STORM MITIGATION PLANNING FOR

AVALON, NEW JERSEY

1984

Stewart C. Farrell
John W. Sinton

New Jersey. Coastal Zone Management Program

Stockton Center For Environmental Research
STOCKTON STATE COLLEGE
POMONA, N.J. 08240 (609) 652-1776

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Introduction: What is Storm Mitigation Planning?

New Jersey has one of the most highly developed coastal margins in the nation. Billions of dollars are invested both publicly and privately in what is one of the most productive tourist and recreation industries in the world. Many people reside permanently along the ocean's coast, so that, while human activity surges and ebbs with the seasons, there are always thousands living in or near storm hazard areas. Powerful storms are awesome to evaluate and plan for, but the task, if carefully done, can reduce the danger of future destruction.

Post-storm planning selects appropriate techniques to protect and rebuild a community after a major storm or hurricane. Preparation for the onset of a storm, including emergency evacuation, is a different problem with which the federal-state Emergency Management Team (formerly the Civil Defense) deals. This aspect of storm planning is not discussed in the Avalon report.

The next storm will probably not be greatly different from past storms in ferocity or pattern of destruction. Therefore, to plan for community responses to the next storm, an analysis of past damages has been undertaken for Avalon, New Jersey (Figure 1). The primary emphasis was on relative storm damage exposure of Avalon's coastline. The effectiveness of protective structures and coastal changes since the last storm has been evaluated. A second effort was directed at what the community had done by way of ordinances, legislation and/or administrative changes to develop post-storm planning.

Much of this report concerns the history of Avalon's development and the impacts of the March 1962 northeast storm. With this understanding plus the knowledge of the general geological processes at work on the island, one can predict the location and nature of damage from the next storm.

The borough of Avalon can best prepare for the next great storm by using these predictions. The residents should take careful note that effective planning will take as much political courage as tax money, especially over the long term. This is in large part due to past expectations by the public of absolute protection from encroachment of the sea upon the land. Coastal planning strategies based on absolute refusal to yield to the sea lead toward economic ruin. The people and the sea must reach a flexible agreement. Flexibility is crucial to future planning and requires a fresh look at methods and creeds long held dear in protection of coastal property.

In the sections that follow, this report discusses the

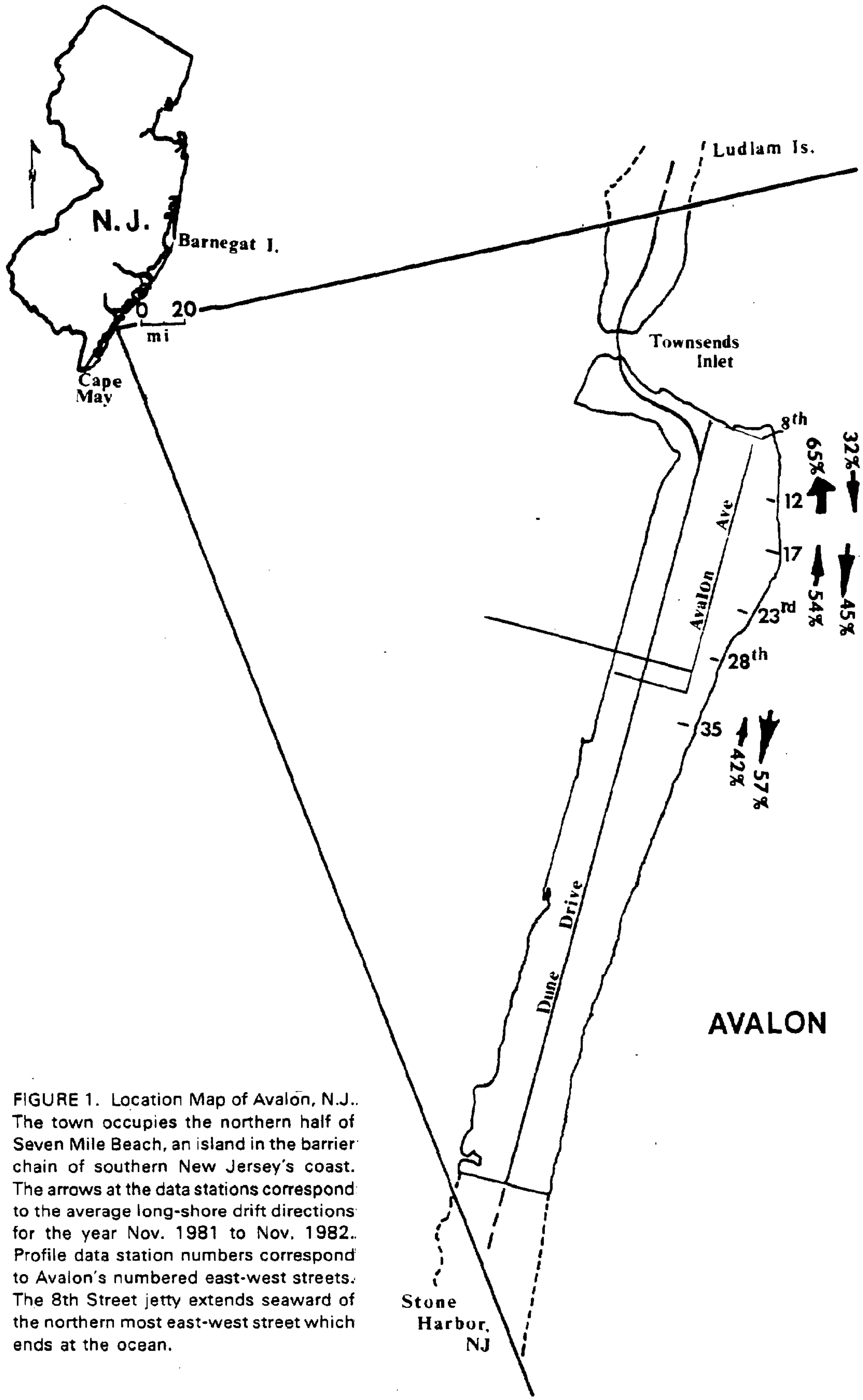

FIGURE 1. Location Map of Avalon, N.J.. The town occupies the northern half of Seven Mile Beach, an island in the barrier chain of southern New Jersey's coast. The arrows at the data stations correspond to the average long-shore drift directions for the year Nov. 1981 to Nov. 1982.. Profile data station numbers correspond to Avalon's numbered east-west streets. The 8th Street jetty extends seaward of the northern most east-west street which ends at the ocean.

geologic factors shaping barrier island communities like Avalon, the effects of previous storms, and the risks which Avalon faces in future storms. It then describes a series of planning options ranging from tasks that can be accomplished quickly to those which require long-term effort and commitment of resources. Finally, the epilogue mentions some actions already underway in the community.

Physical Setting

Geological Processes

The borough of Avalon, New Jersey occupies the northern half of the seventh barrier island in the chain of islands extending from Barnegat Inlet to Cape May Point (Figure 1). It is bounded on the north by Townsends Inlet and on the south by the Borough of Stone Harbor. The entire island has historically been called Seven Mile Beach and is identified as Reach 12 in the New Jersey Shore Protection Master Plan (N.J.D.E.P., 1981).

Seven Mile Beach is similar in shape to the three islands to the north and the one to the south. The wide north end of Avalon extends seaward of Ludlam Island located north of Townsends Inlet. To the south it tapers to a thin tail of a spit at Hereford Inlet. This is a classic offset barrier island shape (Figure 2) created in response to a meso-tidal range of four to six feet and the northeasterly direction of the approach of the dominant waves to the Avalon Beaches (Campbell and Dean, 1975; Hayes et al., 1973). The Hayes' model for barrier island geomorphology places the New Jersey coast in the meso-tidal category. New Jersey's barrier islands are broken into five to eighteen mile segments bounded by tidal inlets. Other barrier islands can grow to extreme lengths along coasts with low tidal ranges (less than one foot), such as the 100-mile long San Padre Island, Texas, or they can disappear altogether on coasts with high tidal ranges such as Cook Inlet, Alaska where the range is about twenty feet or the Bay of Fundy, Nova Scotia with tidal ranges up to fifty feet.

The tidal range, sediment supply, wave energy, and the topographic relief of the coastal margin all contribute to overall barrier island shape and size. The effect of tidal range alone is a rising and falling water level which causes tidal currents to develop as water fills and empties bays and estuaries behind the barrier system. Therefore, the higher the range of the tide, the more likely a large number of inlets will be needed to handle the water volume exchanged between the ocean and bays.

At Avalon, the tidal currents through Townsends Inlet

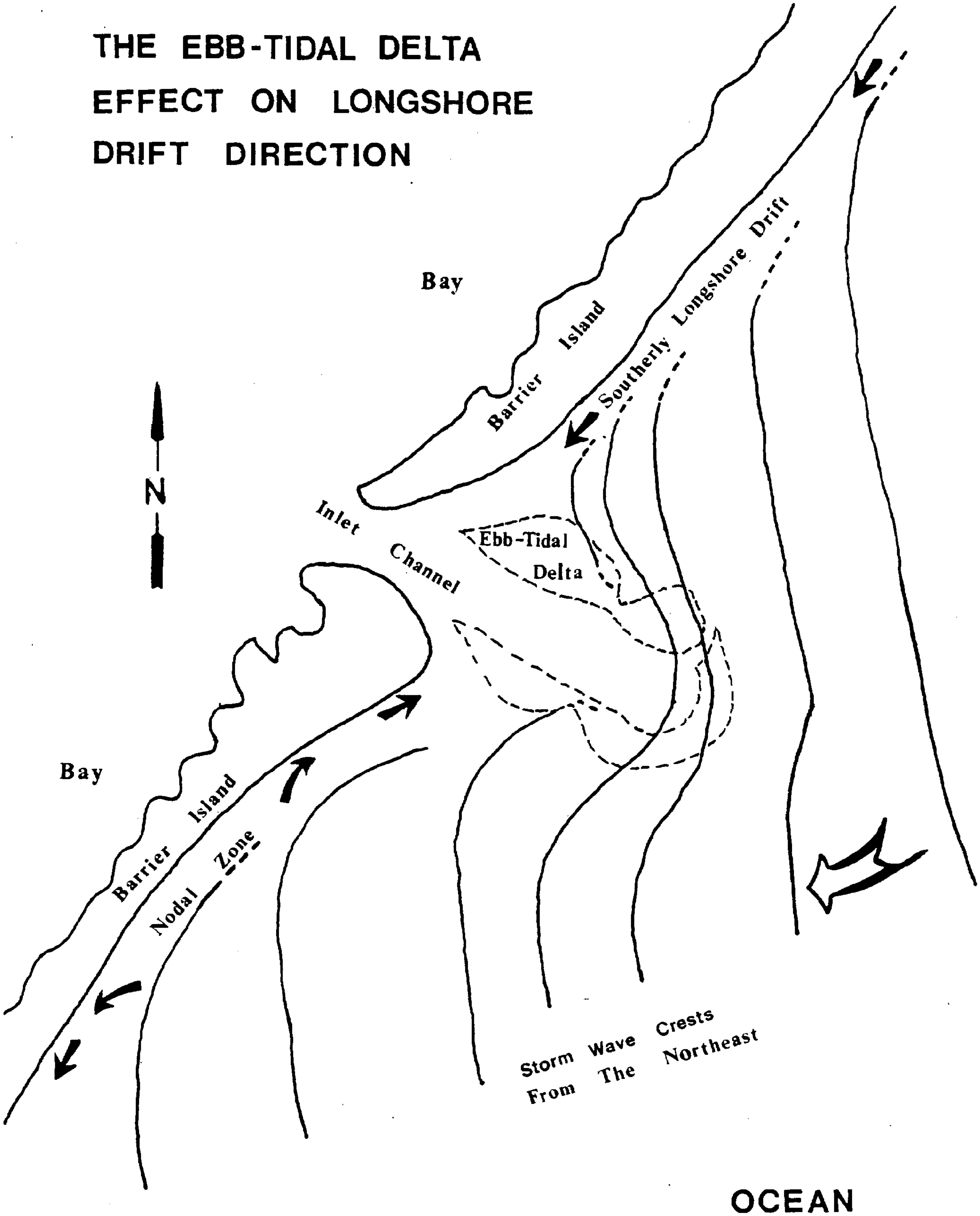

FIGURE 2. The relative enlargement (offset) of one end of each barrier island of a chain of islands is caused by the approach of dominant storm generated waves at some angle to the islands rather than parallel to their long axes. The refraction of these waves around the ebb-tidal delta causes the offset.

transport sand both into the bay on flood tide and back out into the ocean on the ebb tide. As the ebb-tidal flow enters the ocean, it spreads out, slows down, and drops its load of sand. Waves shape this sand into a variety of arcuate shoals and bars known as the ebb-tidal delta (Figure 2). On the New Jersey Coast, northeast storm waves approach obliquely from as much as 60 degrees to the alignment of the shoreline. One effect is the creation of a strong longshore transport of sand which moves most of the sand south along Avalon. Although it is the general tendency for northeast storms to move sand southward as large waves approach the beach, shoals, ridges, and channels can re-direct waves to the north through refraction. Thus, major wave refraction is created by the shoals of the ebb-tidal delta in the inlet area.

