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Noosa River entrance channel dynamics

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CRC for Coastal Zone
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Executive summary

Noosa has become a tourist mecca that attracts large numbers of interstate and international tourists. These visitors are largely attracted by the climate and beaches that have proven popular with a variety of beach users. Noosa Main Beach is located between the Noosa headland and the Noosa River entrance. The river entrance was trained in 1978 with a single rock jetty, and a rock groyne created midway between the river entrance and headland in 1983.

Erosion of Noosa Main Beach has been an ongoing problem, with historical records indicating that storm events have caused cutback of the beach for as long as historical records have been maintained. Prior to the mid 1960s though, the beach and river system essentially remained in a state of dynamic equilibrium. The sand dune was able to accommodate storm cutback and the beach seemed to respond without any major concern. However, large scale development witnessed in the mid 1960s led to modification of the beach system and resulted in the construction of the protective rock seawall, training of the river entrance and construction of the rock groyne.

The seawall and rock groyne failed to address the erosion concerns and resulted in the formation of a new control point for the beach and river system. Beach nourishment activities have been performed in recent times in an attempt to maintain a useable beach. However, the modifications to the beach system and atypical weather conditions in recent years have resulted in a beach that remains in a severely eroded state for the majority of the time.

Erosion concerns have led to the placement of approximately 40 000 m^3 of nourishment sand being placed on the beach annually. The sand reserves from the ‘inactive’ zone adjacent to Noosa Sound have almost been exhausted and restrictions have been imposed by the Environmental Protection Agency (EPA) on dredging locations due to the existence of a fish habitat on the northern side of the entrance. It is now proposed that nourishment sand be obtained from the ‘active’ zone consisting of tidal deltas and deltas inside the river entrance.

A number of solutions to the beach erosion problem have been investigated, including extension of the rock groyne, realignment of the seawall and construction of an artificial reef. All these options have been rejected for a variety of reasons and nourishment has continued in order to maintain a useable beach.

This report focuses on the behaviour of nourishment sand entering the system and the likely consequences should the proposed new dredging scheme proceed. It has been concluded in view of the findings that continued nourishment is not a suitable beach management strategy and that dredging of the active zone will be of limited effectiveness and poses an unacceptable risk to the fish habitat on the northern side of the river entrance.

More available data and better continuity of data is required before an accurate conceptual model of longshore transport and delta response can be developed. Once this is available, detailed modelling of the beach and river system will provide a more thorough understanding of the nourishment sand transport processes and the long-term consequences of the proposed dredging activities. These factors will then assist in determining an effective and longer-term beach management strategy for the region.

1 Introduction

Situated approximately 180 km north of Brisbane, Noosa is a tourist mecca that attracts large numbers of interstate and international tourists. Noosa headland is almost entirely surrounded by water, with tidal lakes to the north connected to the Pacific Ocean by the Noosa River. Noosa has become a favoured holiday destination, with Main Beach's location on Laguna Bay providing protection against southeasterly winds (Cato, 1989) and amenities for a variety of beach activities (Jackson, Black & Tomlinson, 1999).

History has shown that Main Beach is vulnerable to erosion. Prior to the 1960s, it was washed away many times but was able to repair itself in each instance. The movement of shorelines is a complex phenomenon that may result from natural processes, anthropogenic effects or in many cases a combination of both. The impact of anthropogenic effects has become increasingly apparent in recent times, with humans' desire to develop the coast conflicting with natural processes (Camfield & Morang, 1996). Unsuitable developments along Hastings Street and on the foredune of Main Beach have placed property in danger. Attempts to provide protection from erosion led to a beach system that is unable to regenerate itself and as a result, the majority of the beach remains in a severely eroded state (Cato, 1989).

Experience has led to the realisation that modifications to the coastal zone need to be made with caution if adverse economic impacts and environmental effects are to be avoided. It is now recognised that coastal engineering work should be undertaken only if there is sufficient knowledge of the processes at work (Gao & Collins, 1995). While this may assist in future coastal developments, it does little to address the adverse effects that have already been caused. A number of options have been investigated to maintain a useable beach and the visual amenity at the eastern end of Hastings Street, but none have been deemed suitable. As this beach has such a high resource value, there are many benefits in increasing our understanding of the beach and estuary behaviour (*Geomorphology e*ditorial, 2002). This is a major reason for this study being undertaken.

Since the river entrance was trained in 1978, beach nourishment has been used to maintain a useable area on Main Beach. Rapid removal of this sand results in the beach quickly returning to its eroded state. The sand reserves in Noosa Inlet that previously provided nourishment material have almost been exhausted (Jackson *et al.*, 2001), and the council is now looking to use the 'active' zone of tidal deltas as a supply of sand to continue nourishment activities. With this in mind, it has become increasingly important to gain a thorough understanding of the response to nourishment sand entering the system. This report will attempt to develop a conceptual model of inlet response to the addition of nourishment material. In addition, it will discuss the likely implications of the proposed new dredging scheme based on historical observations of the response to developments and extreme weather patterns in the region and a trial dredge of the ‘active’ zone performed in late 2001/early 2002.

2 Objectives

The main objectives of this study are to:

- examine the existing beach management scheme to assess the behaviour of nourishment sand;
- assess the response of estuarine ebb and flood-tidal deltas to nourishment sand entering the system; and
- develop a conceptual model of longshore transport and delta response to assist Noosa Shire Council in deciding upon a suitable beach management strategy.

3 Literature review

3.1 Tidal inlet behaviour

Tidal inlets are dynamic systems found everywhere in the world, with a variety of parameters that makes their characterisation a difficult task. These inlets generally demonstrate continuous change in geometry by varying their length and configuration in response to the transportation of sediment (Bruun, 1979). They impact upon the supply of sand to downdrift beaches and the erosional–depositional patterns on adjacent beaches by interrupting the wave-induced transport of sediment along the shoreline. Often, the greatest magnitude erosional–depositional changes along a shoreline can be witnessed in the region of tidal inlets (FitzGerald, 1988).

When waves are incident upon a shoreline at an angle, a portion of the water is reflected back out into deeper water, while some moves parallel to the shoreline. The volume of water that moves parallel to the shore, referred to as the longshore current, is a function of both wave height and the angle of incidence. Longshore currents and waves are responsible for transportation of large volumes of sand and may result in a net movement of sand in one direction if there is a predominant swell direction (Davis, 1994).

At times, tidal inlets act as sediment sinks, in which case they provide one or all of the following:

- a pathway for the movement of sand into rivers and bays where the sediments are deposited on flood-tidal deltas and marshes;
- storage for littoral sediments in swash platforms and ebb-tidal deltas; and
- temporary storage in other sand bodies such as channel margin bars and sand spits.

Such behaviour plays a significant role in determining the impact on neighbouring beaches (Liu and Hou, 1997), and can result in the reshaping of deltas, estuaries and bays. Should sediments become part of an infill sequence, they may be stored for long periods in the bay/lagoon environment (Morton and Donaldson, 1973; Kumar and Sanders, 1974; Moslow and Heron, 1978 cited in FitzGerald, 1988).

Flood-tidal deltas form on the landward side of a tidal inlet and as such are protected from wave action. They are generally fan-shaped and usually only subject to tidal currents. Ebb-tidal deltas on the other hand are exposed to the open ocean and wave attack that results in their shape and depositional patterns being more varied than flood-tidal deltas. The tidal currents and interaction with wave-generated processes are the controlling factors for the size and shape of ebb-tidal deltas (Davis, 1994).

Ebb-tidal deltas perform a valuable function at tidal inlets. Their shallow nature provides a natural breakwater, thereby reducing the wave energy incident upon the inlet shorelines. This is particularly true at lower tidal elevations when most of the energy is dissipated on the terminal lobe. However, intertidal and subtidal bars still result in waves breaking offshore at higher tidal elevations (FitzGerald, 1988). Hales and Herbich (1972, cited in FitzGerald, 1988) have also shown that ebb-tidal currents influence incident waves and result in a decreased wave height. Together, these factors result in less erosion on shorelines adjacent to the tidal inlet.

Much research has been performed on the relationships between ebb-tidal deltas and tidal inlets. These deltas can contain huge volumes of sand so even slight changes in their volume may have a considerable effect on the supply of sand to adjacent beaches (FitzGerald, 1988). Walton and Adams (1976) compared the idealised ‘no-inlet’ hydrographic charts with actual hydrographic charts for 44 inlets around sandy portions of the United States coast to determine the volume of sand stored in ebb-tidal deltas. The following equation that relates the volume to tidal prism was derived:

$$V = aP^b \qquad \textbf{(Eq. 1)}$$

where V = volume of sand stored in the outer bar/delta of the inlet (in cubic yards of immersed sand)

P = tidal prism of the inlet (ft^3)

a,b = correlation coefficients.

They concluded that more sand is stored in the ebb-deltas of low energy coasts than that of high energy coasts. However, limitations to this model exist in that other factors such as longshore energy flux and sediment size that could present an upper limit to the storage capacity were not considered in this study.

Gao and Collins (1995) claim that a tidal inlet will evolve towards a state of dynamic equilibrium in terms of its cross-sectional area at the entrance under any hydrodynamic and sediment dynamic conditions. Cooper, Hooke and Bray (2001) suggest that over a particular time frame and spatial scale, such systems are capable of maintaining a balance between activity, morphology and sediment transport, and can dissipate energy inputs with no net output from the system. However, this state of dynamic equilibrium can be disturbed by changes to energy inputs (e.g. storm events), coastal defence works that influence the sediment budget, or other human activities that alter the morphology of the system (e.g. dredging). Such interference may cause the system to be altered in such a way that it can no longer dissipate energy inputs without net outputs. This may become apparent through variations in the morphology and/or sediment characteristics and/or sediment transport processes.

Storm impact is an important concern as storms are often responsible for rapid changes to a tidal inlet (Davis, 1994). The corresponding, prolonged transport of sand onto the beach is a poorly understood process that varies from location to location. The balance of sand supply to adjacent beaches is altered considerably during high-energy events and it is difficult to predict where erosion or deposition will occur (Morton, Gibeaut and Paine, 1995). Variations in storm frequency can impact on the longshore transport of sand in a system, which in turn can influence the characteristics and position of tidal inlets and neighbouring beaches (Camfield & Morang, 1996).

During storms, particularly when they coincide with a storm surge and high astronomical tides, waves are able to attack sections of the beach that are not typically vulnerable to erosion. For an undisturbed system, the dynamic response is to sacrifice some of the beach and often the dune to provide material for an offshore bar. Such bars protect the shoreline from further erosion and highlight the importance of retaining the dunal system of the beach. After a storm, when conditions return to normal, the system is dominated by low, long swells. These swells transport the sand that formed the offshore bars back onto the beach, before winds transport the material back onto the dune (USACE, 2001).

Short (1999) emphasises, with regard to human impacts, that structures designed to prevent beach erosion, such as seawalls, tend to accelerate beach erosion and reduce recovery rates due to a reduction in permeability. Groynes are the most commonly used beach stabilisation structure and, *when designed correctly*, can assist in stabilising erosion-prone beaches. By reducing the volume of sand removed by longshore transport, an accumulation of sediment on the updrift side of the structure occurs. This results in a reorientation of the shoreline and a reduction in the incident angle of waves. The net effect is a reduction in the volume of sand passing the structure and hence being removed from the beach (USACE, 1994).

In reducing the volume of sand passing the structure, erosion of the downdrift section of beach is a likely consequence as the system attempts to maintain previous longshore transport rates. These impacts can be reduced by incorporating beach nourishment into the project to help reduce the time required for the system to establish a new state of equilibrium and by encouraging earlier sand bypassing of the structure (USACE, 1994). Beach nourishment is an attractive alternative from a recreational point of view as an increased beach area provides greater potential for tourist use (CUR, 1987).

