CHAPTER 105

CHANGES IN INLET OFFSET DUE TO STABILIZATION

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ABSTRACT

Available evidence indicates southward littoral transport through the Merrimack Embayment. In apparent contradiction, the beach on the southern (Plum Island) side of the inlet has built seaward of the updrift beach. This phenomenon is related to a balance between storm and fair weather conditions. Wave observations under a variety of surf conditions show that during storms, sand is transported southward along the face of the nearshore bar fronting Plum Island. During calm periods sand is moved northward along the beach until it is trapped by the southern jetty and removed from the then active tidal current transfer system. Using discharge data and wave measurements from the Merrimack Inlet area, Bruun's bypassing coefficient ($r = Q_{ls}/Q_{max}$, where Q_{ls} is the longshore transport rate in M^3/yr and Q_{max} is the maximum inlt discharge in M^3/sec) was computed for storm and fair weather conditions. During storms, the bar bypassing observed in the field was clearly indicated. During calmer periods tidal current transfer was predicted. This relationship is considered only an approximation as it does not consider many important physical parameters (grain size, nearshore slope, wave type, etc.).

INTRODUCTION

The literature is replete with references concerning bypassing of sand around tidal inlets. Numerous researchers have considered the importance of this process to engineers (Angas, 1960; Bowman,1960; Bruun and Gerritson, 1960; Caldwell and Lockett, 1965; Dean and Walton, 1975; Herron and Harris, 1967; Hodges, 1955; McDonald and Sturgeon, 1956; Watts, 1962). These studies have generally shown that the type and rate of bypassing that occurs are dependant upon the volume of sediment supplied to the inlet (littoral drift) and the ability of the inlet to flush this material from its throat (related principally to tidal prism). Furthermore, the nature of this relationship will be reflected in the morphology of an individual inlet and its associated sand bodies.

At Murrells Inlet, S. C., (Fig. 1) net longshore transport rate is small and sand tends to reside in the inlet system. The near balance between sand entering and leaving the inlet causes it to be choked with sand. In this case, bar bypassing dominates at the expense of local navigation. At Kiawah Inlet, S. C. (Fig. 2) another type of bypassing, channel abandonment, occurs. Over a period of 10 months, the sand that had accumulated on the updrift side of the inlet was bypassed as the main channel was closed and a path further updrift was initiated (Fig. 2).

Whatever the process responsible for bypassing, introduction of a large structure into the littoral zone (a jetty, for example) results in a significant

Figure 1. Low tide photograph of Murrells Inlet, S. C. Note the large shoal occupying the channel cross-section. This is a result of the near balance of sand moving in and out of the inlet.

Figure 2, Bypassing at Kiawah Inlet, S. C. These photographs show the configuration of the inlet in April, 1975 (A), November, 1975 (B) and February, 1976 (C). Note the abandonment of the main ebb channel between April and November, 1975 followed by swash bar development in February, 1976.

modification of the bypassing process. In most documented cases, the resultant pattern of erosion and deposition is similar to that shown in Figure 3; that is, accretion along the updrift beach at the expense of the eroding downdrift beach.

The Merrimack River Inlet is located in northeastern Massachusetts near the Massachusetts-New Hampshire border (Fig. 4). The inlet separates two active Holocene barriers, Salisbury Beach to the north and Plum Island to the south. A variety of coastal defense structures have been used to stabilize the inlet and retard the rate of erosion along adjacent beaches. Since their construction however, these structures have been responsible for many problems (Hubbard, 1974). The jetties, built in sections since 1912, have effectively stabilized the position of the inlet while causing localized erosion on the nearby beaches and river front. Despite the apparent effectiveness of the jetties as barriers to littoral transport, the downdrift side of the inlet does not show the serious erosion usually associated with structures of this type. In fact, the downdrift beach is presently undergoing rapid progradation. Both field observations and mathematical considerations are presented to explain this phenomenon.

Figure 3. Low tide aerial photograph of the Cape Cod Canal entrance. Note the erosion-deposition pattern resulting from interruption of littoral transport. Sand is moving toward the viewer. Photo by Miles O. Hayes.