During a storm the north end of Avalon down to about 30th Street will experience these refracted waves which will appear to approach the shoreline from the east-southeast. This reverses the general longshore movement of sand to the south and causes sediment to build up at the extreme north end of the island. The ebb-tidal delta can diminish the size of the waves in its shadow and, therefore, wave energy striking the beach is reduced, further enhancing sediment accumulation. Sand moved north accumulates first behind the 8th Avenue jetty, then spills over it into the channel where it is transported out to the delta as is presently occurring. Waves sweeping over the tidal delta bring the sand southwestward closer to shore and return most of it to the beach in the nodal zone. The sand moves to shore as discrete bars migrating landward over the ebb-tidal delta swash platform (FitzGerald, 1976).

A nodal zone is a segment of the beach on a barrier island where the predominant longshore drift direction is neither to the north nor to the south (U.S. Army Corps of Engineers, 1973). Every barrier island along the New Jersey coast has a <u>divergent</u> nodal zone where waves move sand away from the point in opposite directions. In November 1981 Avalon's nodal zone was centered between 25th and 30th Streets. As of October 1983, the zone had shifted approximately ten blocks north. The nodal zone area is subject to large waves and is the highest risk area of the island for such damage.

Sand moving south from the nodal zone replaces 1) sand blown into dunes from the beach, and 2) beach sand which in turn moved south to Stone Harbor. Sand moving north from the nodal zone has built the dunes east of Avalon Avenue between 10th and 23rd Streets and, as described below, is responsible for the sand spit now growing into Townsends Inlet. A moderate volume of sand is added to Avalon annually as sediment from Sea Isle City, north of Townsends Inlet, bypasses the inlet on the ebb-tidal shoals.

The inlet-facing beach along 6th and 7th Streets in Avalon suffers periodic erosion as a result of the interplay between tidal currents in the main ebb-tidal channel and the shifting location of that tidal channel within the ebb-tidal delta. Studies have shown that when the main ebb-tidal channel is directly adjacent to the northern inlet throat of one of New Jersey's barrier islands, that area erodes severely (FitzGerald, 1976; Farrell, 1980). Tidal currents scour sand from the base of the beach face, and the deep channel allows larger waves direct access to the shoreline without previously breaking offshore. When the tidal channel shifts away from this position, sand soon accumulates in large shoals along this section, thus extending the low-tide margin many feet to the northeast. These shoals help protect the landward area from subsequent storm waves.

From 1969 to 1978, the Townsends Inlet channel moved progressively closer to Avalon and worsened a long-term erosion problem. During the summer of 1978, the inlet was dredged and the resulting main tidal channel was moved away from the 8th Street jetty to its present, more medial position between Avalon and Sea Isle City. The predictable, yet dramatic, results were deposition of a 1,017 foot wide, flat beach shaped into a spit curving into the inlet, attached to and burying the 8th Street jetty.

This impressive deposit has developed because high velocity ebb-tidal currents no longer sweep sand spilling over the jetty (Figures 1 and 2) out to the ebb-tidal delta. The spit will continue to grow wider and extend further up the inlet, providing protection for the entire exposed north inlet shore of Avalon. It will exist until the ebb-tidal channel migrates back to the south along Avalon's north shore and scours it away again., This could take anywhere from seven to fifteen years (FitzGerald, 1976).

Between February 24, 1980 and April 30, 1981, the Borough of Avalon contributed significantly to the spit's rapid growth by placing 138,000 cubic yards of dredge spoil at 10th Street. Because this spoil was not composed entirely of sediment suitable for beach nourishment, some silt and fine sands were lost as suspended material and carried offshore.

One negative aspect of this spit's growth is its contribution to the temporary interruption of the recycling of sand via the ebb-tidal delta south to the beaches between 8th and 35th Streets and, thence, by refracted longshore drift back to the 8th Street jetty. The spit is composed of sand, formerly in continuous transit, now in temporary holding as a deposit. Sand is stopping at the new spit and cannot complete the cycle by returning to the ebb-tidal delta and then being recycled to the local nodal zone of wave refraction. In November 1981 dune scarps and narrow beaches along this stretch of beach gave ample evidence that erosion was in process. Since August 1982 the continuing erosion between 8th and 12th Street has begun to pose a threat to several private homes and has assumed serious proportions.

History of Development in Avalon, 1949-1981

A review of aerial photographs from October 21, 1949 (Figure 3), October 12, 1954 (Figure 4), March 8, 1962 (Figure 5), and October 23, 1969 (Figure 6), illustrates the Borough's development. Avalon was sparsely populated in 1949 with two housing concentrations. The first was between 6th and 15th Streets in a north-south direction and on Avalon Avenue and Dune Drive in an east-west direction; the second was between 19th and 38th Streets from north to south and between Avalon Avenue and Ocean Drive from east to west. There was one development on the salt marsh between Pennsylvania Harbor and Princeton Harbor west of Ocean Drive (Figure 3), and only 65 structures existed south of 38th Street, 19 of which were east of Dune Drive. Only one paved street and six sand roads penetrated the relatively unbroken dune ridge east of Dune Drive (Figure 3).

By 1954 new housing had increased the density in the already settled areas. By this time there were 26 houses east of Dune Drive and ten artificial breaks in the dune line south of 38th Street. In addition, development was beginning to proceed east of Avalon Avenue between 8th and 31st Streets (Figure 4).

Development had proceeded at about the same pace until 1962 with further increases in density of housing in the north end virtually merging the two separate clusters of population around 16th Street (Figure 5). Considerable growth had extended east of Avalon Avenue between 8th and 31st Streets. 45 houses stood between Dune Drive and the ocean south of 38th Street.

Between 1962 and 1969 an explosion in construction virtually filled in the map of Avalon. Almost all the east-west numbered streets were cut through and paved. Houses were built south of 38th street to the Stone Harbor line at 80th Street. In 1969 there were 162 houses east of Dune Drive and 22 paved street ends breaching the dune ridge (Figure 6). By June 24, 1981, an aerial count of houses in this stretch found 221 residences and three motels. Therefore, in terms of housing denisty, there is five times the potential for damage as there was in 1962 in this 42-block portion of the city alone.

Figures 3-6: A sequence of aerial photographs from 1949 to 1969 showing the development history of Avalon, N.J. They present a short time-lapse photo essay of the rate and places of development during twenty years.

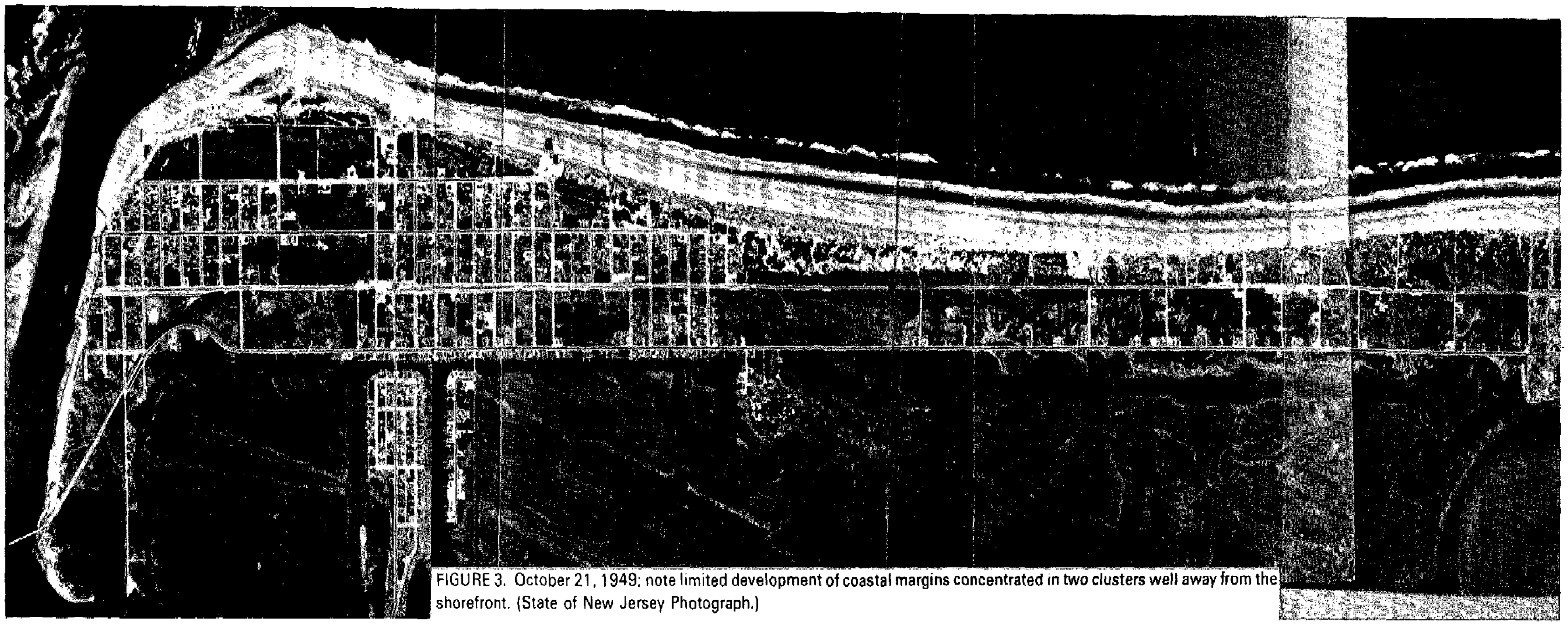

FIGURE 3. October 21, 1949; note limited development of coastal margins concentrated in two clusters well away from the shorefront. (State of New Jersey Photograph.)

