Gold Coast Beach Protection

Numerical Modelling of Sediment Movement and Budget at Seaway

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Numerical Modelling of Sediment Movement and Budget at Seaway

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by

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1. INTRODUCTION

1.1 General

This report was prepared for the Gold Coast City Council as part of Stage Two of the Northern Gold Coast Beach Protection Strategy. Following the completion of the Stage One Master Plan, the objective of Stage Two is to provide Council an assessment of environmental, economic and social impacts of the Strategy.

To achieve this objective, a number of community based and engineering/scientific studies were undertaken to investigate different aspects of the adopted Master Plan. This report presents the results of one of these studies. A conceptual sediment budget for the Seaway is developed, and impacts to the beaches immediately north and south of the Seaway, resulting from the various engineering works proposed by the Strategy, are assessed.

Stage Three of the Strategy will comprise implementation of the proposed works.

1.2 Northern Gold Coast Beach Protection Strategy

The Northern Gold Coast Beach Protection Strategy (ICM, 1997a) proposed a long-term, sustainable plan to maintain and enhance the beaches at Surfers Paradise. The local study area extends from the Northcliffe Surf Life Saving Club to Narrowneck (Figure 1.1). There is, however, explicit recognition within the Strategy that the regional impact(s) of any proposed works must be considered both at the study site, and along up-drift and down-drift beaches to the south and north of Surfers Paradise respectively. The Seaway is the major feature of this otherwise relatively uniform coastline, and therefore its interaction and/or influence to the proposed works need to be carefully considered.

The primary objective of the Strategy is to widen the beach and dunes along the surfers Paradise Esplanade. It is proposed that this be achieved by beach nourishment sufficient to nourish the beaches between Northcliffe and Narrowneck by 30-50 m. Beach widening would provide additional public open space along the Surfers Paradise beach-front, and increase the volume of sand available to withstand erosion by large storms. An increase in the storm buffer at Surfers Paradise is required to prevent the existing seawall becoming exposed by storm erosion.

The <u>second objective</u> of the Strategy is to improve recreational surfing opportunities at Narrowneck. It is recommended that a submerged reef be constructed at Narrowneck, to both act as a coastal control point to stabilise sand nourishment, and to improve surfing conditions at the beach.

1.3 Study Tasks and Methodology

The purpose of this study is to provide a refined conceptual model of the longshore transport and sediment budget in the vicinity of the Seaway. This is then used to model shoreline evolution for a range of possible sand by-passing, sand back-passing, and beach nourishment scenarios. In addition, the regional-scale influence of a submerged reef located at Narrowneck is also examined.

The tasks of this study included (as per Technical Brief):

- Collection and review of existing data;
- Volumetric analysis of ebb delta, tidal channel and flood tidal shoals;
- Beach profile analysis of the immediate up-drift and down-drift beaches to determine erosion and deposition rates;
- Modelling of longshore transport and groyne efficiency at the Seaway and across the ebb delta.
- Modelling longshore littoral transport rates using a one-line shoreline evolution model;
- Modelling the cross-shore distribution of littoral drift transport;
- Modelling the impacts of back-passing or dredging from the delta;
- Modelling the effects of the submerged reef using the one-line shoreline evolution model;
- Estimation of present and long-term sediment budgets.

The methodology adopted to undertake this study is to expand and refine the conceptual model of recent sediment movement at the Seaway as detailed in '*Recommendations for Northern Gold Coast Beach Protection Strategy*' (ICM, 1997b). This is achieved through volumetric analysis of adjacent beach and entrance profiles at the Seaway. An expert assessment is then undertaken to determine the dominant transport mechanisms.

The GENESIS numerical model is used to simulate regional shoreline evolution. This then provides the analytical tool with which various scenarios for by-passing, back-passing, beach nourishment and the proposed artificial reef are simulated. In addition, the UNIBEST-LT numerical model is used to assess longshore transport and groyne efficiency at the Seaway. As is the case for all numerical modelling studies, the predictive capability when simulating complex physical phenomena is limited. However, regional sediment transport trends and the broader-scale response to various management options are successfully investigated.

1.4 Report Outline

Following this introductory Section One, Section Two presents a conceptual model for the sediment budget at the Seaway. Both pre- and post- construction of the existing training-walls is considered, and an assessment is provided of the impacts of the proposed management works. The development of the Seaway sediment budget is based on an expert assessment of present conditions, complimented by volumetric analysis of inlet morphology, and a visual interpretation of recent aerial photography.

In Section Three, the GENESIS one-line shoreline model is used to assess equilibrium sediment transport conditions at the Seaway, and to examine the potential impacts of various proposed management options at Surfers Paradise. Specifically, the adjustment of the shoreline to the proposed artificial reef at Narrowneck is examined, incorporating beach nourishment of the up-drift beach, and the back-passing of sand to nourish the down-drift beach.

Section Four provides a more detailed assessment of the cross-shore distribution of the net northward longshore transport through the study region. The effective blocking of this sediment movement by the Seaway for 'average' annual wave conditions is assessed, and natural by-passing of the Seaway during extreme storm conditions is examined. Conclusions and recommendations of this study and are summarised in Section Five.

This study was undertaken by Unisearch Ltd. at the Water Research Laboratory (WRL), in association with Griffith University GU). The material presented in Section Two of this report was prepared by GU. Sections One, Three and Four were prepared by WRL. Section Five (study conclusions and recommendations) were contributed to by both WRL and GU. Project management was undertaken by WRL.

2. SEAWAY SEDIMENT BUDGET - CONCEPTUAL MODEL

2.1 Introduction

The following assessment of the sediment budget and coastal processes in the vicinity of the Seaway is based on the conceptual model presented in the NGBPS Stage One report '*Recommendations for Northern Gold coast Beach Protection Strategy*' (ICM, 1997b). The detailed analysis of beach profile data and aerial photographs outlined in this section has provided sufficient information to enable a refinement of the conceptual model and clarification of the uncertainties associated with that model.

An analysis of all of the recent studies of sediment budget for the Gold Coast was carried out as part of the Stage One Report. The key findings can be summarised as follows:

- Net littoral sediment supply to the southern end of the Gold Coast Embayment is approximately 500,000m^3/year. This figure varies locally at any particular point in time (such as in the Kirra Coolangatta area where there is some disagreement over the actual variation in rates), but in general it is considered that the Gold Coast is in dynamic equilibrium with around 500,000m^3/year reaching the Spit at the northern end of the embayment.
- Within the overall embayment there are sinks of sediment such as Currumbin and Tallebudgera Creeks and the Broadwater, which is estimated to have trapped some 80,000m^3/year of sediment over recent geological time.
- Burleigh headland is a significant coastal control point that influences the regional position of the coastline. The present day alignment of the Gold Coast results in a nearly continuous regional transport of 500,000m^3/year. Nobbys Headland acts as a localised control.
- At the northern end of the embayment, the Seaway, and associated pumped bypassing system provides a complex control on sediment movement.
- Coastal process studies have not previously been carried out for South Stradbroke Island and the Jumpinpin Entrance.

An understanding of the movement of sand in and around the Seaway, and along the South Stradbroke coastline, is critical to an assessment of the availability of nourishment sand for the project from the bypassing system, or from the Broadwater. Associated with this is the need to understand the potential dynamic equilibrium conditions which may define the long-term future requirements for sand availability along this section of coastline.

2.2 Data Analysis Methodology

The following section briefly describes the methodology used to undertake volume analysis of inlet features, and photographic analysis of South Stradbroke Island .

2.2.1 Volume Analysis of Inlet Features

Survey data was obtained from the Queensland Department of Transport (DoT) and the Queensland Department of Environment (DoE). This distinction has been maintained throughout the analysis as the data sets were provided with different datum, format and coverage.

The DoT data consisted of seven recent surveys from March 1989 until March 1997 (refer to Table 2.1 for survey dates). These data were obtained primarily for the purpose of monitoring the channels in the vicinity of the Seaway. The Low Water Datum (LWD) was used pre-1994, and Lowest Astronomical Tide (LAT) since that time. All surveys are aligned with the entrance channel.

The DoE data (refer Table 2.1) are part of the ETA line surveys established in the late 1960s. The data extend further northward than the DoT data, and consisted of surveys from November 1966 through to November 1993, although not all data was relevant for all the areas analysed (refer below). The datum for these surveys is Australian Height Datum (AHD). Survey lines have a different alignment to the DoT surveys.

TABLE 2.1
Dates of DoE and DoT Surveys

DoE	DoT	DoE
Surveys used in all analysis except South Stradbroke		*South Stradbroke*
Oct-84	Feb-93	Sep-68
Jul-86	Feb-94	Aug-71
Nov-86	Nov-94	Mar-74
May-87	Feb-96	Oct-84
Feb-88	Dec-96	Nov-86
Nov-88	Mar-97	May-87
Dec-90		Feb-88
Nov-91		Nov-88
Nov-92		Dec-90
		Nov-91
		Nov-92
		Nov-93

Six regions within and around the Seaway were defined, following the general practise outlined by Hayes (1990) and Boothroyd (1985). These regions, or areas of significance, are: the ebb delta, the up-drift fillet, the down-drift fillet, the channel, the flood shoal, and South Stradbroke Island.

The Ebb Delta, Up-drift fillet and the Down-drift Fillet

The *ebb delta* or the ebb shoal, as it is also known, extends from the eastern part of the Seaway into the ocean, **area E** on Figure 2.1. The ebb delta forms by sediment being swept out to sea during the ebb tide. Deepening, channel widening and mixing with the ocean waters slow this tidal flow, which eventually slows enough for sediment to fall out of suspension, forming the delta. The defining area is a line from the navigation beacon on the northern training wall to the southern training wall, running perpendicular to the channel. By necessity, the definition of the ebb delta region is, in part, constrained by data availability.

The ebb delta has two additional areas defined within it. The *down-drift fillet*, shown of Figure 2.1 as **area D**, is a part of the ebb delta located offshore South Stradbroke Island. This area is where the northern training wall traps sand, but this sand is not under the full effect of the ebb tide. Likewise, the *up-drift* fillet, shown on Figure 2.1 as **area U** is also a part of the ebb delta, but is located offshore of The Spit. This region is where the southern training wall traps sand, but again this sand is not under the full effect of the ebb tide.

The Channel

The *channel*, shown on Figure 2.1 as **area C**, is defined as the region between the limits of the ebb delta and the sand-bypassing pipeline crosses the Seaway. This area contains a majority of features that were important in the Seaway channel, and the pipeline provided a convenient locator to delimit the area.

Flood Shoal

The *flood shoal*, shown on Figure 2.1 as **area F**, is an area in front of Wave Break Island, as well as the main passages that lead to the channel. The limits of this area were also obtained by inherent limits in the DoT survey data. The flood shoal extends from the westernmost limit of the area defined as 'channel' to the north and south boundaries of Wave Break Island.

South Stradbroke Island

The area of **South Stradbroke Island** that is included in this analysis extends from the northern edge of the ebb shoal, up to the limit of survey data (ETA 89), approximately 3.5km northward. This area is shown on Figure 2.1 as South Stradbroke.

2.2.2 Data Manipulation

A digital terrain model (DTM) was derived for each of the six areas using the 3-D mapping program SURFER. The krigging method was used for spatial interpolation. Examples of a DTM obtained from each of the DoE and DoT data sets are shown in Figures 2.3 - 2.4.