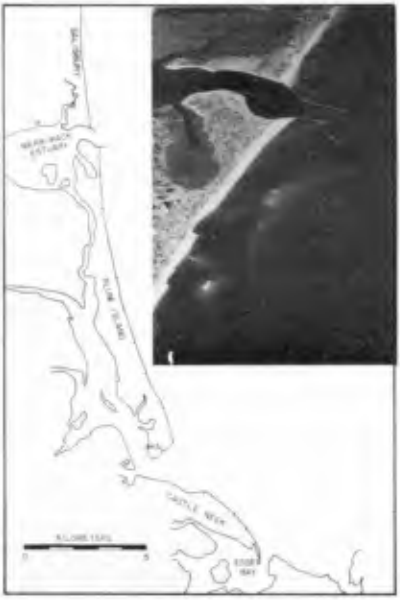

Figure 4. Map showing the location of Merrimack Inlet. The top of the figure follows the Massachusetts-New Hampshire border. The inset is a low tide aerial photograph looking northward over Plum Island (foreground) and Merrimack Inlet. Note the well developed nearshore bar system that extends past the inlet mouth.

Sediment Dispersal

Several lines of geomorphic evidence indicate a southward transport of littoral material through the Merrimack Embayment (Fig. 5). First, the seaward displacement of the 20 meter contour near the southern end of the embayment suggests that Ipswich Bay is a sink for material moving in that direction. Bothroyd (pers. comm.) has observed an accretionary beach at Castle Neck. Also, the southward migration of Plum Island by spit growth on its downdrift end (Farrell, 1969) indicates a sediment supply to the north. Finally, grain-size trends along Plum Island and Castle Neck beaches (Anan, 1971) and on the Merrimack ebb-tidal delta (Hubbard, 1975) also suggest southward littoral transport through the area (Fig. 5).

Morphology and Hydrodynamics

One would expect that under these conditions the beach on the northern side of Merrimack Inlet would be accreting while the southern beach eroded. To the contrary, the downdrift shoreline extends approximately 300 meters seaward of the northern beach. Furthermore, rapid accretion has been observed adjacent to the inlet since the 1967 rehabilitation of the south jetty.

If we consider that this offset is the result of some factor other than the jetties, then the downdrift offset inlet should have persisted when the jetties were absent. Analysis of existing charts of Merrimack Inlet show that although

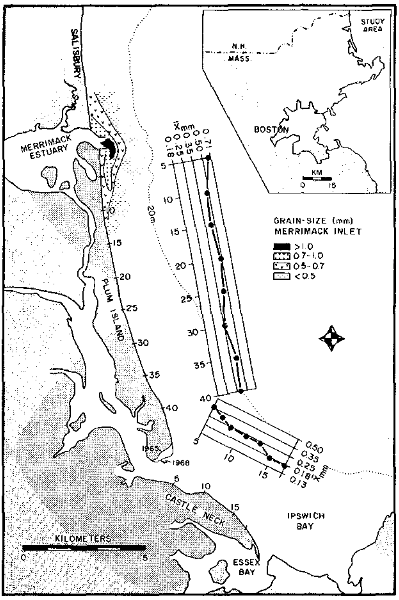

Figure 5. Summary of evidence for southward sand transport in the Merrimack Embayment.

1) seaward displacement of the 20 m contour in Ipswich Bay.
2) recurve spit growth on the southern tip of Plum Island.
3) grain-size trends.

the inlet was offset downdrift in 1741, by 1776 the inlet configuration had changed to that of an updrift offset (Fig. 6). 1809 saw the reestablishment of the downdrift offset. These and other reversals were probably related to the by-passing of sand around the inlet. Under natural conditions, the inlet therefore did not persist as a downdrift offset. The flip-flopping observed between 1741 and 1900 ceased abruptly however after the jetties were built in the early 1900's. A 1940 photograph from Chute and Nichols (1942) shows that the present configuration had already developed at that time (Fig. 7). It seems logical therefore, that the pattern of erosion and deposition observed at Merrimack Inlet is related to the presence of the jetties.

This pattern results from a balance between the dominant northeasterly storm waves and the prevailing southeasterly waves generated during fair weather conditions. It can be seen in Figure 8 that during storms the sediment moves uniformly southward except for a divergence in transport direction occurring immediately downdrift of the inlet. At this point a break in the nearshore bar occurs through which waves pass and break directly on the beach. Immediately updrift of the gap the bar reaches its highest elevation in response to the retardation of sand flow along the shoal. This adjustment of the waves to the topography of the nearshore bar results in northward sand transport during storms along the beach immediately downdrift of the jetty and the retention of sand in this part of the system.

