction.

Graphs were constructed describing the distribution of the longshore currents in the nearshore zone. Considerable variation of the longshore current velocity is known to exist (Saville, 1950; Symonds and Huntley 1980; and Smith et al., 1993), and the results of this investigation support this conclusion. Of the twelve days investigated, only five days (1, 4, 7, 10, and 12) displayed longshore current velocities that increased from the breaker zone to the surf zone (Figure 11). Seven days (2, 3, 5, 6, 8, 9, 11) exhibited highest velocities at station four (the station nearest the breaker zone) (Figure 12).

Two dimensional graphs were produced of the velocity distribution for each
Figure 11: Longshore current velocities that decrease to the breaker zone.

Figure 12: Longshore current velocities that increase to the breaker zone.
day in order to describe the shape of the distributions. A least squares fit was applied to the "xy" coordinate data according to the distance-weighted least squares smoothing procedure (the influence of individual points decreases with the horizontal distance from the respective points on the curve) (Statsoft, 1995). A 25% degree of curve stiffness was administered and the results are presented in Figures 13-24. Recall that Station 1 lay in the surf zone, just shoreward of the trough, station 2 lay over the trough, station 3 lay over the midsurf bar, and station 4 lay seaward of the midsurf bar approximately 30 meters from the zone of active breaking. Days 1, 2, 3, 5, 7, 8, 9, 11, and 12, in which a bimodal distribution was observed, support the results of Larson and Kraus (1991)(Figure 25). Two distinct velocity maxima were observed on each of these days. Larson and Kraus (1991) found that the greatest velocities were located over the bar and shoreward of the trough, but this only occurred on days 3, 5, 7, 8, and 12. On days 1, 2, 9, and 11, maximum velocities were found at stations two and four; in the trough and on the bar respectively. Velocities steadily increased during day 6, reaching a maximum at station four. Quasi-parabolic distributions were observed for days 4, and 10, supporting the findings of Thornton, (1970), Komar and Holman

**Figure 25**

![Diagram of Longshore Current Velocity Distribution](image)

**Source:** Larson and Kraus, 1991
(1986), and Zampol and Inman (1989). In these experiments, maximum velocites were located over the bar in the breaker zone. Reductions in velocity were noted landward of this position, providing evidence of a single velocity maximum with current speeds that decrease on either side of this maximum.

These results are not totally unexpected. Larson and Kraus (1991) and Smith et al. (1993) found that waves broke over the bar, reformed, and broke a second time close to the trough. This led to a persistent peak in longshore current velocity over the bar and shoreward of the trough. This was the case for the Batchelor's Adventure site (days 1, 3, 5, 7, 8, 9, 11, and 12). Propagating waves break at different positions depending on their length and period. Occasionally, waves broke seaward of the bar, just beyond station four, and reformed into consolidated wave fronts. If these reformed waves did not break at or near the trough position, longshore current velocities were accelerated because of deeper water and reduced friction. The other distribution, one in which a single velocity maximum was observed, occurred when waves broke before the trough position and did not reform. Hence, longshore current velocities consistently displayed a prominent peak at the bar location exclusively (days 2, and 6). On days 4 and 10, a single longshore current velocity maximum was also observed. However, this maximum was located over the trough.

An integrated rip current system was present at the study beach. A prominent rip channel was located approximately 35 meters east of the study transect. This channel dissipated some of the currents to the northwest. Thus, two possible explanations for the discrepancies found in the distribution of the
longshore currents from day to day (namely the position of the maximum velocity and the presence of bimodal and quasi parabolic distributions) are: (1) that the ability of propagating waves to reform depends on the position in which they originally broke along the width of the nearshore zone, and (2) that the system was composed of longshore currents and a nearshore circulation system. These two components in effect, change the structure of the distribution depending on their relative contribution to nearshore energy conditions.

6.2 Analysis of Longshore Current Velocity Fluctuations

To evaluate the second hypothesis, that observed breaking wave periods will be exhibited within the range of short period longshore current velocity fluctuations, time histories of the two-second interval data were constructed and spectral analysis was performed in order to isolate the periodic components of these time histories using the Statistica Computer Program (Statsoft, 1995). Examination of the autocorrelation plots for the longshore current velocity time series indicated a statistically-significant lag-one correlation for each of the twelve days (refer to Appendix II). The data were once-differenced, demeaned and detrended (using equations 3, 4, 7) in order to remove serial dependancy and any trends in the time series so that it was stationary. The Statistica Computer Software (Statsoft 1995) was utilized to apply equation (1) and to perform the spectral analysis. A fifteen percent taper was employed to reduce leakage of large spectral energy groups into neighbouring frequencies and the plots were smoothed using a Tukey-Hanning smoothing parameter (equations 5, 6) so that the "jaggedness" was removed and general frequency regions could be identified. The stationary time series and
associated spectral plots are presented in Figures (26-73). An arrow has been placed within all spectral plots denoting the observed incident wave period.

