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New Jersey's Longshore Current Pattern[1]

Gail M. Ashley[a], Susan D. Halsey[b], and Christopher B. Buteux[a]

[a]Department of Geological Sciences
Rutgers — The State University
New Brunswick, New Jersey 08903

[b]Division of Coastal Resources CN-401
New Jersey Department of Environmental Protection
Trenton, New Jersey 08625

ABSTRACT

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The regional longshore current pattern of New Jersey consists of a nodal zone separating longshore currents that flow away from the node in opposite directions. A similar pattern occurs in other coastal compartments in the Mid-Atlantic Bight. The pattern is likely caused by a combination of: (1) wave refraction over paleochannel topography on the continental shelf, (2) residual drift of intruding geostrophic and tidal currents, and (3) a balance in the long term between the seasonal effects of storm and fairweather swell processes. Superimposed on this regional pattern are smaller scaled circulation cells: (A) wave refraction around ebb tidal deltas (>1 km), and (B) rip current circulation (<1 km). Thus, the longshore current pattern is complex and is a function of this hierarchy of circulation cells. Shore protection plans should be designed to accommodate this highly variable (locally and on short time scales) yet quite persistent (regionally and on a long time scale) pattern of coastal currents.

ADDITIONAL INDEX WORDS: *Circulation cells, longshore currents, rip-currents.*

INTRODUCTION

The regional and long-term longshore current pattern displayed by several coastal compartments (Cape Cod, Long Island, New Jersey, Delmarva, and Virginia-North Carolina) of the Mid-Atlantic Bight consists of currents which separate and flow in opposite directions from a nodal zone (FISHER 1967, 1979) (Figure 1). Several studies carried out on the 200 km New Jersey coast using a wide variety of data reveal little agreement on the position of the nodal zone (COOK, 1868, 1882; JOHNSON, 1956; BUMPUS 1965; CALDWELL, 1966; HALSEY, 1968; and BUTEUX, 1982). In addition, smaller local current reversals (on a scale of 100s of m or a few

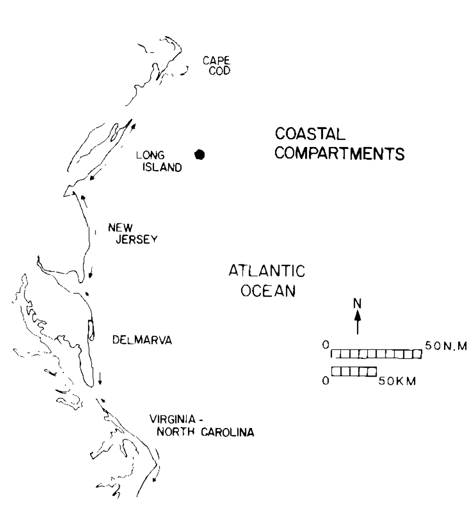

Figure 1. Coastal compartments of the Mid-Atlantic Bight showing longshore current directions (after FISHER, 1967).

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km) are superimposed on the regional pattern (EVERTS, 1975; FITZGERALD, 1981, 1982; SORENSEN and WEGGEL, 1985).

New Jersey is a highly developed coastline and has the dubious distinction of standing as the model for an over-engineered coast (PILKEY, 1981). During the last 100 years, 300 groins have been built, along with extensive revetments, bulkheads, seawalls and five jettied inlets (PSUTY, 1986). In 1981, the New Jersey Department of Environmental Protection (NJDEP) adopted the innovative Shore Protection Master Plan to use as a blue print for future beach restoration measures. The Plan requires non-structural methods such as beach replenishment, dune building and sediment recycling rather than costly hard engineering (structural methods). During the development of the Plan the disparity between the well-entrenched concept of a fixed nodal zone and the apparently highly variable (temporally and spatially) current pattern observed in modern field studies became obvious. Therefore, a provision was established in the Plan that pre-emplacement monitoring programs be implemented before instituting a beach nourishment project to optimize positioning, as well as residence time of the fill.

