CHAPTER 352

# IMPACTS OF INLET STRUCTURES ON CHANNEL LOCATION

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**Abstract**

Barnegat Inlet, New Jersey, has undergone a variety of structural changes in an attempt to provide a navigable channel from bay to ocean. These structures have included shoreline revetments, arrowhead jetties with their crest elevation at mean tide level, a sand dike to better align interior channel flow, a raised impermeable jetty, and now parallel jetties. Each of these structures has had significant influence on inlet hydraulics and sedimentation, which in turn has impacted channel location.

## Introduction and Historical Overview

Barnegat Inlet, New Jersey (Figure 1), is an inlet worth detailed examination as it is rich in history of man's struggle to control nature's scheme. A paper written in the 1970's about the inlet entitled "Barnegat Inlet, Nature Prevails" (Caccese and Spies, 1977) expressed the frustration an inlet can cause coastal engineers and scientists. The natural inlet migrated to the south 1600 m from 1839 to 1932. An inlet shoulder revetment and groin to protect Barnegat lighthouse anchored the south side of the inlet. A pair of "arrowhead" jetties was constructed in the late 1930's, followed in 1943 by a sand dike in the adjacent bay that caused a redirection of flow. Important in understanding the response of the inlet channel in this time frame were the jetties' low crest elevations at mean tide level. These jetties were functioning as "weir jetties," which allowed tidal flow, wave-generated currents, and sand to be transported over these inlet structures. This resulted in creation of sand spits at the inlet gorge and became a new control for channel location, withstanding many dredging attempts to control channel position. During a twenty year period the sinuous channel was completely inverted as this new regime interacted with structural controls.

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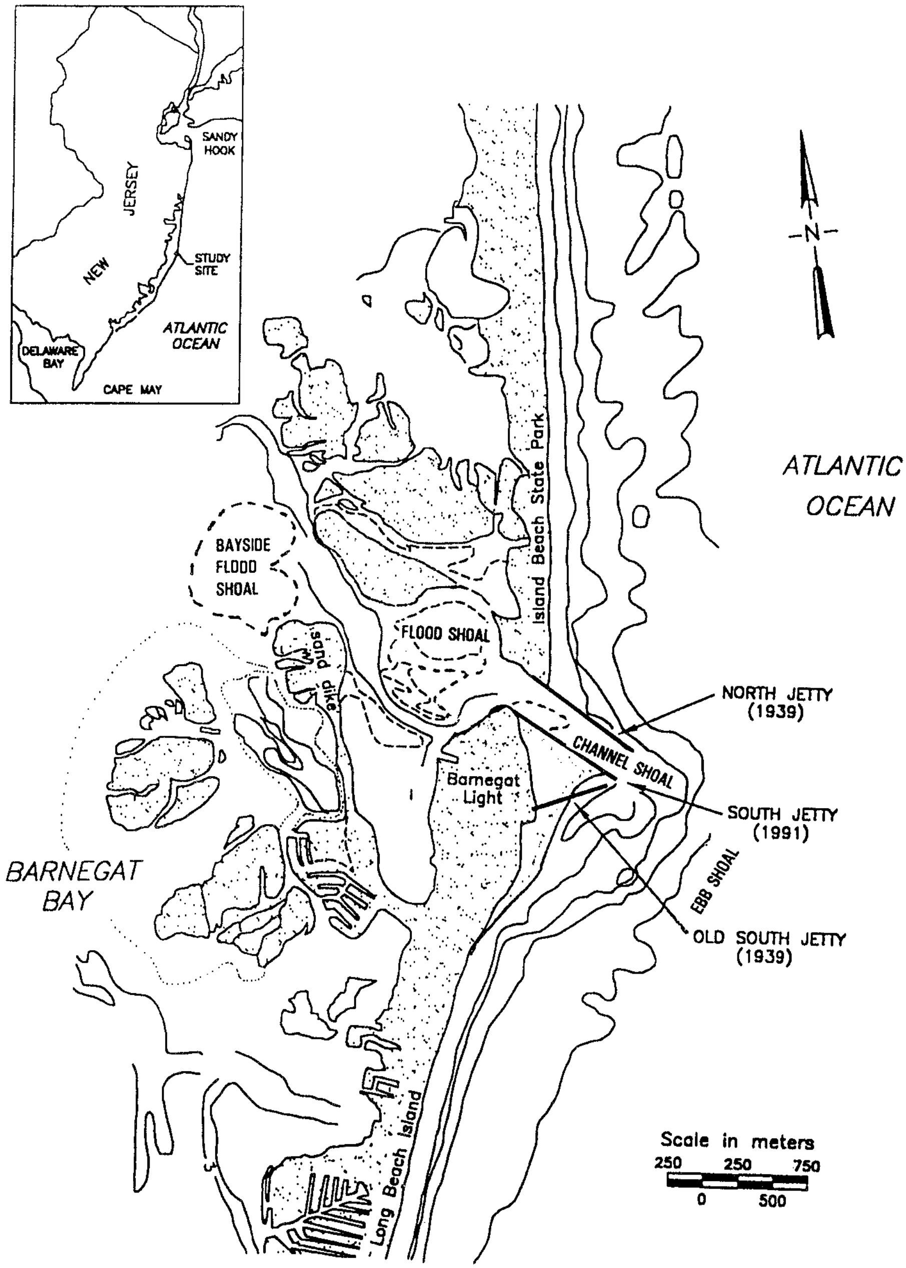


Figure 1. Barnegat Inlet, New Jersey location map and project elements.