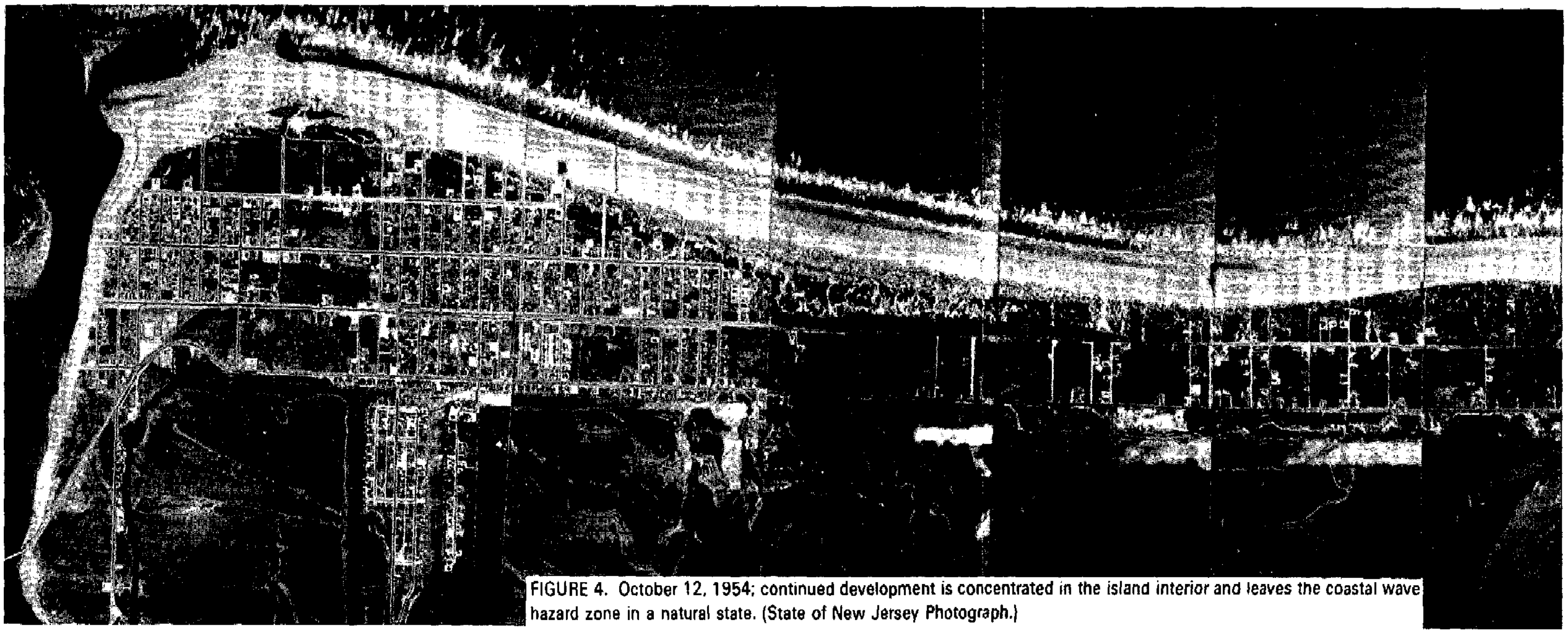

FIGURE 4. October 12, 1954; continued development is concentrated in the island interior and leaves the coastal wave hazard zone in a natural state. (State of New Jersey Photograph.)

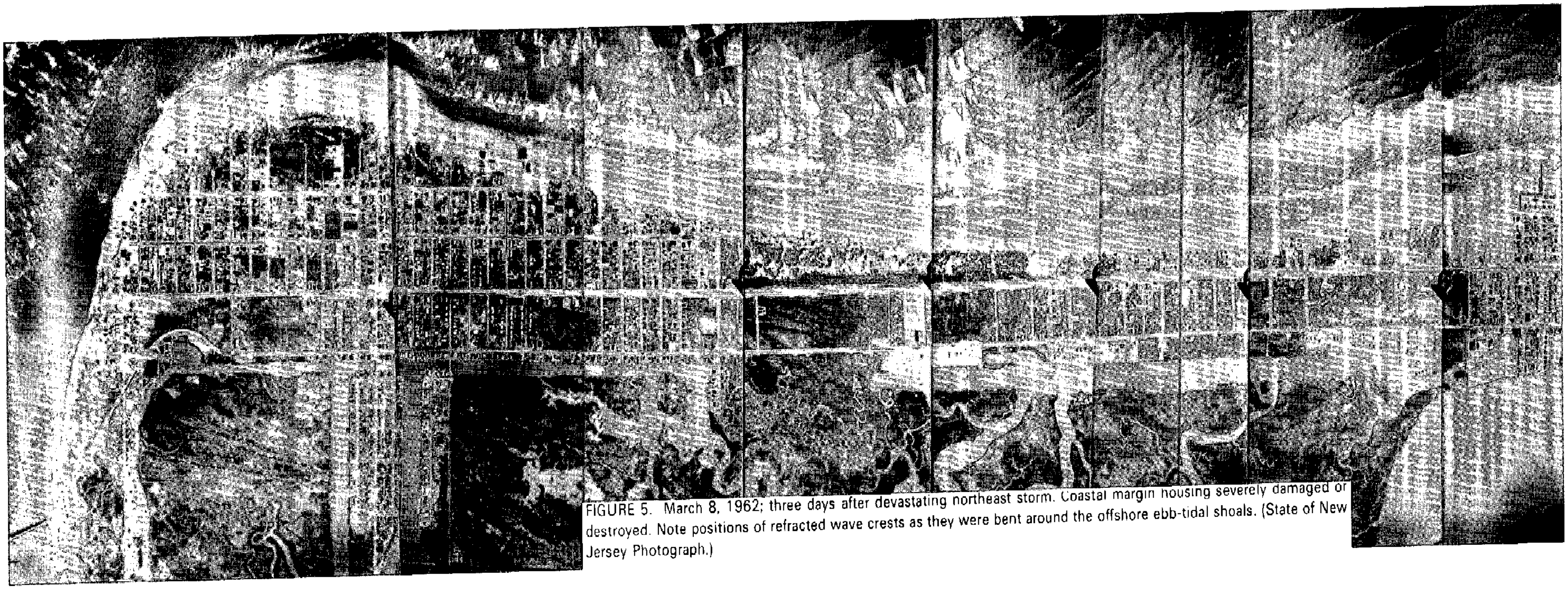

FIGURE 5. March 8, 1962; three days after devastating northeast storm. Coastal margin housing severely damaged or destroyed. Note positions of refracted wave crests as they were bent around the offshore ebb-tidal shoals. (State of New Jersey Photograph.)

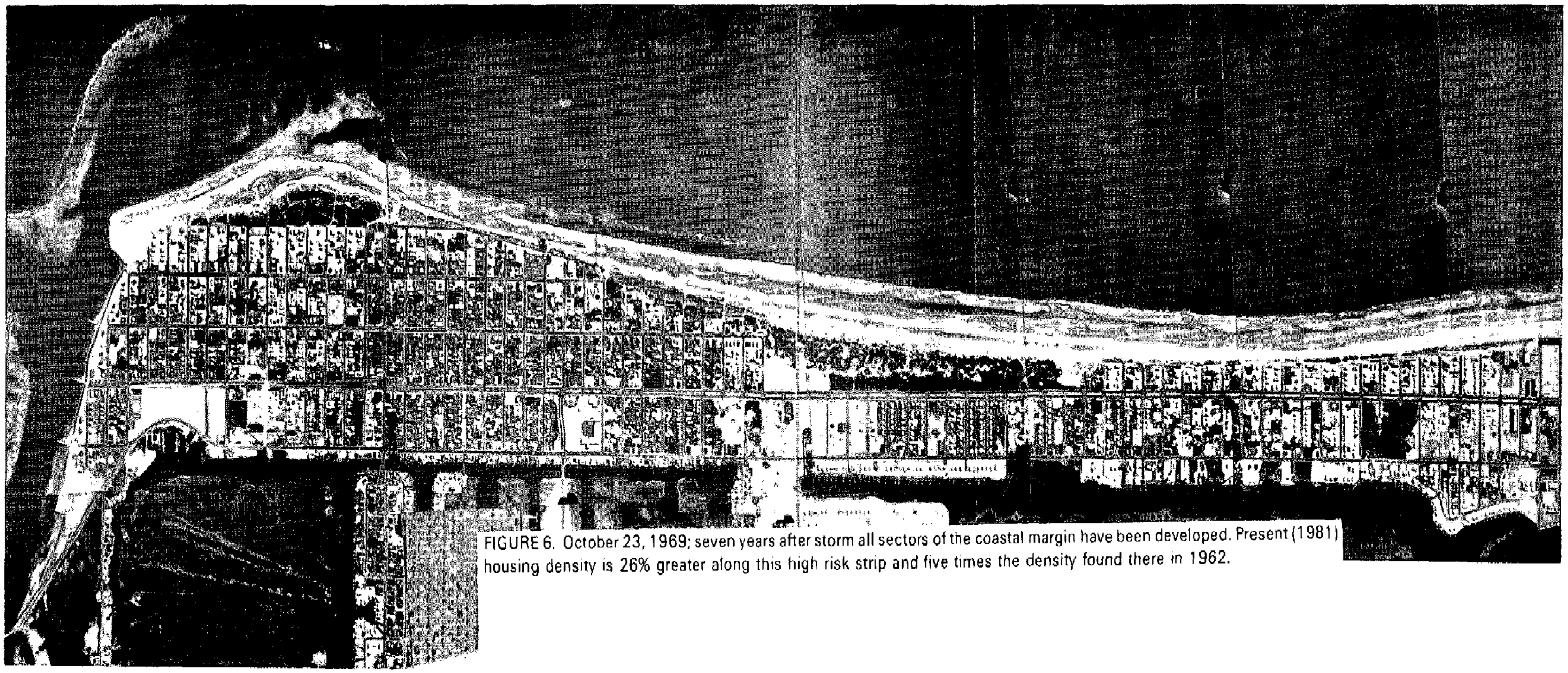

FIGURE 6. October 23, 1969; seven years after storm all sectors of the coastal margin have been developed. Present (1981) housing density is 26% greater along this high risk strip and five times the density found there in 1962.

The Present Storm Hazard

History of Major Storms on the New Jersey Coast

Major northeast storms or hurricanes are presently tracked and plotted with accurate positions and velocities forecast along the storm's path. There is no method to predict exactly an existing storm's path and no way to determine very long in advance, when a storm will strike a particular shoreline. Meteorologists speak of fifty or hundred-year storms. Statistics provide the estimate that the eye of a hurricane will pass over the New Jersey coast once every 50 years. Looking at the history of hurricanes since 1871, one finds that the last eye to pass over the New Jersey coast was in 1904; the only other time the eye passed over Cape May County since 1871 was in 1903. Can one then say that another eye will pass over New Jersey in the next 40 years? The answer is, "Probably."

It cannot be known precisely when the next great storm will hit; we do know that it will. The weather has been kind to the New Jersey coast since the three hurricanes of the 1930s and the one in 1944, all four of which were category three hurricanes (winds from 111 to 130 miles per hour). The New Jersey coast has sustained grave damage from northeast storms in 1950 and 1962; the latter is described later in detail. The coast was also sideswiped by hurricanes Hazel (1954), Donna (1960), Agnes (1972), Belle (1976), and David (1979), all of which caused severe beach erosion in Avalon.

Storm Surge Water Level Elevation

Those familiar with coastal processes know that the twice daily high tides do not all achieve the same exact elevation in water level. Water level is controlled by the following parameters:

1. The position of the moon: The daily rotation of the earth brings Avalon into the effects of the two crests of the tide present at all times in the North Atlantic. The seasonal change in the earth's axis tilt relative to the lunar orbit also produces annual variations in tidal elevation.
2. The added pull of solar gravity: The moon is aligned with the earth and sun twice a lunar orbit (approximately one month). This produces higher than normal high tides and lower than normal low tides called spring tides. At other times, when the moon is not aligned with the earth and sun, this non-alignment acts to reduce the tidal range; these tides are called neap tides.

3. The proximity of the sun and moon to the earth: The pull of gravity on the waters is increased when the moon is closest to the earth in its non-circular orbit. The same is true for the closest approach of the earth to the sun in its orbit. The closest approach of the moon to the earth in its orbit is called perigee. The closest approach of the earth-moon system to the sun is called perihelion. The former effect, when simultaneous with the mutual alignment of the sun, earth, and moon (syzygy) creates Perigean Spring Tides. These extra high spring tides occur from two to five times a year. The perihelion occurs in the early winter and adds about one percent to the heights of the tide levels for about two months.

These three factors make up the astronomical tides and can be predicted in advance. The last two factors are related to each individual storm.

4. Atmospheric pressure: The change in barometric pressure caused by high and low pressure air masses passing over the sea causes an elevation change in the sea. Each one inch of barometric pressure drop produces a water level rise of 13 inches under the storm's center. A hurricane can have a pressure of only 26 inches of mercury (four to five inches below normal) in its eye or center. This change during a hurricane would raise the level under the eye by 5 X 13 inches or five feet five inches.