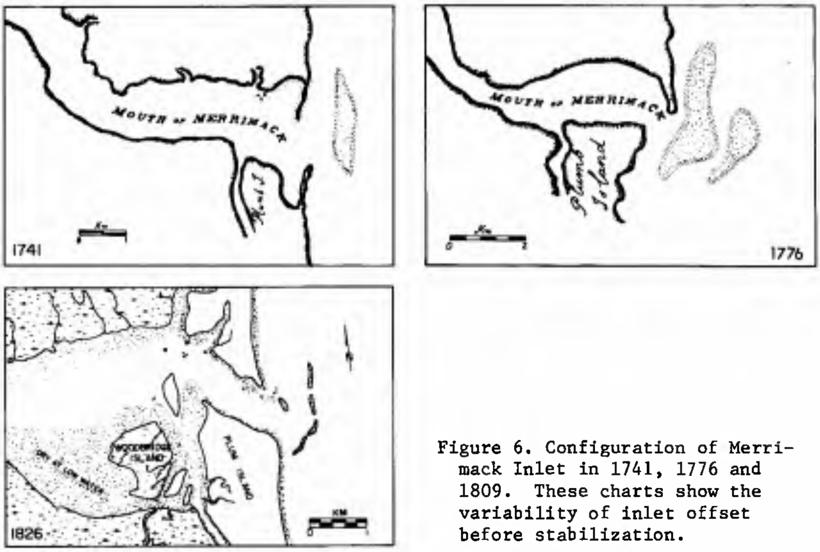

Figure 6. Configuration of Merrimack Inlet in 1741, 1776 and 1809. These charts show the variability of inlet offset before stabilization.

Figure 7. Aerial photograph looking westward across Merrimack Inlet. Note the similarities between this photo and Figure 9. From Chute and Nichols (1942).

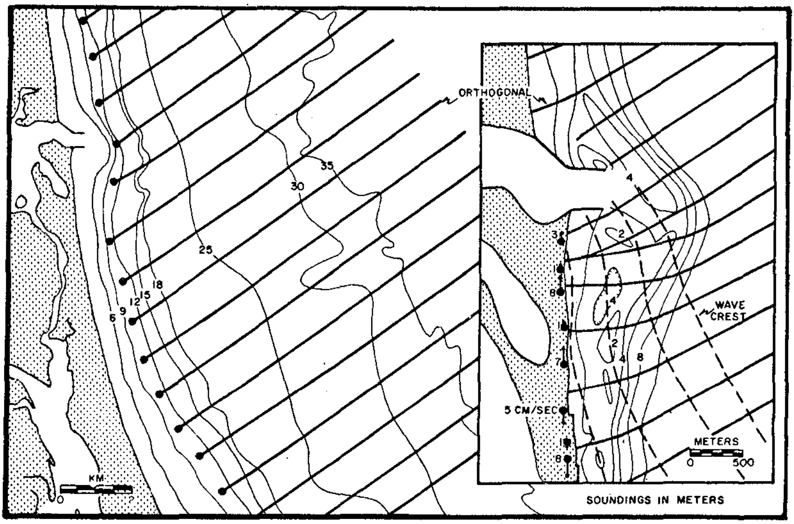

Figure 8. Wave refraction around the Merrimack ebb-tidal delta. The numbers in the inset are longshore current velocities measured during northeast wave approach.

During higher tidal stages, be they astronomical or meteorological, the entire beach comes under severe wave attack. Sand is removed from the beach and moved offshore toward the permanent nearshore bar and to the south (Fig. 9). The bar on the updrift side of the inlet extends nearly to the beach and provides a point of entry for sand into the by-passing system.

During fair weather, sand is moved landward and toward the north under the influence of the prevailing southeasterly waves (Fig. 9). On the south side of the inlet, this landward transport occurs through the migration of entire segments of the permanent nearshore bar onto the beach (Fig. 10). Once on the beach, this sand moves northward until it is trapped by the southern Merrimack jetty.