In the early 1970's, a sequence of steps to improve channel dynamics was developed from a physical model study (Sager and Hollyfield, 1974) which included raising the north jetty and making it impermeable plus the addition of a new south jetty paralleling the existing north jetty. In 1972-74, the north jetty was raised 1.8 m. Sand was diverted offshore along the impermeable jetty and growth of the ebb shoal resulted. The channels adjusted to a reduction of sediment from the north beach.

A significant amount of dredging was done in the late 1970's to maintain the channel at the inlet throat. However, the increase in ebb shoal volume created additional maintenance dredging in that location. Another phase suggested by the model study was implemented beginning in 1989, with the construction of a new south jetty located within the arrowhead system. This jetty paralleled the original north jetty and served as a replacement to the original low south jetty. Upon completion of the project, a monitoring study was initiated to understand the response of the navigation channel to the most recent inlet structures, but, in doing so, an understanding of the historic interaction of the channel and structures was also necessary.

## Physical Factors

The inlet separates Island Beach, a spit to the north, from Long Beach Island, a barrier island to the south. These barriers are characterized by medium to fine sands. Within the inlet region, medium to fine sands (0.25-0.5 mm) are on the ebb and flood shoals and coarser sands (0.50-1.0 mm) are in the deeper channel areas (Stauble and Cialone, 1995). The inlet provides access for commercial fisherman, day fishing excursion boats and small craft. The inlet's design channel is 91.5 m wide by 3 m deep (relative to mean low water), extending through the ebb shoal. The mean ocean tide range is 1.28 m and mean wave height is 1.20 m. Littoral transport estimates at the inlet are 840,000 cubic meters gross transport, with a net of 110,000 cubic meters to the south. These estimates are based on wave heights hindcasted at the 20-m contour near the inlet.

## Effect of Inlet Hydraulics on Channel Dynamics

Throughout the recent history of Barnegat Inlet there has been the interaction of structures, changing sedimentation patterns and inlet hydrodynamics. The inlet system now contains four consecutive, fully-developed shoal features (compared to typical one ebb/one flood shoal), with an ebb shoal seaward of the jetties, a shoal in the intra-jetty region (particularly evident for the arrowhead configuration), a large flood shoal contained by the sand dike and finally a bayside flood tidal delta where flow exits into Barnegat Bay (Figure 1). Development of these shoals initially created a higher friction environment, which with the initial structural configuration, created increased sedimentation and a gradual decrease in tidal prism. Raising the north jetty reduced sediment input from the north beach, and coupled with dredging, and the construction of the new south jetty, some flow efficiency was regained as evidenced by increased tidal prism.

Important in relating the channel response to inlet structures is an understanding of the inlet's hydrodynamics. This inlet has maximum flood currents near high water elevations and maximum ebb currents near low water and is typical for an inlet lagoon which has very large surface area relative to channel cross-sectional area. Essentially the lagoon level fluctuates very little and the ocean tide range oscillates about that level, resulting in maximum head differences across the inlet near high and low waters. This phasing of flow relative to structure crest elevation and flow over shallow shoal areas is important to channel location. Figure 2 shows flow patterns for maximum ebb and flood flows as determined for 1968 conditions from a physical model study (Sager and Hollyfield, 1974). For the mean tide level elevation jetties, maximum flood currents (strongest near high water) had a great potential for introducing sediment to the inlet system and thus the development of a large flood shoal complex. Low water ebb currents are more channelized. This permits shoals to be more effective ebb shields; that is, ebb flow will tend to be deflected around the shoal area if the shoal elevation is higher than low water. Also, maximum ebb flows at low water elevation can lead to incising of channels.