5. Wave set-up or storm surge: This is the most unpredictable and most deadly effect of storms on sea level elevation. High winds approaching shore drive water in the form of waves against the beaches. This "piling-up" of the water level produces a surge of water level which can reach up to 30 feet above low tide position. Timing is important to this sea level elevation. A storm arriving in phase with the astronomical tide will raise sea level higher than one which arrives as the tide is falling. Of additional importance is the timing of a storm with spring tidal levels and/or perigean tides.

Storm Waves

Storm severity is directly related to three functions of wave and wind interaction:

1. Velocity -- the harder the wind blows, the larger will be the waves it generates.

2. Fetch -- the distance over water the wind has to generate waves. A westerly wind of 100 miles per hour will do no wave damage to Avalon's ocean facing coast because the westerly wind has no oceanic fetch.

3. Duration -- how long the wind blows from the same direction over a given fetch at a given velocity.

Of the three factors, the most important is duration. Since all storms in the northern hemisphere are anticlockwise rotating cyclones, their winds blow in a circular fashion around the center. As the storm center moves, each point on land gradually experiences a changing wind direction which is proportional to the storm's speed. Thus a slow moving or stationary storm system will do far more damage than a more powerful storm which is moving rapidly because the faster storm lacks the time to generate large waves from any one direction.

March 1962 Northeast Storm at Avalon

The 1962 March storm did not contain very powerful winds. The average wind speed was only 36 miles per hour with rare gusts to 60 miles per hour, but for 36 hours the storm did not move . A 36 mile per hour wind blowing for 36 hours across an unlimited fetch will generate an eighteen foot wave (Neumann et al., 1955). This size wave, observed in 1962, when added to the 11.4-foot above mean low water storm surge, placed destructive wave power well within Avalon's foredune ridge.

Three areas of Avalon suffered major damage during the 1962 storm:

1. The inlet beaches facing northeast at 6th, 7th, and 8th Streets from Townsends Inlet Bridge to the east.
2. 25th to 35th Streets at Avalon Avenue.
3. 60th Street to the Stone Harbor line.

These areas remain as problems.

Aerial photographs taken March 8, 1962 by the State of New Jersey show the effect of storm wave overwash most dramatically (Figures 7-10). In addition, the post-storm swell still visible in the photos is a classic illustration of the aforementioned wave refraction-generated longshore drift patterns and sheltering effect of the ebb-tidal delta.

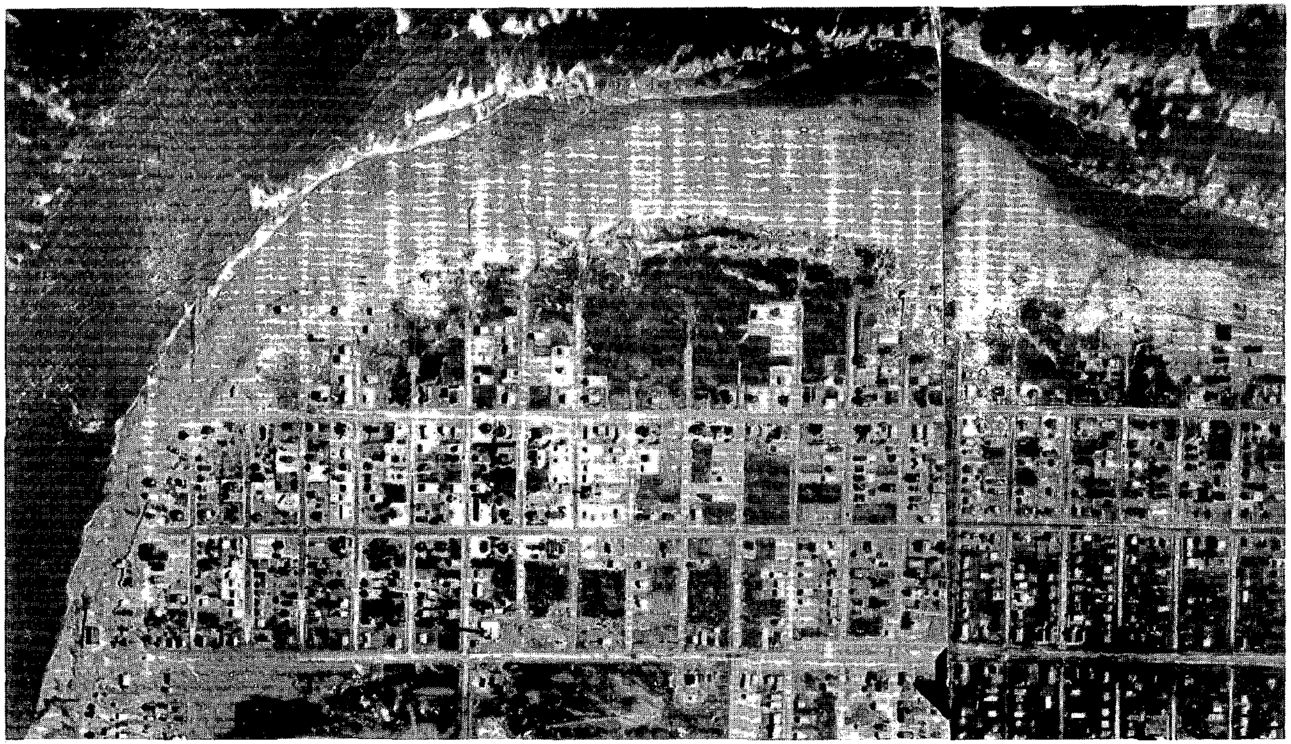

FIGURE 7. Northeast corner of Avalon graphically demonstrating the difference between an unprotected coast (the northeast inlet shore) and an intact dune ridge which absorbed the storm's fury (13th-23rd Streets). The inlet shoreline was almost completely destroyed and although protected now with a seawall, still is vulnerable because homes were built within 20 feet of the crest of the wall.

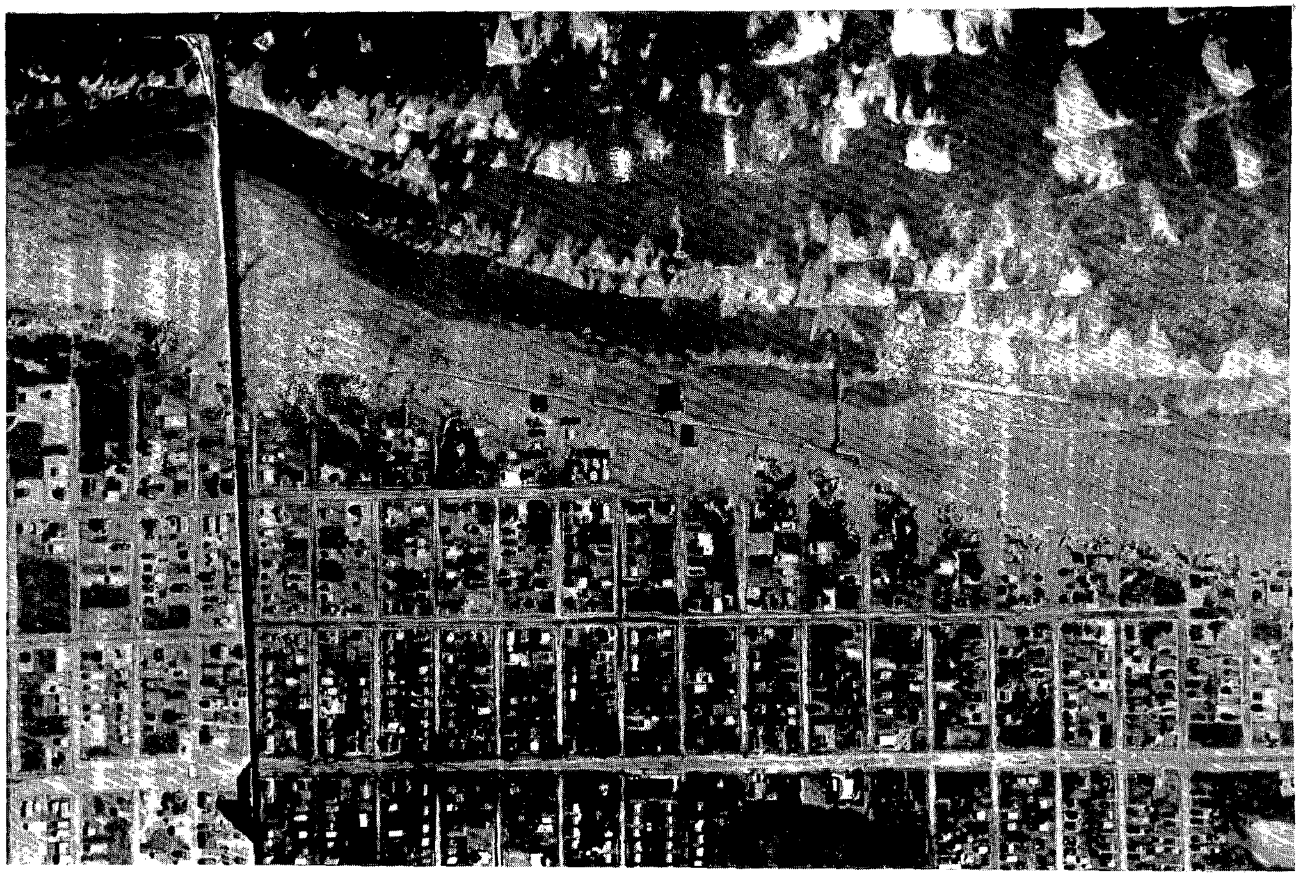

FIGURE 8. 23rd to 38th Streets showing 1962 storm damage in the longshore drift nodal zone. In the absence of street-end dune protection this pattern of overwash will be repeated. The present dune line is still narrow and easily subject to breaching.