Using the Gold Coast City Council's program KEAYS, volumes for each of the six areas at each date of survey were calculated. Change in cumulative volume (relative to the first survey date) are presented graphically in Figures 2.4 - 2.9.

Data Limitations

The reliability of the data in determining volumetric change is limited by the difference in coverage and data density between the DoE and DoT data sets. For comparison, Figure 2.10 shows the relatively dense data coverage provided by DoT surveys, in contrast to the relatively sparse data coverage of the DoE surveys evident in 2.11.

The analysis packages, SURFER and KEAYS, utilise interpolation techniques to provide the necessary number of grid points to carry out volumetric calculations. A scarcity of data in a sequence of surveys can be accommodated and reliable trends produced. However, when comparing the results from one sequence (DoE) with another (DoT), a shift may occur in the volumetric results which does not truly represent the real change.

2.2.3 Photographic Analysis of South Stradbroke Island

Photographs of South Stradbroke Island were interpreted visually in order to assess recent shoreline alignment trends. Photographs were analysed with the assistance of the Beach Protection Authority. 1:12,000 scale aerial photographs were determined to be of the necessary quality to detect changes on South Stradbroke Island, and methods similar to those described by Liu et al. (1993) were used. Run 6 was chosen, due to the full coverage of South Stradbroke Island. This run was photographed in 1973, 1975, 1979, 1982, 1986, 1990 and 1994. Unfortunately, the only photographs available to be viewed were from 1979, 1982, 1990, and 1994. However, this still gives an indication of both pre- and post-stabilisation of the Seaway.

Transects were chosen with the requirement that a local control point was easily identifiable in all photographs, and reasonable coverage of South Stradbroke Island was obtained. Figure 2.12 shows the location of these transects. The location of each transect is as follows:

Transect A: from marina situated on the western shore of The Broadwater
Transect B: from a large recognisable tree in area of non-uniform coloration
Transect C: from unusual cluster of trees
Transect D: from a morphological point on a river
Transect E: from an area cleared of vegetation
Transect F: from a region of discoloured foliage
Transect G: from a large tree in a sparsely vegetated region

From these local control points, the distance to various morphological indicators was determined. The indicators included the vegetation line, incipient vegetation line, high water mark and shoreline. The results of this analysis are shown in Figures 2.13 - 2.16.

2.3 Pre Seaway Conditions

The first step in the process of establishing a sediment budget is to examine what is the known behaviour of the Nerang River Inlet prior to the construction of the Seaway. Previous studies (Polglase, 1987) indicate that prior to 1900, the entrance to the Nerang River was located in the Main Beach vicinity. It is reasonable to assume that at this time, the entrance behaved in a similar manner to other natural entrances on littoral drift coastlines in that it would have migrated in a cyclic fashion. Northward movement of the entrance under the influence of the predominant northerly littoral drift would have been punctuated by episodic breakthroughs further to the south. Other entrances in the region such as the Tweed River and Currumbin Creek are known to have behaved in this fashion.

The location of the entrance has been recorded since the mid 1800s and this data has been interpreted as shown in Figure 2.17. Although there is some conjecture about these locations, there is evidence presented in Delft (1976) that the entrance was observed to move south during the period from 1870 to 1900. This may have indeed been a southern breaching.

This assumed pattern of episodic break-through and migration was changed around the turn of the century when the Jumpinpin entrance formed, creating what is now known as North and South Stradbroke Islands. This event occurred around 1898 and resulted in a fundamental change in the tidal dynamics of the Broadwater (McCauley, 1997). The redistribution of tidal flow resulting from this event would certainly have reduced the tidal flow through the Nerang River Inlet. Under these circumstances the rate of movement of sand alongshore would be greater than the capacity of the tidal flow to remove it and as a result sand deposited on the Spit on the southern side of the entrance and erosion occurred on the northern side. This resulted in the entrance progressively migrating northward at a faster rate. This rate has been estimated as high as 60 m/year (Munday, 1995) with an average rate of movement between 20 and 40 m/year.

The evidence presented above suggests that around 1900 the entrance was near the current location of Marina Mirage. The rate of migration northward since then would clearly be related to the occurrence of major storm event and floods, although there is no evidence of the cyclic migration which is assumed to have occurred previously.

An examination of the behaviour of the Junpinpin entrance this century (McCauley, 1997) has shown that since the original breach, the entrance has remained open continuously. However, episodic events have caused a second channel to open at a location about 1 km to the south of the main Jumpinpin channel. This subsequently closes under the influence of spit migration during normal conditions. The impact of this on the Nerang River Inlet was to cause a cyclic variation in the tidal flow through the inlet, and consequently a variation in the rate of migration. Associated with this was a variation in the supply of littoral sand to the southern end of South Stradbroke island. The long-term stability of the island would not have affected, but cyclic recession and accretion of the shoreline would have been superimposed on the usual shorter time-scale storm event erosion and recovery cycles.

Over the last 25 years or so Jumpinpin has been going through a second channel closure phase following a breach in 1974, which may have accounted for the increasing tidal flow and scour that has been observed at the Seaway in recent years. However, it is also likely the rapid development of the Broadwater over the same period, and the dredging activity associated with it has also resulted in an increase in tidal flow through the Seaway.

In the absence of the Seaway construction, it is reasonable to assume that the Nerang River Inlet would have continued to migrate northward, either until a major event caused a breach to the south, or until a geomorphological or sedimentological control (similar to the indurated sand control at Jumpinpin McCauley 1997) retarded its migration.

The evidence of sediment infilling of the Broadwater throughout this century (Delft, 1970 and Chapman, 1981), suggests that a considerable quantity of sand was being removed from the active littoral transport system at the Nerang River Inlet. The rate of infilling is uncertain, with value of 80,000 to 180,000 m^3/year being estimated.

Longshore transport along the northern Gold Coast beaches is taken to be 500,000m3/year net comprising of 610,000 m^3/year south to north and 110,000m^3/year north to south. These rates were first estimated by Delft (1970) and have subsequently been confirmed by a number of other studies including work carried for this report. Transport rates have not previously been estimated for South Stradbroke Island. However, a detailed projection of the shoreline as part of this study has indicated a more easterly alignment suggesting that it has been in equilibrium with a net transport of less than 500,000 m^3/year.

Combining the above assessments of coastal processes a conceptual model of sediment movement since 1900 has been developed as presented in Figure 2.18. The basis of this model is that the erosion of South Stradbroke Island as the entrance migrated northward was balanced by the accretion on the Spit, and that the ebb delta contained a quasi-steady volume of sand at all times. The significance of this model for the current proposal is that over the 100 years or so prior to the construction of the Seaway the shoreline of South Stradbroke island was in dynamic equilibrium with the supply of sediment bypassing the migrating Nerang River inlet. The rate of this supply is difficult to estimate but it is less than the 500,000 m^3/year estimated for the northern Gold Coast beaches.

This conceptual model is supported by the trends shown in the beach profile analysis carried out for this study. For example the analysis of aerial photographs taken over the period from 1978 to 1985, Figures 2.13 - 2.16, shows a marginal recessional trend. This would most likely reflect the earlier view that development of the Broadwater and closure of the second channel at Jumpinpin over the last few decades may have resulted in a short-term increase in tidal flow and hence a reduction in the bypassing rate at the Nerang River Inlet leading to a possible recession on South Stradbroke. However, it should be equally noted that the result of this project show clearly that South Stradbroke coastline has a more easterly alignment than the rest of the Gold Coast, and will be in equilibrium with a lower net littoral transport rate. This suggests that overall South Stradbroke beaches have been stable over the last 100 years or so.

In summary, prior to the construction of the Seaway the Nerang River Inlet was migrating northward due to the re-distribution of tidal flow which occurred around 1900 with the opening of the Jumpinpin entrance. Sediment infilling of the Broadwater was occurring at rates of the order of 80,000 m^3/year.

Natural bypassing of the entrance occurred providing South Stradbroke with a supply of sand in equilibrium with the littoral transport potential. As a result, no long-term recession or accretion was evident on South Stradbroke Island.

2.4 Post Seaway Conditions

Subsequent to the construction of the Seaway and its associated bypassing system there have been significant changes to the overall dynamics of sediment movement. These changes are still very much in a transitional state as a new dynamic equilibrium is established. There is currently a limited understanding of what the long-term equilibrium conditions might be, and a major research programme is underway to clarify the situation. However, sufficient analysis has now been undertaken to enable a reliable assessment to be made of the current sediment behaviour. By adapting the conceptual model of pre-Seaway dynamics to accommodate the artificial by-passing of the entrance it is also possible to make a somewhat less reliable estimate of the longer-term behaviour.

With reference to Figures 2.4 -2.9, the following assessment can be made of the recent movement of sediment in the vicinity of the Seaway.

2.4.1 Beach stability

From the aerial photograph analysis (Figures 2.13 - 2.16) it is apparent that since 1985, there has been either a net zero change in beach alignment or a marginal net accretion at all locations along the South Stradbroke coastline. This would suggest that in general terms the rate of sand bypassing of the inlet has met the transport potential of that section of coastline. This bypassing would have initially been by natural processes from the remnants of the old ebb delta which was isolated on the down-drift side when the entrance was opened. Subsequent to this, the artificial bypassing has played the major role in meeting the sediment transport potential.

The quantity of pumped sand has been monitored by Department of Transport since the commencement of pumping in 1986. It took until 1990 for the system to become fully operational, however, and since then the annual rates of pumping have varied from 290,000 m^3/year up to 570,000 m3/year. The average rate over that period has been 450,000 m^3/year.

Surveys since 1985 show that on the beach immediately to the north of the Seaway (Figure 2.9) there was a period of erosion due to the trapping effect of the Seaway. This was followed by rapid accretion due mainly to the improvement in the operational characteristics of the by-passing system and to the redistribution of the old ebb delta into the active littoral system.

Since 1988 the section of the coastline to the north of the Seaway has remained fairly stable. Recent aerial photographs suggest that the majority of the old ebb delta has now been re-distributed and that accretionary trends evident in the aerial photograph analysis and in the survey of the beach immediately to the north of the Seaway may only reflect the over-supply of sand from the redistribution of the old ebb delta. This leads to the view that supply to South Stradbroke in the short term future at least is in equilibrium and that a net zero change can be expected.

To the south of the Seaway there was accretion as expected as the walls were constructed. As the bypassing system became operational the accretion in the immediate up-draft vicinity of the Seaway has stabilised (Figure 2.4), except for the period in 1992/1993 when the average pumped bypassing rate fell to around 287,000 m^3/year (advice from Department of Transport). The effect of this is seen in an accumulation of sand in the up-drift fillet of the ebb delta. Subsequent return to higher pumping rates (569,000 m^3/year) in 1993/1994 saw a return to stability on this section of the Spit. Overall, the Spit can be expected to be stable or in a marginal accretionary state at present.