Results from the plots and the associated histograms of periodogram values indicated that series were stochastic in nature (refer to appendix III). Periodogram histograms that follow an exponential distribution are indicative of noisy series (Statsoft, 1995). This noise has contributed to perturbations in the plots, and are identified by peaks in the very high frequency regions (areas of low periods). Water turbulence associated with bottom friction and other short term random fluctuations in current speed were the main causes of such noise. While investigating the morphology of riffle-pool sequences, Richards (1976) found that a second order autoregressive process suggested a stochastic process. In his examination of stream meandering, river current velocity pulsations associated with large scale turbulent eddies were found responsible for accretion and erosion which interacted with the flow to maintain velocity perturbations. This second-order autoregressive process (termed a Yule-Walker process) expressed the flow as a combination of steady and/or undulating current velocities and a noise sequence. Following Richard's (1976) example, a second-order autoregressive model was applied to the two-second interval time series occupying the trough location and examples of the associated ACF plots are given (refer to Appendix II). The Yule-Walker process was employed as a diagnostic for the trough location (station 2) because highly significant autocorrelations were observed despite differencing the series. Significant autocorrelations were removed by applying this model, implying that a Yule-Walker process was present and the current velocity was composed of a
Figure 26: Stationary time series transformed using equations (3, 4, 7).

Figure 27: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 28: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (Station 4, Day 2)
\[ x - 0.432 - 0.465 x(t-1) \]
Hamming weights: 0.241 0.0934 0.2319 0.3012 0.2319 0.0934 0.0241

Figure 29: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 30: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 3)

Hamming weights: 0.0182 0.0488 0.1227 0.1767 0.2273 0.1967 0.1227 0.0488 0.0182

Figure 31: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 32: Stationary time series transformed using equations (3, 4, 7).

Figure 33: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 34: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 5)

x - 1403 - 331 * x(t-1)
Hamming weights: 0241 0934 2319 3012 2319 0934 0241

Figure 35: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 36: Stationary time series transformed using equations (3, 4, 7).

Figure 37: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 38: Stationary time series transformed using equations (3.4.7).

Spectral analysis: (STATION 4, DAY 7)

\[ x = 1343 - 237^2 x(t-1) \]

Hamming weights: 0.0241 0.0934 0.2319 0.3012 0.2319 0.0934 0.0241

Figure 39: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 40: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 8)

\[ x = 1215 - 152x(t-1) \]

Hamming weights: 0.0241 0.0934 0.2319 0.3012 0.2319 0.0934 0.0241

Figure 41: Smoothed, tailed Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 42: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 9)

x = 0.921 - 470*x(t-1)

Hamming weights: 0.0241 0.0934 0.2319 0.3012 0.2319 0.0934 0.0241

T = 7.4 s

Figure 43: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 44: Stationary time series transformed using equations (3, 4, 7).

Figure 45: Smoothed, tapered Spectral Graph computed from equation (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Time Series Plot (STATION 4, DAY 11)

\[ x = 0.628 - 585x(t-1) \]

![Time series plot showing longshore current velocity (m/s) over time (seconds)].

**Figure 46:** Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 11)

\[ x = 0.628 - 585x(t-1) \]

Hamming weights: .0241 .0934 .2319 .3012 .2319 .0934 .0241

![Spectral density graph with period (seconds) and spectral density (Hz)].

**Figure 47:** Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).

Note: Arrow indicates the observed incident wave period.
Time Series Plot (STATION 4, DAY 12)

\[ x = 0.883 - 455x(t-1) \]

![Time Series Plot](image)

**Figure 48:** Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 4, DAY 12)

\[ x = 0.883 - 455x(t-1) \]

Hamming weights: 0.0241 0.0934 0.2319 0.3012 0.2319 0.0934 0.0241

![Spectral Analysis Plot](image)

**Figure 49:** Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).

Note: Arrow indicates the observed incident wave period.
Figure 50: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 1)

\[ x - 0.679 - 8.11^t x(t-1) \]

Hamming weights: 0.041 0.0934 0.2319 0.3012 0.2319 0.0934 0.041

Figure 51: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).

Note: Arrow indicates the observed incident wave period.
Figure 52: Stationary time series transformed using equations (3, 4, 7).

Figure 53: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
**Figure 54:** Stationary time series transformed using equations (3, 4, 7).

**Spectral analysis: (STATION 2, DAY3)**

\[ x = 0.066 - 931^*x(t-1) \]

Hamming weights: 0.241 0.934 0.2319 0.3012 0.2319 0.934 0.0241

\[ T = 7.15 \text{ s} \]

**Figure 55:** Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 56: Stationary time series transformed using equations (3, 4, 7).