Bruun (1966) presented a formula to determine whether the movement of littoral material past an inlet would occur by the development of an inlet shoal or by tidal current transfer. Using a ratio between littoral drift (Q_{ls} in M^3/yr) and maximum inlet discharge (Q_{max} in M^3/sec) in twenty-eight inlets, he was able to determine whether tidal current transfer or bar bypassing would dominate in each case. Empirically, r values ($r = Q_{ls}/Q_{max}$) less than 10 - 20 indicated predominant tidal current transfer while values greater than 200 - 300 implied bar bypassing.

Using the maximum spring-tidal discharge of 2500 m^3/sec measured in the Merrimack Inlet, a value of 7.5×10^4 M^3/yr was calculated as the volume of

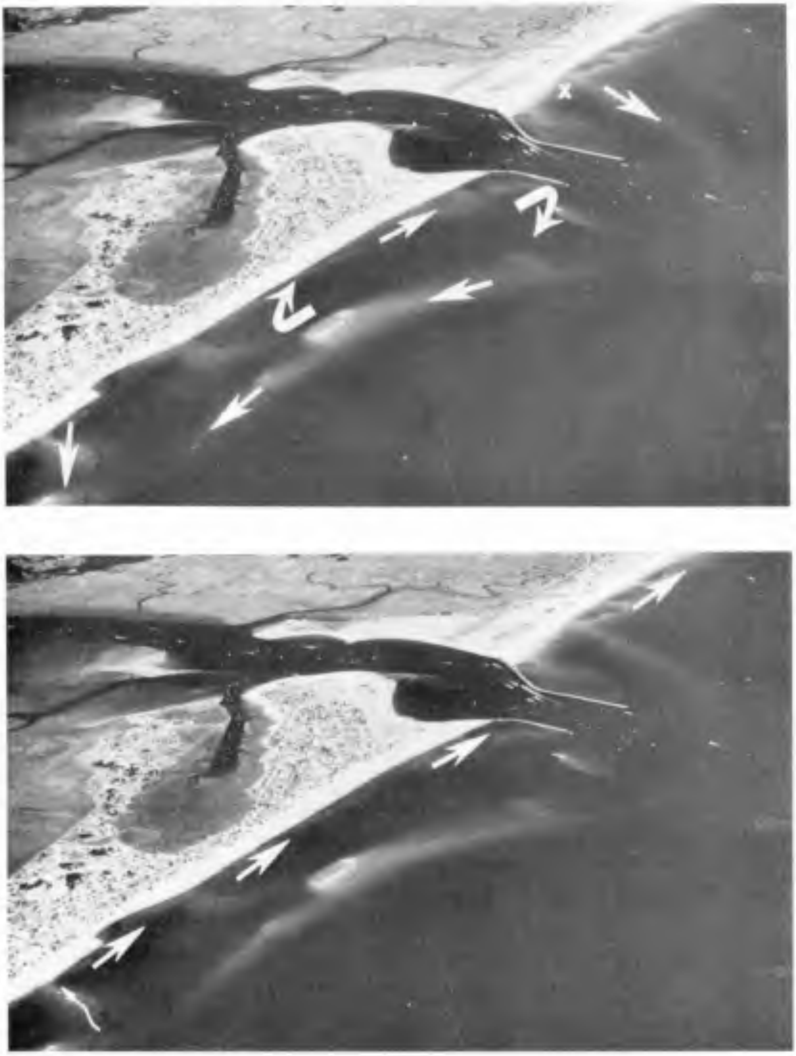

Figure 9. A (above). Sand transport patterns observed during storm conditions. The X indicates the point of attachment of the nearshore bar on the northern side of the inlet.
B (below). Sand transport patterns observed during fair weather.