2.4.2 Ebb delta

Analysis undertaken for this study would suggest that the between the 1986 and 1992 surveys (DoE data), deposition was occurring on the ebb delta at an average rate of the around 185,000 m^3/year. This is considerably less than the growth rates estimated by Munday (1995) of 290,000m3/year reported in the Stage One report (ICM, 1997b). This difference can be explained in that Munday's definitional area for the ebb delta only included that portion of the overall delta which was actively accreting. The current analysis covers the whole of the DoT ebb delta survey area and consequently included areas where consistent scour has been occurring.

Since 1992, the average rate of deposition has slowed significantly to around 75,000 m^3/year (Figure 2.7). The total volume of sand now trapped in the new ebb delta is estimated at 1,750,000 m^3. As previously discussed in Section 2.2.2, methodological problem exist with combining the data sets used for this analysis and this will impact on the reliability of value of the total volume trapped on the new delta. An error band of around 200,000 m^3 has been estimated and should be applied to this result. However, given the general uncertainties in interpreting beach profile data it is felt that the methodological problems are of no greater significance, and that the overall trends in the trapped volume can be taken as being sufficiently reliable for the purposes of this project.

The portion of the delta immediately down-drift of the Seaway - the down-drift fillet, Figure 2.5 - also show the trend of initial recession followed by accretion as the old delta migrated on shore. Since 1990 this section of coastline has been stable. This suggests that the sedimentary processes associated with the formation of the ebb delta may be reaching an equilibrium of sorts.

2.4.3 Entrance Channel and Flood Tide Shoals

The volumetric analysis of the entrance channel and shoals in the vicinity of Wave Break Island (Figures 2.6 and 2.8) shows a continuing trend of scouring of the main channel, deposition of the southern approach channel and deposition at the confluence of the northern and southern approach channels in front of Wave Break Island. These trends are punctuated with changes which can be linked to dredging activities in the Broadwater. In particular, dredging of the southern approach channel in late 1993-early 1994 of some 100,000 m^3 resulted in rapid infilling of the flood shoals due to the increase in tidal flow from the southern part of the Broadwater. The source of this sand is likely to be from within the Broadwater as infilling from the littoral system would have been restricted by the high rates of pumped bypassing at that time (569,000 m^3/year). The higher than normal pumping rate would have also masked the impact of the bulk of the dredged material being discharged onto the northern end of the Spit. It should be noted that these changes are not translated to the ebb delta or the adjacent beach to the north, suggesting that the tidal flow driven processes are decoupled from the longshore transport.

2.4.4 Assessment of Current Situation

Survey data of the beach to south of the Seaway indicates that around 50,000 m^3/year was accreting in the early years after the construction of the Seaway. As the bypassing system is now fully operational at an average of 450,000 m^3/year, and as the beaches to the immediate south appear to in equilibrium, an amount of around 50,000 m^3/year can be expected to be bypassing the southern wall. This sand would be carried into the entrance during the flood tide or deposited on the ebb delta on the ebb tide.

The current state of the ebb delta would suggest that the growth of the delta is dominated by deposition of sediment transported offshore from the Seaway by ebb-tidal flow. This deposition is occurring in water depths of 6 to 7 metres, and under these conditions the normally wave-induced transport mechanisms are considerably less significant and the delta is not likely to be naturally bypassing to any great extent (Tomlinson, 1991). Some sand will be bypassing the delta, particularly under major storm conditions, but this would only be of the order of 50,000 m^3/year on average.

To the north of the Seaway, the survey evidence indicates that, except for short term responses to event immediately after the breaching of the Seaway channel, the beaches are experiencing a net zero change or possibly a marginal accretion. The latter would support the previous assumption that some net bypassing of the delta is occurring, which combined with the known pumping rates would provide a marginal oversupply to South Stradbroke. Given the relatively short-term availability of survey data and the incomplete understanding of sediment dynamics of the ebb delta, a conservative position would be that South Stradbroke is currently in equilibrium with available supply.

The conclusion to be drawn from this is that the current processes resulting in net transport of sand along the beaches from the spit to South Stradbroke are decoupled from the tidal flow processes transporting sand into and out of the Seaway.

The sediment budget analysis also indicates that tidal-flow driven sediment movement is ebb-dominated. This is likely to remain the case while the bypassing system effectively controls the bulk of the littoral supply. The growth of the ebb delta under these conditions is dependent on sediment transported off shore from the Seaway and not on the littoral supply as is the case for naturally bypassing inlets.

The current situation is presented as Figure 2.19.

In summary, at the present time a net northerly littoral transport rate of 500,00 m^3/year occurs along the Gold Coast Embayment. The net littoral transport potential of the South Stradbroke coastline is less than this due to a more easterly alignment. Beaches in the vicinity of the Seaway are currently in "equilibrium", with South Stradbroke beaches showing a net zero change or possibly a marginal accretionary trend.

The current average annual pumping rate for the bypassing system of 450,000 m^3/year, combined with some natural bypassing of the ebb delta, are in balance with the littoral transport requirements of the adjacent beaches.

Sand transport driven by tidal flows at the Seaway is de-coupled from the longshore littoral processes, and is ebb-tide dominated.

2.5 Future Trends and Implications of Proposed Nourishment Options

The preceding assessment of the existing sediment transport and budget trends at the Seaway is based on the limited available data covering the period from the construction of the Seaway in 1986 until the present. Extrapolation of these data to predict future trends is somewhat unreliable. However, the overall understanding of the behaviour of the entrance over the last 100 years leads to the following assessment of the probable trends over the next 100 years and the implications of the proposed nourishment options.

2.5.1 Future Trends

In the absence of any large-scale dredging in the vicinity of the Broadwater it is predicted that the sediment budget will remain substantially unchanged from the current situation. Provided the bypassing system continues to operate at the current average pumping rates, or higher, then the beaches to the south and north will remain in dynamic equilibrium. Minor increases in the natural bypassing rate of the ebb delta may occur as the ebb delta continues to slowly grow under the influence of ebb-tide dominated transport offshore from the Seaway. This could be countered by a reduction in the pumping rates, but this would be accompanied by an accretion on the Spit which would need to be managed. Given that South Stradbroke appears to be in equilibrium with sand supply rates less than 500,00 m^3/year, shoreline stability could be managed by appropriate operational strategies.

The major impacts on this overall "balanced" system are likely to be continuing development of the Broadwater and cyclic behaviour of the Jumpinpin entrance. Extensive dredging of channels and the development of cut-and-fill canal estates in the future may lead to a significant increase in tidal prism of the Broadwater system. This would result in increased tidal flows through the Seaway and the subsequent increase in the volume of sand transported offshore onto the ebb delta. Associated with this is a predicted increase in the entrance channel depths.

In the event of future breachings of the second channel at Jumpinpin, it is expected that the tidal flow at the Seaway will decrease. This would lead to increased deposition in the entrance and approach channels and a subsequent reduction in transport offshore onto the ebb delta.

In either event it is expected that the stability of South Stradbroke could be managed by appropriate operational strategies for the bypassing system. A fuller understanding of the characteristics of the ebb-tide dominance of the entrance is required before reliable predictions can be made.

2.5.2 Implications of Proposed Nourishment Options

It has been predicted above that, in the absence of any major influence on the sediment budget in the immediate vicinity of the Seaway, the resultant impacts of changes further afield can be managed by operational strategies for the bypassing system. However, the three major options for the provision of nourishment sand, in addition to the regular maintenance dredging of the approach channels are assessed as having a more significant effect on the sediment dynamics. These options are:-

1. Dredging of large quantities of sand from the approach channels in the Broadwater:
2. Dredging of the ebb delta,
3. Back-passing from the bypassing system.

From the discussion presented above it can be concluded that the dredging of sand from the Broadwater in the vicinity of the Seaway at levels comparable to that occurring over the last decade, will not affect the stability of South Stradbroke Island.

However, the other options may have the following more significant effects. Large-scale dredging would have the immediate effect of increasing the tidal flow and scour of the main channel, and a subsequent increase in deposition on the ebb delta. This would lead to an increase in natural bypassing rates, requiring short term variations in pumping rates to ensure stability of the adjacent beaches. It is believed that this response would be self-regulating with delta growth stabilising as the approach channels infill from within the Broadwater or from sand bypassing the southern wall of the Seaway due to the reduced pumping rates required to manage the supply of sand to South Stradbroke Island.

Equally, substantial removal of sand from the ebb delta will have only a minimal affect. This would at worst result in the natural bypassing rate reducing to zero until subsequent events lead to an increase in the size of the ebb delta. As demonstrated earlier the South Stradbroke beaches stability is primarily dependent on the pumped bypassing of the littoral sand supply which is de-coupled from the tidal flow driven processes.

The key requirement for beach stability is the maintenance of the current operational capacity of the bypassing system to ensure the continuation of the longshore littoral supply of sand. Under these circumstances, back-passing could only be carried out up to a maximum rate equal to difference between the net longshore transport rate on the Spit and the current average annual pumping rate. This is of the order of only 50,000m^3/year. However, as indicated above a number of events my result in the requirement of the management of the supply rates to South Stradbroke. This effectively precludes the use of the system for back-passing.

In summary, sediment dynamics at the Seaway are expected to be ebb-tide dominated and decoupled from the littoral processes for the foreseeable future. The stability of the Spit and South Stradbroke beaches is dependent on the bypassing system being fully operational.

The nourishment options which involve the dredging of the approach channels to the Seaway are less desirable than the dredging of the ebb delta. Either can be undertaken however with minimal impact on the stability of the adjacent beaches.

Back-passing from the bypassing system is not recommended.

3. SHORELINE EVOLUTION MODELLING

3.1 Introduction

The Northern Gold Coast Beach Protection Strategy (ICM, 1997a) proposed a number of coastline management options for the Seaway and Surfers Paradise, including sand back-passing, beach nourishment and the construction of an artificial reef at Narrowneck. The following section presents the results of numerical simulation of these options.

The 'one-line' shoreline model GENESIS (Hanson and Kraus, 1991) is used. A description of the model and underlying assumptions is presented, and the necessary input data are described. Following model calibration, simulation results are presented in two groups: the first set focus on alternative mechanical by-pass scenarios for the Seaway; and the second set of simulations elucidate the potential impacts of the proposed submerged reef at Narrowneck, including beach nourishment at Surfers Paradise and back-passing/nourishment of the down-drift beach.

3.2 The GENESIS Model - an overview

The acronym GENESIS stands for GENEralised Model for SImulating Shore-line change. Since its public release by the US Army Corps of Engineers in 1989, the model has become an industry standard for one-line modelling of shoreline change in response engineering structures and beach nourishment.

The term 'one-line' model refers to the fact that the landward or seaward movement of a single elevation contour is predicted. In principle, the movement of any contour could be simulated, but since the mean shoreline position (i.e., zero-depth contour) is conveniently measured, the representative contour position is taken to be the shoreline.

3.2.1 Basic Assumptions

A common observation from beaches around the world is that the beach profile maintains an 'average' shape that is characteristic of any particular coastline. Although storms and seasonal changes in wave climate cause the position of the shoreline to move shoreward and seaward in a cyclic manner, with corresponding change in shape and slope of the profile, the deviation from the average beach slope over the total active profile is relatively small. This fact underlies the basis for shoreline modelling; namely that, if the 'mean' profile shape does not change, any point on the profile (for convenience the shoreline) can be used to describe changes in beach plan shape and volume as the beach erodes or accretes.