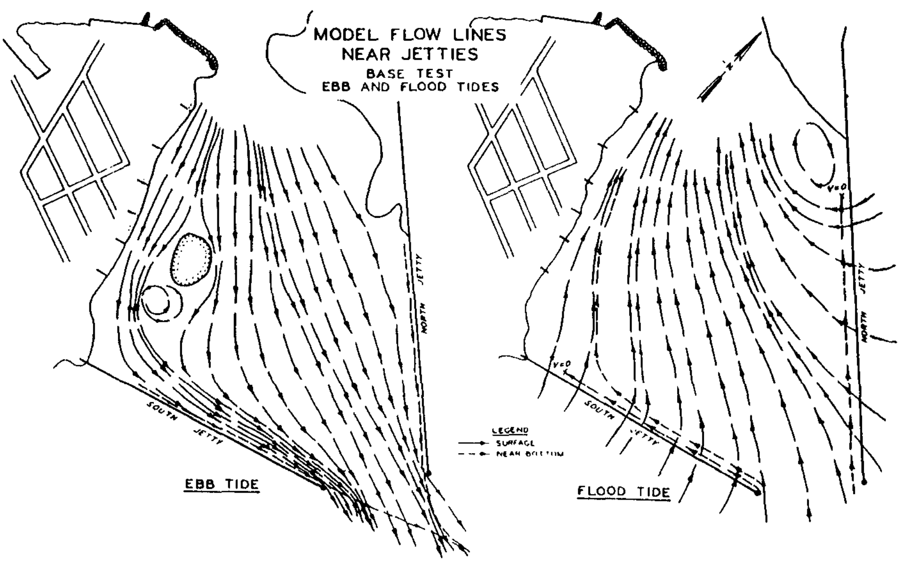


Figure 2. Model study flowlines, ebb and flood currents.(Sager and Hollyfield, 1974)

## Historic Bathymetric Analysis

A review of historical bathymetry was performed to provide a basis for interpreting recent bathymetric changes at Barnegat Inlet and in providing guidance to anticipate future changes. Some historical information was derived from US Army Engineer District, Philadelphia, (1981) and Fields and Ashley (1987).

*Pre-jetties* In 1937 (Figure 3a) the pre-jetty inlet bathymetry shows that the interior channel swept south then turned east to northeast to exit the inlet, then turned southeast, on the ebb shoal, in response to predominant waves from the northeast. The 1937 interior channel was more than 460 m southeast of its current position (1996). The channel probably owed its large curvature to the infilling of the natural inlet on its north side as the inlet and channel both migrated south. The predominant portion of the tidal prism exited the bay from the north, channelizing around the large flood shoals due to a strong ebb shield factor resulting from this inlet's hydraulic phasing.

*Arrowhead Jetties* In 1939 arrowhead jetties were constructed and a channel, about parallel to the north jetty, was dredged into the bay in an attempt to provide a more direct route to the bay. Figure 3b shows the new interior channel in 1941. Also note the deflection of the ocean channel resulting from having the south jetty placed directly in its path.

*Sand Dike* By 1943 (Figure 3c), the sand dike was constructed in order to cut off the strong ebb flow from the dominant interior channel which was causing excessive scour on the inside shoulder of the inlet behind the lighthouse. It was anticipated that flow would be diverted to the straight interior channel, providing a deeper direct channel connecting ocean and bay. In addition, groins were constructed along the ocean shoreline inside the south jetty to mitigate shoreline erosion.

The 1946 bathymetry (Figure 4a) indicated a slight deflection of the navigation channel at the inlet's intersection with the shoreline as sediment moved over the low jetties at this location. On the south side of this region there was a shoal extending seaward from the lighthouse area, probably derived from sediment moving toward the inlet gorge along the shoreline inside the south jetty, then deflecting seaward on ebb. A buildup of sand at the shoreline is noted just inside the south jetty indicating an influx from the south beaches.

By 1953 (Figure 4b) the main navigation channel had shifted slightly south and rotated somewhat to the southeast. Sediment was moving over the low north jetty into the inlet gorge region. The interior region between the inlet gorge and the north tip of the sand dike contained flood shoals and three smaller channels. On the ocean side of the inlet, the navigation channel was close to the north jetty, as it had been for the previous ten years.

As of 1959 (Figure 4c) the navigation channel through the inlet gorge rotated away from the north jetty to the south and a scour area reappeared adjacent to the outer portion of the south jetty. The influx of sediment over the north jetty contributed to this rotation. Interesting to note was the shifting of the deepest area at the bayward end of the sand dike, which moved to the southeast side (compared with earlier conditions).