The purpose of this paper is to describe the temporal and spatial variations in the longshore current pattern of New Jersey. This investigation is based on our field measurements and a compilation of interpretations from other studies. Such a summary has many applications. First, knowledge of the location and areal extent of the regional nodal zone is critical to all shore protection projects (NJDEP, 1981). In order to accommodate the apparently variable (regionally and over long time scales) pat-

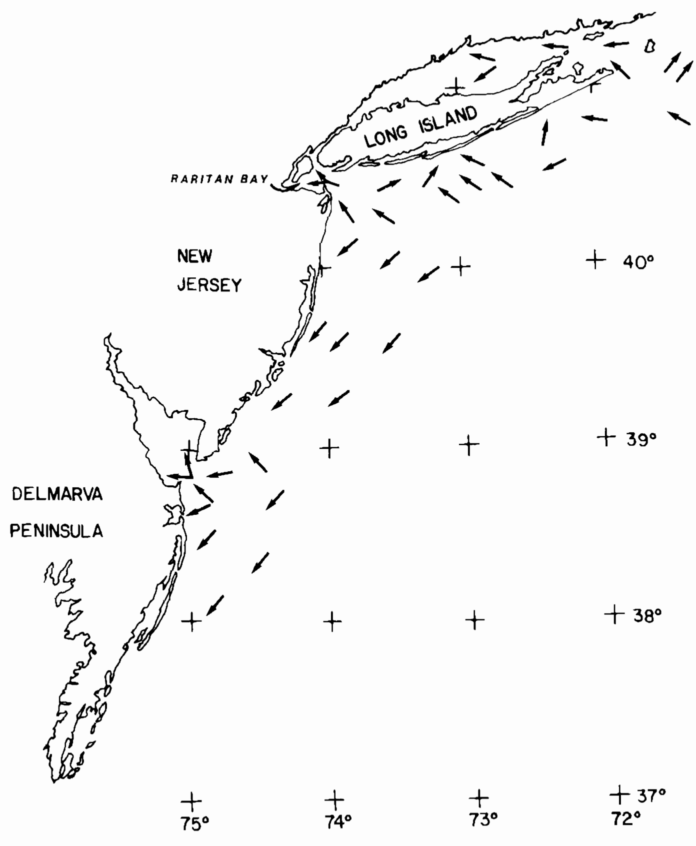

Figure 2. Diagrammatic representation of the residual bottom current on the continental shelf (after BUMPUS, 1965). Flow is predominantly to the south except in the north where flow is north and westward into Raritan Bay.

tern of coastal currents it is clear that more flexible and environmentally sensitive shore protection designs should be implemented. Second, knowledge of the historic variability of the nodal zone, (*i.e.*, changes in location and extent during the last few hundred years) may indicate the range of variability that can be expected in the future. The concept of a permanently fixed nodal zone is unfortunately a very well-entrenched idea. Third, a descriptive model developed for New Jersey's longshore currents may be used as a guide for examining similar patterns in the other coastal compartments.

REGIONAL LONGSHORE CURRENT PATTERN

Possible Causes

The direction of longshore currents on oceanic coasts varies both seasonally and with passing weather systems. Analyses of regional currents for long time periods remove local and short term variations to provide a common longshore current pattern that is repeated over several coastal compartments (JOHNSON, 1965; FISHER, 1967, 1979) (Figure 1). This pattern is exemplified by the New Jer-