It is also commonly observed that the longshore transport of sediment occurs between two well defined limiting elevations on the profile. The shoreward limit is located at the top of the active berm, and the seaward limit is located at the depth where no significant depth changes are observed, the so-called 'depth of closure'. The area of the profile between these two elevations therefore defines the region where sediment transport results from the oblique angle at which breaking waves arrive at the shore.

In summary, the standard assumptions of shoreline change modelling are (Hanson and Kraus, 1991):

1. The beach profile shape is constant for the entire study region.
2. the shoreward (berm) and seaward (depth of closure) limits of the profile are constant.
3. Sand is transported alongshore by the action of breaking waves.
4. The detailed structure of the nearshore circulation is not considered.
5. There is a long-term trend in shoreline evolution.

These basic assumptions define a flexible and well tested scheme for simulating shoreline changes in response to coastal engineering/management practices.

3.2.2 Theory

The equation governing shoreline change modelling is formulated from the concept of conservation of sand volume. Put most simply, all sand transported along the shoreline must always be accounted for, either by beach <u>accretion</u> (widening), beach <u>erosion</u> (narrowing), or the special case of <u>no net change</u>, that results when the rate at which sand is added to a particular location is matched by the rate at which it is transported away.

The empirical predictive formula for the longshore sand transport rate used in GENESIS is

$$Q = \left(H^2 C_g\right)_b \left[\underbrace{a_1 \sin 2\theta_{bs}}_{1^{st}\ term} - \underbrace{a_2 \cos\theta_{bs} \frac{\partial H}{\partial x}}_{2^{nd}\ term} \right]_b \tag{1}$$

where

H = wave height

C_g = wave group speed (linear theory)

θ_{bs} = angle of breaking wave to the local shoreline

b = subscript denoting condition at wave breaking.

The first term in equation (1) is the so-called "CERC formula" (SPM, 1984), and accounts for longshore sand transport produced by obliquely incident breaking waves. The second term is included to describe the effect of the longshore gradient in breaking wave height ($\partial H_b / \partial x$), another generating mechanism of longshore transport. This contribution of the longshore transport rate is usually much smaller than that arising from oblique wave incidence on the open coast, but can be significant in the vicinity of structures due to wave diffraction (Ozasa and Brampton, 1980; Kraus, 1983; Hanson and Kraus, 1991).

The non-dimensional parameters a_1 and a_2 in equation (1) are given by:

$$a_1 = \frac{K_1}{16(\rho_s/\rho - 1)(1-p)(1.416)^{5/2}}$$

$$a_2 = \frac{K_2}{8(\rho_s/\rho - 1)(1-p)\tan\beta(1.416)^{7/2}} \qquad (2)$$

where

K_1, K_2 = empirical coefficients, i.e., calibration parameters

ρ_s = density of sand (2.65 × 103 kg/m^3)

ρ = density of sea water (1.03 × 103 kg/m^3)

p = porosity of sand on the bed (0.4)

$\tan\beta$ = average bottom slope from the shoreline to the depth of closure.

These parameters describe properties of the sediment, water and nearshore geometry. The inclusion of the two empirical terms K_1 and K_2 is very convenient to the present study. Combined with the extensive previous studies of coastal processes at the Gold Coast, the otherwise rather onerous task of model calibration and sensitivity testing is greatly simplified (refer to later Section 3.4).

3.2.3 Capabilities and Limitations

As is the case with all numerical modelling investigations, in interpreting model results it is necessary to be aware of both the capabilities and limitations of the particular numerical scheme used.

The GENESIS model was developed to describe long-term trends (one year to a decade) of the beach plan shape in the course of its approach to an equilibrium form. This change is usually caused by a notable perturbation to the shore; in the present study the existence of the rock breakwaters at the Seaway, and the simulated construction of the proposed submerged reef at Narrowneck. GENESIS is particularly suited to the assessment of shoreline response to such structures, because it works best when used to identify the resulting longer-term trend that is distinct from the normally occurring 'random' movement of sand on a beach (Gravens, Kraus and Hanson, 1991). In other words, shoreline change modelling is best suited to the assessment of shoreline movement in transition from one equilibrium state to another.

For the purpose of regional planning (as opposed to localised detailed design), the aerial extent of the study region may extend several 10's of kilometres (for a relatively straight and uniform coastline such as the Northern Gold Coast - South Stradbroke Island). The duration of simulation is of the order of a few years to a decade.

GENESIS is not applicable to evaluating shoreline changes other than those associated with spatial differences in wave-induced longshore sand transport and coastal structures. The model is therefore not applicable to situations where beach changes are produced by tidal flow, wind generated currents, storm-induced beach erosion, dominant cross-shore transport processes and scour in the lee of structures. For example, it is not possible to incorporate into the model the impact of extreme (but infrequent) storms, instead these are indirectly included by their contribution to the 'mean' annual longshore transport rate.

The extensive body of literature that has previously examined regional coastal processes operating at the Northern Gold Coast (e.g., DELFT, 1970; Patterson and Patterson, 1983; Tomlinson and Foster, 1987; Beach Protection Authority, 1981; DELFT, 1992;) confirm that wave-induced longshore sand transport is the dominant mode of shoreline change. However, in the interpretation of results derived from all numerical models, it is important to recall that, at best, what is being simulated is a much simplified representation of the interactions between a range of complex physical processes. For this reason, the results of shoreline simulation should be interpreted as indicative (rather than predictive) of likely shoreline changes.

3.3 Input Data

GENESIS Version 3.0 was used to undertake this study. The Windows95-based GENESIS-95 graphical user interface was used for model setup and preliminary assessment of simulation results. Model output was exported to an external package for further analysis and the preparation of figures.

The sources and pre-processing of all input data are detailed below.

3.3.1 Initial Shoreline

The model reach extends from approximately 10 km south of the Seaway to 10 km north of the Seaway (AMG 6899100 m N to 6919000 m N - refer Figure 1.1). A 20 km length of coastline was selected in order to minimise possible boundary effects at the central region of interest, i.e., beaches adjacent to the Seaway and Narrowneck. A longshore grid spacing of 100 m was used, resulting in a total of 200 calculation cells. The AMG easting 541000 m E was used to define the reference baseline for all data, conveniently situated such that its orientation mirrors the general north-south trend of the coastline.

The initial shoreline data was digitised from the three 1:25,000 Topographic Image Maps (1995) that cover the study reach [9541-11 BURLEIGH; 9542-22 SOUTHPORT; 9542-21 SANCTUARY COVE (SPECIAL)]. These maps are produced by Sunmap (Department of Lands, Brisbane), and show topographic information projected onto fully rectified aerial photography taken in May 1994.

An expert examination of the beach morphology at the time the aerial photography was taken revealed that the beaches were in a lower-energy, intermediate state. *Low Tide Terrace* to *Transverse Bar Rip* morphology is apparent, with relic (higher energy) rhythmic longshore bar morphology visible in the nearshore (refer Wright and Short [1984] for details of beach classification scheme). This is indicative of a preceding period of relative calm, which is an advantage for the purpose of defining a 'mean' initial shoreline. It is also evident that the photography was taken at a lower stage of the tide, as the swash zone can be seen to coincide with the low tide terrace where it welds onto the beach face. The wetting-front of the swash zone on the lower beach face is clearly evident on the maps when viewed using a magnifying glass, which was used to define the shoreline for digitisation.

It is estimated that total maximum error in definition of the shoreline is +/- 25 m. This worst-case error represents the sum of publish map accuracy (+/- 12.5 m), error in interpretation of the shoreline (+/- 7.5 m) and digitising error (+/-5 m). From a comparison with the surveyed location of the existing boulder wall (refer to Section 3.3.3), it is concluded that the actual accuracy of the initial shoreline data is considerably better than this maximum worst-case error, and is estimated to be of the order of +/- 10 m.

The shoreline data was digitised at a high density (longshore spacing < 10 m), and then interpolated to 100 m longshore increments for input to the model.

3.3.2 Directional Wave Climate

Fundamental to shoreline modelling is the requirement for a time-series of directional wave information (i.e., wave height, wave period and direction). In fact, the GENESIS model basically consists of two major sub-models: one that calculates breaking wave height and angle alongshore as determined from wave information given at a distance offshore, and the other sub-model which uses these results to calculate longshore sand transport rate and shoreline change.

It is important to recall that the aim of regional shoreline modelling is to assess trends in shoreline change, and therefore the objective is to utilise directional wave information that reproduces the 'average' transport conditions. By careful calibration (refer to Section 3.4), previously determined mean annual transport rates within the study region can be reproduced, permitting the influence of new engineering structures to be evaluated. As shoreline evolution is typically simulated over a period of several years to a decade, the occurrence of statistically 'calm' or 'stormy' years are therefore of lesser importance, as their influence is indirectly incorporated by their contribution to the mean annual transport rate. A common approach used in shoreline modelling, and adopted for the present study, is to calibrate the model using one full year of directional wave information, and then this input wave file is repeated for all subsequent years.

The Northern Gold Coast region is characterised by approximately straight and parallel ocean bottom contours, which parallel the trend of the shoreline. For this case, the so-called 'Internal' wave transformation model contained within the GENESIS package is applicable, and wave refraction and diffraction (by nearshore structures) is determined from a single offshore wave record located at a known reference depth.

Wave-rider buoys located offshore of the Brisbane, Gold Coast and Tweed River regions have provided non-directional wave data for over 20 years (Department of Environment, 1997a). The sources of directional wave data, however, are much more limited. The DELFT (1992) report considered directional wave information specific to the Gold Coast from three sources: Visual observations made from ships (Royal Dutch Meteorological Institute), British Meteorological Office Hindcast Model, and non-directional wave-rider buoy observations combined with hindcast direction information determined from Bureau of Meteorology synoptic weather charts. In the absence of explicit measurements of wave direction, in the DELFT (1992) study the directional wave climate was estimated in 30° sectors by assigning the British Meteorological Office directions to non-directional Brisbane wave-rider buoy wave height and period data.

It is fortuitous for the purposes of the present study that in late November 1996 a directional wave-rider buoy was installed 10 kilometres east-north-east of Point Lookout (North Stradbroke Island), in 80 m of water depth (Department of Environment, 1997a).

Directional wave data from the new buoy was obtained for this study for the nominal period 21/11/96 to 30/11/97. The data record consisted of hourly time-series of significant wave height (H_s), peak wave period (T_p) and peak wave direction (*Dir_p*). Seasonal variation in wave climate at the Gold Coast is defined for the two distinct periods of Winter [1 May - 31 October] and Summer [1 November - 30 April] (Department of Environment, 1997b), and this seasonality was taken in to account during pre-processing the data for input to GENESIS. Gaps in the data in December 1996 and January 1997 were filled using the equivalent time periods from November 1997 (substituted for missing data in November 1996) and February 1997 (substituted for missing data in January 1997).

In this manner, a full 12 month time-series of hourly directional wave data was obtained. The final step of pre-processing involved rotating the co-ordinate system so that it matched the model co-ordinate system defined by the reference baseline (refer to Section 3.3.1), and re-sampling of the data at 6 hourly intervals, as is standard practice for input to the GENESIS model (Hanson and Kraus, 1991; Gravens, Kraus and Hanson, 1991).