Figure 57: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 58: Stationary time series transformed using equations (3, 4, 7).

Figure 59: Smoothed, tapered Spectral Graph computed using equation (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 60: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 6)

$X - 0.186 - 6.94^x(t-1)$

Hamming weights: 0.182 0.0488 1227 1967 2273 1967 1227 0.0488 0.182

Figure 61: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Figure 62: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 7)

x - 0.008 - 0.996^x(t-1)

Hamming weights: 0.0357 2.411 4.464 2.411 0.0357

Figure 63: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
Time Series Plot (STATION 2, DAY 8)

\( x = 0.016 \times 980^* x(t-1) \)

Figure 64: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 8)

\( x = 0.016 \times 980^* x(t-1) \)

Hamming weights: 0.0182 0.048 0.1227 0.1967 0.2273 0.1967 0.1227 0.048 0.0182

Figure 65: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
**Figure 66**: Stationary time series transformed using equations (3, 4, 7).

**Spectral analysis: (STATION 2, DAY 9)**

\[ x \cdot 0.006 - 984 \cdot x(t-1) \]

Hamming weights: 0.0357, 0.2411, 0.4464, 0.2411, 0.0357

**Figure 67**: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Time Series Plot (STATION 2, DAY 10)

$x = 0.025 - 971^*x(t-1)$

![Time Series Plot](image)

Figure 68: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 10)

$x = 0.025 - 971^*x(t-1)$

Hamming weights: 0.0241 0.0934 0.3012 0.2319 0.0934 0.0241

![Spectral Analysis](image)

Figure 69: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6). Note: Arrow indicates the observed incident wave period.
Figure 70: Stationary time series transformed using equations (3, 4, 7).

Spectral analysis: (STATION 2, DAY 11)

x=0.012-986*x(t-1)

Hamming weights: 0.357 2411 4464 2411 0.357

Figure 71: Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).
Note: Arrow indicates the observed incident wave period.
**Time Series Plot (STATION 2, DAY 12)**

\( x(t) = 0.031 + 0.01x(t-1) \)

![Time Series Plot](image)

**Figure 72:** Stationary time series transformed using equations (3, 4, 7).

---

**Spectral analysis: (STATION 2, DAY 12)**

\( x(t) = 0.031 + 0.01x(t-1) \)

Hamming weights: 0.0357 2.411 4.464 2.411 0.0357

![Spectral Analysis Plot](image)

**Figure 73:** Smoothed, tapered Spectral Graph computed from equations (1, 2, 5, 6).

Note: Arrow indicates the observed incident wave period.
combination of steady and/or undulating flow and a stochastic process.

Despite the presence of noise, considerable agreement between periods of high spectral energy and incident wave period was apparent at station four. Several days (1, 2, 3, 4, 8, 9, 10, 12) demonstrate significantly high peaks at or near the incident wave period for station four (Figures 27, 29, 31, 33, 41, 43, 45, and 49).

Station two however, does not seem to exhibit such well defined peaks with high spectral energy at the incident wave period range. Consider the explanation of the velocity distribution given in the discussion of hypothesis 1. The midsurf bar affords station two considerable protection from incoming waves. Wave periods underwent breaking just beyond station four, and in many cases, the waves did not reform. Thus, clear and distinct peaks at the incident wave period were not present in many of the spectral plots at station two. However, of the days when the waves reformed before the trough position (days 3, 5, 7, 8, 12), days (3, 5, 7) did exhibit spectral energy peaks at or near the incident wave period at station two, further supporting this explanation (Figures 55, 59, and 63). There were also clear peaks near the incident wave period, at station two on days 2, 6, 10, 11 (Figures 53, 61, 59, and 71).

Given that the majority (approximately 63%) of the spectral plots exhibited peaks at or near the observed incident wave period, hypothesis 2 is accepted. Generally speaking, station four exhibits greater agreement than station two, largely because of the nearshore topography and the station's proximity to the incident breaker zone.
CHAPTER SEVEN

LIMITATIONS and CONCLUSIONS

7.1 Limitations

Several limitations were present during the data collection phase of this investigation. This investigation made inferences based on a collection of small measurement samples in time and space. Most investigations of longshore currents utilize sampling techniques that collect and record velocity values simultaneously at several transects, over several hours. Wave recorders and tidal guages are typically used in investigations of this nature to monitor sea conditions. Given this, the limitations placed on this analysis include potential inaccuracies in velocity readings, wave periods, and topographical inflections.