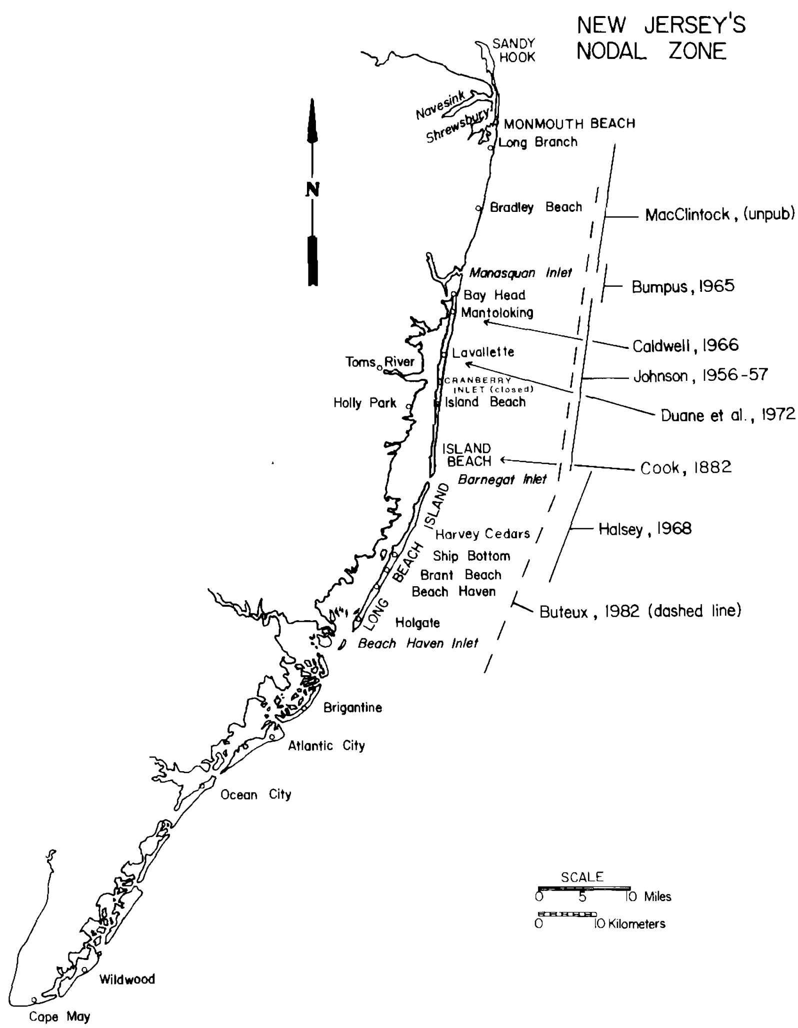

Figure 3. Locations of the nodal zone (or nodal point) as concluded by previous workers (solid lines); this study (dashed line).

sey coast and consists of a nodal zone in which separate longshore currents flow away from the node in opposite directions. Ideas on the mechanisms responsible for this current pattern fall into three categories: (1) seasonal variation in wave approach, (2) wave refraction around shelf topography, and (3) residual southward drift of intruding shelf (geostrophic) currents with a northward tidal component into Raritan Bay.

The first idea involves the complex interplay between long term effects of storm waves (predominantly northeast storms but occasionally hurricanes) and the normal effects of the prevailing fairweather swell waves from the east-southeast (NORDSTROM *et al.*, 1977). The longshore current direction and the nodal zone are therefore dependent on the long term balance between storm and swell processes. Ultimately this balance is a function of the vagaries of the wave climate of the region.

The second idea was first suggested by MacClintock (in LEET and JUDSON, 1965) who attributed the bifurcation of longshore currents to refraction around shallow offshore remnants of eroding headlands. Erosion of headlands was also the mechanism responsible for the current pattern displayed in FISHER's (1967) coastal compartments. More recent workers such as (V. Goldsmith, pers. comm.) have attributed nodal zones in the Mid-Atlantic Bight to wave refraction over paleochannel topography on the continental shelf. Thus, New Jersey's nodal zone could be created by refraction of deep water waves over the Hudson Canyon and the shelf topography between it and the New Jersey shoreline.

The third idea is based on studies of water circulation on the continental shelf of the Mid-Atlantic Bight (BUMPUS, 1965). His work revealed a general southward current (residual drift) along the coastline of New Jersey except in the vicinity of Sandy Hook where flow diverges north and westward into Raritan Bay (Figure 2). An interpretation of his data suggests that the overall pattern of geostrophic shelf circulation and tidal driven flow produces a current bifurcation and therefore the point of bifurcation (the nodal zone) in the headlands portion of New Jersey.

Previous Studies

The concept of a bifurcation in the longshore currents was introduced by early geomorphologists such as COOK (1868, 1882) and MacClintock (in LEET and JUDSON, 1965) as they attempted to explain coastal landform development. These workers hypothesized that during the Holocene transgression, waves refracted around an approximately 30 km long eroding headland area from Monmouth Beach to Bay Head (Figure 3). They believed sediment eroded from the headland area and transported northward built the baymouth barriers across the Shrewsbury and Navesink estuaries as well as the Sandy Hook spit, while sediment transported southward was responsible for the formation of the Squam Beach — Island Beach barrier extending south from Bay Head (COOK, 1868, 1882; MacCLintock, in LEET and JUDSON, 1965; HAUPT, 1906; LEWIS and KUMMEL, 1914; JOHNSON, 1938; and KUMMEL, 1940).