Although beach nourishment is regularly regarded as an effective tool in combating the effects of beach erosion, studies have shown that sand volumes required do not decrease with time as was once believed (Trembanis & Pilkey, 1999). Nourishment activities in the past have applied design criteria that have been qualitative rather than quantitative. The emphasis has been in many cases on providing an increased useable beach area with little attempt being made to predict the behaviour of the beach fill. This results in non-optimum designs being used, which in turn reduces the cost-effectiveness of the project. To achieve optimum results, the hydraulic and morphological processes of the relevant area must be thoroughly understood (CUR, 1987).

In order to be effective, the nourishment material must be similar to the material that characterises the beach. Removal of nourishment sand can be accelerated by an unnatural steepness of beach fill and/or a large percentage of fine-grained material present in the nourishment sand (Bruun, 1990). Using material with a finer texture than the original beach material will result in its rapid removal and reduce the economic viability of the project. Sources of material having similar characteristics to the native beach material and which will not be adversely affected by their removal are often a limiting factor in the continued success of nourishment activities (Davis, 1994). Furthermore, those responsible for the implementation of beach nourishment activities should not expect the beach fill to be stable when it is placed on a continuously eroding coast (CUR, 1987).

Bruun and Gerritson (1959 cited in Kidson, 1963) have shown that sand bypassing tidal inlets is a naturally occurring process. They derived the equation:

$$r = M_{mean}/Q_{max} \qquad \textbf{(Eq. 2)}$$

where r equals the ratio between the longshore sediment transport rate (M_{mean} (yd^3/yr)) and the maximum discharge at the outlet during spring tidal conditions (Q_{max} (yd^3/s)).

Three methods of inlet bypassing were defined. These are:

- wave-induced sand transport along the periphery of the ebb-tidal delta (terminal lobe);
- transport of sediment in channels by tidal currents; and
- migration of tidal channels and sand bars.

For inlets with high r values (r = 200–300), Bruun and Gerritson were able to demonstrate that sand bypassing occurred via wave action along the terminal lobe, whereas bypassing occurred by the other two methods for inlets with low r values (r = 10–20). Bypassing may also be a result of a combination of these methods. Bruun and Gerritsen’s (1959) original work has been refined by FitzGerald et al. (1978 cited in FitzGerald, 1988) who proposed three models to explain inlet sediment bypassing. These models are discussed below and illustrated in Figures 1 to 3.

3.1.1 Inlet migration and spit breaching

The quantity of material crossing an inlet varies, with a large proportion being deposited in the mouth of the inlet resulting in the formation of spits and bars. The growth of these spits directly influences inlet migration. Material deposited in an inlet results in the constriction of the inlet throat, which leads to increased current velocities and hence scouring potential. As sand deposition, due to the transport of sediment by longshore currents, typically occurs on one side of the inlet, erosion of the opposite bank occurs as the channel attempts to maintain its cross-sectional flow area. The net result of these processes is migration of the tidal inlet (FitzGerald, 1988). The optimal time for spit deposition at a tidal inlet is during the flood tide when longshore currents are reinforced by flooding tidal currents (Oertel, 1988).

As depicted in Figure 1, migration of an inlet often corresponds with an elongation of the inlet channel. This longer channel typically results in inefficient tidal flows due to reduced hydraulic efficiency. Breaching of the updrift spit results in a shorter, more efficient route for tidal exchange. This new pathway will typically remain the dominant flow path as the older inlet closes. This process of spit breaching essentially provides large quantities of sand to the downdrift shoreline (FitzGerald, 1988).

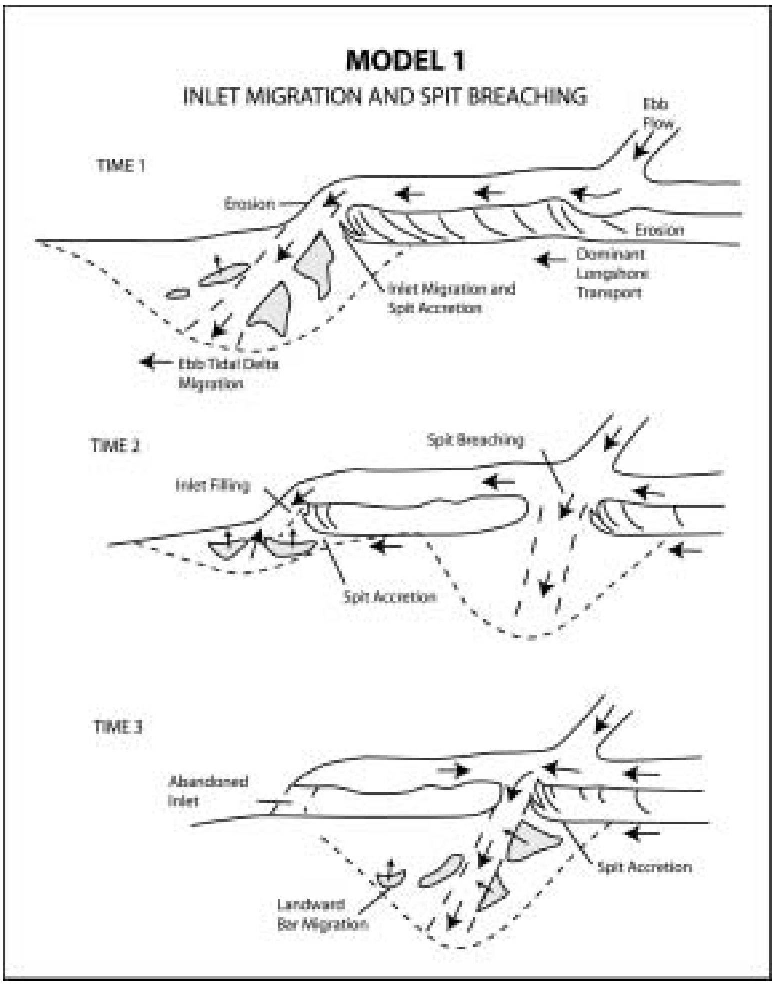

Figure 1. Model 1 of inlet sediment bypassing proposed by FitzGerald *et al.* (1978 cited in FitzGerald, 1988)

3.1.2 Stable inlet processes

This term describes inlets that have a stable throat position and non-migrating main ebb channel and is shown in Figure 2. Such inlets bypass sand through the formation, landward migration and eventual welding of bars to the downdrift shoreline. These bars develop due to the stacking of swash bars on the ebb-tidal delta. Swash bars are accumulations of sand formed by waves and are made up of material that has been transported seaward by ebb-tidal flows. Wave action on the ebb-tidal delta assists flood currents and retards ebb currents, resulting in a net landward movement of sediment on both sides of the channel. These bars begin to stack on one another due to a decrease in the rate of onshore migration as they approach the shoreline (FitzGerald, 1988). This onshore migration essentially provides a means of inlet bypassing.

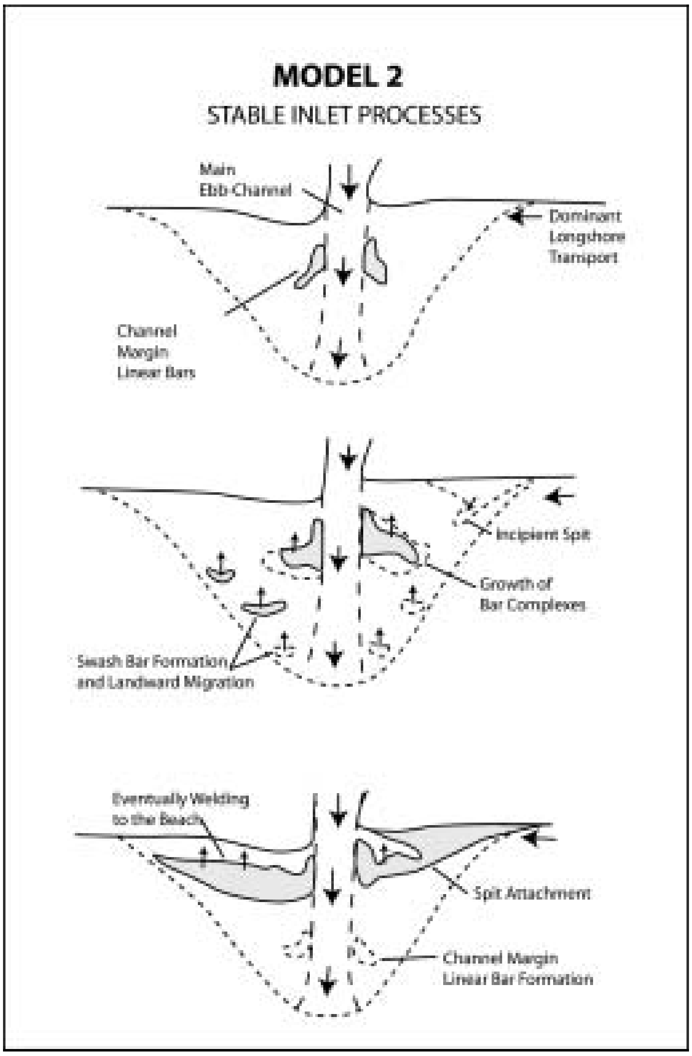

Figure 2. Model 2 of inlet sediment bypassing proposed by FitzGerald *et al.* (1978 cited in FitzGerald, 1988)

3.1.3 Ebb-tidal delta breaching

Bypassing sand by breaching of ebb-tidal deltas occurs at inlets that have a stable inlet throat position but a main channel that is able to migrate (Figure 3). A dominant longshore transport direction results in a preferential accumulation of sediment on the updrift side of the ebb-tidal delta. This in turn causes the main ebb channel to be deflected. Migration of the main ebb channel may continue until it interferes with the downdrift beach, resulting in erosion of the shoreline on this side. Such a configuration is hydraulically inefficient and results in the inlet taking a more direct route to sea through a spillover channel. This process may occur gradually or, in the case of a storm event, catastrophically when the scour potential of the ebb jet has been increased by floodwaters. Once the delta has been breached, the major portion of flow will pass through this new channel and the abandoned channel will gradually fill. The result of this process is the bypassing of a large volume of sand that was previously stored in the ebb-tidal delta (FitzGerald, 1988).

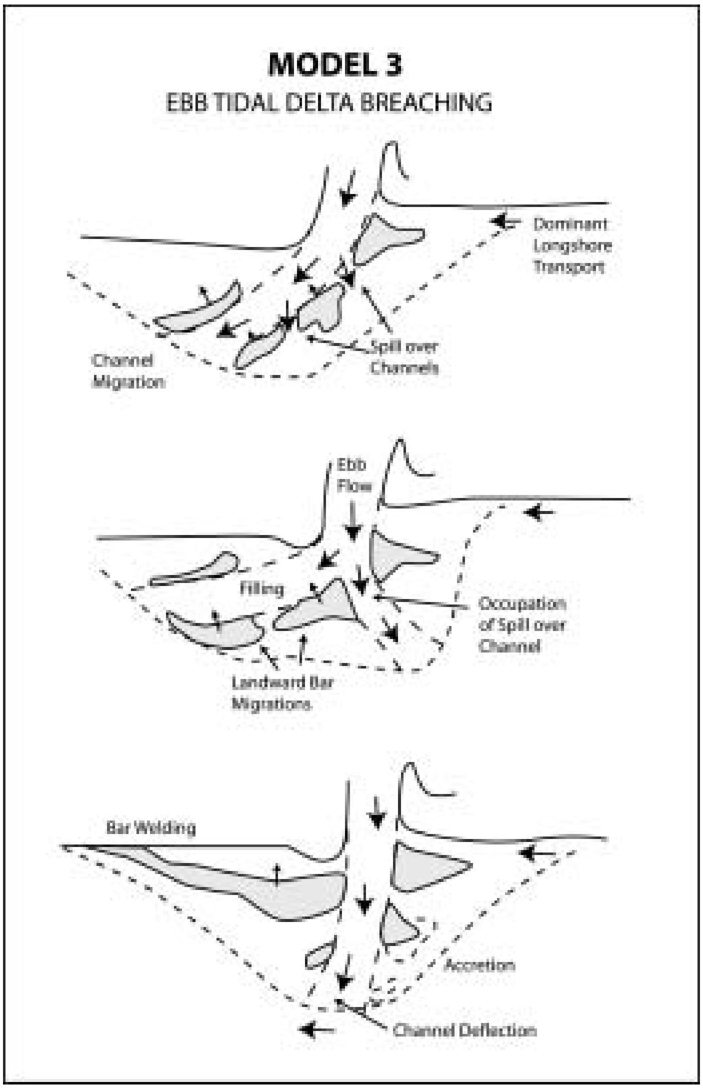

Figure 3. Model 3 of inlet sediment bypassing proposed by FitzGerald *et al.* (1978 cited in FitzGerald, 1988)

3.2 History of Noosa beach and estuary system

Erosion of Noosa Main Beach has been an ongoing problem, resulting in property damage and adverse effects for tourism and businesses in the area. Historical records indicate that prior to the 1960s, the Noosa beach and estuary system appear to have been in a state of dynamic equilibrium. Figure 4, taken in the 1960s, shows that the entrance to the river was wide, containing large ebb- and flood-tidal deltas and able to migrate freely. Severe storm events in 1967, combined with pressure to protect coastal developments, led to modification of the Noosa beach and estuary system. The system is still responding to these changes and possibly to the atypical climatic conditions in recent years. As such, behaviour of the system has been divided into pre- and post-1960s behaviour (Jackson, Black & Tomlinson, 1999).