Prior to its use for shoreline modelling, an assessment was undertaken to compare this new time-series of measured directional wave data, to previous statistical analysis of the Gold Coast wave climate. The non-directional parameters of significant wave height and peak wave period compare very favourably with analysis by the Queensland Beach Protection Authority for the 10 year period 1987 - 1997 (Department of Environment, 1997b). The percentage occurrence for all H_s (0.2 metre bins) were within 5%, and T_p (2 second bins) agree better than 10%. Wave direction also shows reasonable agreement with the hindcast analysis contained in DELFT (1992); although a reliable comparison is more difficult, as the new data set is at 1° resolution, rather than the broad 30° sectors defined for the hindcast data. This higher resolution is preferable, as the calculated longshore transport rate is sensitive to breaker angle at the shore (refer to Equation 1).

In summary, the 12 month directional wave data provides the necessary input time-series of wave height, period and direction, at a known reference depth offshore of the study region. By calibration to reproduce the known mean annual longshore transport rate, (refer to Section 3.4), this data set is repeated for every year of simulation, to reproduce mean annual wave conditions at the shore.

3.3.3 Boulder wall (Seawall)

The alignment of the existing boulder wall extending southward from The Spit, was supplied in digital form by Gold Coast City Council. The section of seawall at Narrowneck was constructed in 1923 to protect the newly constructed highway, and is some 35 m seaward of the general seawall alignment. As a result, it is regularly exposed by erosion and at such times there is no usable beach at high tide (ICM, 1997).

The seawall alignment ('Seawall Line A') is defined by the top seaward edge of the wall. Advise was provided by GCCC that the top of the wall is 4.9 m AHD and the front face slopes down at approximately 1V:1.5H to 0.00 m AHD, 7.35 m seaward of the Seawall Line A. The wall itself consists of three layers - front boulders 1.5 to 4 tonne (3.5 m horizontal depth), rock fill (90 - 360 kg) 1.7 m horizontal depth, and clay and shale fill (2.75 m horizontal depth).

The Seawall Line A is defined by the City's planning scheme to an accuracy of +/-1 mm. This is necessary as the line defines the usable land area for planning purposes, and for building shadow control. In practice, it is understood that there were many walls built prior to the gazetting of the Seawall Line A, and as a result the line was placed through as many walls as possible. Commonly rocks are 1 - 5 m off the line, and the newer walls were built within 2 m of the line (GCCC, *pers. com.*).

The seawall alignment used for this study was determined by the 0.00 m AHD alignment of the front face of the wall (i.e., + 7.35 m seaward of the gazetted Seawall Line A alignment). The data was interpolated at 100 m longshore increments, prior to input to the model.

3.3.4 Seaway

In shoreline change modelling, engineering structures exert two direct effects (Hanson and Kraus, 1991):

1. Structures that extend into the surf zone block a portion or all of the sand moving alongshore on their up-draft sides, and reduce the sand supply on their down-drift sides. Blocking can be direct, as by a groyne or breakwater, or indirect, as by the calmer region of water in the lee formed by a detached breakwater or reef.
2. Detached breakwaters, reefs and other structures with seaward ends extending well beyond the surf zone produce wave diffraction. The diffraction pattern causes the local wave height and direction to change, which may alter the longshore sand transport rate.

The locations of the two rock training-walls defining the entrance to the Seaway were determined from the SOUTHPORT (9542-22) 1:25,000 Topographic Image Map. The AMG co-ordinate of the tip of each breakwater was determined, and this was used within the model to define two parallel groynes, aligned perpendicular to the model reference baseline (refer to Section 3.3.1). A transmission coefficient of 0.0 was assigned to both groynes, so by definition no sediment can be transported through the structures. It was determined through subsequent sensitivity testing that no difference was observed in shoreline response in the vicinity of the Seaway if the breakwaters were defined as either diffracting or non-diffracting. This is consistent with the regional scale at which the model is defined.

3.3.5 Empirical Parameters

The mathematical formulation for longshore sediment transport rate and hence net profile change (refer section 3.2) requires some information about the geometry of the characteristic beach profile. These parameters are identified below.

'Average' Profile Shape and Slope (D_{50})
Calculation of the rate of shoreline change does not require the explicit specification of the bottom profile shape, since it is assumed that the profile moves parallel to itself. However, to determine the location of breaking waves alongshore and to calculate the average nearshore bottom slope used in the longshore transport equation (Equation. 1), a profile shape must be specified. The recommended technique used for input to GENESIS is based on the 'equilibrium profile' concept. Brunn (1954) and later Dean (1977) demonstrated

from a wide variety of field sites that the average profile shape at any particular location can in general be represented by the simple mathematical function

$$D = Ay^{2/3} \tag{3}$$

where

D	= water depth
y	= distance offshore
A	= empirical scale parameter.

The scale parameter A has been shown by many authors to depend on the grain size of sediment at any particular location. For use in GENESIS, the design curves for A given by Moore (1982) as a function of D_{50} (median grain size), and reproduced in Hanson and Kraus (1991), are used as templates to determine an 'effective' median grain size. Put simply, beach profiles from the study site are compared to the theoretical profile shape predicted by Equation 3, and the best match is used to determine the corresponding 'effective' D_{50}.

For the present study an extensive assessment of the available profile data from profile lines ETA63 (south of the Seaway) and ETA89 (north of the Seaway) was examined to determine the representative profile shape (refer to Figure 1 for profile locations). As most transport occurs in the surf zone (i.e., within approximately 200 m of the shoreline), the best-fit curve in this region of the profile was selected, determining an effective mean grain size of D_{50} = 0.25 mm. This is consistent with the reported mean grain size for north Gold Coast beaches of 0.24 mm (Jackson and Mcgrath, 1993).

Depth of Closure

Repeated profile data from profile lines ETA63 and ETA89 were used to assess the depth of closure. A consistent trend of the convergence of profiles seaward of 15 m water depth (-15 m AHD) was determined, indicating the effective seaward limit of significant longshore sediment transport.

Berm Height

Again, an expert assessment of profile lines ETA63 and ETA89 was used to determine average berm height. Both north and south of the Seaway this was concluded to be 2.0 m AHD.

3.3.6 Boundary Conditions

As previously noted, the extent of the study region was chosen so that the areas of particular interest adjacent to the Seaway and at Narrowneck are sufficiently distant from the boundaries that possible boundary effects are minimised. The northern and southern boundaries located at 6919000 m N and 6899100 m N respectively were defined as 'open pinned', in other words, there location remains fixed throughout the simulation period. Sediment moves across the boundary to satisfy conservation of mass.

3.4 Model Calibration

Before the GENESIS model can be used to evaluate the coastal management scenarios proposed in the Northern Gold Coast Beach Protection Strategy, calibration of the model is required. This was achieved by the adjustment of calibration parameters so that the model reproduces the accepted mean annual longshore transport rate within the study region determined by pervious studies.

3.4.1 Calibration (Transport) Parameters

The terms K_1 and K_2 defined in Equation 2 have been empirically estimated by various authors (e.g., Komar and Inman, 1970; Kraus et al., 1982; Kraus, 1983), but in practice it is usual to treat these coefficients as parameters in order to calibrate the model (Hanson and Kraus, 1991). For this reason K_1 and K_2 are commonly referred to as "transport parameters". The transport parameter K_1 controls the time scale of the simulated shoreline change, as well as the magnitude of the longshore sand transport rate. The second transport parameter K_2 specifically controls the secondary contribution to the longshore sand transport rate resulting from any longshore gradient in breaking wave height.

3.4.2 Mean Annual Transport Rate

Model calibration is relatively straight-forward for the Northern Gold Coast study region, due to the number of previous investigations that have detailed and quantified the predominant coastal processes (e.g., DELFT, 1970; Beach Protection Authority, 1981; Patterson and Patterson, 1983; Tomlinson and Foster, 1987; DELFT, 1992). In particular, there is a consensus in the literature that on straight, open-coast beaches within the study area, the average annual net longshore transport of sand is directed to the north, at a rate of approximately 500,000 m^3/yr. This net transport is comprised of approximately

600,000 m^3/yr gross transport south to north, and 100,000 m^3/yr gross transport north to south (refer to ICM, 1997b for a summary).

3.4.3 Calibration Results and Sensitivity Testing

The model was run for an initial period of 12 months, and the parameters K_1 and K_2 adjusted to reproduce a net annual longshore transport rate of ~500,000 m^3/yr at Narrowneck. The values of K_1 and K_2 to obtain this calibrated transport rate are tabulated in Table 3.1, as well as the calibrated values for net transport rates of ~400,000 m^3/yr and ~600,000 m^3/yr, used later for sensitivity testing (refer below).

TABLE 3. 1
Calibration Parameters K_1, K_2

mean annual longshore transport rate m^3/yr (Narrowneck)	K_1	K_2
~500,000	0.12	0.06
~400,000	0.095	0.05
~600,000	0.14	0.07

Figure 3.1 shows the results of a five year simulation for the calibrated net longshore transport rate of ~500,000 m^3/yr at Narrowneck. The upper panel depicts a plan view of the study area, with the Seaway and Narrowneck indicated. Note that in this and all subsequent figures, the curvature of the coastline is greatly exaggerated to assist the interpretation of model results. The Seaway training walls are incorporated in these calibration simulations, but no other structures, bypassing or nourishment operations are simulated.

The second panel shows the net annual transport rates calculated for each year of simulation. By convention, northerly transport (directed right-to-left in all figures) is negatively signed, and southerly transport (left-to-right) is positive. During year 1 some minor longshore variation in net transport rates are apparent, as local crenulations of the shoreline, present at the start of the simulation, are smoothed out. A regional trend is evident, with net annual transport rates decreasing north of the Seaway, due to the eastward rotation of the coastline along South Stradbroke Island. It is apparent that, for the 'mean' annual wave climate, the northern and southern breakwaters at the Seaway are simulated to act as a total barrier to longshore transport (refer to Section 4 for an analysis of Seaway bypassing during extreme storm conditions). Transport rates decrease from year 1 to year 5 adjacent to the Seaway, consistent with shoreline adjustment to the interrupted along-shore sediment pathway in this region.

The two lower panels in Figure 3.1 show the gross northerly and gross southerly annual transports rates for each year of simulation. At Narrowneck the net transport rate of ~500,000 m^3/yr can be seen to comprise approximately 600,000 m^3/yr directed to the north, and 100,000 m^3/yr directed south. These total transport rates are consistent with the consensus of previous longshore transport studies of the northern Gold Coast region (refer ICM, 1997b for summary). The fact that both net and gross transport rates are well simulated increases the confidence with which the results of the model simulations may be interpreted.

To permit later sensitivity testing of the various proposed management scenarios, Figure 3.2 shows the results of a five year simulation in which the net annual transport rate was calibrated to ~400,000 m^3/yr. Similarly, simulation results for net annual transport rate of ~600,000 m^3/yr are depicted in Figure 3.3. In both these simulations, similar regional trends to the ~500,000 m^3/yr simulation are apparent. Net transport rates decrease northward along South Stradbroke Island, and the Seaway acts as a total barrier to net northerly transport by the mean annual wave climate.