JOHNSON (1956, 1957) was one of the first workers to attempt a regional synthesis of geomorphic-based interpretations of longshore current directions. Johnson suggested that the long term average position of the New Jersey nodal zone was located somewhere south of Manasquan Inlet possibly near Lavallette but was north of Barnegat Inlet (Figure 3). This description delineated a 15 km zone, some 10 km south of MacClintock's more northerly zone. Caldwell's work in 1966 designated Mantoloking as the long term average position of the nodal zone based mainly on air photo analysis of sand trapped by groins and jetties.

An extensive oceanographic study by BUMPUS (1965) using thousands of seabed drifters over a 3 year period produced a shelf and nearshore current pattern which contains a nodal zone approximately 20 km long centered on Manasquan Inlet (Figures 2 and 3). A study examining the genesis of sand ridges on the New Jersey continental shelf suggested the nodal zone is in the vicinity of Lavallette (DUANE, *et al.* 1972) (Figure 3).

Other interpretations of the position of the nodal zone have been based on the examination of historical documents and charts. One study indicated that Cranberry Inlet (now closed) migrated northward approximately 6 kilometers between 1690, when it was charted as open, and 1812 when it closed naturally (MILLER, 1981). This migration implies that the northern extent of the nodal zone during that time was somewhere south of Toms River (Figure 3).

After the closure of Cranberry Inlet, Barnegat Inlet underwent migration to the south (800 m in 50 years) causing destruction of the original Barnegat Lighthouse. This inlet migration indicates a net southerly longshore drift during this period along Squam Beach — Island Beach and this direction of net drift appeared to persist until just before Barnegat Inlet was stabilized (1939-1941). Examination of U.S. Coast and Geodetic Survey charts indicate that by 1938, the inlet had begun to migrate northward (FIELDS, 1984).

Analysis of the geomorphology of the ebb tidal delta and main ebb channel of Barnegat Inlet through time (ASHLEY *et al.*, 1981) revealed that net longshore drift had been directed both to the north and the south of Barnegat Inlet each for extended periods between 1940 and 1980. This analysis indicates that historically the nodal zone may have been located both north and south of the inlet.

From the predominant buildup of sand on the north side of groins along the lower one-third of Long Beach Island and the southerly migration of the Holgate spit at the southern end of Long Beach Island (HALSEY,1968), the southern limit of the nodal zone during 1967-1968 was interpreted to be located somewhere near Brant Beach on Long Beach Island (Figure 3).