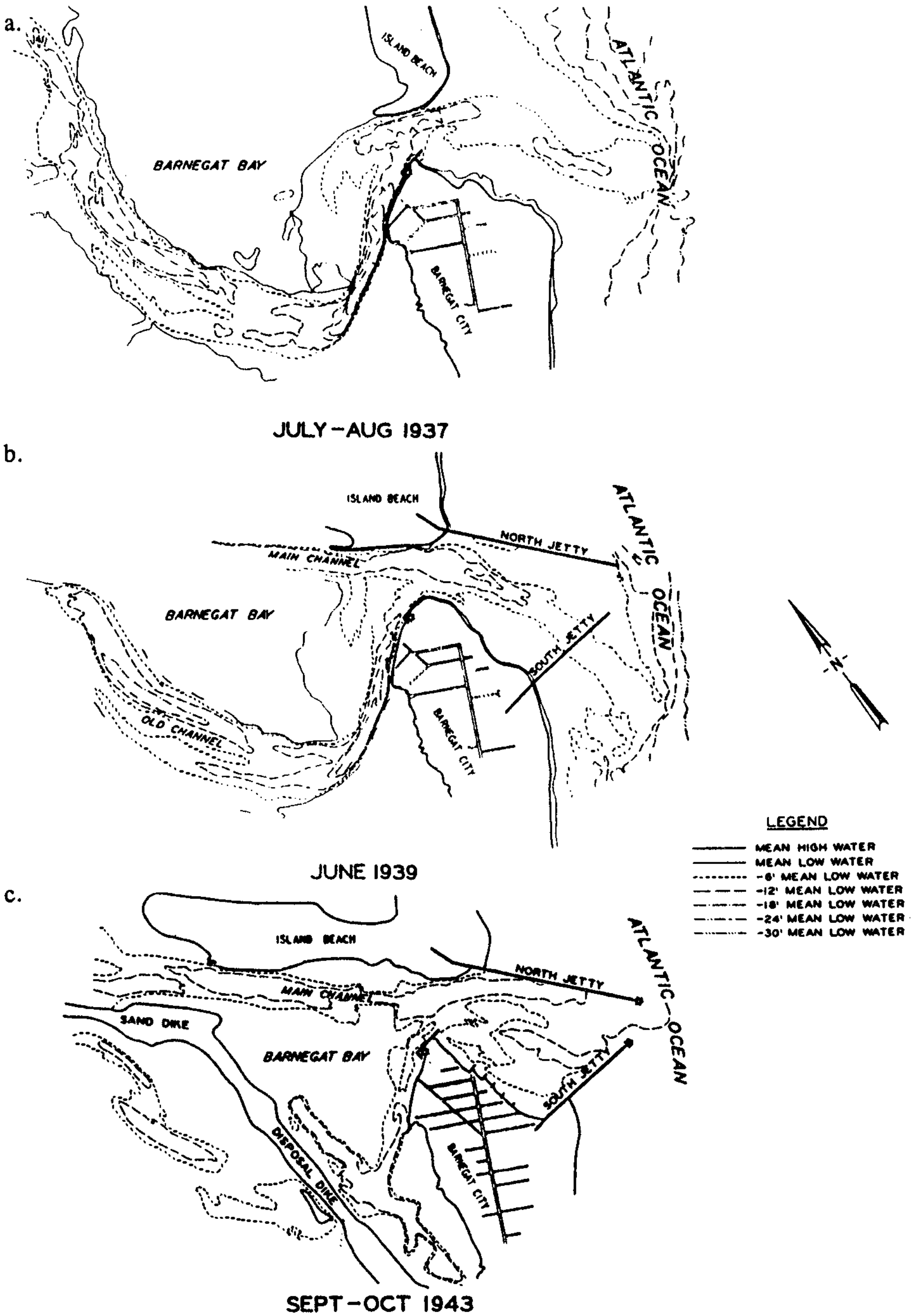


Figure 3. Barnegat Inlet bathymetry, July-August 1937, June 1939 and Sept-October 1943.