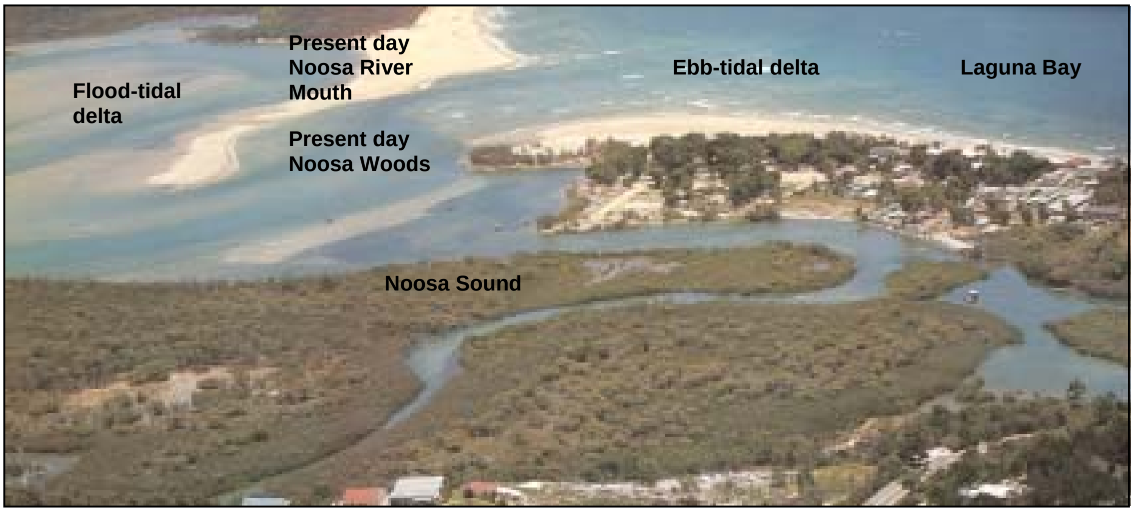

Figure 4. The Noosa River entrance in the 1960s (Source unknown)

3.2.1 Pre-1967 coastal behaviour

Records of the earliest surveys of the system performed in 1870 and 1876 are contained in hydrographic charts that show the entrance to be located at the site of the present day Noosa Woods. The main channel passed through a series of flood-tidal deltas, before discharging north into Laguna Bay. During this period, the Noosa spit had a protective dunal system, the back of which was densely vegetated with casuarinas (Jackson, Black & Tomlinson, 1999). The beach was much wider than it is presently, with locals recalling the beach stretching as far as First Point (roughly 300 metres) (Cato, 1989).

Although storm events disrupted the system at times, it always recovered without any major concern. The typical response of the estuary to these disruptions was the formation of a more direct southeastern channel and migration of the entrance to a more easterly position. Records indicate that the system response was similar to this until the late 1960s (Jackson, Black & Tomlinson, 1999).

In the early 1900s, property development along Hastings Street allowed for variation in beach widths. It was typically temporary in nature and if necessary could be relocated away from the erosion scarp. Many cyclones were reported in the first half the 20th century, all of which resulted in considerable beach erosion.

The storm induced erosion extended to within the property boundaries on Hastings Street, and flooding of the estuary resulted in the channel breaking through in a more easterly position and flowing directly to the sea (Jackson, Black & Tomlinson, 1999). Figure 5 indicates the extent of erosion, showing the dressing sheds on Hastings Street falling into the sea as a result of the 1947–48 cyclones (Cato, 1989). From the available information, it can be concluded that the beach and estuary system was relatively stable prior to 1967.

The impact of regular cyclones had no long-term recession effects and in fact recent investigations into the sediment transport processes have led to the conclusion that cyclones play two different roles. They are responsible for immediate beach erosion as well as providing the driving mechanism to release large quantities of sand from Alexandria Bay around the headland into Laguna Bay. This sand is then used to rebuild the beach, and is how the Noosa system was able to repeatedly regenerate itself after storm events prior to the mid 1960s (Jackson, Black & Tomlinson, 1999).

Figure 5. Dressing sheds on Main Beach falling into the sea as a result of the 1947–48 cyclones (Source unknown)

3.2.2 Post-1967 behaviour

With an increase in property development occurring along Hastings Street, the major storm events of 1967–68 proved to be the catalyst for construction of the rock wall along Main Beach. Initially, the individual rock walls were made by property owners. This was later extended by the Noosa Council to cover the whole length of the beach, as shown in Figure 6. Although it provided protection for beachfront properties it failed to address the locals concerns over erosion and the beach remained unusable at high tide (Cato, 1989).

Figure 6. The rock wall in 1972-73 after it was extended the entire length of the beach (Source unknown)

Recovery of the beach was slow after the rock wall was constructed, and when the storms of 1972–1974 struck, it had still not fully recovered from the 1967–68 storm events. Flooding in 1972 resulted in breakthrough of the southern channel at the river entrance and by 1973 it had established itself as the dominant flow path. By 1975, the northern channel was completely closed. The storms and associated events during this period resulted in significant erosion, particularly at Noosa Woods in 1976. Channel dredging associated with the Hayes Island development further encouraged the dominance of the southern flow path and at the same time resulted in erosion problems for the development (Jackson, Black & Tomlinson, 1999).

After the numerous floods and storm events of the early to mid 1970s, a dry year was experienced in 1977. This resulted in large amounts of sand returning to the beach, but not enough to cover the rock wall. Normal flow regimes returned to the estuary, and the northern channel began to re-establish itself as the main flow path. Continued concern over the erosion of Hayes Island led to the Beach Protection Authority (BPA) recommending the river entrance be relocated and that beach nourishment exercises be implemented. Their study concluded that approximately 143 000 m^3/year of sand was being removed by longshore transport, and that approximately 13 500m^3/year had been passing into the estuary over the previous thirty years (Jackson, Black & Tomlinson, 1999).

In 1978, the training wall at the entrance to the Noosa River was completed, resulting in a new beach system being established. Training of river entrances is generally performed to stabilise the entrance and improve navigation. Oddly, a single training jetty was constructed even though these structures had proven almost worthless in other locations. An investigation by Floyd (1968) concluded that with the construction of single jetties, entrances remain unstable and were no better than if left untouched. The effect of the training wall was to move the ebb delta westward. Combined with the Hayes Island development, associated channel dredging and infilling of the new entrance, the ebb-tidal delta was unable to grow and the protection it provided was removed. As such, the northern migration of the entrance and re-establishment of the northwestern channel was unable to occur (Jackson, Black & Tomlinson, 1999).

A similar series of events occurred at Morris Island in the USA. In the late 1800s, jetties were constructed in an attempt to stabilise the main channel leading into Charleston Harbour. After the jetties were installed, the longshore supply of sand to the deltas was cut off and resulted in their size decreasing. This decrease corresponded to a decrease in the protection provided by the deltas and resulted in the adjacent shorelines eroding at three times the rate they had prior to jetty construction (FitzGerald, 1988).

Completion of the entrance works along the Noosa River was followed by the placement of 200 000 m^3 of nourishment sand on the beach. This was eroded right back to the seawall within two years and led to further investigation by the BPA that focused on the longshore transport rates. Their recommendations were that a rock groyne and additional nourishment was required. In 1982–83, a 160 m rock groyne was constructed and a further 220 000 m^3 of nourishment sand added. This was quickly eroded and in 1988 another 140 000 m^3 was pumped onto the beach and recommendations made that further nourishment be used to maintain a useable beach (Jackson, Black & Tomlinson, 1999).

Since then, regular beach nourishment exercises have placed approximately 80 000 m^3 of sand on the beach every two years. Combined with these nourishment activities, the rock groyne has resulted in a ‘dynamically stable’ beach system, though Main Beach remains cut back to the seawall for much of its length and for most of the time. Studies of the region have identified a number of factors contributing to the erosion of Main Beach since the new control point was established by construction of the rock groyne. However, the primary cause of erosion is due to the misalignment of the wave crests with the seawall. The predominant southeasterly swell results in longshore movement of sand from Main Beach in a northerly direction towards the river, bypassing the tip of the groyne. A number of solutions have been considered but all have been rejected for a variety of reasons (Jackson et al., 2001).

In order to maintain fish habitats inside the Noosa River inlet, the EPA has restricted where dredging can be undertaken. The ‘inactive’ zones adjacent to Noosa Sound (formerly Hayes Island) have been used in the past but the supply of sand from this region has almost been exhausted. Continued nourishment is not seen as a viable option as doubt exists over the continuing availability of a suitable sand source.

4 Methodology

Many investigations have been performed at Noosa including the collection of large volumes of wave, current and bathymetric data. These have been used to gain an understanding of and to model coastal processes, in an attempt to evaluate options to solve the erosion problem (Jackson et al., 2001). However, no studies have been undertaken that describe the history of the inlet in as much detail as presented here. No previous research has investigated the behaviour of nourishment sand introduced to the system, and the impact that it has on the inlet configuration. Therefore, this study will complement those that have been undertaken in the past by explaining in more detail the processes occurring at the inlet as a result of nourishment sand entering the system.

Flights over the Queensland coastline are performed at regular intervals by the BPA, with aerial photography incorporated to monitor the state of the beaches. These photographs provide a valuable resource that can be used to describe the coastal response to weather conditions and human- related impacts. This project will use these historical aerial photographs of the region to develop a time series account of how the system has been behaving.

More accurate quantitative results could be provided by studies using radioactive tracers and recording devices, or sophisticated computer or physical modelling (for example). However, the resources and necessary time for such projects were currently unavailable and data contained in the historical aerial photographs provided the best opportunity for this investigation to be undertaken. The ability to correlate the dredging records provided by Noosa Council and the storm events described in previous reports allows an accurate description of the system's response to be obtained.

The analysis described in the following chapter follows standard photographic interpretation techniques. A qualitative assessment will be made of the movement of channels, direction of flow, vegetation changes, bank erosion and delta deposition.

5 Aerial photograph analysis

The following sections describe the aerial photographs available for the project that contain information relevant to this study. All photos form part of the BPA's aerial photography collection and can be viewed in Figures 9–40 in Appendix 1.

5.1 19 May 1972 (Figure 9)

There is very little useable beach area along Hastings Street and the rock wall is visible for the entire length of beach.