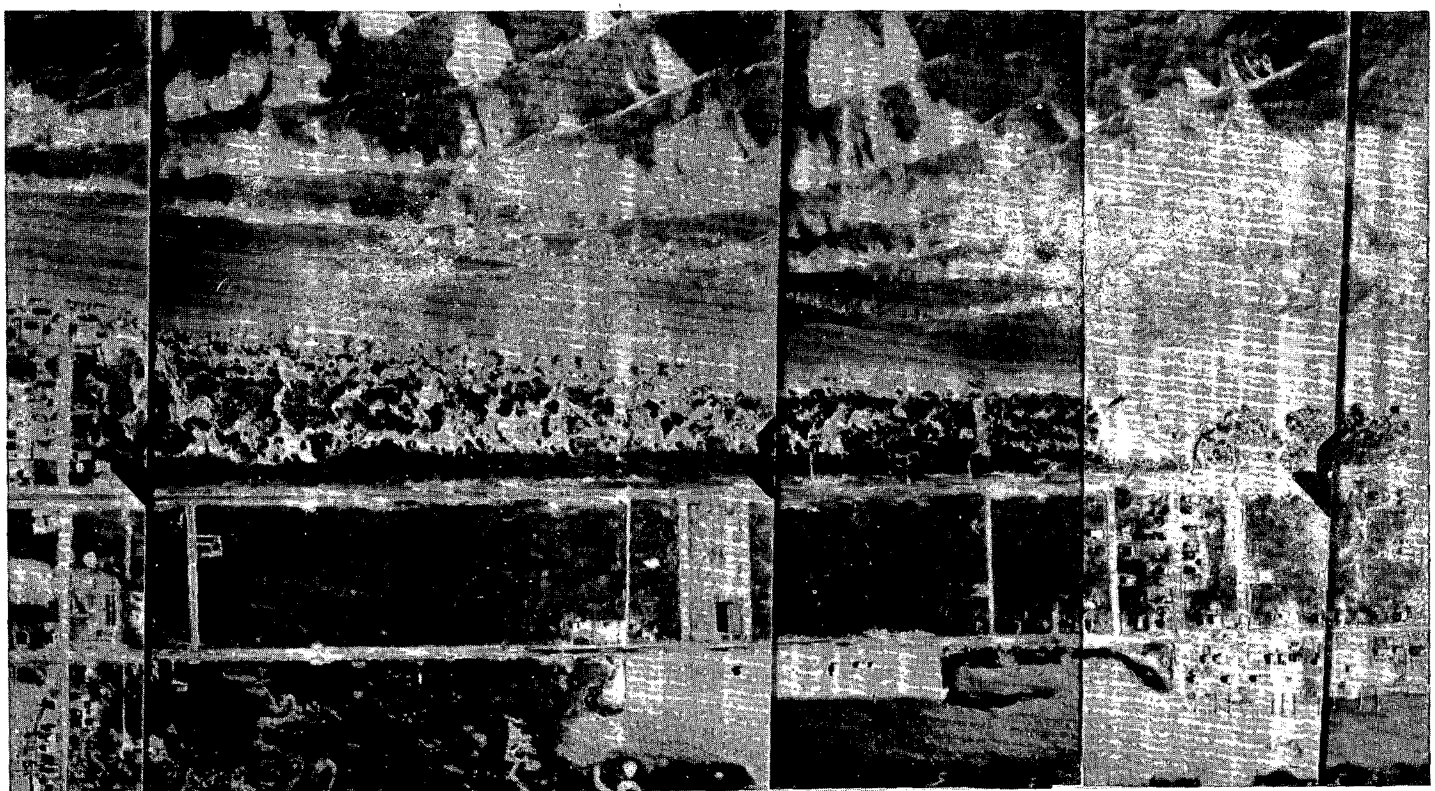

FIGURE 9. 38th to 60th Streets. The high dunes were 100% effective in preventing the entry of high velocity waves or wave overwash.

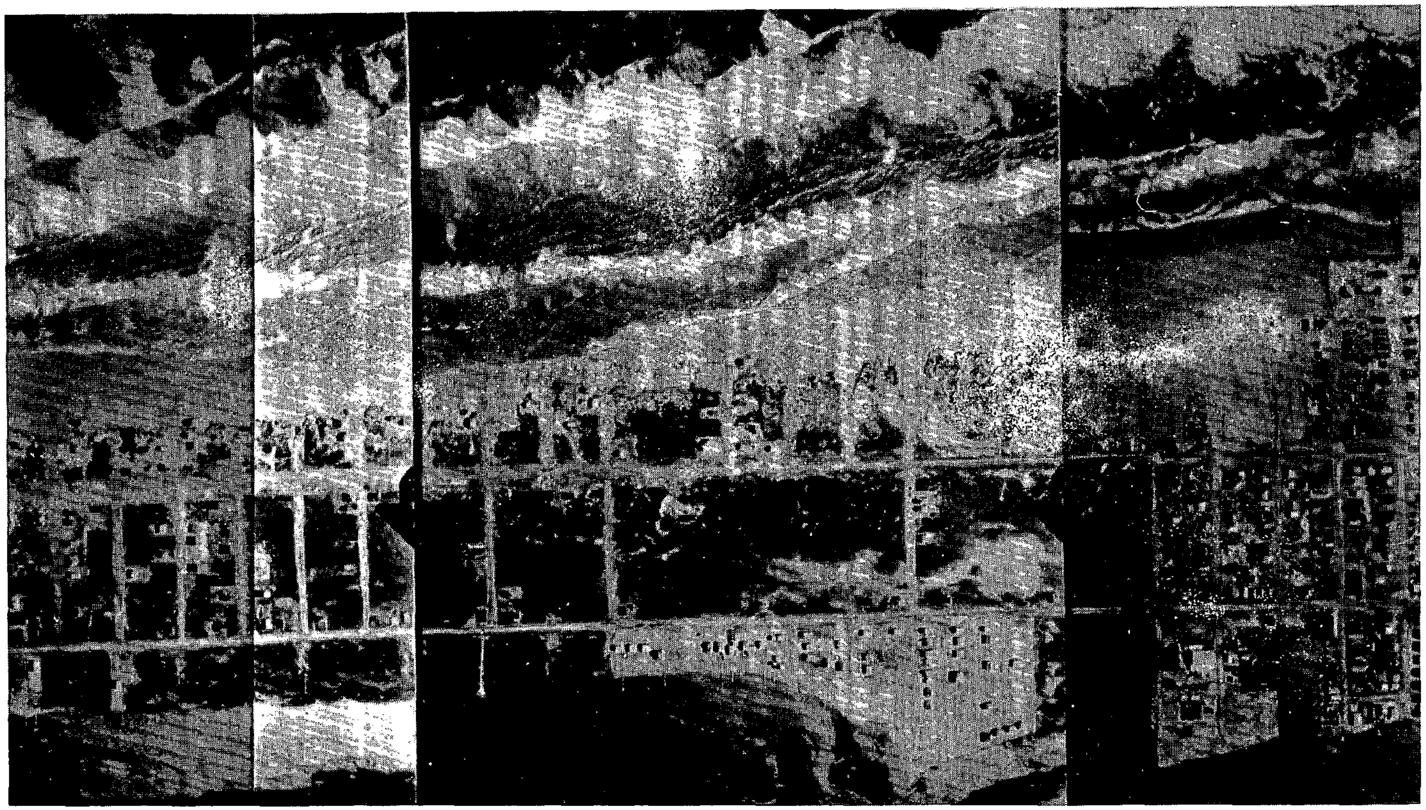

FIGURE 10. 60th to 80th Streets. Unprotected street-ends channelled water and waves inland to the bay. Today there are five times as many homes east of Dune Drive. While the street-ends are raised to a level near that of the dune crest, foot traffic wears a notch which, if breached will allow a repeat of 1962 overwash.

Problem Areas in Avalon

Problem Area 1: The Northeast Facing Inlet Shore

This exposed area of coast had no structural defenses in 1962 and was overwashed and buried by 1 to 6 feet of sand to a distance of 1,000 feet inland (Figure 7). Ground pictures show gutted houses and smashed foundations. Some structures were moved a block or more inland. After the 1962 storm a rock seawall and bulkhead were constructed from Townsends Inlet bridge eastward to a jetty built at the end of 8th Street with four short stone groins placed perpendicular to the seawall about 1,500 feet apart. These structures will prevent the major portion of wave energy of a future storm from being expended inland of the seawall. However, the construction of houses immediately behind the wall was probably a mistake. These properties will be subject to explosive wave spray and overtopping damage. Floating debris can be hurled with destructive force through walls or windows. Most significantly, extreme turbulence of overtopping waters can erode sediment from behind the wall, causing foundation failure.

In 1962 the main ebb tidal channel was immediately adjacent to the Avalon side of the inlet. The deep water just off the inlet beach allowed waves to reform and to approach closely the high tide line before they broke and washed inland. The presence of the seawall structure plus a buffer beach strip of at least 100-foot width in front of the seawall would greatly reduce the risk of destruction of the inlet-front houses. The spit growing into the inlet from the 8th Street jetty will eventually provide such a buffer to dissipate breaking wave energy. This strip of sand should have a dune field developed upon it as soon as possible. American beach grass plantings together with sand fencing has been initiated above the mild storm tide limit. This protective sand barrier should be made as potent a defense as possible.

As stated before, all inlet-facing beaches of offset barrier islands are subject to cyclic erosion and deposition and should be left undeveloped. The newly formed spit will again be subject to erosion and only non-structural erosion retarding measures should be employed. To build upon this new deposit would cause long term problems as the spit begins to erode and the cycle continues.

Problem Area 2: 8th to 32nd Streets

The 1962 storm invaded all street ends in this area and waves washed sand and debris back to Avalon Avenue (Figure 8). Building density was only half of what it is today and the current beach width and dune protection is less than it was in 1961.

The sand that has now built the 8th Street spit has come in part from this zone of the beach. The island's local longshore drift nodal zone has moved north along the beach toward a center at 15th Street during this study. In November 1981 it was centered at about 25th Street and sand moved away both to the north and south. The spit is now a reservoir for northerly drifting sand, so that little if any returns to these beaches via the ebb-tidal shoal offshore. Fall 1982 beach profile cross sections (see Epilogue) did show substantial volume increases, however, and the storm of October 25, 1982 did not cut a scarp in the dunes as did the storm of November 18, 1981 which was the impetus for the year long study. The general observation of northerly nodal zone shift was documented during this study (Figure 1).

This twelve-block stretch (20th to 32nd Streets) is the highest risk beachfront in Avalon. The beach is narrow, the dune line low and narrow, and the wide, flat paved surfaces behind the dune would accelerate a landward-traveling wave rush. The boardwalk's destruction would yield abundant heavy floating debris to smash structures landward of it. The wide open parking lot between 28th and 29th Streets will be a certain pathway of destruction in a major storm. The northern part of this area, 8th to 12th Streets, was not seriously at risk in October 1981, but by March 1983, after 135 feet of dune erosion (centered at 9th Street), this four block portion of Avalon has become part of the high risk zone. A one-half block setback on the south side of 12th Street places the ocean front homes, located south of 12th Street, 250 feet back from the dune scarp. This wide strip of dune protection tapers down to less than 20 feet at 20th Street. Let there be no misunderstanding: 8th to 12th and 20th to 32nd Streets between Avalon and First Avenues will bear the brunt of the next major storm's destruction.

<u>Problem Area 3: 60th Street South to 80th Street</u>

Eighteen years ago only 40 houses existed in this beach strip east of Dune Drive. The pre-storm 1962 dune line was narrow, low, and broken at all street ends. Because it is south of the sheltering effect of the ebb-tidal delta, this portion of the island receives the highest wave energy conditions within the Borough limits. The sand overwash map (Figure 11) shows that the street ends were the sites of all penetration of high velocity waves beyond the dune line. All 22 existing streets were breached and in some cases, such as between 65th and 72nd Streets, destruction of the beach block was complete (Figure 10).