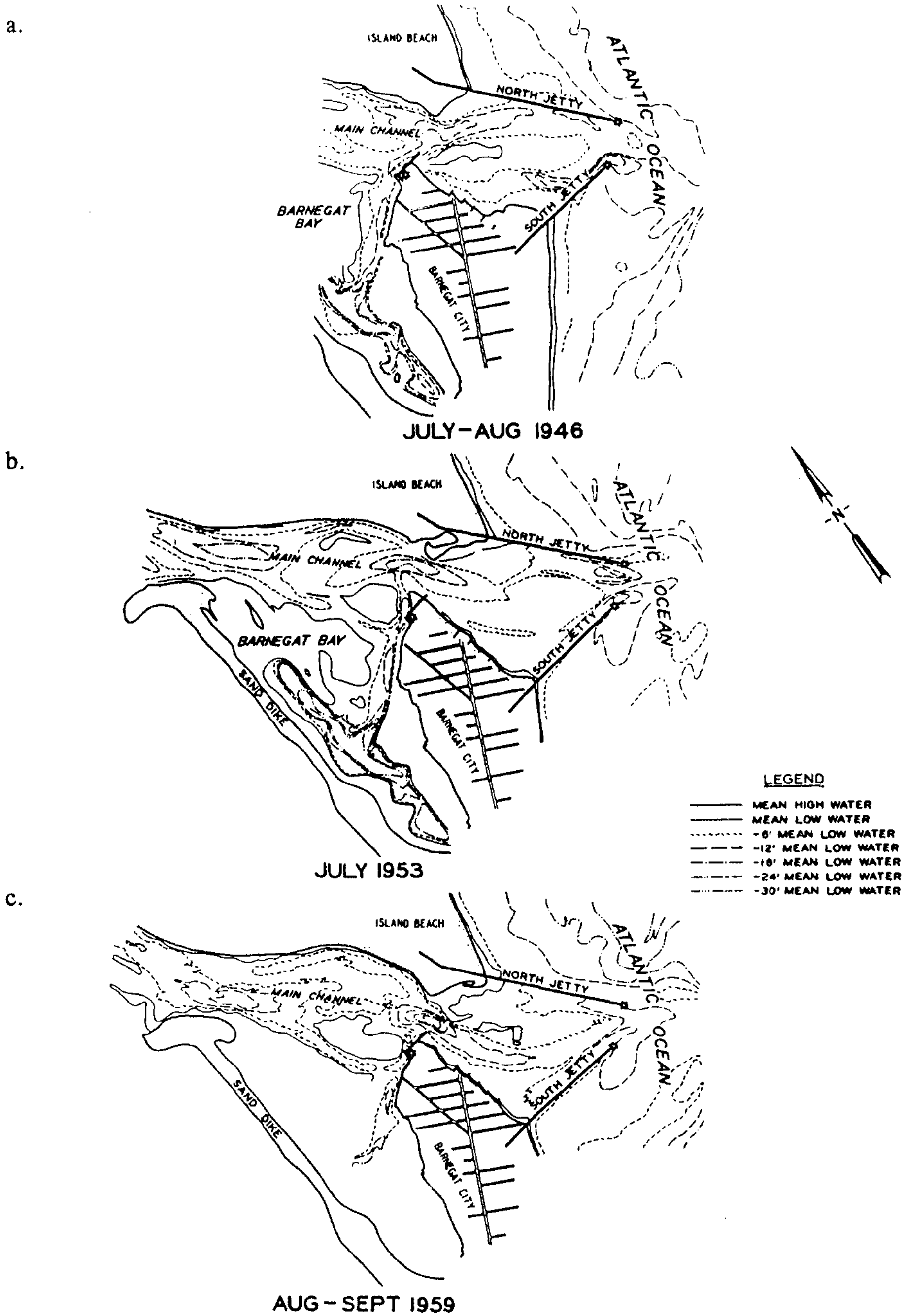


Figure 4. Barnegat Inlet bathymetry, July-August 1946, July 1953 and August-September 1959.

Nineteen-sixty-two (Figure 5a) showed a new part of the flood shoal developing from sediment stripped from a spit which extended further from the north beachline into the inlet gorge. The minimum width of the inlet was reduced considerably due to sediment movement over the north jetty. The seaward portion of the channel migrated against the south jetty.

By 1968 (Figure 5b), the flood shoal occupied the location of the original dredged interior navigation channel. The interior channel was still bifurcated, but the region south of the flood shoal was widening and becoming the main interior ebb channel. It was forming in a similar configuration as was seen for the pre-jetties condition, except not as far southeast due to the presence of the sand dike. Sediment movement over the north jetty almost closed off the inlet gorge. The region between the arrowhead jetties was shoaling considerably except for the channel which had migrated against the south jetty. This sinuous channel was eroding the ocean-facing shoreline inside the south jetty and creating toe erosion which endangered the integrity of the oceanward portion of the south jetty. The trend of flood shoal growth and interior channel shifting south continued until the north jetty was raised 1.8 m from its original mean tide level crest elevation in the 1972-74 period.

*Raised North Jetty* The 1975 bathymetry (Figure 5c) indicated a major reorientation of the navigation channel through the jetty region. Dredging at the inlet gorge combined with cutting off sediment input by raising the north jetty permitted a straighter channel which was more in alignment with and closer to the north jetty. This channel orientation is reinforced by a concept presented by Keislich (1981) where a channel at a single-jettied inlet migrates toward the structure independent of whether or not the jetty structure is situated on the side of stronger longshore sediment drift. The Barnegat system probably can be considered a single jetty system in this respect due to the free flow of sediment and currents over the mean tide level south jetty, which helps move the channel toward the "single" north jetty.

Raising the north jetty caused a significant change in sediment pathways. The ebb shoal began to increase in magnitude (Figure 6a). This most likely can be attributed to the movement of sediment along the outside of the north jetty which previously had passed over the landward end of the low north jetty and contributed to flood shoal building and the movement of the inlet gorge towards the south. The same trend of channel alignment seen in the 1970's continued through the 1980's (Figure 6b). The interior navigation channel moved more towards its pre-project (1930's) location and the channel between the jetties was concentrated on the north side adjacent to the raised north jetty. This configuration was maintained until the construction of a new south jetty which occurred between late 1987 and 1991.