Both the northern and southern channels are open. The flood of 1972 has resulted in the southern channel passing directly to the sea through the site of the present-day Noosa Woods and the ebb-tidal delta has formed some distance off the beach. The northern channel follows the path of the shoreline and is directed a long way (about 800 m) south by the northern spit before joining the southern channel.

The flood-tidal delta separating the channels is very large, being approximately 950 m across at its widest point.

5.2 12 September 1973 (Figure 10)

The condition of Main Beach appears relatively unchanged since the previous photo (from 1972). The Hayes Island development has been completed and the southern channel passes alongside the development before being directed northeasterly by the end of Hastings Street. This deflection has resulted in erosion back to the car park and vegetation line in this area.

5.3 13 February 1974 (Figure 11)

Still very little useable area exists on the eastern end of Main Beach. Additional development has occurred next to Munna Point and at the entrance of Weyba Creek. A large dredge hole that supplied material for this development is apparent in front of Munna Point.

Although both channels are open, deposition of the northern spit and southeastern corner of the flood-tidal delta has constricted the northern channel. This has resulted in the southern channel becoming the dominant flow path and may be a result of the decrease in frictional resistance due to the dredge hole.

5.4 6 February 1978 (Figure 12)

Still very little useable beach exists along Hastings Street and the rock wall remains visible for the entire length of beach. Deposition on the southern side of the inlet has resulted in the formation of a sand spit that extends around 180 m from the vegetation line. Growth of this spit indicates that longshore transport mechanisms are acting to move sand off Main Beach and into the ‘active’ zone. This sand would have been transported from Alexandria Bay during the cyclones of the mid 1970s, combined with the small amount pumped onto the beach after the 1972–74 storms.

The southern and northern channels remain open, with the southern channel running directly alongside Noosa Sound (formerly Hayes Island). The northern channel appears to be the dominant flow path (as evidenced by the narrowing of the channel alongside Noosa Sound). Deposition along the southern spit results in the channel switching back to the west, before exiting in a northeasterly direction. This area remains eroded back to the car park and vegetation line at the end of Hastings Street.

Because of the channel migration, the northern spit has eroded but remains quite large (approximately 600 m length). Erosion here would be in response to the channel attempting to maintain its cross-sectional flow area and is common on the opposite bank to where deposition occurs (FitzGerald, 1988).

The southern channel becomes quite narrow at the middle of Noosa Sound. This would have resulted in an increase in flow velocity through this section and hence the erosion concerns for the development.

The size of the flood-tidal delta separating the channels remains similar to previous photos, although the shape has changed slightly.

5.5 9 April 1978 (Figure 13)

The quality of this photo reduces the ability to determine the finer details of the beach and estuary system but once again the area of useable beach along Hastings Street remains minimal and the rock wall is visible.

Both the northern and southern channels remain open but the northern channel still appears to be the dominant flow path. Deposition of the southern spit has caused the inlet to migrate slightly to the north, resulting in erosion of the northern spit. This spit has been breached, resulting in the tip of the northern spit becoming separated from the north shore.

The flood-tidal delta separating the two channels remains virtually unchanged, as does the cutback of the southern channel to the car park and vegetation line at the end of Hastings Street.

5.6 26 June 1978 (Figure 14)

Noosa Main Beach remains eroded but there is a deposition of sand evident on the southern spit.

In response to channel dredging near Munna Point, and hence a decrease in frictional resistance, the southern channel has become the dominant flow path. Flood tides have moved sand into the channel in an attempt to fill the dredge holes. Pumping of sand to enable construction of the training wall has resulted in a blockage of the northern channel that now appears to be in the process of breaking through the spit closer to the vegetation line of the north shore.

5.7 13 July 1978 (Figure 15)

The eastern end of Main Beach remains eroded.

The northern channel has breached the northern spit and nourishment works associated with the training wall development have closed the southern channel. Sand now fills the area that is the present-day Noosa Woods and connects the flood-tidal delta that typically separates the northern and southern channels. Part of the northern tip of this flood-tidal delta has been dredged, leaving a small sand ‘outcrop’.

5.8 4 September 1978 (Figure 16)

A section of the training wall has been constructed. Continued sand nourishment associated with the training wall (200 000 m^3) has provided a wide beach along Hastings Street and has continued to fill the area that represents the present-day Noosa Woods. A second ‘finger’ of sand is connected to the flood-tidal delta in the middle of the entrance.

The northern channel has developed a more meandering configuration and has resulted in slight erosion of the northern spit. In addition, the outcrop resulting from previous dredging on the northern tip of the flood-tidal delta (refer to Section 5.7, 13 July 1978) has being removed (presumably to fill the dredge hole), resulting in an increased cross-sectional flow through this region.

5.9 13 October 1978 (Figure 17)

Once again, the quality of this photo makes the minor changes difficult to determine, but it does appear that sand from the eastern side of the training wall is starting to migrate around the tip of the wall. Other than this, little change can be detected.

5.10 5 December 1978 (Figure 18)

There is little change evident on Noosa Main Beach, but erosion does appear to be occurring on the eastern side of the training wall.

Deposition on the north shore has resulted in the northern spit becoming elongated. The channel is moving back towards the training wall in response to the growth of the northern spit and in an attempt to maintain its cross-sectional area. This has resulted in a slightly longer channel length due to the increased meandering.

The area in front of Noosa Sound remains virtually unchanged while the northern tip of the flood-tidal delta has eroded slightly due to channel migration resulting from the elongation of the northern spit.

5.11 23 May 1979 (Figure 19)

The eastern end of Hastings Street is not visible in this photo but deposition on the eastern side of the training wall suggests that longshore transport mechanisms are removing sand from Main Beach. This deposition around the training wall is resulting in the formation of a southern spit.

The northern spit has moved almost parallel with the training wall, and a small delta has formed in the middle of the inlet. This has resulted in the separation of flow paths through the inlet and is deflecting the more dominant southern channel towards Noosa Woods. Dredge holes are apparent near Munna Point and the north shore, with signs that the system is attempting to fill them on the flood tides. This would be consistent with the movement of sand off Main Beach and into the ‘active’ zone and would be encouraged by the decrease in frictional resistance associated with the dredge holes.

The first signs of vegetation are appearing on the newly formed Noosa Woods area.

5.12 14 June 1980 (Figure 20)

Once again, the area of useable beach at the eastern end of Hastings Street has been greatly reduced. Deposition at the training wall extends to the end of the structure and has resulted in a spit formation that has welded to the flood-tidal delta that typically separates the two channels. As a result, the southern channel has been blocked.

Deposition of the flood-tidal delta and the southern spit/delta formation has resulted in a northerly migration of the channel. This migration has resulted in a shortened northern spit, as the channel attempts to maintain its cross-sectional flow area.

The dredge hole closest to the north shore (and visible in previous photo) appears to have been filled and a deposition of sediment in this region is apparent. The hole closest to Munna Point is now only slightly visible. Vegetation on the Noosa Woods site is becoming more established.

5.13 5 March 1981 (Figure 21)

The eastern end of Main Beach remains in an eroded state, providing very little useable beach area. The 200 000 m^3 of nourishment material added after completion of the training wall has been eroded back to the seawall (Jackson, Black & Tomlinson, 1999).

Deposition of the ebb-tidal delta has resulted in the channel exiting in a more northerly direction. The amount of sand on the beach between the training wall and the river end of Hastings Street has reduced (presumably to form the ebb-tidal delta).

The northern spit has grown in size with little change to its shape. This has resulted in erosion and re-shaping of the southern spit as the channel attempts to maintain its cross-sectional flow area. The southern channel still remains cut off by this spit and delta formation while the northern channel has increased its length through additional meandering.

The dredge holes are continuing to fill and are becoming less visible.

5.14 7 July 1982 (Figure 22)

The eastern end of Main Beach is not visible in this photograph but the width of beach between the training wall and the western end of Hastings Street has increased. Around 220 000 m^3 of nourishment sand was added in 1981, some time after 5 March, as the dredge holes are not apparent in the previous photo. The southern spit and ebb-tidal delta have enlarged, as would be expected after beach nourishment is performed. The channel remains in a similar position and shape to the previous photo but the entrance has migrated further north due to growth of southern spit and ebb-tidal delta. The northern spit has been eroded as a result of this migration as the channel attempts to maintain its cross-sectional flow area. The northern channel is the dominant flow path but it appears the southern channel may be re-opening.

Beach nourishment has resulted in a large volume of sand being introduced to the system as evidenced by the infilling of the channel and formation of many deltas inside the entrance. Flood tides are transporting sand as far back as Munna Point at low tide (when flow is restricted to the channel), as indicated by the formation of deltas in this region and further upstream. The flood-tidal delta has grown in size considerably due to the deposition of sediment at higher tides when water passes over this region.
Dredge holes are apparent at Munna Point and adjacent to Noosa Sound, while the vegetation on Noosa Woods is becoming well established.

5.15 26 June 1983 (Figure 23)

The width of the eastern end of Main Beach appears quite small but the area between the groyne and training wall appears to have remained relatively constant.

The southern channel has reopened and cuts back slightly into the Noosa Woods area, but the northern channel remains the dominant flow path. The volume of sand in the ebb-tidal delta has decreased. The northern spit has grown and resulted in the entrance migrating towards the training wall. The inlet now faces its more characteristic easterly direction compared to its previously northern orientation.

The flood-tidal delta between the two channels remains a dominant feature of the system.

5.16 23 November 1984 (Figure 24)

The eastern end of Main Beach is not visible in this photo but the area between the groyne and training wall appears to be eroding, as evidenced by the removal of sand from the tip of the training wall. It appears this sand is moving into the system to fill the southern channel, as it is now only a minor flow path.

Considerable deposition of the northern spit is obvious and has forced the channel to meander back towards the training wall before exiting alongside it. This meandering has increased the channel length, and migration towards the training wall has almost entirely removed the southern spit.

The flood-tidal delta between the two channels appears to be growing in size and is responsible for the blockage of the southern flow path.

5.17 12 September 1985 (Figure 25)

The useable area of Main Beach appears quite small and erosion along the western side of the rock groyne is apparent. This sand is moving into the system and has resulted in deposition of the southern spit and ebb-tidal delta.

Deposition of the northern spit has increased the channel length, resulting in it cutting further back into the Noosa Woods area before exiting in a northeasterly direction. In addition, a second minor channel has formed on the north shore that appears to be discharging at higher tides. There are signs that the northern channel is infilling, as shown by the decreased channel width between the flood-tidal delta and northern spit. In addition, it appears that the southern channel is conveying larger flows.

Growth of the deltas opposite Munna Point is evident, further indicating the transport of sand into the system in an attempt to fill the dredge holes.

5.18 28 August 1986 (Figure 26)

The eastern end of Hastings Street is not visible, but deposition on the eastern side of the rock groyne extends approximately two-thirds of the length of the structure. However, erosion on the western side of the rock groyne is obvious.

The northern spit is quite long and hooks back towards the north shore inside the river entrance. It connects to the flood-tidal delta and effectively blocks the northern channel. The southern channel is now the dominant flow path and has migrated towards the north shore due to growth of the southern spit and ebb-tidal delta.

The dredge holes near Munna Point are less visible and the volume of sand contained in deltas in this region appears to have decreased.

5.19 23 July 1987 (Figure 27)

Once again, the eastern end of Main Beach is not visible in this photo but the amount of sand on the eastern side of the groyne has reduced and further erosion between the groyne and training wall is apparent. Sand appears to be bypassing the inlet on the ebb-tidal delta and being deposited on the north shore, as deposition is evident in this region.

The northern channel has breached the northern spit and become the dominant flow path. The material that previously formed the southern spit has been transported back into the system, effectively blocking the southern flow path. Deposition on the ocean side of the northern spit has forced the entrance towards the training wall. As material is deposited on the northern side, the channel migrates towards the training wall in an attempt to maintain its cross-sectional flow area.