Fortunately, since 1962 an aggressive community-led

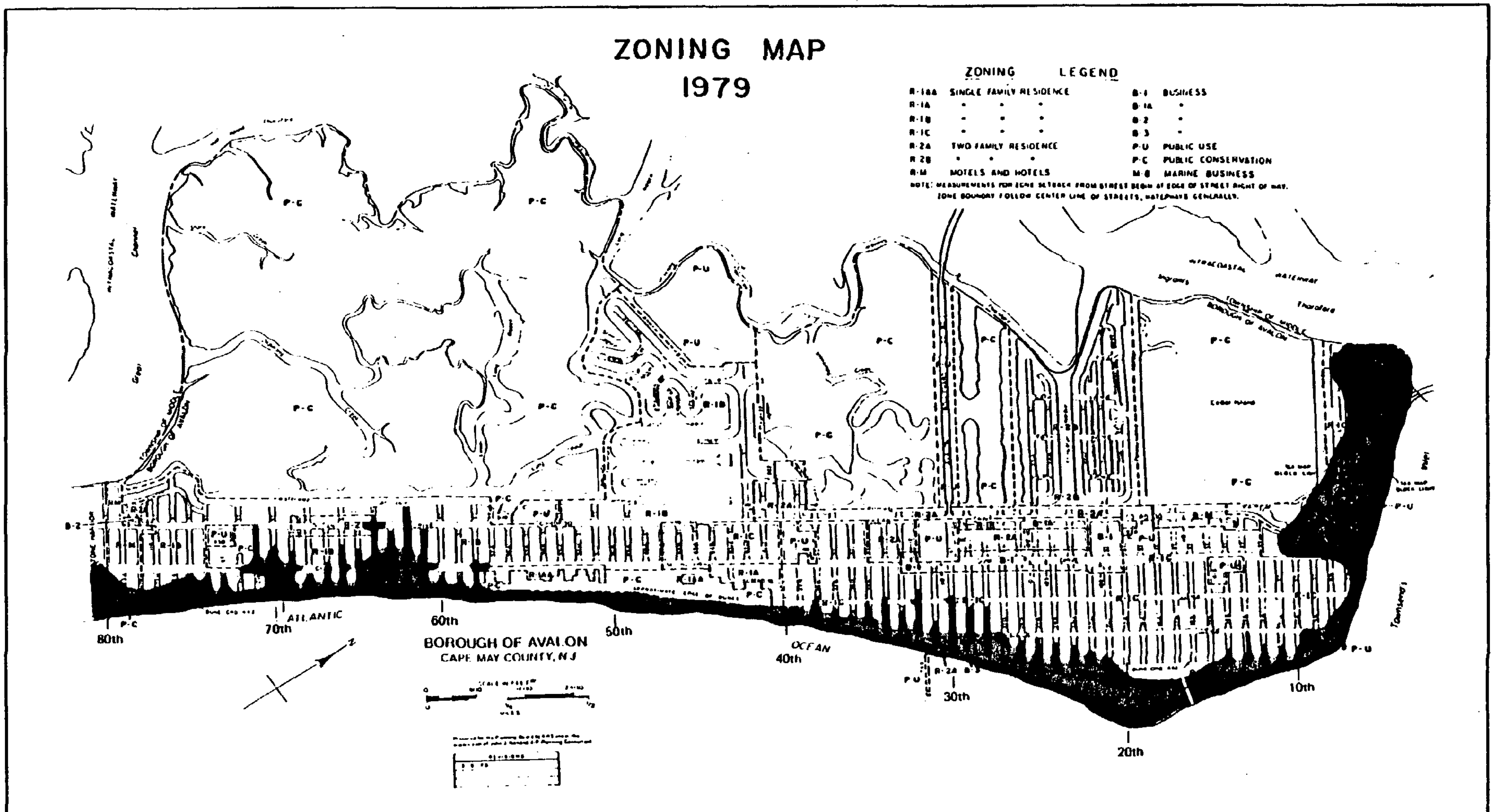

FIGURE 11. Avalon Zoning Map 1979 with a dot screen overlay of sand deposited as overwash resulting from the 1962 storm. The inland boundary approximates a sand thickness of 1.0 foot.

effort has produced a dune line vastly superior to that before the 1962 storm. Street-end paths are elevated and dunes are at least 5 feet high through this region. The photographs show that in most cases two dune lines exist along this reach. The newest dune fencing is creating a two to four foot ridge fifty to eighty feet east of the older dune line. No effort should be spared to increase the dune height and secure the street-end pathways more adequately. The present risk to storm damage is moderate and would be severe only where the double dune line fails.

Other Areas of Avalon Damaged in 1962

From 8th to 23rd Streets the lack of development east of Avalon Avenue in 1962 plus the wide, vegetated dune field prevented any invasion of high velocity waves to this area. However the north end of this 16-block area (9th to 11th Streets) is presently subject to a change in the position of the divergent nodal zone. This change which began in August 1982 and accelerated during the winter of 1982-83, has increased the storm risk in this beachfront section.

Between 38th and 56th Streets only six houses sit within the highest dunes on the ocean-facing coast of Avalon (Figure 9). While water flooded Dune Drive in 1962, neither waves, surge, nor explosive spray reached the homes west of it. The 50-foot height of these dunes makes them the best natural storm protection and the envy of other, less fortunate coastal communities.

Recommendations for Avalon's Storm Mitigation Plan

The purpose of our studies on the coastal geology of Avalon was to provide the town with data on which to base a storm mitigation plan. Such planning is not legally defensible unless based on hard data. The background to this attempt was New Jersey Assembly Bill #1825, submitted in June 1980, to prohibit the rebuilding of any structure which had been more than 50 percent damaged by a coastal storm. The result would have reduced future damage to rebuilt structures in critical hazard areas by allowing dunes to replace those structures. While this attempt to impose such standards by legislation made ecological sense, it was politically unfeasible. The proposed bill produced such an outcry from many state legislators and the public that the bill was withdrawn two months later. The Department of Environmental Protection is now attempting to aid barrier island communities in developing their own post-storm plans.

Avalon was chosen as a pilot project because it already has a head start on post-storm planning in terms of the residents' consciousness of storm danger, their progressive environmental commission (an advisory group which reports to the municipal governing body), and the dune areas which had already been protected. The hope was that a successful plan in Avalon would spur other towns to undertake similar planning action.

A host of alternative structural and nonstructural techniques are available to planners, many of which have been described in the recent literature (American Society of Civil Engineers 1980 and 1983). There exists a wealth of information (see bibliography below) on strategies and tactics for post-storm planning, hazard reduction strategies, evaluation of procedures, conflict management, and intergovernmental coordination. From the literature and our field investigations the authors chose the most appropriate alternatives and tailored them to fit the town's needs.

A. Short-Term Hazard Reduction Strategies

Short-term hazard reduction methods have a short duration of usefulness or implementation and are often stopgap measures to reduce expected storm damage while long-term measures are enacted. Some strategies, such as dune building, can be started as short-term activities, but can become important long-range shields against storms.

1. High Water Level Problems
The housing inspector must continue to enforce Avalon's building code requirement that new construction in Avalon meet the FEMA (Federal Emergency Management Agency) base flood elevation standard.
2. Wind Damage Problems
Incorporate FEMA Publication FIA-7 Design and Construction Manual for Residential Buildings in Coastal High Hazard Areas (1981) in the local building code as a minimum standard for structural integrity.
3. Wave Velocity Hazards
    - (a.) Promote dune growth in as wide a zone as possible at the 8th Street spit. Build them as high and as wide as nature will allow.
    - (b.) Continue a double dune line south of 56th Street to place as much complexity as possible of dune topography between the mild-storm tide line and the residences. Protect street ends from break through by zig-zag fencing and elevation equal to that of the dune line.
    - (c) 12th to 32nd Streets: Dunes will be hard to build in much of this area due to the narrowness of the beach and its potential for recession. Options include:

(i) Beach nourishment from the excess of the 8th Street spit. This excess sand could be pumped in a slurry pipeline and discharged onto this beach, or during fall and winter months, a pan scraper could be used to scoop up sand at 8th Street and haul it 20 blocks on the beach to lay out in front of the existing dune line. Sand from the 8th Street area should be taken as far as possible from the section near shore where dune building should occur (see Problem Area 1).

(ii) Build sandbag-cored artificial dunes which would then be vegetated (see Appendix A for cost estimates).

(iii) Move the dune system back onto Borough property in the area of the parking lot.

(iv) Higher cost structures, such as wood/stone seawalls, are an option for the section from 12th to 35th Streets. This option is not recommended since structures of this type cause additional problems at their terminus (example, Stone Harbor's south end) and breed a false sense of security similar to that along the inlet where structures are within 20 feet of the seawall. (See Appendix A for cost estimates.)

d. 8th to 12th Streets and 38th to 56th Streets: Preserve, protect, and nurture these natural defenses.

B. Long-Term Measures

1. Avalon's Master Plan and Zoning Ordinance

New Jersey is not, according to its state constitution, a "home rule" state, although many of its residents consider it such. Control over land-use decisions is retained by the state, not the municipality. The State Legislature, however, has granted wide-ranging powers to municipalities under the Municipal Land Use Law (N.J.S.A. 40:55D-1 et seq.). The passage of state planning and regulatory laws such as the Pinelands Act, the Wetlands Act, and the Coastal Area Facility Review Act (CAFRA), demonstrate that the Legislature will supersede home rule when necessary to protect resources of regional or state-wide significance. Nonetheless, the Borough has considerable power to control its destiny through its master plan and zoning ordinance.

It is suggested that the Borough's master plan and zoning ordinance be changed to protect several critical areas:

(a) It is the Division of Coastal Resources legal opinion that unless the Borough owns vacant property in the areas (b-f) discussed below, the Bourough cannot change any present zoning to public use without a public safety justification. It would be considered a taking of privately owned land to change the zoning unless the Borough bought it. If the Borough wants land for public use, it must acquire it. If the Borough wants to keep land undeveloped for legitimate public safety reasons, it can do this by zoning and zone the land for conservation.

(b) Rather than encouraging infill in back bay areas from 20th to 25th and 39th to 49th Streets, the master plan should carefully reevaluate the zoning of these sections which are presently zoned medium-density residential. Recent history has shown the back-bay developments are prone to severe flooding and water damage, and, after a major storm, the town will have to pay a high cost to clean up and rebuild roads, utilities, sidewalks, and lighting.

(c) Zoning for vacant land on the northeast corner of the intracoastal waterway (now zoned medium density) and between the Inlet and Dune Drive (now high-density residential or motel) should be reconsidered. Structures in this location will be badly damaged in the next major storm, more likely from water damage and sediment than from wave action.

(c) No permanent structures should be erected in any public use zone located on the back bay, inlet, or coastal section of Avalon, and the zoning ordinance should incorporate that change.

(d) Minimum setback lines from the edge of the present dunes should be changed from the present 10 feet to at least 25 feet. In reality setback lines must, in the long run, be flexible to conform to the movement of the dunes westward. The Environmental Commission should sponsor a study as soon as possible to determine dune migration rates on different parts of the island; the study should include both natural migration rates, such as occur in the middle of the island, and those modified by humans at the south end and in the nodal zone.

(e) A more controversial option would allow the town to use its zoning power under the current law to zone high hazard areas for conservation to protect the health, safety and welfare of its citizens and to change current residential zones to conservation zones based on the scientific findings of this study. If Avalon were to do this, then the structures which now exist in high-hazard areas would become "non-conforming uses" (residential buildings in a conservation district) and, after the next storm, could not be rebuilt if they were severely damaged (i.e. more than 50 percent destroyed).

The question is whether such action constitutes a "taking" without due compensation of private property by the municipal government. There is little case law to provide an answer, and none in New Jersey. In Rhode Island and Florida courts have upheld the towns' rights in just such instances, although New York State recently gave the town of Islip an adverse opinion.* Given the New Jersey Supreme Court's decisions over the past decade, it is probable that the Court would rule in the township's favor in a similar case. It was suggested to the Borough that Avalon seriously consider using its zoning power in selected high-hazard areas, such as the nodal zone, and that it undertake an economic feasibility study over the next year to determine the costs and benefits of this action contrasted to those which would ensue from no action.

2. Beach Watch Program

Avalon's Environmental Commission has done some extraordinary work building and preserving dunes. It is suggested that the Commission be charged with establishing a Citizen's Beach Watch Program, similar to Ocean City's, to monitor changes in the shape and size of the dunes and beaches on a monthly basis and immediately after a storm. The information which the Beach Watch groups could gather would be invaluable in helping the town determine future critical areas and in suggesting remedial action for endangered sites.

3. The Nodal Zone: 12th to 35th Streets

The present conditions of the municipal parking lot and lifeguard area between 25th and 35th Streets constitute not only a probable hazard to township land, but also to private property owners adjacent to it. Besides undertaking short-term structural and dune-building programs, Avalon needs to consider a plan for this section before the next major storm. This area represents a clear lane for storm surge wave attack which can cause unusually severe damage. While the parking lot is presently a convenience to its users, it is a threat to property owners, and its highest and best use would be for dune protection rather than income generation. The conversion of the seaward edge of the borough property in this site into dunes before the next storm could prove to be a preventative measure which would more than compensate for the loss of convenient parking.

*(Florida) Indiatlantic vs. McNulty, 400 Southern Second 1227; (Rhode Island) Annizelli vs. Town of South Kingston (no cit., decided Feb. 1981) and Milardo vs. Coastal Resources Management Council of R.I. (no cit., decided Sept. 1981); (New York) 394 N.Y. Suppl. 2nd 517, 439 Northeast 2nd 352 (Seidner vs. Town of Islip); see also 392 Atl. 2nd 582, 448 Atl. 2nd 124.