## Hydraulic Response to New South Jetty

In order to build the new south jetty (Figure 7) from the revetted region on the south shoulder of the inlet beneath the lighthouse, shallow shoals were removed from

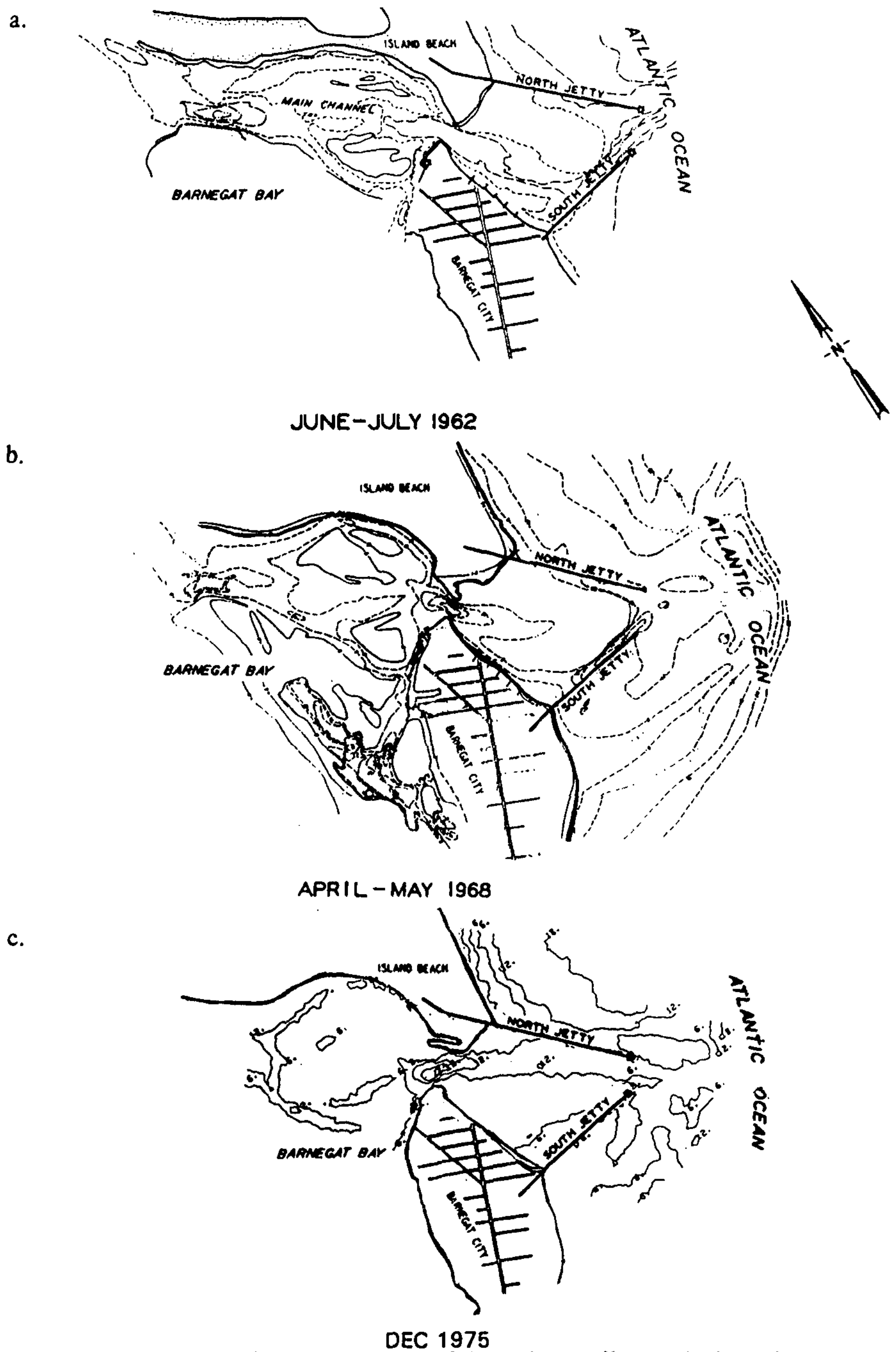


Figure 5. Barnegat Inlet bathymetry, June-July 1962, April-May 1968 and December 1975.

a.

b.