Combining the findings over the last 300 years

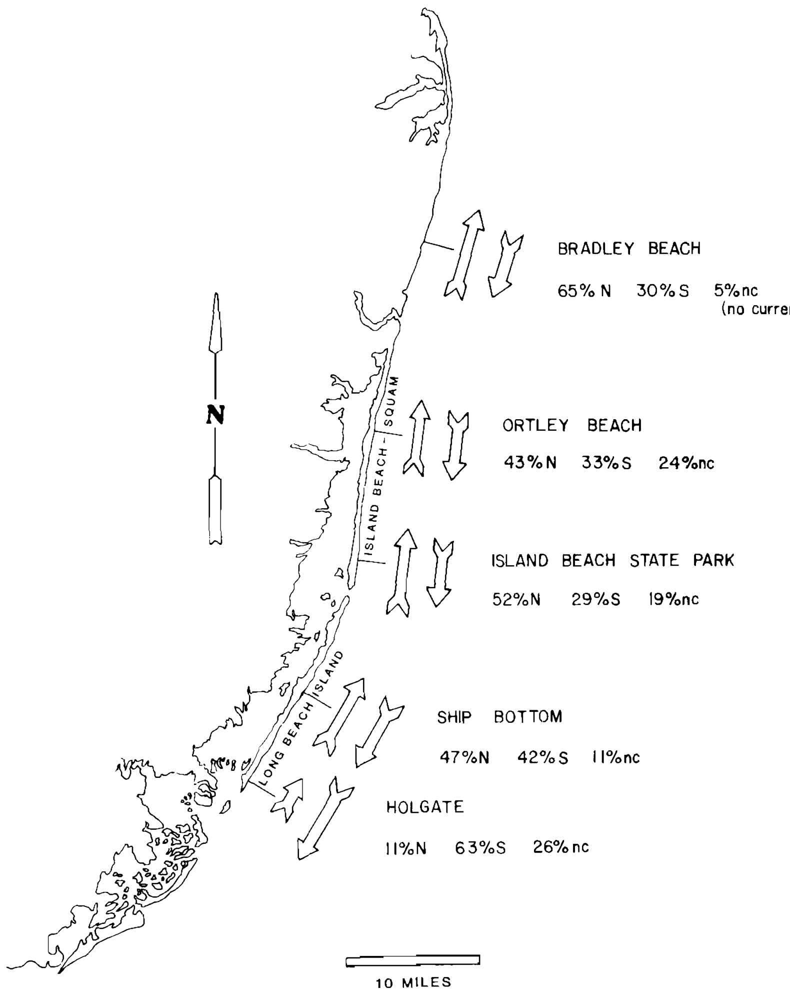

Figure 4. Results of regional longshore current study conducted in 1980 (BUTEUX, 1982). Percent of the 20 observations (days) are shown diagrammatically by length of arrow.

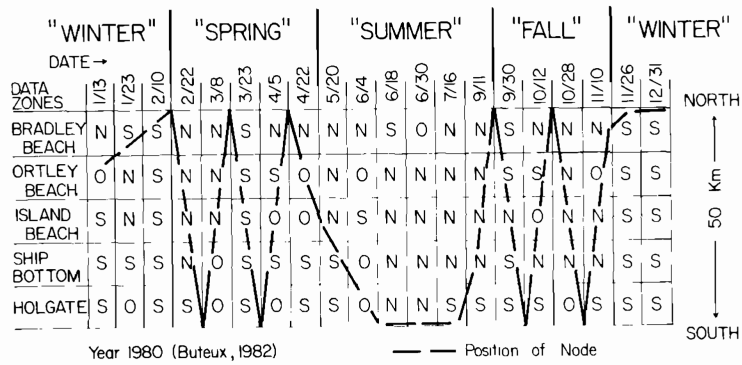

Figure 5. Longshore current directions (N = Northward, S = Southward, O = no current measured) within a 6 hour period at the 5 locations shown on Figure 4. Heavy dashed line depicts schematically the seasonal migration of the longshore current bifurcation nodal zone.

(Figure 3), the area interpreted to be included by the mean annual position of the nodal zone may be 100 km in length along a 200 km coast extending as far south as Brant Beach (HALSEY, 1968) and as far north as Lavallette (JOHNSON, 1957).

Modern Field Study

A modern process field study (BUTEUX, 1982) was conducted in 1980 to: (1) examine the variation in direction of wave generated currents along a 100 km stretch of coastline in central New Jersey, and (2) determine the geographic position of the nodal zone on a given day under reasonably consistent weather and wave conditions. Five sites were selected which spanned the suspected range of the regional nodal zone (Figure 4). Wave driven longshore currents were measured (using drogues) inside the surf zone at each of these sites, generally within a 5-6 hour period. Direction and magnitude of longshore currents were measured at two locations (0.5 km apart) at each site and the results of the two were averaged to represent the site. Data were collected approximately every two weeks for a year yielding 20 separate observation days representing the four seasons and a wide variety of wind and wave conditions.

The results of the directional aspect of the study are shown in Figure 5. During the summer months (May-September), the nodal zone was located south of Barnegat Inlet and commonly south of Beach Haven Inlet. The regional longshore current pattern during summer is dominated by S-SW fairweather winds and an occasional northeast storm, tropical storm or hurricane. During the winter months (December-February), the point of current bifurcation is well north of Barnegat Inlet, often to the north of Bradley Beach. The regional current pattern during winter appears to be dominated by northeast storms. The times in between these two extremes (spring and fall) tend to be more unsettled and the position of the nodal zone showed no consistent pattern. BUTEUX (1982) concluded that during 1980 the stretch of coastline over which the nodal zone occurred on any given day is similar to the areal extent documented from previous studies (Figure 3). He also concluded that these were seasonal trends and that the average for the year placed the nodal zone north of Barnegat Inlet. The results of this study clearly reveal the wide range of coastline over which the position of longshore current bifurcation may occur on a variety of time scales and should dispel the well entrenched concept that the nodal zone is fixed or migrates within a narrow (a few tens of kilometers) geographic range. In fact, on a given day the longshore currents can move to the north along the entire coastline, or to the south, or separate in the middle. It is only by averaging the current direction over a long time period (years) that a persistent pattern emerges.