3.5 Shoreline Modelling Results

The results of shoreline modelling are presented below in two groups. The first set of simulations focus on alternative mechanical by-passing scenarios at the Seaway, to determine the optimum equilibrium conditions. The second set of simulations examine the potential impacts of the proposed submerged reef at Narrowneck, including beach nourishment at Surfers Paradise, and the back-passing of sand to nourish the down-drift beach. A 10 year simulation period was chosen for all model runs, a physically reasonable duration for regional shoreline modelling.

3.5.1 Shoreline Evolution adjacent to Seaway

No mechanical by-passing

Figure 3.4 depicts simulated shoreline evolution for the case of no mechanical by-passing at the Seaway. The net longshore transport rate is ~500,000 m^3/yr, and apart from the training walls at the Seaway, there are no other structures, by-passing or nourishment operations included in the study region. In this and all subsequent figures, the upper panel shows the initial, intermediate, and final (10 year) shoreline positions. The middle panel shows corresponding shoreline change (relative to the initial shoreline), and the bottom panel shows the net annual longshore transport rate alongshore.

With no mechanical sand by-passing at the Seaway, the rapid build up of sediment against the southern breakwater and corresponding erosion of the down-drift beach on South Stradbroke Island is readily apparent. With the Seaway acting as a barrier to net northerly longshore transport, erosion in excess of 150 m is simulated, matched by corresponding accretion adjacent to the southern training wall. By the tenth year of simulation, erosion/accretion extends more than 2 km north and south of the Seaway respectively.

Mechanical by-passing

Figure 3.5 shows shoreline evolution with the operation of the mechanical sand by-passing system at the Spit now included. Again, a net longshore transport rate of ~500,000 m^3/yr is assumed. The annual by-passing rate of 450,000 m^3/yr is simulated, which is the average annual pump rate since the by-pass system became operational (ICM, 1997b). In contrast to the previous simulation, the rapid build up of sand south of the Seaway is now absent, and the erosion rate to the north greatly reduced. For a distance of approximately 1.5 km to 2 km north of the Seaway, shoreline erosion at a net rate of 1 m to 5 m per year is simulated. This erosion rate slows through the simulation period, with up to 40 m of shoreline erosion occurring 500 m to 700 m north of the Seaway within the first 5 years, in contrast to a further 10 m of erosion during the following five year period.

Figures 3.6 - 3.9 are included to examine the sensitivity of shoreline evolution to the mechanical by-passing rate and the mean annual rate of longshore sediment transport. Figure 3.6 shows the results of the same simulation, with the mechanical by-passing rate increased to 550,000 m^3/yr. South Stradbroke Island now exhibits net accretion, however shoreline erosion is apparent adjacent to the sand by-passing intake on the southern side of the Seaway. After 10 years, this simulated erosion extends for a distance of approximately 2 km south of the Seaway.

Figure 3.7 shows the results of reducing the mechanical by-passing rate to 350,000 m^3/yr. The build up of sediment on the southern side of the Seaway is matched by marked erosion on southern Stradbroke Island. After 10 years, both down-drift erosion and up-drift accretion are simulated to extend for a distance of approximately 2 km, north and south (respectively) of the Seaway.

To assess the effect of varying the assumed longshore transport rate, in Figure 3.8 the mean annual mechanical by-passing rate of 450,00 m3/yr was again simulated, but with the net annual longshore transport rate now increased by 100,000 m^3/yr to ~600,00 m3/yr. Similarly, in Figure 3.9 the net longshore rate reduced by 100,000 m^3/yr to ~400,000 m^3/yr. As anticipated, the increase in net annual transport rate results in shoreline accretion adjacent to the southern training wall, and extensive shoreline erosion (up to 75 m shoreline retreat after 10 years) on the up-drift beach of southern Stradbroke Island. In contrast, the shoreline response to a decrease in the assumed net transport rate is less pronounced. Significant erosion adjacent to and up-drift of the sand by-passing pier on the southern side of the Seaway is simulated. However, the corresponding accretion at the by-passing outlet on south Stradbroke Island is localised and relatively minor.

For all the results so far presented that incorporate mechanical sand by-passing, implicit within each simulation is the assumption that there is no exchange of sediment between the ebb tide delta at the Seaway and adjacent beaches. In Section 2 however, it was concluded that approximately 50,000 m^3 of sediment is transported from the delta to the beach immediately north of the Seaway, providing an additional supply of sand to this area of the study region. Figure 3.10 shows the results of a simulation which incorporates this natural by-passing of sand from the delta to the beach. Onshore transport from a deltaic source cannot be explicitly incorporated within the GENESIS model, however this mechanism may be approximated by defining a sediment 'source' at the location on the shoreline where sediment accumulation occurs. The simulation results depicted in Figure 3.10 incorporate the net 'average' annual longshore transport rate of ~500,000 m^3/yr, 450,000 m^3/yr mechanical by-passing at the Seaway, and the addition at a rate of 50,000 m^3/yr of sand to the beach immediately north of the Seaway. Under these conditions, the beaches in the study region are approaching an equilibrium state, and the model results are indicative of the recorded shoreline response (refer to Section Two). Localised and relatively minor erosion at the mechanical by-passing intake and immediately north of the Seaway are apparent, balanced by regional trends of net accretion along southern Stradbroke Island and little net change along the Spit and Northern Gold Coast beaches.

In Summary, it is concluded from the shoreline modelling results that to prevent the erosion of South Stradbroke Island beaches for a distance of 1 km to 2 km north of the Seaway, it is required that mechanical by-passing be maintained at the current rate of approximately 450,000 m^3/yr. With natural by-passing assumed to be occurring from the ebb tide delta to the beach immediately north of the Seaway at an annual rate of approximately 50,000 m^3/yr, the simulation results indicate that a near equilibrium shoreline is maintained within the study region. Limited erosion immediately north of the Seaway simulated under these conditions may reflect the erosion of the beach back to its original orientation prior to the construction of the Seaway.

Simulation results indicate that erosion/accretion of beaches immediately north and south of the Seaway is sensitive to the mechanical by-passing rate and net annual longshore transport rate. A management strategy is therefore recommended that permits the mechanical by-passing rate to be periodically re-assessed, and temporarily increased or decreased
(± 50,000 - 100,000 m^3/yr) in response to natural inter-annual variation in the regional longshore sediment transport rate.

It is therefore recommended that the present by-passing operations not be considered as a sediment source for the back-passing of sediment to nourish Northern Gold Coast beaches.

3.5.2 Impacts of Proposed Artificial Reef

The proposed artificial reef at Narrowneck is simulated within the GENESIS model as a shore-parallel, diffracting offshore breakwater. Wave transmission greater than zero is used to approximate the partial transmission of incident wave energy across the reef. This simplified representation precludes the detailed assessment of localised effects such as beach scour resulting from altered nearshore circulation at the reef, and three-dimensional bathymmetric changes. However, broad-scale impacts to regional sediment transport and associated shoreline changes can be investigated.

Wave Transmission

Figures 3.11, 3.12 and 3.13 show the results of three 10 year simulations incorporating the proposed artificial reef. The dimensions of the simulated artificial reef (400 m long, 200 m offshore) were selected to match the conceptual reef design proposed in the Northern Gold Coast Beach Protection Strategy (ICM, 1997b; Figure 41). The difference between these simulations is the assumed wave transmission across the reef. Wave transmission refers to the amount of incident wave energy that passes over (or through) a coastal structure to be dissipated or reflected at the shoreline, the remaining energy being dissipated by the structure. For completeness, the calibrated model conditions incorprating mechanical by-passing at the Seaway (450,000 m^3/yr) and natural bypassing from the ebb tide delta to the adjacent northern beach (50,000 m^3/yr) are also included in these simulations. The simulated net annual longshore transport rate is ~500,000 m^3/yr. In these figures the top panel depicts the evolving shoreline, and the middle and lower panels again show shoreline changes and net transport rates. One additional feature is included. In the middle panel the distance from the shoreline to the seawall alignment at the back of the beach (refer to Section 3.3.4) is also shown.

In Figure 3.11 the reef was defined for a wave transmission of 70%. Alternatively expressed, this means that 30% of the wave energy incident to the reef is dissipated, and the remaining 70% passes across the reef to be dissipated or reflected at the shoreline. Until the results of more detailed hydrodynamic modelling become available, this value for wave transmission is anticipated to provide a physically reasonable representation of the proposed reef.

The simulated shoreline response to the reef is beach widening in the lee and along the up-drift southern beach, and corresponding erosion of the down-drift beach to the north. Initial accretion in the lee of the reef (often referred to as a shoreline 'salient') is rapid, with the beach increasing in width by 30 m in the first year. By the tenth year the beach has continued to grow at a slower rate to approximately 50 m, however the southern extend of beach widening increases significantly. Beach widening greater than 10 m extends approximately 2 km south of Narrowneck at the end of the 10 year simulation period.

It is apparent that energy dissipation and wave diffraction at the reef reduces the net annual transport rate in the vicinity of Narrowneck. After several years of simulation the model results suggest the net transport rate in this region converge to approximately 400,000 m^3/yr, or 100,000 m^3/yr less than the simulated transport rate in the absence of the reef. As a result, distinct down-drift erosion is predicted. After 10 years the beach immediately north of Narrowneck is simulated to erode by up to 40 m. Less than 10 m of beach width remains between the eroded shoreline and the seawall alignment. The degree of shoreline retreat reduces with increasing distance northward of the reef, with shoreline adjustment simulated to extend 1.5 km to 2 km north of Narrowneck.

The results presented in Figure 3.12 and Figure 3.13 provide an assessment of the sensitivity of simulated shoreline response to different reef transmissions. In Figure 3.12 reef transmission was reduced to 50%, i.e., increased energy dissipated occurs at the reef. As a result the net annual longshore transport rate in the lee of the reef is simulated to reduce to approximately 300,000 m^3/yr, or 200,000 m^3/yr less than when the reef absent. The shoreline salient in the lee of the reef continues to increase in width throughout the ten year simulation period, reaching a width in excess of 100 m by the end of year 10. The upstream extent of beach widening does not increase significantly however, with beach widening in excess of 10 m extending approximately 2 km south of Narrowneck. Major erosion down-drift of Narrowneck is simulated, with the beach eroding back to the seawall alignment for a distance of approximately 2 km north of the site. By the end of the ten year simulation, erosion of the shoreline extends for a distance in excess of 3 km north of Narrowneck, or along more than half the beach between Narrowneck and the Seaway.

The results presented in Figure 3.13 show simulated shoreline evolution when wave transmission at the reef is assumed to be 90%, i.e., just 10% of incident wave energy is dissipated by the reef. The growth of the salient in the lee of the reef is much reduced, and by the end of the ten year simulation period beach widening of 20 m is simulated. This increase in beach width is not simulated to extend up-drift of Narrowneck, and erosion of the down-drift beach is minor (< 5 m). The net longshore transport rate in the vicinity of the reef exhibits only minor decrease in the first year of simulation, and in subsequent years converges to the equivalent transport rate of the immediate up-drift and down-drift beach.

Back-passing of Sand to Down-Drift Beach

It is proposed in the Northern Gold Coast Beach Protection Strategy (ICMa, 1997) that sand could be supplied to the beach north of the artificial reef, to maintain its pre-reef alignment. It is suggested in the Strategy that the back-passing of surplus sand from the mechanical by-passing system at the Seaway may be a potential source for this sand. However, in Section 2 and Section 3.5.1 it was concluded that the full 450,000 m^3/yr to 500,000 m^3/yr of sediment captured by the by-pass system is required to maintain the southern beaches of South Stradbroke Island. An alternative source of continuous sediment supply would therefore be required for back-passing operations to be undertaken.