The flood-tidal delta inside the entrance has grown in size considerably and the previously dominant southern channel now contains significant amounts of sand.

5.20 12 June 1988 (Figure 28)

Erosion on the western side of the rock groyne has continued, resulting in a relatively narrow section of beach.

The colour of the water suggests a recent fresh (i.e. rainfall) event that would have increased the volume of ebb-tidal flows. The southern channel has reopened and both channels are operating. The southern spit is quite large and has recently been breached by ebb flows in an easterly direction.

The northern spit has grown in size compared to the previous photo (from 1987). It forces the channel to meander back ‘sinusoidally’ before joining the southern channel flow path. At this point, the channel exits in a northerly direction.
The large flood-tidal delta still separates the northern and southern channels.

5.21 17 December 1990 (Figure 29)

Between October 1988 and January 1989, 140 000 m^3 of nourishment sand was added to the beach. The effect of this material on the useable area of beach is not clear as the eastern end of Hastings Street is not visible in this photo. It can be seen that the western side of the rock groyne remains in an eroded state.
In this photo, both channels are open although it appears that the northern channel may be in the process of filling between the tip of the northern spit and the flood-tidal delta.

The volume of sand contained in both the northern and southern spits remains virtually unchanged since the previous photo (from 1988), although the shape of each has altered slightly.

5.22 15 April 1991 (Figure 30)

The width of useable beach towards the middle section of Hastings Street is relatively narrow, but more sand is evident than in previous photos. This is due to the addition of 41 570 m^3 of nourishment sand between June 1990 and November 1990.

The northern channel was blocked by overwash of the northern spit into the channel. However, the northern spit had recently been breached close to the vegetation line on the north shore. The more direct southern channel remains the dominant flow path (Jackson, Black & Tomlinson, 1999).

The southern channel cuts back towards Noosa Woods. Deposition of the southern spit then forces the channel toward the north shore, before exiting in a north-northeasterly direction. Some erosion is evident on the eastern side of the training wall at Noosa Woods.

The flood-tidal delta separates the northern and southern flow paths but has changed little since the previous photo (from 1990). Flood tides are transporting sand further up the river, as evidenced by the formation of deltas where the northern channel changes direction near Munna Point.

5.23 6 June 1992 (Figure 31)

There is very little useable beach area towards the eastern end of Hastings Street (about 50 m wide) and the volume of sand accumulated on the eastern side of the rock groyne has reduced slightly. Considerable erosion between the groyne and the training wall is also apparent.

Both the northern and southern channels are open, but the dominant flow path is a ‘middle’ channel that cuts through the flood-tidal delta and flows directly to the sea. This direct flow path is typical of a flood/storm event and resulted as a response of the river to cyclones Betsy and Fran in January and March 1992, respectively. Figure 7 highlights the response of the system to a flood event. Cyclone Betsy resulted in a breakthrough of the southern channel and has effectively removed the cutback effect/meandering into Noosa Woods. This new ‘middle’ channel has all but removed the southern spit formation.

Figure 7. Aerial photograph of the beach and estuary system highlighting the response to a flood event in 1992

5.24 31 July 1992 (Figure 32)

The width of Main Beach at the eastern end of Hastings Street and the area between the groyne and the training wall remain virtually unchanged.

The northern channel remains open but the northern spit has been removed. The ‘middle’ channel remains the dominant flow path but both it and the southern channel appear to be infilling.

5.25 2 March 1993 (Figure 33)

The width of Main Beach and the area between the rock groyne and the raining wall appear to be relatively unchanged since the previous photo (from 1992) and deposition at both northern and southern spits is minor. This suggests there is a shortage of material available for longshore transport processes as deposition on the spits is usually the first opportunity for sediments to settle.

The northern and dominant middle channel remains open but some changes are apparent. Growth of the northern spit has resulted in the northern channel having a more meandering configuration at its exit and it appears the spit may be in the process of connecting to the flood-tidal delta.

Growth of the flood-tidal delta is causing a deflection of flow towards Noosa Woods. This in turn is putting pressure on the southern channel to reopen. The delta formations further inside the entrance (towards Munna Point) remain relatively unchanged.

5.26 25 May 1994 (Figure 34)

There are much larger volumes of sand between the groyne and the training wall visible at this time, while accumulations of sand are maintained towards the eastern end of Hastings Street. In addition, both northern and southern spits have experienced considerable growth. As this has occurred in the absence of nourishment activities, it is assumed that this material was transported around the headland from Alexandria Bay by the cyclones of 1992.

The northern channel is completely blocked off with the spit having welded to the flood-tidal delta. The southern spit has forced the channel to migrate to a more northerly position and it exits in front of the north shore.

The middle channel remains the dominant flow path. The growth of the southern spit has resulted in the channel moving away from Noosa Woods and extending its length. The southern channel now contains considerable amounts of sand and growth of the flood-tidal delta has continued.

5.27 5 September 1997 (Figure 35)

Between August and November 1994, 146 000 m3 of nourishment material was added to Main Beach, with an additional 74 930 m3 added between October and November 1996. However, this material has been removed as the northwestern end of Main Beach and the area between the groyne and the training wall are again eroded.

The river entrance has returned to a more characteristic location, exiting in a northeasterly direction midway between the training wall and the north shore. The northern channel has reopened, though it is only a minor flow path. The southern channel has a ‘sinusoidal’ appearance due to growth of the southern spit and of the flood-tidal delta towards Noosa Woods. This has resulted in the channel cutting back into the Noosa Woods area.

5.28 9 October 1997 (Figure 36)

The scale and glare of this photo make the finer details of Main Beach difficult to determine, but the configuration of the channels can be seen.

Little change can be noted between this and the previous photo (from September 1997) other than that continued growth of the flood-tidal delta is further restricting flow to the Noosa Woods side of the meandering southern channel.

5.29 23 July 1999 (Figure 37)

The eastern end of Main Beach remains eroded, as does the western side of the groyne.

The northern channel remains open, but is still only a minor flow path. Growth of the northern spit has resulted in the channel moving closer to the training wall. However, signs of the previous, northerly-oriented channel that exited parallel to the north shore still exist (refer to Section 5.26, 25 May 1994).

The southern channel remains open but has lost its characteristic meander into Noosa Woods. The extension of the flood-tidal delta towards Noosa Woods has been breached, resulting in the formation of a ‘middle’ channel that appears to be the dominant flow path. This may have been encouraged by recent freshwater flushing events that would have increased the volume of ebb tides and gives the water its brown colour.

5.30 7 July 2001 (Figure 38)

In October 1999, 80 190 m3 of nourishment sand was taken from offshore and used to build up the beach profile. In addition, between May and August 2000, 65 000 m3 of nourishment material was added to Main Beach. The impact this has had on the eastern end of Main Beach cannot be determined as it is not visible in this photo. However, the growth of the southern spit would suggest that this material is being removed, as this is generally the first opportunity for deposition of material removed from Main Beach by longshore transport mechanisms.

The southern flow path appears now to be more dominant. Dredge holes are visible in the ‘active’ zone opposite Munna Point. This would have reduced the frictional resistance in this region and encouraged flood flows through the southern channel. This increase in flow would increase the scour potential and assist in filling the dredge holes.

Growth of the northern spit is threatening to close this channel, while the southern channel is beginning to regain its characteristic meandering shape by cutting back into the Noosa Woods area. Combined with the growth of the southern spit, the southern channel is regaining a ‘sinusoidal’ shape and is effectively increasing the channel length.

5.31 24 October 2001 (Figure 39)

The area of useable beach on Main Beach has increased when compared to the photo of 23 July 1999 (refer to Section 5.29). However, continued deposition around the training wall would suggest that longshore transport mechanisms are removing the material from the beach. This is in response to the trial dredge area inside the “active” zone that the system is attempting to fill.

Growth of the southern spit is forcing the channel to migrate towards the north-shore (about 370 m at the furthest point). The northern spit is also growing, and has blocked the northern channel. It has ‘welded’ to the flood-tidal delta, though there are signs of a minor flow path around the tip of the groyne at high tide. In addition, a minor middle channel exists across the flood-tidal delta and would transmit a small volume of flow at high tide.

The southern channel cuts back into Noosa Woods before being forced away from the training wall by the southern spit. The ‘sinusoidal’ shape it was beginning to obtain in the previous photo (Section 5.30) is now much more defined.

5.32 18 January 2002 (Figure 40)

Around 29 700 m3 of nourishment sand taken from the ‘active’ zone between October and December 2001 (refer to Appendix 2 for sand nourishment records) has resulted in a beach width of approximately 105 m at the eastern end. However, erosion is apparent between the groyne and training wall.

The southern channel remains the dominant flow path and the additional dredging in the ‘active’ zone would further encourage this. Continued growth of the southern spit has forced the channel to migrate even further towards the north shore. The ebb-tidal delta has continued to grow, resulting in a constriction of the channel entrance and more than one discharge point is visible in this region.

There are signs that the northern spit has been breached on the flood tide, and the minor flow path around the tip of the northern spit is still operating during high tide. In addition, the middle channel through the flood-tidal delta is still conveying minor flows during high tide.

Sand is continuing to be transported back into the ‘active’ zone to fill the dredge hole. The trial dredge zone and breaching of the northern spit performed in late 2001 can be seen.

6 Discussion

As previously mentioned, training of the river entrance and other modifications to the beach system have altered the control point and affected the way in which the system now responds. Since 1978, when dredging for nourishment sand commenced, the entrance has been infilling and channels realigning in response to the altered flow regime (Jackson *et al.*, 2001). In performing this study, a major objective was to determine the fate of nourishment sand introduced to the system and its effect on the Noosa River inlet. By investigating the recovery after the 1972 flood and comparing this with the recovery after the 1992 flood event, it was hoped that similarities could be observed and used to develop a conceptual model of how the system now responds. Furthermore, behaviour of the tidal deltas and shoals and channel movement has been investigated in times of limited and abundant sand supply.

The typical response of the system to flood events is the formation of a direct channel to the sea. In 1972, this channel was deflected by the flood-tidal delta in the middle of the lagoon area and exited via the southern channel at the end of Hastings Street. Following this period, the system responded by forming a more dominant northern channel. This was during a period where beach nourishment was not being undertaken. Deposition of sand on the southern spit, however, suggests that longshore transport mechanisms were in action and that the storm event transported a ‘slug’ of sand around the headland that helped to rebuild the beach system.

In recent times, the typical response of the system to flood events has been the formation of a middle channel that cuts through the dominant flood-tidal shoal and flows directly to the sea. Figure 8 indicates the location of the flood channel formed in 1992 and compares it with the pre-flood configuration of 1988. The recovery period generally results in the dominant middle channel reverting to the more characteristic meandering southern channel.