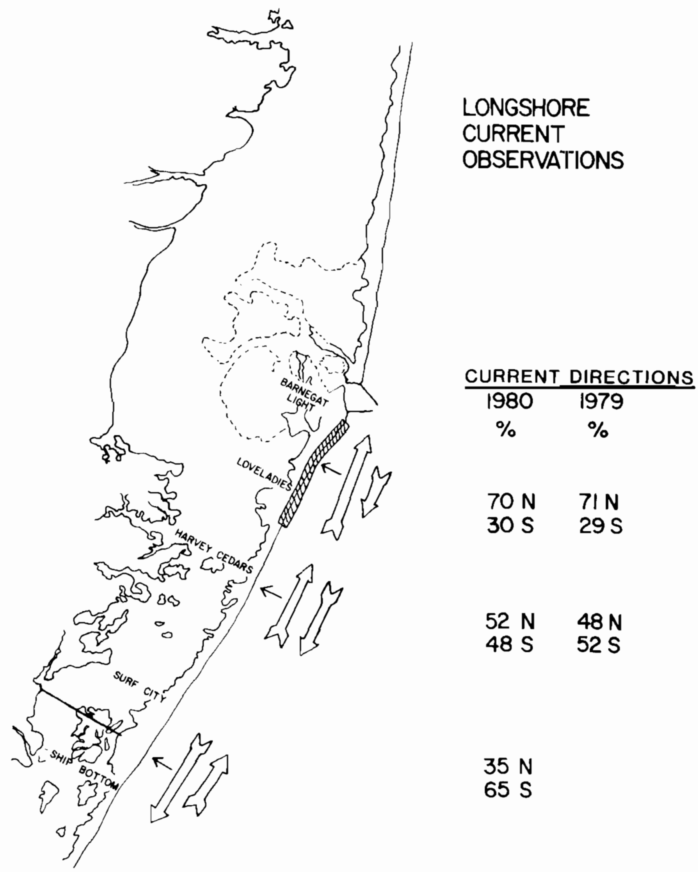

Figure 6. Inlet-wave refraction cell. Percentage of daily longshore current measurements taken during post-beach fill monitoring study at Barnegat Inlet (1979-1980). Area beachfilled is shown by hatched lines.

LOCAL VARIATIONS IN LONGSHORE CURRENT PATTERN

Inlet-wave Refraction Cells

Local reversals in the longshore current direction have tended to complicate observations and thus obscure the regional pattern. Most of the 12 inlets of New Jersey are likely to have a local current reversal which develops due to wave refraction around the ebb tidal delta as predicted by the work of HAYES (1979). He demonstrated that wave refraction over and around the ebb tidal delta shoals produces a local reversal in the regional current direction and consequently an erosional zone at the location of current reversal. Longshore drift moves sediment away from this zone not only in the direction of regional longshore currents but also against the regional trend (updrift) towards the inlet and consequently these areas are sites of erosion (WALTON and DEAN, 1976; HAYES, 1979).

An evaluation of the 1979 U.S. Army Corps of Engineers beach nourishment project for the northern end of Long Beach Island provided an opportunity to examine in detail the longshore current pattern in a restricted area a few kilometers in length (ASHLEY *et al.*, 1980; HALSEY *et al.*, 1981; ASHLEY *et al.*, 1981; HALSEY *et al.*, 1982). The project was initiated in March 1979 as a result of critical erosion from a trio of severe northeast storms during the winter of 1977-1978. Sand was pumped from the shoals within the intra-jetty area of Barnegat Inlet and emplaced along a 4.5 km reach south of Barnegat's south jetty (Figure 6).

As part of the data collection to assess longevity

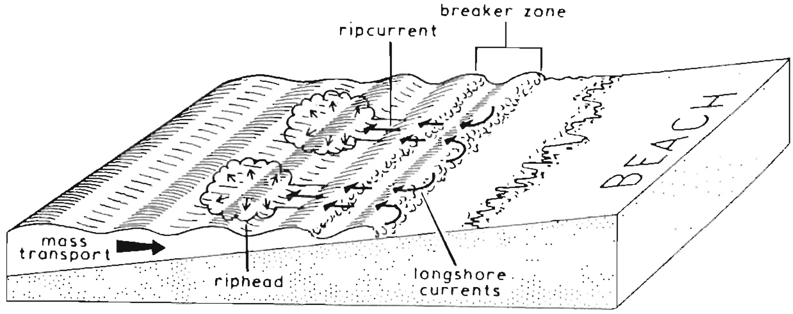

Figure 7A. Rip current cell circulation (from PETHICK, 1984).