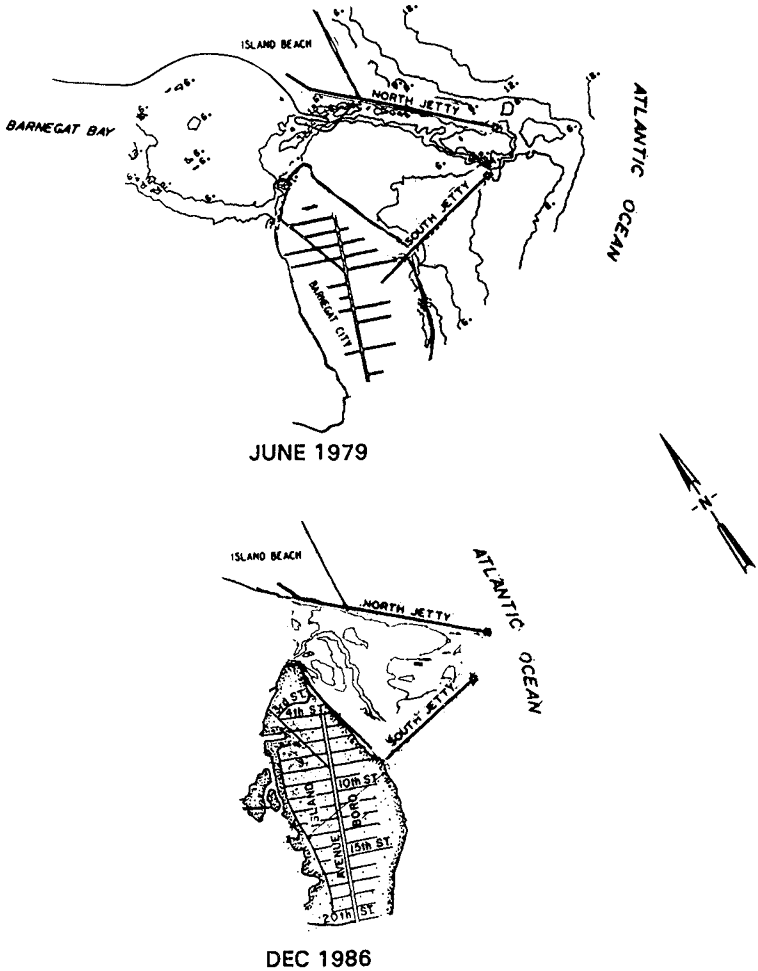


Figure 6. Barnegat Inlet bathymetry, June 1979 and December 1986.

this region. The inlet system became more efficient hydraulically due to an increase in minimum cross-sectional area which resulted from this shoal removal. This follows from O'Brien's (1969) relation between minimum inlet area, $A_C$ ($m^2$) and tidal prism, P ($m^3$) at dual jettied systems: $A_C = 7.489 \times 10^{-4} P^{0.86}$. With minimal sediment entering the inlet system the increase in prism has been maintained since completion of the new south jetty. Figure 8 shows the variation in prism for the duration of the project. After the construction of jetties (1941), the inlet initially had the same tidal prism as the natural inlet, but the addition of the inside sand dike (Figure 1) lengthened the inlet channel and the newly dredged interior navigation channel had a reduced channel area compared to the old sinuous one. Sediment influx reduced areas and thus prism. The new south jetty prevented the influx of sediments that had previously occurred for the low south jetty and so the new, larger, minimum area has been maintained.

a.


b.


Figure 7. Barnegat Inlet 1994 bathymetry and 1996 air photograph.

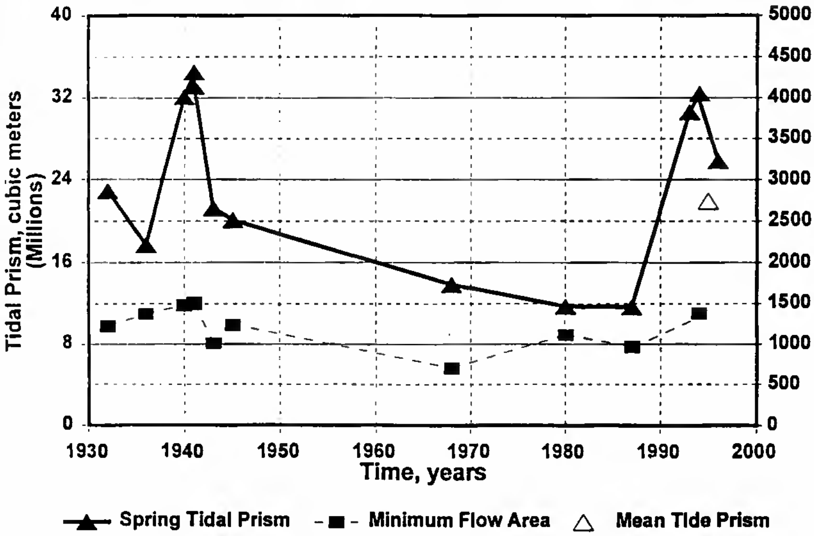


Figure 8. Historical measured tidal prism variation.

## Channel Response To New South Jetty

Analysis of the channel response to the most recent addition of the new 1250-m long south jetty reveals what appears to be an evolutionary change in channel depth in the region between the north jetty and new south jetty (Figure 9). The net sediment mass is translating bayward in the region of the parallel jetties. An important aspect of this is the flood dominance of currents on the south side of the intra-jetty region of the channel. Flood currents tend to enter the inlet region from the north jetty side (due to greater ebb shoal depth on the north and shallower ebb shoal depth on the south side, Figure 7a) and sweep toward the south jetty. Also the outer 305 m of the north jetty remains at the mean tide level elevation, permitting maximum flood currents to flow over this low section into the channel perpendicular to flow coming through the oceanward jetty tips. This also helps guide flood currents to the south side of the intra-jetty region. The occurrence of a shoal region between stations 200 and 400 is essentially a nodal point between ebb and flood flow dominance. Flood flow pushes sediment through the channel mostly on the south side, (based on velocity distribution measurements taken in 1994-96 by the authors). Ebb currents from the curved interior channel shear this shoal and sediment moves along the north side of the shoal (where ebb flows are concentrated) towards the ocean. Dredging of the channel shoal and, evidently, a net oceanward sediment circulation out of the intra-jetty region have caused a progressively deeper channel.