4. Land Acquisition

Land acquisition and long-term development restrictions are the crucial and most difficult problems in any long-term planning. The mix of local, county, and state efforts to acquire land and restrict development depends on state law, the distribution of various powers among different government levels, and their willingness to work together. The Borough should develop a priority list of sites to acquire, and seek State assistance (Green Acres) for funding.

a. The Municipal Level

It was suggested that in their year-long fiscal and financial feasibility study (see above, Long-Term Measures, section B (1)(e)) that Avalon consider funding alternatives for land acquisition. Funding could be tied to an option used successfully at Captiva Island, Florida called the Municipal Service Taxing Unit. Properties are assessed based on a formula which increases the value of a property in direct proportion to its proximity to the replenished beach, so that those who benefit most also pay more for those benefits (Olsen, 1981). Property which is to be acquired could be designated on the town's official map. Once on the map, the town would have one year to purchase properties during which time no development could occur. Extension of the one-year limit would be at the discretion of property owners involved (N.J.S.A. 40:55D-32 to 44).

b. The County Level

The county in New Jersey, compared to that in a western state, such as California, has little power to control land-use patterns. It can, however, through its official map, set priorities for easement and fee simple acquisition, and it has the option to establish an Improvement Authority (N.J.S.A. 40:37A et seq.) which has to power to raise money through bonding. To repay bonds, municipalities could lease back from the Authority the land the Authority bought, and the lease payments would be structured to pay off the bonds over a set number of years, after which the land would be part of the public domain. In addition, payments for Improvement Authority bonds are exempt from the New Jersey "cap" law which limits the amount of money a municipality can raise in increased taxes.

c. The State Level

The State has the power to fund large-scale projects through bonds, and a $50 million shore protection bond was passed on the general election ballot of November 1983. Further, the State has already given Avalon high priority for its beach development through the Shore Protection Master Plan (N.J.D.E.P., 1981). The Department of Environmental Protection's Division of Coastal Resources can provide technical assistance and can fund planning projects.

Summary

Over the next three years the authors hope that Avalon will be able to adopt the recommendations of this report. We must, in conclusion, stress that public involvement and intergovernmental coordination are necessary adjuncts to any successful project. Time and again planning projects have failed because of a poor understanding of the critical nature of public involvement and cooperation on various levels of government. This work must begin when planning begins, and governmental bodies must be aware of their options in terms of public involvement and the approaches which fit their goals (Glass, 1979; White, 1979). In the case of Avalon, the borough itself must implement the plan, so that without a public involvement program of local citizens, one cannot expect success in planning and implementation. Timing, good personnel, and mutual trust are critical components. Final judgment on the effectiveness of Avalon's post-storm plan rests on the success of a public involvement program and intergovernmental coordination.

An Epilogue
A Study of Avalon's Beach Dynamics

In order to gain a quantitative, first approximation of the magnitude of Avalon's beach changes, a year-long study of five beach profiles was undertaken by the senior author. Of these, four profiles were selected to include the nodal zone and its effects. The fifth was used to measure the changes in the spit which is building into Townsends Inlet.

Beach Profiles

The five beach profile stations were established November 24, 1981 and surveyed twice a month until November 10, 1982. Figure 12 summarizes the profile data into three sets of information for two of the profile locations. These data were grouped into the following seasonal comparisons: The winter period (11/24/81 to 4/7/82), the summer period (4/7/82 to 9/17/82), and the fall of 1982 including a storm on October 25, 1982. The annual change profiles were both taken respectively 11 and 16 days after significant northeast storms. The pattern of beach erosion is substantiated by the Littoral Environmental Observations (LEO) data in demonstrating a ten-block shift to the north of the divergent nodal zone in the last year or so.

Table I
Avalon Beach Profile Volume Envelope Changes*

Beach Profile Numbers:	17	23	28	35
Season				
Winter	- 76.9	+62.1	+31.1	+16.4
Summer	- 27.9	+14.8	+ 1.6	- 8.5
Fall	- 55.6	-58.6	+13.9	+29.1
Sum of seasons	-160.4	+15.6	+46.6	+37.0
Total**	-157.0	+16.4	+45.8	+34.3

* All measurements are in cubic yards.
**The total volume change was arrived at separately from a direct first profile to last profile comparison from 11/24/81 to 11/10/82.

Profile 17, located at the end of 17th Street, is the northernmost station; it is 2,500 feet south of the Townsends Inlet jetty at 8th Street. The volumetric changes in this profile's cross sectional area are shown in Table 1 and define this beach as an erosion zone (see Figure 12). The high water line, which is a scarp cut into the dunes, retreated 26 feet during the study year. Responding to this

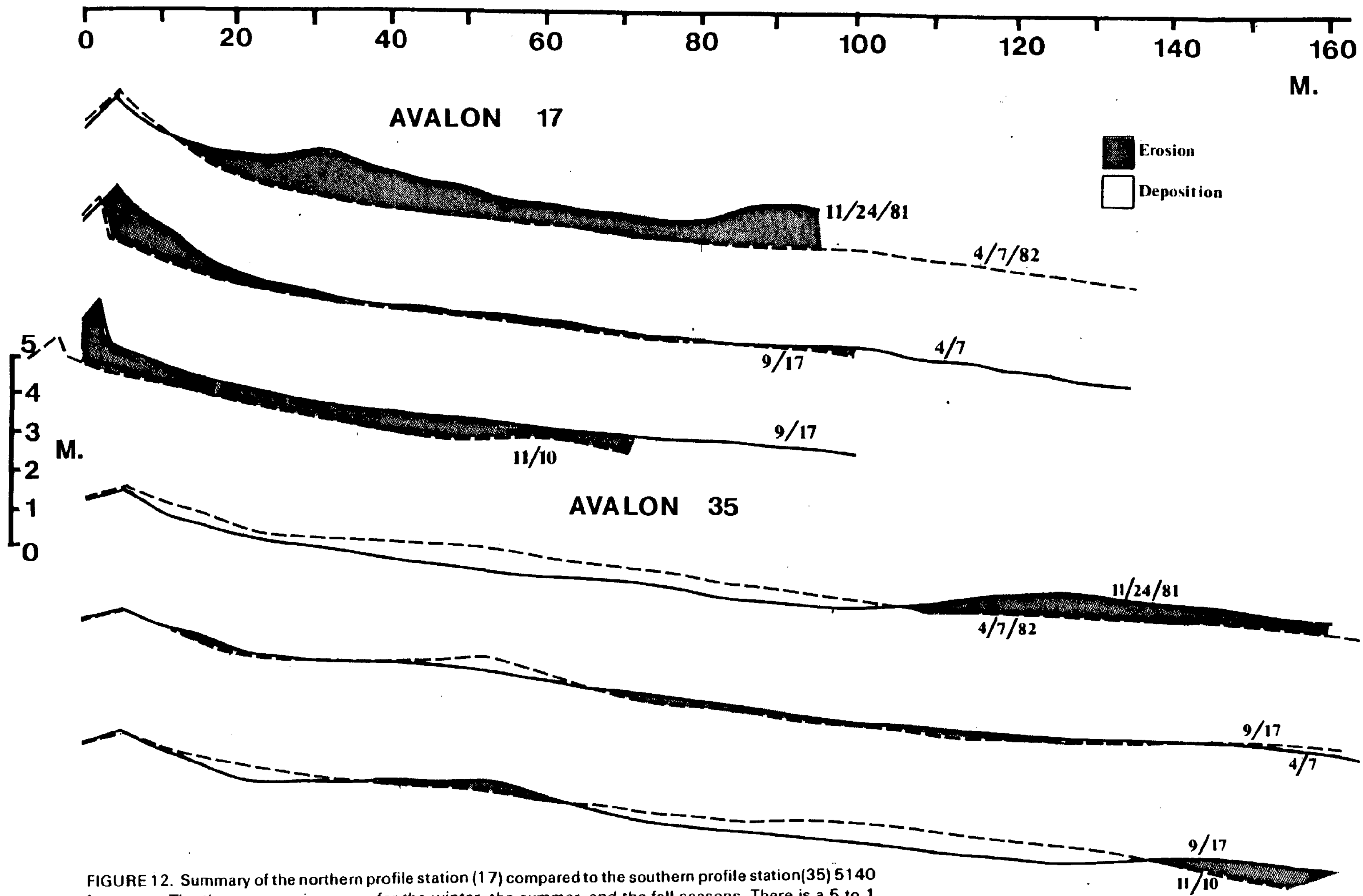

FIGURE 12. Summary of the northern profile station (17) compared to the southern profile station(35) 5140 feet away. The three comparisons are for the winter, the summer, and the fall seasons. There is a 5 to 1 vertical exaggeration.

dune scarping, the borough placed approximately 9.2 cubic yards of sand per yard of beach in this segment twice, once in November 1981 and again in January 1982.

Using the evidence gained from ground photographs taken to the north of profile 17, the approximate average sediment removal from this 2,500 foot section of Avalon's beach amounted to 120,000 cubic yards. This volume is conservative since the retreat of the dune line increases slightly to the north.

Profile 23 is 1,700 feet south of profile 17. Like the latter, this beach was nourished during November and January by the borough with about 9.18 cubic yards of sand per yard of beach. In all cases this sand was dumped from trucks in a staggered double row of piles in front of the dune scarp and left for the waves and winds to distribute.

The winter and summer gains of 1981-82 were almost eliminated by the huge losses during the fall of 1982. This profile's losses are probably due to the actual dune line retreat from 19th Street north to the jetty. An averaging of the total volume changes for profiles 17 and 23 produces a volume loss for the six-block interval of 36,000 cubic yards.

Profile 28 is 1,440 feet south of profile 23. It gained during the winter of 1981-82. The dunes were also artificially widened and raised. The summer 1982 gain continued at an increased rate during the fall as sand moved south. A volume of 13,600 cubic yards was deposited in the interval between profiles 23 and 28.

Profile 35 is 3,000 feet south of profile 28 and is the southernmost of the study transects (Figure 12). The beach volume of this profile gained sediment during the winter of 1981-82, lost some in the summer of 1982, and received accelerated sediment accumulation during the fall as did profile 28. The net volume gain for the interval between profiles 28 and 35 was 24,000 cubic yards.

During the study year, the northern 4,200 feet of Avalon's beach between 8th and 23rd lost 157,000 cubic yards of which at least 38,000 cubic yards moved to the south, aiding the growth of beaches south of 23rd Street. The remainder, 118,000 cubic yards, was added to the rapidly growing sand spit north of the 8th Street jetty.

Beach profile data show a seaward growth of 623 feet during the study year from a midpoint on the 8th Street deposit. This accumulation of sand has been solely derived from northerly drift washing over and around the 8th Street jetty. The deposit did not exist in 1978. On January 30, 1980 the stake reference position was still subtidal (a small spillover of sand had occurred). The first profile, run November 24, 1981, extended 230 feet from the seawall to the low tide mark. There was a 131-foot wide intertidal ridge seaward of the low tide mark. The last profile at this station was run June 2, 1982 and extended 1,017 feet to the low tide mark from the bulkhead. An estimate of the volume added to this spit during the six months time is 640 cubic yards per yard of beach.

Potential Damage From Future Storms

As a result of the information provided by these continuing beach profile data, an up-to-date assessment of potential damages to Avalon's coast can be made. Assuming a repeat of the March 1962 northeast storm conditions, the elevated water level and storm waves will probably cause the following damages (Figure 13).

1. Storm wave overtopping damage to inlet front homes. The width of the spit in front of the inlet seawall at the time of the next storm can mitigate potential damage. Should southerly migration of the main inlet channel remove all of the sand as it returns to a 1969-1978 configuration (Figure 6), this area could be severely damaged immediately landward of the seawall.

2. Current erosion zone from 8th to 15th Streets. A severe northeast storm will destroy the three homes just landward of the bulkhead at 9th, 10th and 11th Streets. The low-tide swash presently runs up against the rock toe of the bulkhead, and storm overtopping is a virtual certainty.