In the simulation results presented in Figure 3.14, Figure 3.15 and Figure 3.16 wave transmission of 70% was assumed for the simulated artificial reef. In all three simulations a continuous supply of sediment to the beach adjacent to the northern end of the reef is also included, at an annual rate of 50,000 m^3/yr, 100,000 m^3/yr and 150,000 m^3/yr respectively. Relative to the case of no back-passing (Figure 3.11), the supply of 50,000 m^3/yr to the down-drift beach (Figure 3.14) provides moderate reduction in down-drift erosion. A beach width of approximately 20 m is maintained in front of the seawall alignment, however, up to 30 m of shoreline erosion is simulated.

The continuous supply of a simulated 100,000 m^3/yr of sand to the down-drift beach (Figure 3.15) significantly reduces down-drift erosion. Initial erosion of approximately 10 m in the first year is simulated as the salient in the lee of the reef grows rapidly, but by year 10 this decreases as local accretion occurs and the beach moves towards a new equilibrium state. It is anticipated that this initial phase of erosion adjacent to the northern end of the artificial reef could be further reduced if the beach in the lee of the reef were nourished following its construction.

Simulation incorporating a continuous sediment supply to the down-drift beach of 150,000 m^3/yr (Figure 3.16) suggests this increase in supply results in only a modest further improvement. Approximately 10 m of shoreline erosion is again predicted in the first year immediately north of the reef; the more significant change being an increase in the width of the salient that is simulated to develop in the lee of the reef. Acceleration of the recovery rate of the down-drift beach to its pre-reef alignment is also evident.

In interpreting the above results, it is important to note that the design of the modelled reef is preliminary only, and the actual nourishment requirements will depend on the final reef design, i.e., its size, orientation and hence effective wave transmission.

Nourishment of Up-Drift Beach

It is further proposed in the Northern Gold Coast Beach Protection Strategy (ICMa, 1997) that in addition to the construction of the artificial reef, sand nourishment should be undertaken to increase the beach amenity between Narrowneck and Surfers Paradise. The simulation of beach nourishment operations can be explicitly incorporated within the GENESIS shoreline model. In the following simulations, one-off nourishment (occurring within the first 6 months of the 10 year simulation period) to increase the width of the beach by 30 m, is simulated along the shoreline for a distance of 2000 m between Narrowneck and Surfers Paradise.

In Figure 3.17 the results of a simulation are shown that incorporates the proposed reef (transmission = 70%), continuous sediment supply to the down-drift beach (100,000 m^3/yr), and the proposed beach nourishment between Narrowneck and Surfers Paradise. The net annual longshore transport rate is set to ~500,000 m^3/yr. For completeness, both mechanical by-passing at the Seaway and natural by-passing from the ebb delta to southern South Stradbroke Island are again included. To provide a useful comparison, in Figure 3.18 the same nourishment operations are simulated, however the artificial reef is not included.

In both simulations, significant widening of the beach is maintained between Narrowneck and Surfers Paradise for the entire 10 year simulation period. It is particularly encouraging to note that the benefits of simulated beach widening in both cases extend for approximately 1 km south of the region of initial nourishment, due to the re-alignment of the shoreline along the up-drift beach.

In addition to the increase in beach width at Narrowneck, the primary benefit of the simulated reef is that it acts as partial barrier to northward sediment transport. At the reef the simulated net annual transport rate is reduced by approximately 100,000 m^3/yr to ~400,000 m^3/yr (Figure 3.17). As a result, the nourished beach to the south is maintained and even increases in width, relative to the case of no reef. By year 10 the increased width of the beach approximately 1 km south of the reef is maintained at approximately 30 m to 40 m. For the case of no reef this is simulated to reduced over the same time period to approximately 20 m.

The results of two further simulations shown in Figure 3.19 and Figure 3.20 are included to provide an assessment of the sensitivity of simulated shoreline response to a reduction or increase in the net annual sediment transport rate. In Figure 3.19 this was set to ~600,000 m^3/yr, and in Figure 3.20 the net annual transport rate was defined as ~400,000 m^3/yr. Comparison of these results suggest that both the growth of the shoreline salient in the lee of the reef and the extend of up-drift beach widening are relatively insensitive to the assumed net annual longshore transport rate. In all three simulations net transport at the reef is reduced by the order of ~100,000 m^3/yr relative to the adjacent open coast, and therefore the up-drift surplus and down-drift deficit in sediment supply remain constant.

In summary, it is concluded from the shoreline modelling results that the proposed artificial reef, in conjunction with nourishment of both up-drift and down-drift beaches, is anticipated to have the positive effects of both increasing and maintaining beach width. The simulated response to the reef is beach widening in the lee and along the up-drift beach. Results indicate that the reef as modelled retards the longshore transport rate by approximately 100,000 m^3/yr, and therefore to prevent erosion of the down-drfit (northern) beaches, approximately ~100,000 m^3/yr beach nourishment/back-passing to these beaches is required.

Beach nourishment at Surfers Paradise is simulated to result in significant beach widening, both in the presence and absence of the proposed reef. Resulting beach widening is maintained for the full 10 year simulation period, with the additional benefit that this is simulated to extend for an additional distance of approximately 1 km south (up-drift) of the initial nourishment region. Simulation results suggest that the primary benefit of the proposed reef is that an increased beach width is maintained.

4. MODELLING OF SEAWAY GROYNE EFFICIENCY

4.1 Introduction

The preceding results of simulated shoreline evolution in the vicinity of the Seaway and proposed artificial reef consistently indicate that, for the 'average' annual wave conditions simulated, the training-walls at the Seaway effectively block the longshore transport of sediment. In other words, other than by mechanical pumping, for most wave conditions the net northward transport of sediment past the Seaway is effectively zero.

During extreme storm wave conditions, however, natural by-passing of sand around the Seaway is anticipated. To investigate the degree of natural by-passing, and to determine under what storm wave conditions this seaward by-passing is likely, the UNIIBEST-LT model (DELFT, 1994) was used to investigate the cross-shore distribution of longshore transport at the Seaway. In Section 4.2 a brief overview of the UNIBEST model is provided, followed in Section 4.3 by a description of the model setup. Results of simulation and sensitivity testing are presented in Section 4.4.

4.2 The UNIBEST-LT Model - a brief overview

The UNIBEST (<u>UNI</u>form <u>BE</u>ach <u>S</u>ediment <u>T</u>ransport) software package was developed by Delft Hydraulics of the Netherlands, to simulate sediment transport processes at the coast (DELFT, 1994). The UNIBEST-LT (<u>L</u>ongshore <u>T</u>ransport) sub-model is - as its name implies - a tool to examine longshore transport processes.

In some respects UNIBEST is more limited than the GENESIS model (e.g. the complexity of the wave climate that can be simulated), however it does incorporate superior formulations for sediment transport, and in particular it provides an additional capability that is very useful to the present study. Unlike the GENESIS model which calculates net longshore transport as a bulk transport rate at any particular location along the shoreline, the UNIBEST-LT model provides the ability to determine the <u>cross-shore distribution</u> of this longshore transport. In other words, the transport rate at any particular depth or distance offshore can be investigated. In this manner it is possible to examine rates of sediment transport seaward of the Seaway training-walls during extreme storm wave conditions, and therefore to asses natural by-passing of the Seaway.

Briefly, within UNIBEST-LT surf zone dynamics are computed by a built-in random wave propagation and decay model (Battjes and Stive, 1984). The model transforms offshore wave data to the coast, taking into account the principal processes of wave energy changes due to bottom refraction, shoaling and dissipation by wave breaking and bottom friction. The resulting longshore current distribution is then calculated using the momentum equation, incorporating bottom friction, the gradient of radiation stress and the tidal surface slope alongshore (if the tide is included). The cross-shore distribution of the longshore sediment transport rate is then evaluated by any one of several total-load transport formulae. The formulation of Bijker (Bijker, 1971) is used in the present study, as previous investigations by WRL have found this to be both reliable and robust.

4.3 Model Setup

4.3.1 Beach and Nearshore Profile

Analysis of repeated surveys from profile line ETA 63 was used to determine the 'mean' representative beach profile. This location was chosen due to its close proximity to the Seaway and proposed artificial reef, and because of the large number of surveys that have been undertaken at the site over the period 1976 - 1997. The profile was extended out to 80 m water depth (the depth of the offshore wave rider buoy) by bathymmetric chart.

4.3.2 Wave Conditions

The cross-shore distribution of longshore sediment transport was modelled using both a summary of time-varying annual 'average' conditions, as well as additional model runs using a constant (storm) wave height, period and direction.

As previously mentioned, a limitation of the UNIBEST model is that the input wave climate is limited, with no more than 100 separate wave conditions (height, period, direction) being incorporated. For this reason, the full 6 hourly, 12 month directional wave climate (total wave 'events' = 1460; refer Section 3.3.2) used for the GENESIS modelling could not be simulated.

To circumvent this limitation, a statistical summary of the full 12 month directional wave climate was generated. The data set was grouped into six 30° directional classes (-90° to +90°), eight 2 sec wave period classes (2 sec - 14 sec)) and nine corresponding 0.5 m wave height classes (0.5 m to 4.0 m). This wave climate summary is tabulated in Table 4.1. The wave 'events' of duration greater than one day (total = 77) were used to define the 'average' wave climate for input to the UNIBEST-LT model.