Figure 7B. Air photo looking south along Island Beach reveals circulation cells approximately 500 m wide.

of the beach fill, three longshore current stations were established and Littoral Environmental Observations (LEO) (SCHNEIDER, 1981) were taken daily during several 2-3 month periods spanning 2 years. Results were based on 103 observations over 44 days in 1979 and 153 observations over 75 days in 1980. The results are summarized on Figure 6 and reveal a zone of current reversal 1.5-3 km south of the inlet. This local nodal zone is predicted by the inlet-wave refraction model of HAYES (1979).

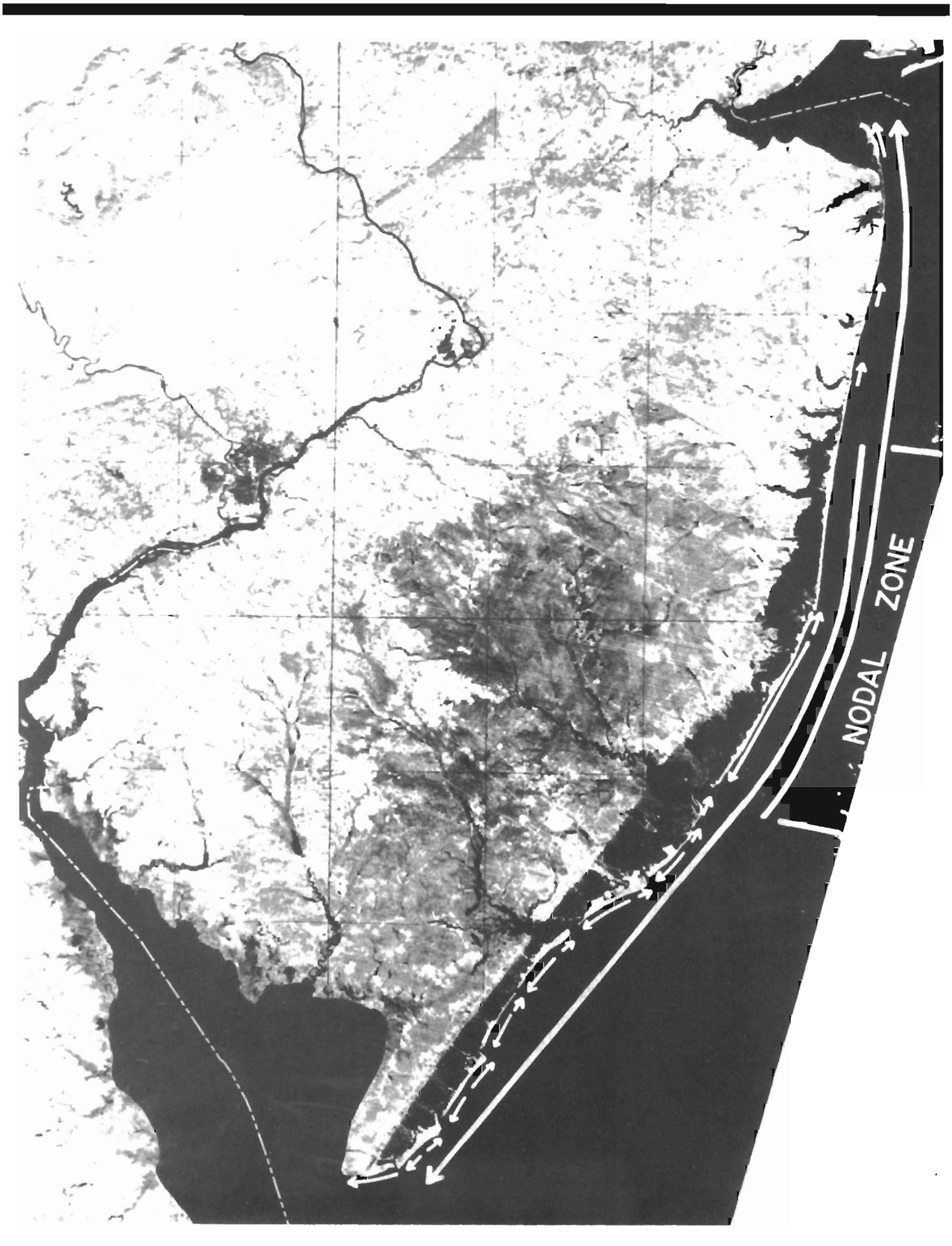

Figure 8. Landsat photograph of the New Jersey coast showing the probable location of current reversals (associated with wave refractions around inlet shoals) superimposed on the regional longshore current pattern. Rip-current circulation cells would be too small to be visible.

In order to determine whether the current reversal south of Barnegat Inlet represented the regional nodal zone or a local circulation cell (produced by inlet shoal wave refraction), we used the results from BUTEUX's (1982) regional study and correlated simultaneous measurements. On 6 days that Buteux measured southerly currents at all his sites, northerly currents were measured in the vicinity of the inlet. Thus, it appears that the Barnegat Inlet flow reversal was a local phenomenon (wave-refraction circulation cell) superimposed upon the regional current pattern.

Rip Current Circulation Cells

The development of evenly spaced circulation cells in the littoral zone is common and a well documented phenomenon (BOWEN and INMAN 1969, KOMAR and INMAN 1970, MAY and TANNER 1973, STAPOR and MAY 1983). The cells develop from slow onshore mass transport which is transformed into longshore currents shoreward of the breakers (Figure 7A). Shore parallel flow is then returned by narrow streams (rip currents) moving offshore. It has been suggested that the presence of edge waves provides the necessary along shore variation in wave height to drive the circulation (PETHICK, 1984). The presence of small-scale (<1 km) circulation cells has been observed along portions of the New Jersey coastline which have no engineering structures (Figure 7B). No detailed studies on these features have been published.

DISCUSSION AND CONCLUSIONS