3. 20th to 32nd Streets. Storm overwash and dune breaching is most likely in this section of the borough. A narrow, low dune would not withstand severe attack. Overwash similar to what occurred in 1962 would engulf homes and streets west of the parking lots on Avalon Ave. Structural damage could be severe to the boardwalk, which, if it collapses, would endanger homes landward of it. 32nd Street is a particularly dangerous pathway for overwash, since it is the beach patrol access road and is at street level.

4. Areas south of 32nd Street. Wave and overwash damage to Avalon south of 32nd Street will be limited because of the wide setback of structures protected by the dunes and managed carefully since 1962. A few street end breaches could occur in the south end from 70th to 80th Streets, but not as severely as the total overwash which occurred in 1962.

5. Flooding of low-lying buildings. Severe flooding will, unfortunately, recur as in 1962 because most of the homes built prior to FEMA base-flood elevation requirements still exist. Photographs of 1962 flood levels for Avalon's homes built on one or two courses of cinder block above ground level showed three to six inches below the first-floor window sills. In addition, homes on the exposed bay front and on the main access road will again suffer bay-fetch wave damage when the salt marsh is covered with five to seven feet of storm surge waters.

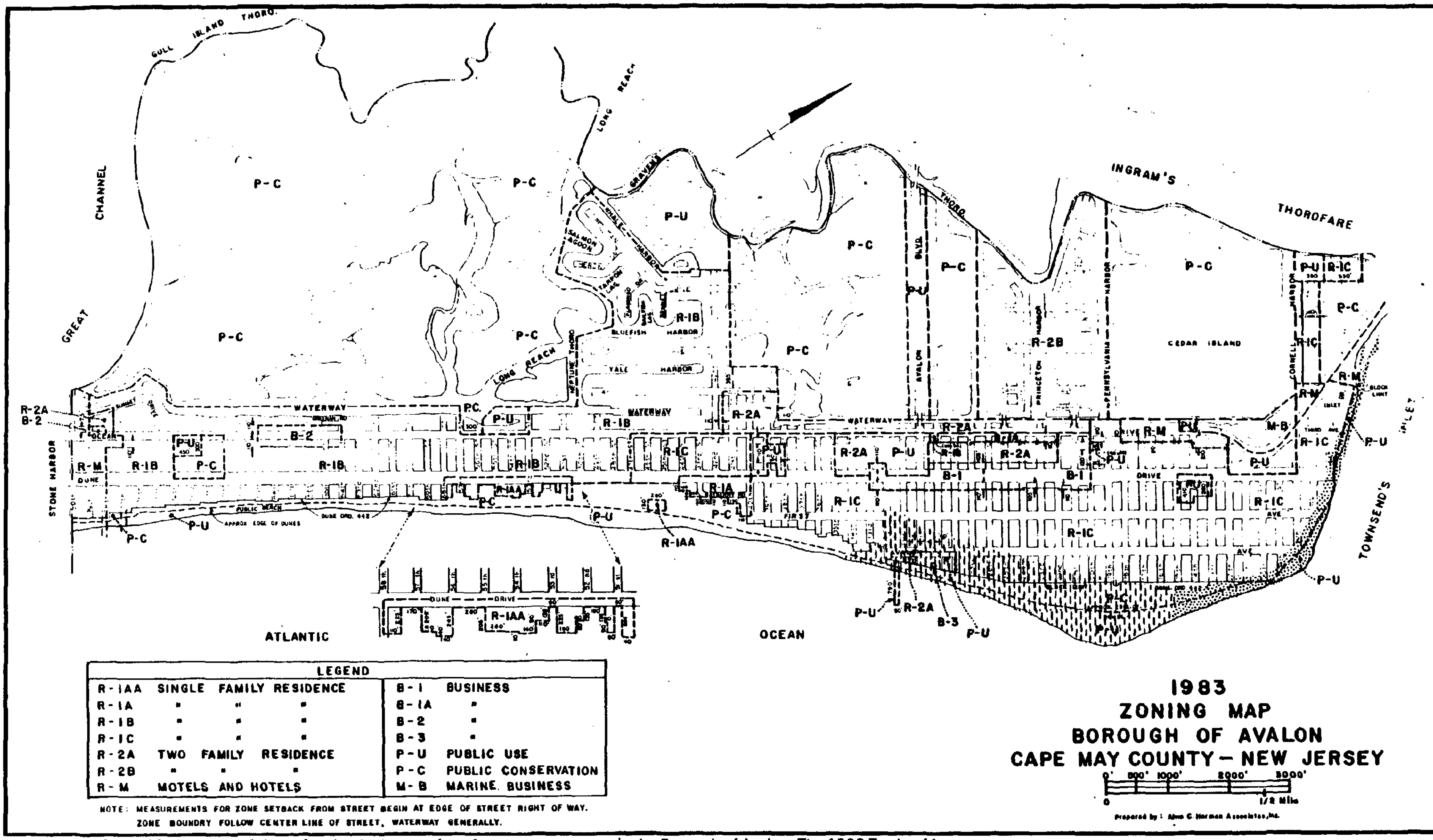

FIGURE 13. Location of sites of probable damage from future severe storms in the Borough of Avalon. The 1983 Zoning Map is used as a base map to show both wave uprush damage sites (dots) and positions of likely storm overwash (dashed lines). Regions of storm flooding damage while concentrated along the bay side of the borough, will also depend on individual home site elevation on its foundation.

Littoral Environmental Observations (LEO)

LEO measurements were made on 166 of a possible 334 days at three sites along Avalon. The information gathered was that specified on the Coastal Engineering Research Center's Littoral Environmental Observations form (Schneider, 1981). Daily LEO measurements began December 9, 1981.

Almost at once it became apparent that the longshore current direction and magnitude at 17th and 35th Streets were not defining the divergent nodal zone as originally indicated on previous aerial photographs. Originally the northernmost station was 17th Street. However, on March 3, 1982 another station was begun at 12th Street, five blocks to the north and only four blocks from the 8th Street jetty at the island's northeastern tip.

The summary of the LEO data (Table II and Figure 1) demonstrates the pronounced tendency for the littoral current to move north at 12th Street (65% of the time), have a nearly even split at 17th Street, and to move south 57% of the time at 35th Street. The mean value of the northerly current velocity decreases at the southern locations. The extreme value for longshore drift was 418 feet per minute or 7.0 feet per second northerly, measured April 3, 1982 with similar values at the other two stations. On this day the wind was 40 miles per hour out of the south, the waves were from the south-southeast with a 6.5 second period and 4.0 feet high at breaking crest.

Table II
Longshore Drift Summary

	North	Zero	South	Total
12th Street				
3/2/82 to 11/8/82	79*	3*	39*	121*
Direction Percentage	65%	3%	32%	
Mean Velocity	88 ft./min.	--	76 ft./min.	
17th Street				
12/9/81 to 11/8/82	90*	2*	74*	166*
Direction Percentage	54%	1%	45%	
Mean Velocity	69 ft./min.	--	72 ft./min/.	
35th Street				
12/9/81 to 11/8/82	70*	2*	94*	166*
Direction Percentage	42%	1%	57%	
Mean Velocity	61 ft./min.	--	61 ft./min.	

* = number of measurements

As the fall progressed, the magnitude, but not the frequency of southerly longshore currents increased dramatically at all three stations. This correlated with the increased velocity of northeast winds as the storm frequency increased.

The pattern of drift currents changed during the year at all three stations. Starting in the month of August, the values of current velocity departed from their previous history of low values in one direction persisting for 3 to 7 days to a sequence of readings of high magnitude in opposite directions every other day or so. This measured wave activity expressed itself as increased beach erosion at or near the littoral current nodal zone on Avalon.

Conclusions to the Year Long Study

The twelve-month study of Avalon's beaches indicated the importance of knowing detailed information on the distribution of littoral current energy. These date are necessary to illuminate reasons behind otherwise rather sudden changes in beach profile behavior. The shift in the divergent nodal zone north (previously centered from about 25th Street and now north to about 14th Street) has important consequences to property owners from 17th Street north to 8th Street. During the study interval, the loss of shore property has been confined to undeveloped city dunes. However, the retreat of the high-water line at the end of 10th Street has already exceeded 130 feet from June of 1981 to February of 1983.

The community's foresight in prohibiting housing in this dune area has had the immediate benefit of avoiding a costly battle with the sea on the seaward side of the bulkhead. Erosion of the beachfront from 8th south to 15th Street is presently being retarded by a rock-toed wooden bulkhead built after the 1962 storm and long buried by dunes. In the long run, low cost sand nourishment from the inlet spit can satisfy the erosional demand and protect developed property. The borough is currently taking these steps just as they acted to stem the erosion in 1981 at 28th to 23rd Streets.

Appendix A
Relative Costs for Structural and Non-Structural Options

1. Sandbag-Cored Dunes

Nylon bags are made in sizes to hold from one to four cubic yards of sand each. The cost of excavation runs about \$2.50 per cubic yard. To withstand any long-term severe weather or back-to-back storms, the sandbag core of the dune must be set 6 to 8 feet below the surface and then be covered with loose sand to improve its aesthetics and reduce vandalism. The bags could cost between \$650 and \$900 per linear yard emplaced (based on extrapolation of costs in 1979 at Sandy Hook Gateway National Recreation Area).

2. Creosoted Wooden Sheet Pile Bulkhead

This bulkhead would be 20 feet tall and be set 15 feet onto the sand surface. Pilings are driven on alternate sides on four-foot centers with double 2" by 8" tongue and groove sheeting tied together with appropriate horizontal timbers and support members. The cost of this structure ranges from \$500 to \$900 per linear yard of bulkhead emplaced.

3. Rock Seawalls

Costs for rock seawalls, the most effective and most expensive structural solution, are the most difficult to estimate. Generally the rock is used in three sizes: mat stone (5-50 lb. ea.) for the foundation; core stone (100-200 lb. ea.) for the central mass of the wall; and the armor stone (5-8 tons ea.) for the surface protection of the structure. It, too, must be placed 12-18 feet below the sand surface to prevent undermining. A modest size structure has a trapazoidal cross section 70 feet wide at its base, 30 feet total height, and 10 feet wide at its top. It would have a cross sectional area of 1,200 square feet. Rock weighs about 200 pounds per cubic foot, and the structure is about 65% rock and 35% air space. Therefore, the cross sectional volume of rock equals 1,200 X .65 X 200 - 156,000 pounds per linear foot or 75 tons per foot. The rock alone costs \$30 per ton delivered to the site. Not counting any of the costs for emplacement, a seawall of the above dimensions would cost \$2,500 per foot or \$7,500 per yard for the rocks alone. The rocks represent about one-third of the total cost per yard of structure.

4. Man-Made Concrete Protective Objects

Recently sea-structure designers have used three different concrete shapes to fabricate wave barriers:

a. Dolos (plural of dolosse) are concrete units consisting of a pair of mutually perpendicular horizontal bars joined at their respective centers by a vertical section, most recently used to rehabilitate the Manasquan Inlet jetties.

b. The tetra-pod has four segments extending outward from its center toward opposite corners of a cube.

c. The stay-pod has elements extending to the corners of a triangular-based pyramid.

All these shapes can be made in various sizes or weights and offer a lower transportation cost over rocks, better wave energy absorption, and better structural integrity because the concrete shapes interlock. Since they are new, no reliable cost estimate can be given even for the Manasquan project since research costs, dolos mold costs and dolos lifting and placement gear development costs are factored into the project engineering costs. Each 40-ton dolosse costs about $1,000.

5. Well-Tile Revetment

The well-tile revetment, a low cost concrete structure used on Chesapeake Bay shores has not, to the authors' knowledge, been used on the open ocean coast. Concrete well tiles are three-inch thick reinforced cement rings, three feet in diameter and two feet high. These are stacked side by side in a trench four or five high, filled with coarse stone, and protected in front by a sloping stone revetment toe. This could also be buried in sand and vegetated.

All the above information is designed to give an approximate comparison of different levels of protection. The data are drawn from verbal communication with personnel at the Philadelphia District Corps of Engineers and from cost data on recent coastal projects.

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