7.2 Conclusions

The objectives of this investigation were: to measure longshore current velocities across a non-planar beach and; to determine the relationship between longshore current velocity and wave and topographical parameters for the study beach; and to determine the spatial and temporal composition of these velocities in the surf zone. Achievement of these objectives involved several analytical procedures.

Wave, water, and topographical parameters collected in the field were utilized to compare observed longshore current velocities to velocities estimated by the model of Galvin and Eagleson (1965) in which:

\[ v_t = 2k_1 \tan \beta \sin \alpha \cos \alpha \]  

(8)
Agreement between the observed and predicted velocities was established. This supports the theory that a continuity of water mass exists where longshore forcing of currents is present due to a nearshore beach bathymetry which "drains" the water mass. The spatial distribution of the observed currents were then plotted. Considerable daily spatial variation existed, supporting the notion that no "true" longshore current velocity maximum exists. Maximum velocities were generally found close to the nearshore bar and over the longshore trough. The majority of velocity distributions increased to the breaker zone (approximately 58 %) and bimodal and quasi-parabolic distributions were present.

Spectral analysis was conducted on short term velocity measurements taken at stations two and four. In order to obtain spectral estimates, several steps were followed. They are as follows:

1. Plot the time series.
2. Detrend the time series so that it is stationary.
3. Calculate the Fourier estimation.
4. Calculate the periodogram.
5. Apply a taper so that leakage is reduced.
6. Smooth the periodogram.

Examination of the spectral plots and their associated distribution of periodogram values demonstrated that the series were composed of considerable noise due to turbulence and other random fluctuations in longshore current velocity. Despite this, the incident wave period was represented by high energy peaks in the spectral plots.

The variability of observed longshore current velocity in time and space is the main problem with assessing its distribution. Thus, the study of these currents
in the nearshore zone present a particular problem due to the unsteady fluid motion complicated by interfaces with topography and other flow dynamics which may be present. This investigation has suggested that no single distribution is present, and that time dependent studies are required. The inclusion of site specific measurements in future studies will ensure that the dispersion of pollutants and the erosion and deposition of sediment are adequately explained. This is of considerable importance to the coast of Guyana, where managers of coastal areas, coastal engineers, and marine geologists are faced with problems related to the very high sediment load being transported via currents into Guyana's shore.
REFERENCES


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Lakhan, V.C. 1990. The Influence of Ethnicity on Recreational Uses of Coastal


APPENDIX I

Statistical Reports
Correlation and Regression results corresponding to hypothesis 1

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<thead>
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<th></th>
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N of Cases = 46

Correlation, 1-tailed Sig:

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Equation Number 1  Dependent Variable: O_V_SQRT

Block Number 1. Method: Stepwise  Criteria PIN .0500  POUT .1000
E_V_SQRT

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<th>F(Eqn)</th>
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Multiple R | .75339|
R Square    | .56759|
Adjusted R Square | .55776|
Standard Error | .05376|

Analysis of Variance

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F = 57.75516  Signif F = .0000

89
Var-Covar Matrix of Regression Coefficients (B)  
Below Diagonal: Covariance  Above: Correlation

E_V_SQRT

E_V_SQRT   .01434

Equation Number 1  Dependent Variable: O_V_SQRT

---------------------- Variables in the Equation ----------------------

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Equation Number 1  Dependent Variable: O_V_SQRT

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Total Cases = 47

Durbin-Watson Test = 1.49378
APPENDIX II

Autocorrelation Plots
Autocorrelation Plots of two second interval time series used to construct Spectral plots for hypothesis 2. Left side indicates raw data series, right side indicates series which has been differenced using equation 7.
Autocorrelation Plots (continued)
Autocorrelation plots (continued)
Autocorrelation plots (continued)
Autocorrelation Plot examples for days in station 2 which exhibited a Yule Walker Process. A second order autoregressive model was applied to the data.
APPENDIX III

Histograms of Periodogram Values
Histograms of periodogram values

Station 4, Day 1
Fisher Kappa: 5.230, Bartlett K.5.5 d. 1765

Station 4, Day 2
Fisher Kappa: 8.574, Bartlett K.5.6 d. 1515

Station 4, Day 3
Fisher Kappa: 6.023, Bartlett K.5.6 d. 1479

Station 4, Day 4
Fisher Kappa: 7.385, Bartlett K.5.6 d. 1306

Station 4, Day 5
Fisher Kappa: 5.320, Bartlett K.5.6 d. 1023

Station 4, Day 6
Fisher Kappa: 5.615, Bartlett K.5.6 d. 8920

103
Histograms of periodogram values (continued)
Histograms of periodogram values (continued)
Histograms of periodogram values (continued)
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<td>University of Windsor, Windsor, Ontario 1990-1993 B.A. Geography (Resource Management)</td>
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