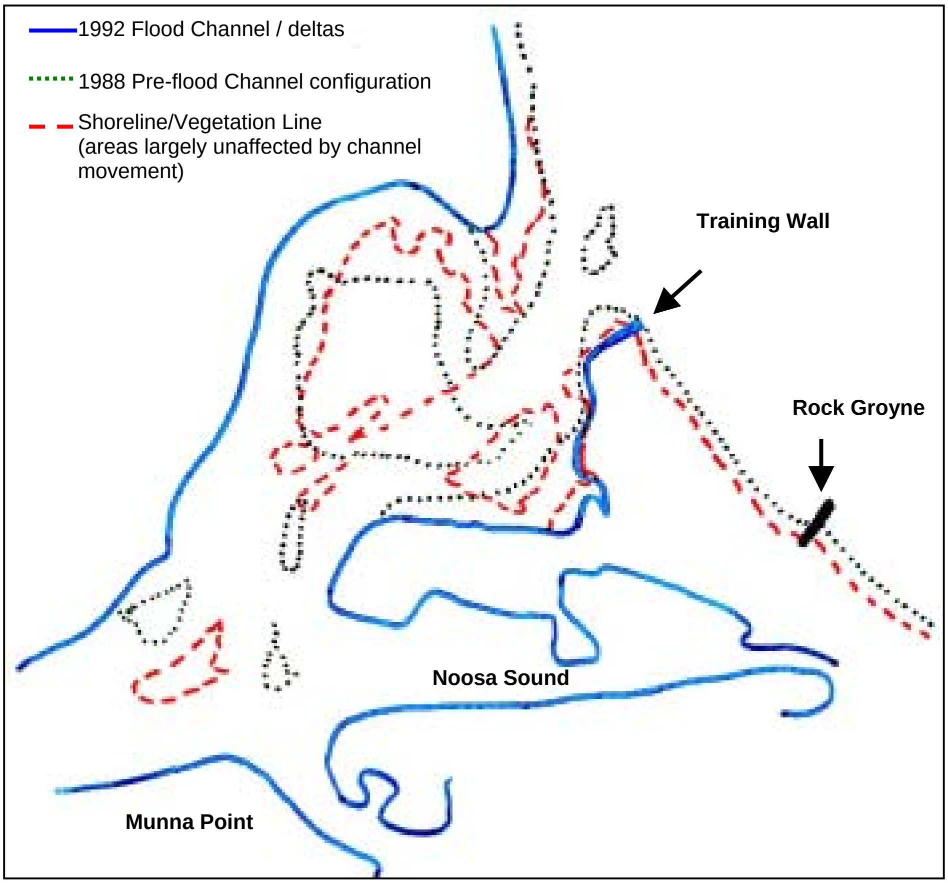

Figure 8. Overlay of Noosa Beach and estuary system indicating the response to storm events

As conditions return to normal, flood tides begin transporting sand through the inlet. At low tides, the flow is restricted to the channel so sediments are transported further up the estuary towards Munna Point. However, at higher tidal elevations, the deltas are covered and sheet flow occurs. This corresponds with a slower flow velocity and hence an opportunity for sediments to settle on the deltas. As the northern spit enlarges, it forces flow over remnants of the dominant flood-tidal delta. This results in growth of this delta and the delta on the southern side. These two features generally result in the deflection of flow towards the Noosa Woods area as the previously dominant middle channel becomes constricted.

This behaviour is further illustrated by comparing the photos of 23 July 1999 and 24 October 2001 (Appendix 1, Figures 37 and 39 respectively). Although there was no significant flood event in 1999, the colour of the water indicates a considerable volume of fresh water has been introduced into the system. This would have increased the ebb-tidal flow and encouraged the formation of the more direct middle channel that can be seen (Figure 37). By 2001 though, this channel had been filled, the flood-tidal delta had grown considerably and the meandering southern channel was again the dominant flow path.

The models described by FitzGerald *et al.* (1978 cited in FitzGerald, 1988) (refer to Section 3.1, Figures 1–3) are very useful in describing the processes observed at the Noosa River inlet. It should be noted that during the history of an inlet, all three models may be the dominant bypassing process at any one time (FitzGerald, 1988). This is certainly the case for Noosa, and will be described in more detail in the following paragraphs.

Excess sand in the system results in growth of the southern spit which ultimately forces the channel to discharge in a much more northerly position. As described by Fitzgerald *et al.* (1978 cited in FitzGerald, 1988) in Model 1, this migration typically corresponds with an elongation of the inlet channel. Such a configuration results in inefficient hydraulic flows and an unstable system. A similar situation can be observed a few times throughout the history of the Noosa River inlet.

In 1981, nourishment activities added 220 000 m^3 of sand to the beach. The photo taken in July 1982 (Appendix 1, Figure 22) suggests the effect of this sand was to force the channel to discharge in a more northerly location. As the volume of sand available for longshore transport decreased, the spit would have been breached and the channel returned to a shorter, more stable configuration (Camfield & Morang, 1996). This action effectively bypasses a large volume of sand to the downdrift shoreline (FitzGerald *et al.*, 1978 cited in FitzGerald, 1988). The July 1982 photo shows that the southern spit has been breached and by June 1983 (Appendix 1, Figure 23), this shorter, more efficient southern flow path has become the dominant channel.

In 1988, the inlet had returned to a similar, unstable northerly orientation (refer to Appendix 1, Figure 28). In this photo, the southern spit has been breached and the channel appears to be returning to a more efficient configuration. However, there are no photos taken shortly after this to verify this hypothesis, so it is difficult to determine whether the channel favoured this shorter flow path. The next available photo is in late 1990 (Appendix 1, Figure 29), and shows the channel to be in a similar northerly orientation. However, between October 1988 and November 1990, 181 570 m^3 of nourishment sand was added to the beach (refer to Appendix 2 for sand nourishment records). This is a considerable volume of sand and may have been responsible once again for forcing the system out of equilibrium. By 1991, the inlet moved back closer towards the training wall

(Appendix 1, Figure 30), while by 1992 a direct middle channel to the sea had been formed by the flood event in that year (Appendix 1, Figure 31).

The photo taken in May 1994 (Appendix 1, Figure 34) again shows the inlet to be in an unstable northerly orientation. As previously mentioned, the excess sand responsible for this channel migration would have been due to cyclones Fran and Betsy in 1992. These events would have been responsible for transporting large 'slugs' of sand around the headland into Laguna Bay, before smaller swells transported the material back onto the beach under normal conditions.

Unfortunately, there are no subsequent photos available until late 1997 (Appendix 1, Figure 35) so it is difficult to determine the immediate response of the system after this unstable configuration was identified. By 1997 though, it had resumed its more usual northeasterly orientation.

In the past year or so, the inlet throat has remained stable while the main channel has migrated. Such behaviour is described by Model 3 (Figure 3) proposed by FitzGerald *et al.* (1978 cited in FitzGerald, 1988). By comparing the inlet in October 2001 and January 2002 (Figures 39 and 40 respectively), it can be noted that although the inlet throat has remained stable, the ebb-tidal delta has been breached resulting in migration of the channel. Such actions are responsible for bypassing a large volume of sand contained in the ebb-tidal delta to the downdrift shoreline and would be responsible for the southerly deflection of the channel visible in 2002.

7 Conclusions

The third main objective of this project was to develop a conceptual model of the behaviour of nourishment sand entering the system. Although the first two objectives have been achieved and described in previous sections, the third has not, due to the nonavailability of data to describe the processes that were occurring. The analysis technique used here is effective and allows an accurate description of system response to be determined. However, the lack of continuity of the data set and the inability to correlate other important information (such as dredging records and storm events) with the photos has made it difficult to fully achieve the final objective.

The photographic surveys of the coast are performed at a minimum of every four years. In some instances there is a photo missing that proves vital to the description of the system response. In spite of this, a number of conclusions have been made based on the available data. These conclusions are discussed below in order of decreasing significance.

- Although the system remains in equilibrium (i.e. the volume of sand supplied to Main Beach by nourishment activities is enough to fulfil the longshore transport requirements), the northern channel does not break through. The nourishment activities being performed supply enough sand to maintain the ebb-tidal delta that protects the northern spit from breaking through. The consequence of this will be that the southern channel will remain the dominant flow path and the Noosa Shire Council will have to continue to deal with bank erosion on the southern side at Noosa Woods.

- A consistent feature of the system is the flood-tidal delta located in the middle of the lagoon. Analysis of the aerial photographs indicates that the system responds to changes in this delta and other features of the ‘active’ zone by transporting sand on flood tides to replace any material that may have been removed. Figures 39 and 40 (Appendix 1) confirm this by showing the system responding quickly in an attempt to fill the holes created by a trial dredge performed in late 2001/early 2002. Processes in the ‘active’ zone have visibly been influenced by these activities. Removal of sediment from this region effectively decreases frictional resistance to flow. In turn, this affects (increases) the hydraulic gradient of the channel and encourages flow through the channel that has been influenced by the dredging activities. This increased flow corresponds to an increase in scouring potential that may result in the exploitation of any ‘weak spots’ in the system.

The breaching of the northern spit evident in the photo of 18 January 2002 (Appendix 1, Figure 40) may have been a result of this dredging. The question raised by this hypothesis is what will happen if dredging of the ‘active’ zone occurs on a much larger scale, as has been suggested to continue beach nourishment activities. Based on observations when this relatively small volume of sand (29 700 m^3) was removed from the ‘active’ zone in late 2001, if dredging on a larger scale occurs, the hydraulic gradient will be affected even more. This would correspond with larger flood-tidal flows being generated to transport material into the ‘active’ zone to fill the holes. As a result, there would be a considerable increase in scouring potential.

Therefore, large-scale dredging of the active zone may be the catalyst for the current flow regime to change and may result in a switch of the dominant channel location (from southern to northern). Although this may be beneficial from the council’s point of view when relief in the scouring of the southern bank would result, the fish breeding area on the northern bank may be adversely affected and would result in a decline in the fish reserves of the region. This would obviously have some serious effects for fishers and many local businesses in the area.

The proposed new dredging scheme will fail to address the erosion problems of Noosa. Although it will provide a plentiful supply of sand for nourishment activities and a useable beach area for holidaymakers, it will be rapidly removed as witnessed in the past. Indeed, it could be expected that it will be removed at an even faster rate. The decreased hydraulic resistance of the channel will encourage even larger flows and the system will respond by attempting to fill the disturbance in the ‘active’ zone. It is therefore suggested that Noosa Council would benefit more from investing in a scheme that addresses the underlying problem and by trying to gain a better understanding of the processes being dealt with than investing in the proposed new dredging scheme.

- As previously discussed, beach nourishment activities require a thorough understanding of the hydraulic and morphological processes that occur in the area of interest if they are going to achieve an optimal solution (CUR, 1987). It has been identified that approximately 80 000 m^3/yr of nourishment sand is required to maintain Main Beach (Jackson *et al.,* 2001). The dredging and nourishment records contained in Appendix 2 indicate that nourishment sand is generally added over a period of a few months. The fact that the large volumes of sand added in the past have been rapidly eroded suggests that the addition of this material in such large quantities is not suited to local conditions and weather patterns.

Optimum application of nourishment sand would be achieved by trickle-feeding sand onto the beach as it is required. However, from an economic point of view, it may be beneficial to add this material rapidly and maximise the width of the beach for the busy holiday periods. Furthermore, as no permanent pumping system is in place at Noosa, the cost of installing the pipe and sand delivery system makes it more viable to deliver the sand in one go. From an environmental point of view, this technique is unsustainable as the rate of sand removal is rapid, leading to modifications of the inlet and estuary and the requirement for more dredging.

- Based on the model proposed by Walton and Adams (1976), as sea levels rise and tidal prisms increase, the volume of material stored in ebb-tidal deltas will increase also. Although some of the material will come from channel scouring, it could be expected that some will be eroded from the adjacent beaches. Therefore, in the future, it will be vital to have a more thorough understanding of the coastal processes occurring at Noosa. If nourishment activities are to continue, they will have to be designed more effectively to achieve optimum results. With sand supplies nearing exhaustion, the likelihood of causing damage to the fish habitat should dredging of the ‘active’ zone be increased, and the fact that nourishment does not address the cause of erosion, it is more likely that some form of coastal structure will be required to reduce the generation of longshore currents caused by the misalignment of the rock seawall.

  However, as has been witnessed in the past, modifications to the beach leads to the establishment of a new control point for the system. It may take some years before the new system approaches a state of equilibrium and the long-term consequences of these actions are fully realised. Therefore, before any new structures are put in place, coastal engineers and planners must make certain that the ramifications of any new structures are fully understood. This would require extensive modelling of both current and future predicted conditions.

The design and modelling of an artificial reef to realign wave crests has been investigated, but these have been rejected due to the risk of human injury under certain weather conditions. The inability to arrive at an optimum solution suggests that the system is still not fully understood and more detailed modelling is required to gain a greater understanding of the processes at work.