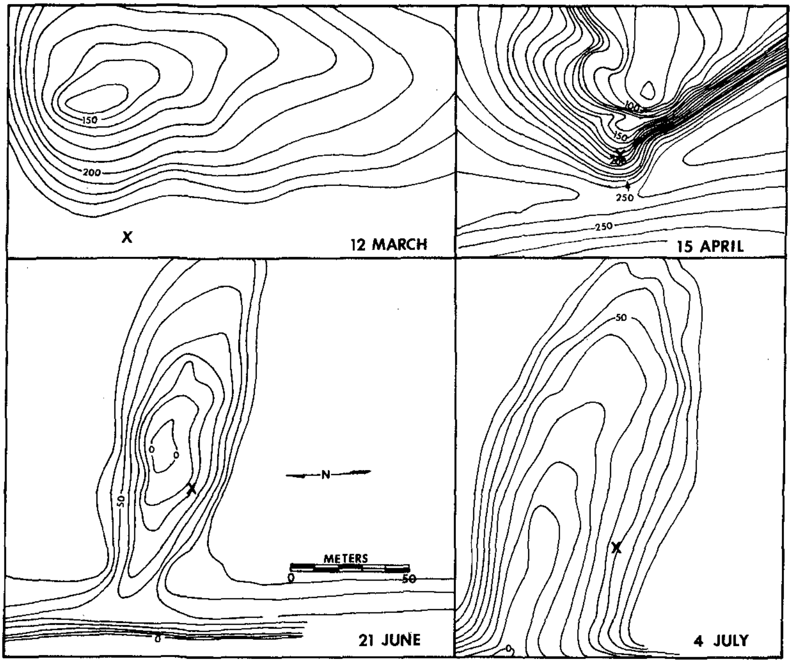

Figure 10. Bar migration under fair weather conditions. Note the transition in morphology from that of a longshore bar on 12 March to a transverse bar on 4 July. The X is in the same location on all maps.

longshore drift necessary to initiate bar by-passing. Using these data and formulas from the Shore Protection Manual (U.S. Army, 1973), longshore transport rates for the Merrimack Inlet area were computed. Using the relationships,

$$P_{ls} = 100.6\ (H_b^3/T)\ \sin\alpha_0 \qquad (1)\ \text{and,}$$

$$Q = (7.5 \times 10^3)\ P_{ls} \qquad (2)$$

where: P_{ls} = surf zone approximation for the longshore component of wave energy flux
H_b = breaker height
T = wave period
α_0 = angle between deepwater wave crest and shoreline
Q = longshore transport rate

it was determined that an 8 ft. (2.4 m) wave with a deepwater approach angle between 30° and 45° and a period between 6 and 9 seconds could initiate bar bypassing. Waves observed during northeasters are commonly above this height. Also due to the strong effect of local waves during storms, these periods and angles are representative.

Waves in excess of three meters were observed by Abele (1972) during a northeaster on 19 February 1972. According to the U. S. Army (1973) relationships,

$$Q = (7.5 \times 10^3)\ P_{1s} \qquad (2) \text{ and,}$$

$$P_{1s} = 32.1\ H_b^{5/2} \sin 2\alpha_b \qquad (3)$$

where α_b = angle between crest of breaker and shoreline, breaking waves with a height of 10.7 ft (3.25 m) and an approach angle of ten degrees (values consistent with Abele's (1972) data) could transport volumes of 8.75×10^5 M^3/yr. The corresponding r value of 350 is above the value needed to initiate bar bypassing. Prevailing southeasterly waves during fair weather periods average 1 ft (30 cm) in height and have characteristically small breaker angles. Equations 2 and 3 were used to determine longshore transport rates and subsequent r values for 30 cm waves approaching at various angles. The bypassing coefficient corresponding to a breaker angle of 45 degrees (most breakers approach at angles less than five degrees) was computed as 2.8. This is well below the value of r = 20 for tidal current transfer. It should be pointed out that because the nearshore bar is a permanent feature it is both the wave condition and littoral drift volume (which are admittedly related) that determine the mechanism of inlet bypassing in this case. Bruun's relationship is therefore an indication of what is going on rather than an explanation of the process itself.

CONCLUSIONS

1) Several lines of evidence indicate net southward littoral transport through the Merrimack Embayment.

2) Despite this, the beach south (downdrift) of Merrimack Inlet is presently accreting.

3) This phenomenon is the result of a balance between storm and fair weather conditions:
   a) During storms, sand moves off the beach and southward along the permanent nearshore bar that extends past Merrimack Inlet.
   b) During fair weather, sand moves landward and toward the north along the beach. Under these conditions, sand is trapped by the southern jetty.

4) Bruun's bypassing relationship can be used to at least partially explain this phenomenon. During storms the volume of drift is high enough to bypass the inlet along the nearshore bar face. Under calmer conditions, tidal current transfer which is blocked by the jetties occurs.

ACKNOWLEDGMENTS

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