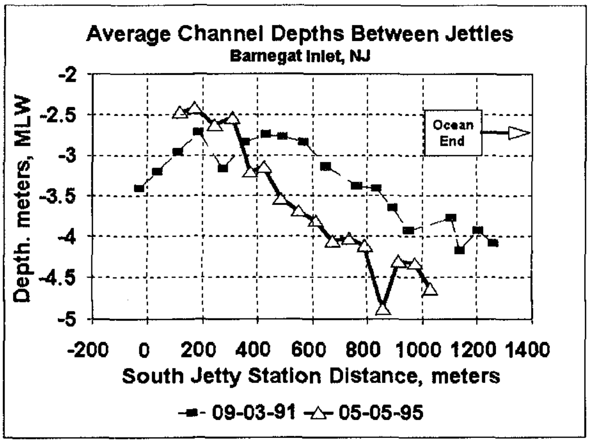


Figure 9. Average channel depths between jetties, 1991 and 1995.

The interior navigation channel is moving southward, as the flood shoal flattens out since sediment is not reaching it from the north or south adjacent shorelines or the ebb shoal. This channel has migrated south about 90 m in the last three years (1994-96). Flood currents plus ocean waves traveling with the currents move sediment towards the bayside of the flood shoal. On ebb, the current shears off sediments from the back edge of the flood shoal and moves it counter-clockwise along the edge of the shoal. Sediment settles out on the south edge of the flood shoal as strong ebb currents move away from the shoal to the outside of the curved channel. This spreading out of sediment may decrease the effectiveness of the flood shoal as an ebb shield and gradually permit more ebb flow over the shoal. Some incised cutting of the center of the flood shoal can be noted in Figure 7b.

## Lessons Learned

The concept of arrowhead jetties to provide concentration of ebb flows at the oceanward terminus (in order to cut through the ebb shoal) and for wave attenuation due to diffraction as waves propagated into the expansion area, were positive design attributes. The hydraulics of such a system with regard to the velocity phasing at Barnegat Inlet (maximum flood currents near high water and max ebb near low water) combined with mean tide level jetties would permit broad, less concentrated flood currents to approach the inlet, presumably having less potential to carry sediments into the inlet. Strong ebb flow concentration in the navigation channel would flush sediments out of the channel as water surface elevation dropped. However, the sediment influx over these low jetties overshadowed the positive elements of the plan. Apparently most of the sediment movement was at the shoreline intersection with the jetties.

It was learned from the historical analysis of bathymetries that the interior navigation channel moved back to its pre-structure alignment, probably due to the influx of sand coming over the low north jetty, which enlarged the flood shoal significantly and helped deflect ebb currents coming from the bay towards the southeast. There was a similar situation for the natural inlet, which had been migrating south, thus infilling on the north side and accumulating sediments to help deflect ebb currents to the south.

Raising of the north jetty crest elevation cut off direct sediment influx from the north but sediments from the south maintained the same minimum area at the inlet gorge. Channel migration to the now dominant north jetty, plus dredging, cut off input to the flood shoal and redirected beach sediments to the ebb shoal.

The effects of sediment input into an inlet system in equilibrium usually is balanced by sediment moving out. At Barnegat Inlet, initially structural changes effectively lengthened the channel which led to increased friction, reduced currents, followed by sedimentation and reduction in tidal prism. The addition of a new higher south jetty paralleling the north jetty along with an increase of minimum channel area due to dredging and the prevention of sediments entering from the south into the inlet gorge permitted a larger tidal prism.

It took over 20 years (1941 to 1965) for the straight interior navigation channel to move to the south back to its historic curved configuration. However, recent incising of the flood shoal and the apparent reduction in sediment supply to the flood shoal indicates a potential for ebb currents to eventually “short-cut” across the flood shoal and deepen a channel there.

## Conclusions

Inlet channel location is a complex function of inlet hydraulics, littoral influx to the channel system, and inlet structures. Historic analysis of structural effects has provided a clear picture of inlet response and impacts on channel location. Initially low arrowhead jetties followed by an interior sand dike, then sand tightening of one jetty with increased jetty elevation, and finally conversion to a parallel jetty system, affected inlet hydraulics and sediment input, which in turn changed shoaling patterns and thus channel location. With the low arrowhead jetty system, sedimentation reduced channel cross-sectional area with a corresponding reduction in tidal prism. Today's inlet, which is still adjusting to the new parallel south jetty, appears to allow a more stable channel to exist due to the restriction of sediment input into the navigation channel. These factors along with an increase in minimum channel area due to dredging have changed the tidal prism back to pre-structure conditions.

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