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Appendix 1. Historical aerial photograph collection

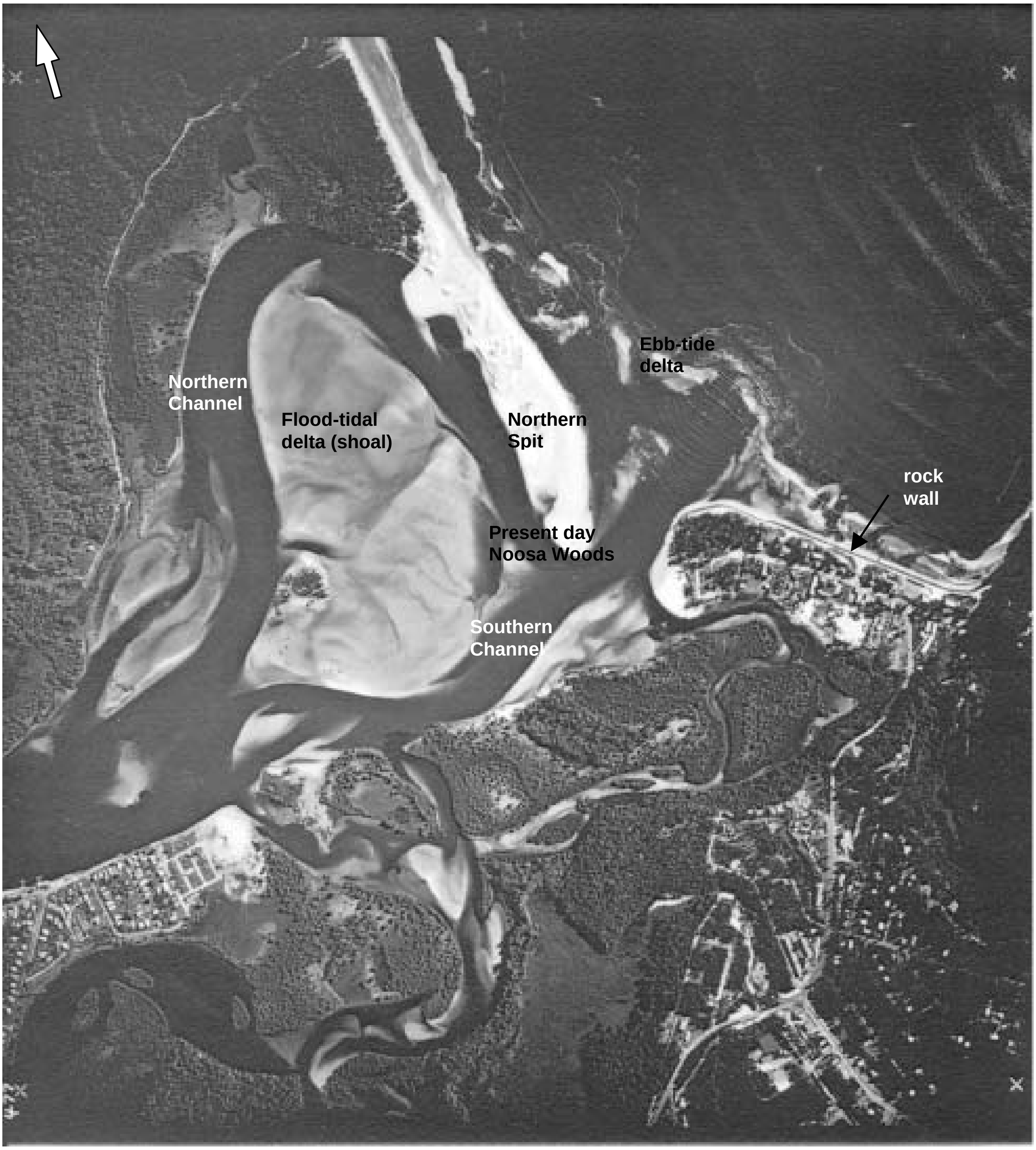

Figure 9. Noosa beach and estuary system, 19 May 1972 (Source: Beach Protection Aerial Photography, 1972)

Figure 10. Noosa beach and estuary system, 12 September 1973 (Source: Beach Protection Aerial Photography, 1973)

Figure 11. Noosa beach and estuary system, 13 February 1974 (Source: Beach Protection Aerial Photography, 1974)

Figure 12. Noosa beach and estuary system, 6 February 1978 (Source: Beach Protection Aerial Photography, 1978)

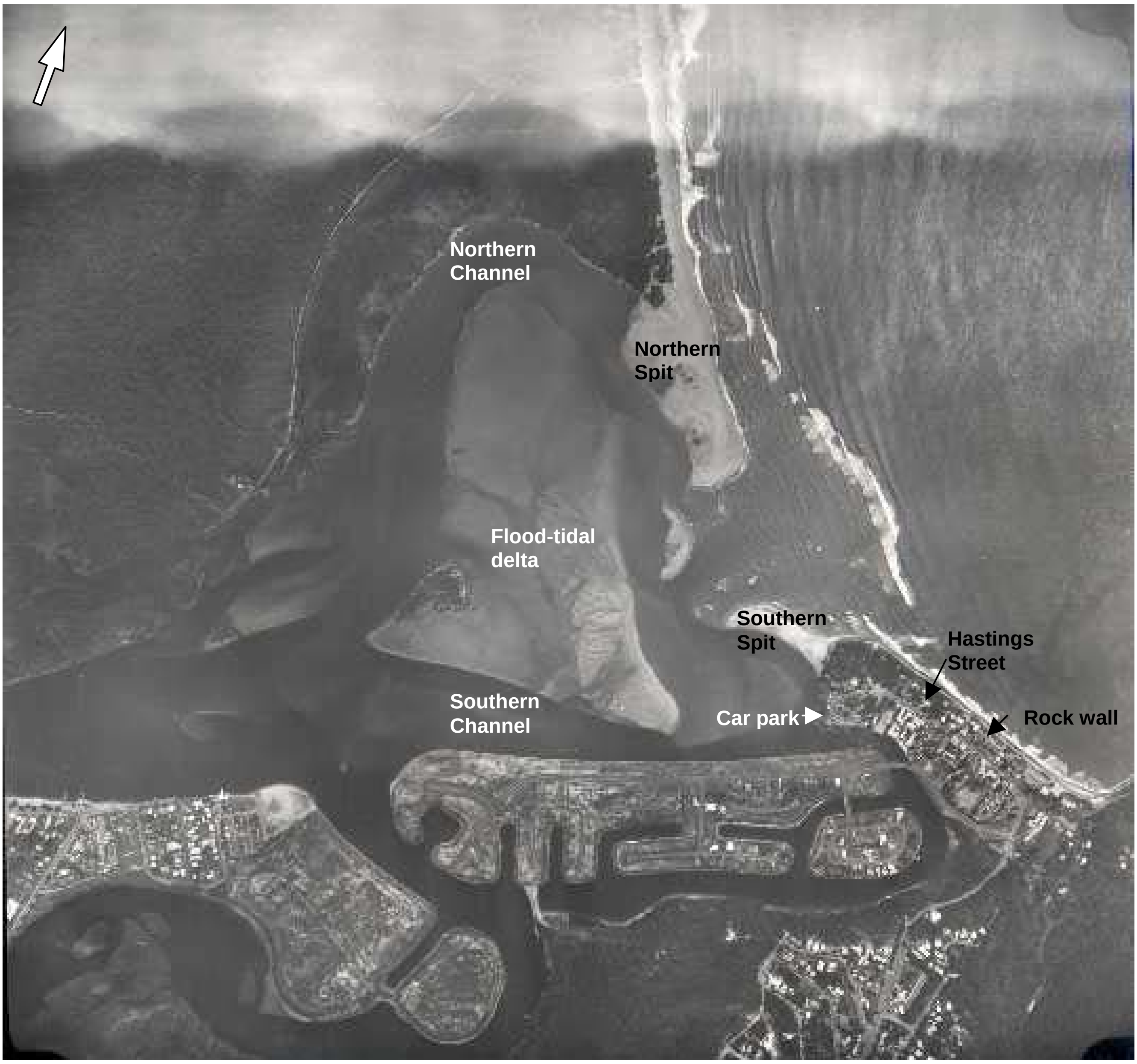

Figure 13. Noosa beach and estuary system, 9 April 1978
(Source: Beach Protection Aerial Photography, 1978)

Figure 14. Noosa beach and estuary system, 26 June 1978
(Source: Beach Protection Aerial Photography, 1978)

Figure 15. Noosa beach and estuary system, 13 July 1978 (Source: Beach Protection Aerial Photography, 1978)

Figure 16. Noosa beach and estuary system, 4 September 1978
(Source: Beach Protection Aerial Photography, 1978)

Figure 17. Noosa beach and estuary system, 13 October 1978 (Source: Beach Protection Aerial Photography, 1978)

Figure 18. Noosa beach and estuary system, 5 December 1978
(Source: Beach Protection Aerial Photography, 1978)

Figure 19. Noosa beach and estuary system, 23 May 1979 (Source: Beach Protection Aerial Photography, 1979)

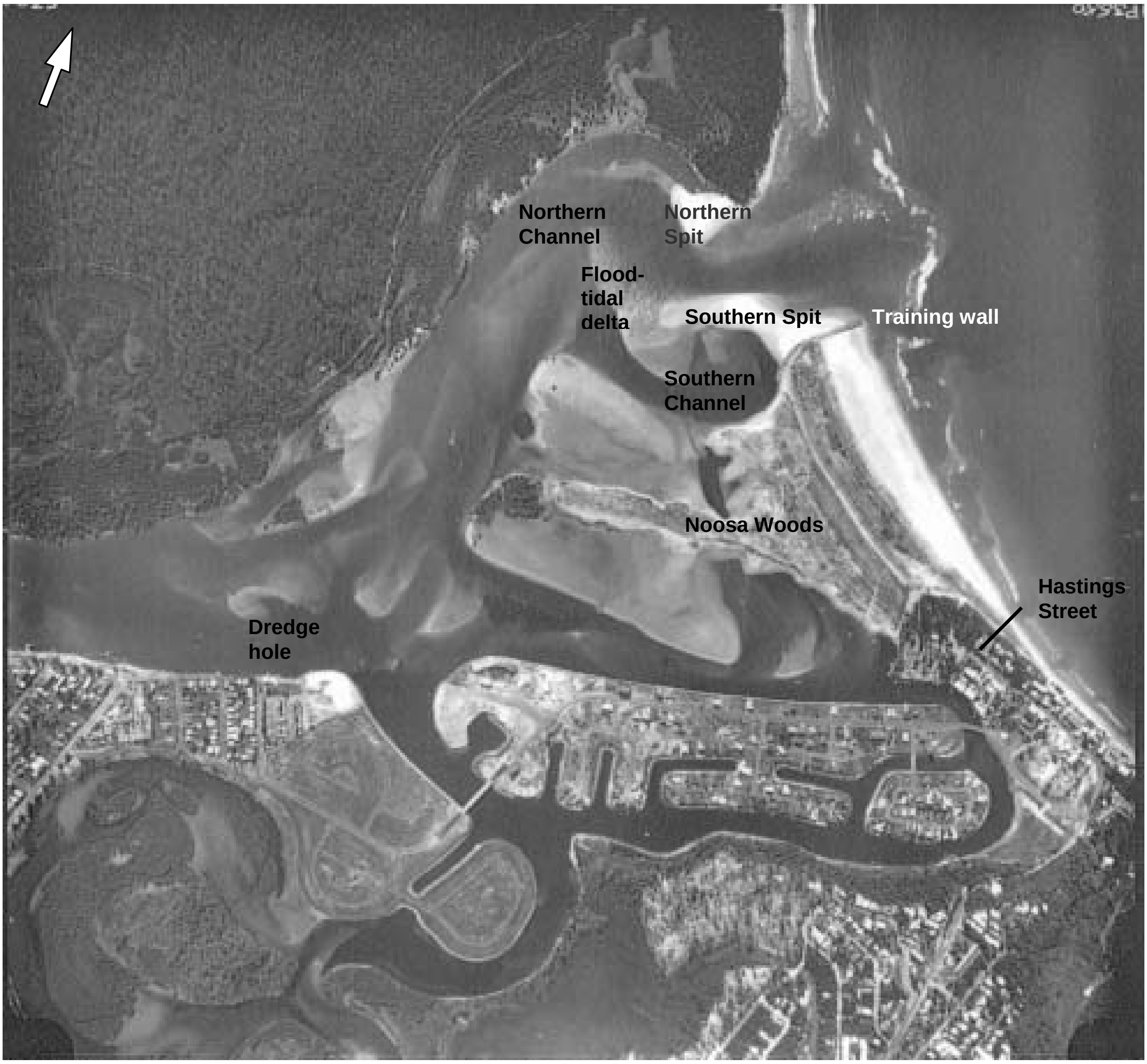

Figure 20. Noosa beach and estuary system, 14 June 1980 (Source: Beach Protection Aerial Photography, 1980)