Although the cause of the regional nodal zone was not the focus of this study, results of analyses carried out by others under a variety of time scales indicates multiple causes. Seasonal variation in wave approach, large-scale wave refraction and residual drift of ocean currents on the shelf probably all interact and play a part in the persistent current pattern common to New Jersey and other coastal compartments in the Mid-Atlantic Bight. All investigations of the regional and long term longshore current pattern of New Jersey have interpreted a current bifurcation zone of flow reversal, however the designated position of that zone varies over a distance of 100 km of the 200 km ocean coastline. It appears that timing (when and for how long the currents were studied) has a significant affect on the results, *i.e.* the interpretation of the nodal zone position. The study with the shortest data base (1 year), BUTEUX (1982) (dashed line Figure 3) shows the longest stretch of shoreline (100 km) over which the nodal zone migrates. The study with the longest data base (3 years) is BUMPUS (1965) and his nodal zone is the shortest (20 km). This indicates that on the short term the regional longshore current pattern is quite variable however long term averages smooth out the variability. An overall average of the studies, places the zone of bifurcation in the vicinity of the communities of Mantoloking and Lavallette. Because the regional nodal zone is a long term average of both northward and southward moving currents the coastline in the nodal zone area is not expected to experience a negative sediment budget (erosion).

Superimposed on this regional state-long current pattern are smaller-scaled current reversals (Figure 8): (1) relatively permanent reversals (longshore current circulation cells) associated with wave refraction around ebb tidal deltas, such as Barnegat Inlet and which are estimated to be a few kilometers wide, and (2) small circulation cells likely related to rip currents and probably are on the order of 1 km wide.

Both of these smaller-scale current reversals that are likely to be fixed geographically are expected to show negative sediment budgets (*i.e.* be sites of erosion) as currents are moved consistently away from the sites. DOLAN (1971) examining North Carolina barriers, KOMAR (1971), the Oregon coast, and WRIGHT and SHORT (1982), the Australian coast have all noted an association between accentuated erosion and the location of rip-current cells.

In conclusion, shore protection plans utilizing non-structural methods should be designed to accommodate this highly variable (locally and short time scales) yet quite persistent (regionally and long time scales) pattern of coastal currents.

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