Figure 21. Noosa beach and estuary system, 5 March 1981 (Source: Beach Protection Aerial Photography, 1981)

Figure 22. Noosa beach and estuary system, 7 July 1982 (Source: Beach Protection Aerial Photography, 1982)

Figure 23. Noosa beach and estuary system, 26 June 1983 (Source: Beach Protection Aerial Photography, 1983)

Figure 24. Noosa beach and estuary system, 23 November 1984 (Source: Beach Protection Aerial Photography, 1984)

Figure 25. Noosa beach and estuary system, 12 September 1985 (Source: Beach Protection Aerial Photography, 1985)

Figure 26. Noosa beach and estuary system, 28 August 1986 (Source: Beach Protection Aerial Photography, 1986)

Figure 27. Noosa beach and estuary system, 23 July 1987 (Source: Beach Protection Aerial Photography, 1987)

Figure 28. Noosa beach and estuary system, 12 June 1988 (Source: Beach Protection Aerial Photography, 1988)

Figure 29. Noosa beach and estuary system, 17 December 1990 (Source: Beach Protection Aerial Photography, 1990)

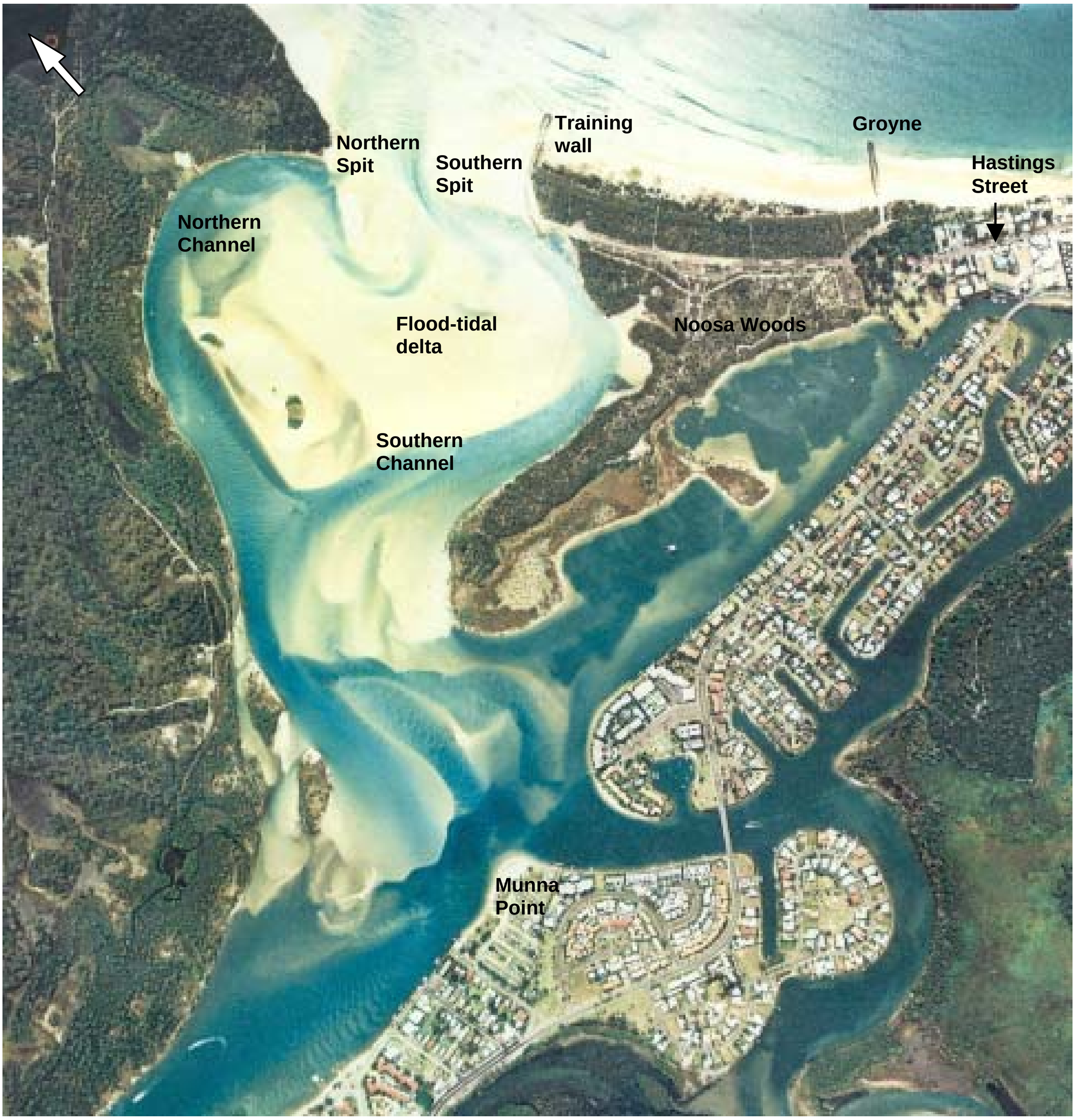

Figure 30. Noosa beach and estuary system, 15 April 1991 (Source: Beach Protection Aerial Photography, 1991)

Figure 31. Noosa beach and estuary system, 6 June 1992 (Source: Beach Protection Aerial Photography, 1992)

Figure 32. Noosa beach and estuary system, 31 July 1992 (Source: Beach Protection Aerial Photography, 1992)

**Figure 33. Noosa beach and estuary system, 2 March 1993
(Source: Beach Protection Aerial Photography, 1993)**

Figure 34. Noosa beach and estuary system, 25 May 1994 (Source: Beach Protection Aerial Photography, 1994)

Figure 35. Noosa beach and estuary system, 5 September 1997 (Source: Beach Protection Aerial Photography, 1997)

Figure 36. Noosa beach and estuary system, 9 October 1997 (Source: Beach Protection Aerial Photography, 1997)

Figure 37. Noosa beach and estuary system, 23 July 1999 (Source: Beach Protection Aerial Photography, 1999)

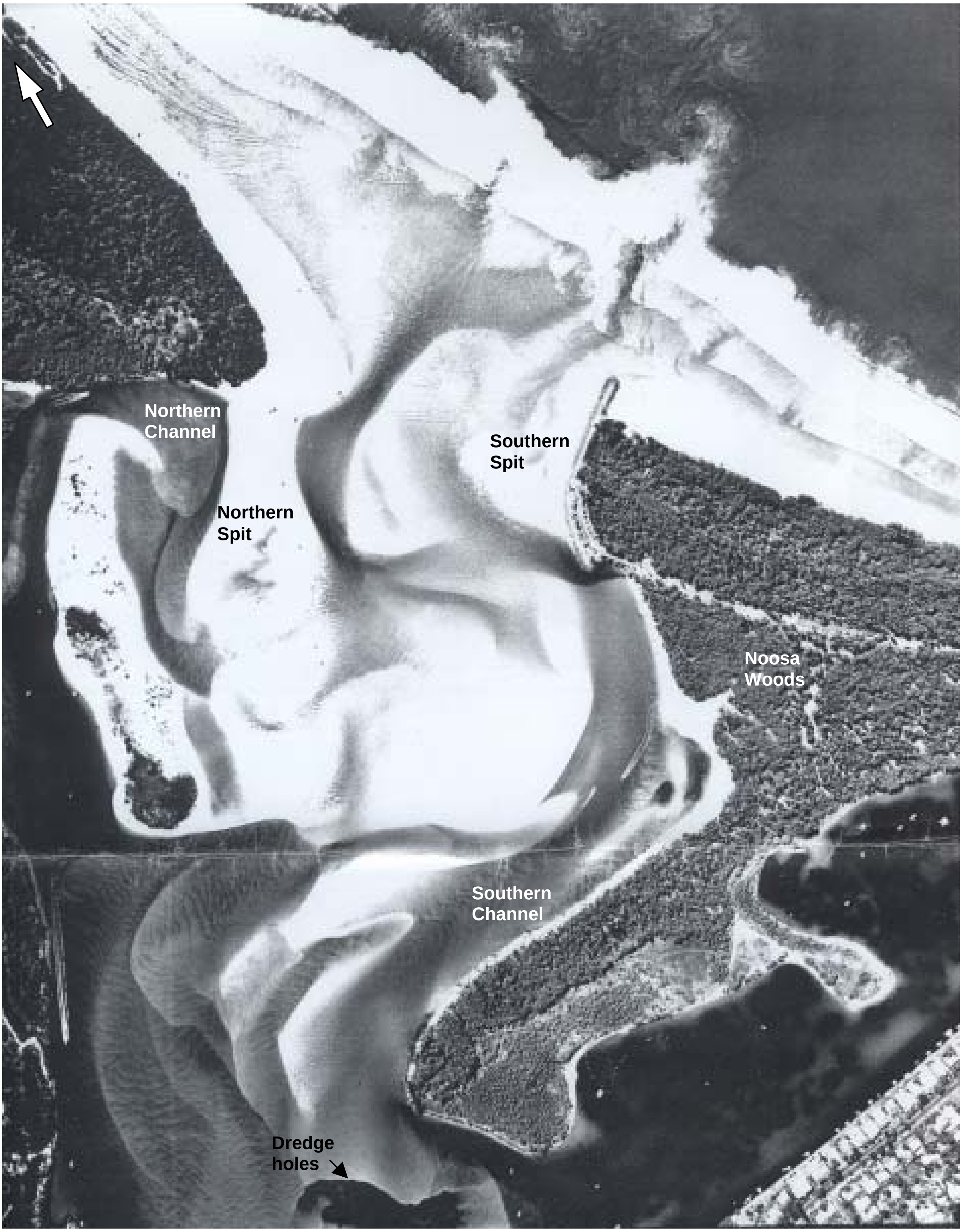

Figure 38. Noosa beach and estuary system, 7 July 2001 (Source: Beach Protection Aerial Photography, 2001)

Figure 39. Noosa beach and estuary system, 24 October 2001 (Source: Beach Protection Aerial Photography, 2001)

Figure 40. Noosa beach and estuary system, 18 January 2002 (Source: Beach Protection Aerial Photography, 2002)

Appendix 2. Dredging records for sand nourishment works at Noosa Beach

Table 1. Records of when and how much sand was removed from the Noosa river estuary for nourishment activities on Noosa Main beach

Date	Amount
1978	200 000 m^3
1981	220 000 m^3
October 1988 – January 1989	140 000 m^3
June 1990 – November 1990	41 570 m^3
August 1994 – November 1994	146 000 m^3
October 1996 – November 1996	74 930 m^3
October 1999 (from offshore by barge—not from estuary)	80 190 m^3
May 2000 – August 2000	65 000 m^3
October 2001 – December 2001	29 700 m^3