TABLE 4.1
Wave Climate Summary for Input to UNIBEST

Direction: -90 to -60
No days = 23.450 Wave height (m)

T (sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0	0.51	0	0	0	0	0	0	0.51
4-6	0	0	3.06	2.8	0.25	0	0	0	0	6.12
6-8	0	0	0.51	2.55	0.76	1.27	0.51	0	0	5.61
8-10	0	0	0.51	1.78	2.04	0.51	0.25	0	0	5.1
10-12	0	0	1.27	1.27	2.04	0.76	0	0	0	5.35
12-14	0	0.25	0	0.51	0	0	0	0	0	0.76
>14	0	0	0	0	0	0	0	0	0	0
	0	0.25	5.86	8.92	5.1	2.55	0.76	0	0	23.45

Direction: -60 to -30
No days = 155.227 Wave height (m)

T(sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0	0	0	0	0	0	0	0	0
4-6	0	0	1.53	3.57	1.02	0	0	0	0	6.12
6-8	0	0.51	6.88	5.35	7.65	3.06	0.76	0.51	0	24.72
8-10	0	1.78	8.67	6.12	6.63	3.82	2.04	1.27	0.25	30.59
10-12	0	2.8	26	16.31	13.25	10.45	4.59	0.76	0.76	74.94
12-14	0	0.51	7.65	3.82	2.04	0.25	0	0.25	0	14.53
>14	0	0	2.55	1.02	0.25	0.25	0	0.25	0	4.33
	0	5.61	53.27	36.19	30.84	17.84	7.39	3.06	1.02	155.23

Direction: -30 to 0
No days = 81.309 Wave height (m)

T (sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0	0	0	0	0	0	0	0	0
4-6	0	0	0	1.27	0	0	0	0	0	1.27
6-8	0	0.51	9.18	2.8	4.33	3.82	0.51	0	0	21.16
8-10	0	2.55	5.1	6.12	4.84	0	1.02	0.25	0	19.88
10-12	0	4.33	15.04	7.9	4.08	2.29	0	0	0	33.65
12-14	0	2.04	1.53	0.51	0.25	0	0.51	0	0	4.84
>14	0	0	0.51	0	0	0	0	0	0	0.51
	0	9.43	31.35	18.61	13.51	6.12	2.04	0.25	0	81.31

TABLE 4.1 (continued)
Wave Climate Summary for Input to UNIBEST

Direction: 0 to 30
No days = 73.153 **Wave height (m)**

T (sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0	0	0	0	0	0	0	0	0
4-6	0	0.51	0	0.25	0	0	0	0	0	0.76
6-8	0	4.84	14.02	4.59	5.86	0.51	0	0	0	29.82
8-10	0	0	4.33	6.63	6.37	2.8	0.51	0	0	20.65
10-12	0	2.04	2.55	3.06	3.82	3.31	2.8	0	0	17.59
12-14	0	1.02	1.02	0.51	0	1.27	0	0.25	0	4.08
>14	0	0	0	0.25	0	0	0	0	0	0.25
	0	8.41	21.92	15.29	16.06	7.9	3.31	0.25	0	73.15

Direction: 30 to 60
No days = 10.450 **Wave height (m)**

T (sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0	0	0	0	0	0	0	0	0
4-6	0	0.51	1.78	0.25	0	0	0	0	0	2.55
6-8	0	1.02	2.55	1.02	0.51	0.51	0	0	0	5.61
8-10	0	0	0.76	0	0	0.25	0.25	0.25	0	1.53
10-12	0	0	0.25	0	0.51	0	0	0	0	0.76
12-14	0	0	0	0	0	0	0	0	0	0
>14	0	0	0	0	0	0	0	0	0	0
	0	1.53	5.35	1.27	1.02	0.76	0.25	0.25	0	10.45

Direction: 60 to 90
No days = 21.411 **Wave height (m)**

T (sec)	<0.5	0.5-1.0	1.0-1.5	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5	3.5-4.0	=>4.0	
<2	0	0	0	0	0	0	0	0	0	0
2-4	0	0.51	1.02	0	0	0	0	0	0	1.53
4-6	0	3.31	11.98	2.29	0.25	0	0	0	0	17.84
6-8	0	0	1.02	0.76	0	0.25	0	0	0	2.04
8-10	0	0	0	0	0	0	0	0	0	0
10-12	0	0	0	0	0	0	0	0	0	0
12-14	0	0	0	0	0	0	0	0	0	0
>14	0	0	0	0	0	0	0	0	0	0
	0	3.82	14.02	3.06	0.25	0.25	0	0	0	21.41

It is noted from Table 4.1 that the occurrence of significant wave heights in excess of 4.0 m is a rare event. This is consistent with the extensive analysis by the Department of Environment of the Gold Coast non-directional wave climate for the period 1976 - 1997 (DOE, 1997a) which found the probability of occurrence of H_s (significant wave height) greater than 4.0 m is much less than 1%. During the 22 year wave recording period, H_s greater than 4.0 m has been measured on a total of 51 occasions, with the maximum event of $H_s = 7.4$ m recorded in March 1993.

Assessment of the potential for natural by-passing of the Seaway during such extreme storm events was undertaken for constant wave heights of H_s = 4 m, 5 m, 6 m and 7 m. Three wave periods of T = 10 sec, 12 sec and 14 sec were examined, for representative offshore wave directions of 22.5°, 45° and 67.5°, relative to the north-south orientation of the coast.

4.4 Results

4.4.1 'Average' Annual Wave Climate

Figure 4.1 presents the cumulative cross-shore distribution of longshore sediment transport, simulated using the summary 'average' annual wave climate. This figure shows the percentage of the total annual transport that occurs between the shoreline and any distance between 0 m and 600 m offshore. Also indicated is the seaward tip of the southern breakwater at the Seaway, located approximately 400 m offshore. Because much of the detail of the full 12 month directional wave data set was summarised into six 30° directional classes, sensitivity analysis to wave direction was also undertaken. Each of the six wave direction classes were rotated by ±5 °, ±10 °, ±15° and the model re-run for each case.

Figure 4.1 indicates that 50% of the simulated 'average' annual transport occurs within 200 m of the shoreline, with negligible transport (<5%) occurring greater than 400 m seawards of the shoreline. This supports the findings of the GENESIS modelling, where it is recalled the Seaway was found to act as an effective barrier to longshore transport. Figure 4.1 also shows that this conclusion is insensitive to wave direction. Artificial rotation of the incident wave climate by up to ±15° can be seen to have only minor effect on the cross-shore distribution of sediment transport.

In summary, subjected to 'average' annual wave conditions, the Seaway effectively acts as a total barrier to the longshore transport of sediment.

4.4.2 Extreme Storm Conditions

Figures 4.2, 4.3 and 4.4 show the cumulative cross-shore distribution of longshore sediment transport for offshore wave directions 22.5°, 45° and 67.5° respectively. Again, a distance of 400 m seaward of the shoreline is indicated, corresponding to the seaward tip of the Seaway's southern breakwater. For all combinations of wave period and direction, significant by-passing of the Seaway is simulated for all wave heights in excess of 4.0 m.

For the maximum observed significant wave heights of the order of $H_s \approx 7.0$ m, greater than 50% and up to 80% of the total longshore transport at these times is simulated to occur seaward of the Seaway breakwaters. During such extreme events, waves would be breaking so far offshore that significant transport occurs in water depths where, during lesser storm events, no sand would be mobilised. On these rare occasions, significant natural by-passing of the Seaway is anticipated.

In summary, simulation of the cross-shore distribution of longshore sediment transport for the Northern Gold Coast confirms that, for the 'average' annual wave conditions, negligible (<5%) natural by-passing of the Seaway is anticipated. This is likely to represent a lower estimate of the actual rate of natural by-passing, due to local 2-D surf zone circulation in the vicinity if the Seaway training-walls, and the diurnal tidal exchange through the Seaway.

During major (= rare) storm events, significant natural by-passing of the Seaway is simulated. For wave heights in excess of 5m, natural by-passing rates of 50% and greater are anticipated.

5. CONCLUSIONS AND RECOMMENDATIONS

- Prior to the construction of the Seaway, the Nerang River Inlet was migrating northward due to the re-distribution of tidal flow which occurred around 1900 with the opening of the Jumpinpin entrance. Sediment infilling of the Broadwater was occurring at rates of the order of 80,000 m^3/year. Natural bypassing of the entrance occurred, providing South Stradbroke Island with a supply of sand in equilibrium with the littoral transport potential. As a result, no long-term recession or accretion was evident on South Stradbroke Island.

- At the present time (i.e., post Seaway construction) a net northerly littoral transport rate of 500,00 m^3/year occurs along the Gold Coast Embayment. The net littoral transport potential of the South Stradbroke coastline is less than this due to a more easterly alignment. Aerial photo interpretation indicates that beaches in the vicinity of the Seaway are currently in "equilibrium", with South Stradbroke beaches showing a net zero change or possibly a marginal accretionary trend.

- Volumetic analysis and aerial photo interpretation indicate that the current average annual pumping rate for the bypassing system of 450,000 m^3/year, combined with some natural bypassing of the ebb delta, are in balance with the littoral transport requirements of the adjacent beaches.

- Volumentic analysis of the Seaway and adjacent beaches confirms that the existing conditions of sand transport driven by tidal flows at the Seaway is de-coupled from the longshore littoral processes, and is ebb-tide dominated.

- It is anticipated that ebb-dominated sediment dynamics at the Seaway and de-coupled littoral and entrance processes will continue for foreseeable future. The stability of the Spit and South Stradbroke Island beaches is dependant on the bypassing system remaining fully operational.

- From the refined Seaway conceptual sediment budget (Figure 2.19) it is concluded that the preferred source of beach nourishment material is the ebb delta. It is estimated that of the order of ~1M m^3 of sand is available, provided more detailed modelling is undertaken to determine the effect on entrance tidal hydraulics. Dredging of the approach channels within the Seaway is less desirable. However, either source can be utilised with minimal impact on the stability of the adjacent beaches. Back-passing from the bypass system is not recommended.

- Shoreline modelling (GENESIS) confirms that mechanical by-passing at the Seaway should be maintained at the current rate of approximately 450,000 m^3/yr. With natural by-passing assumed to be occurring from the ebb tide delta to the northern beach at an annual rate of approximately 50,000 m^3/yr, the simulation results indicate that a near equilibrium shoreline is maintained within the study region. Limited erosion immediately north of the Seaway simulated under these conditions may reflect the erosion of the beach back to its original orientation prior to the construction of the Seaway.

- Shoreline modelling (GENESIS) indicates that erosion/accretion of beaches immediately north and south of the Seaway is relatively sensitive to the mechanical by-passing rate and net annual longshore transport rate. A management strategy is therefore recommended that permits the mechanical by-passing rate to be periodically re-assessed, and temporarily increased or decreased (± 50,000 - 100,000 m^3/yr) in response to natural inter-annual variation in the regional longshore sediment transport rate. It is therefore recommended that the present by-passing operations should not be considered as a sediment source for the back-passing of sediment to nourish Northern Gold Coast beaches.

- Simulation (UNIBEST) of the cross-shore distribution of longshore sediment transport at the Northern Gold Coast confirms that, for the 'average' annual wave conditions, negligible (<5%) natural by-passing of the Seaway is anticipated. This is likely to represent a lower estimate of the actual rate of natural by-passing, due to local 2-D surf zone circulation in the vicinity if the Seaway training-walls, and the diurnal tidal exchange through the Seaway.

- During extreme storm events, significant natural by-passing of the Seaway is anticipated. For wave heights in excess of 5m, natural by-passing rates of 50% and greater are simulated (UNIBEST).

- Shoreline modelling (GENEISIS) incorporating the proposed artificial reef at Narrowneck, in conjunction with nourishment of both up-drift and down-drift beaches, indicates that the structure is anticipated to have the positive effects of both increasing and maintaining beach width. The simulated shoreline response to the reef (+ up-drift/down-drift nourishment) is beach widening in the lee and along the up-drift beach.

- Shoreline modelling (GENESIS) suggests that the reef as modelled (70% transmission) effectively retards the longshore transport rate by approximately 100,000 m^3/yr, and therefore to prevent erosion of the down-drift (northern) beaches, approximately ~100,000 m^3/yr beach nourishment/back-passing to these beaches would be required. Sediment by-passing of the protoptype reef will depend on the final reef design (size, orientation effective wave transmission), and therefore the actual nourishment requirements could be reduced.

- Simulated (GENESIS) beach nourishment at Surfers Paradise results in significant beach widening, both in the presence and absence of the proposed reef. Resulting beach widening is maintained for the full 10 year simulation period, with the additional benefit that this is simulated to extend for an additional distance of approximately 1 km south (up-drift) of the initial nourishment region. Simulation results suggest that the primary benefit of the proposed reef is that an increased beach width is maintained.

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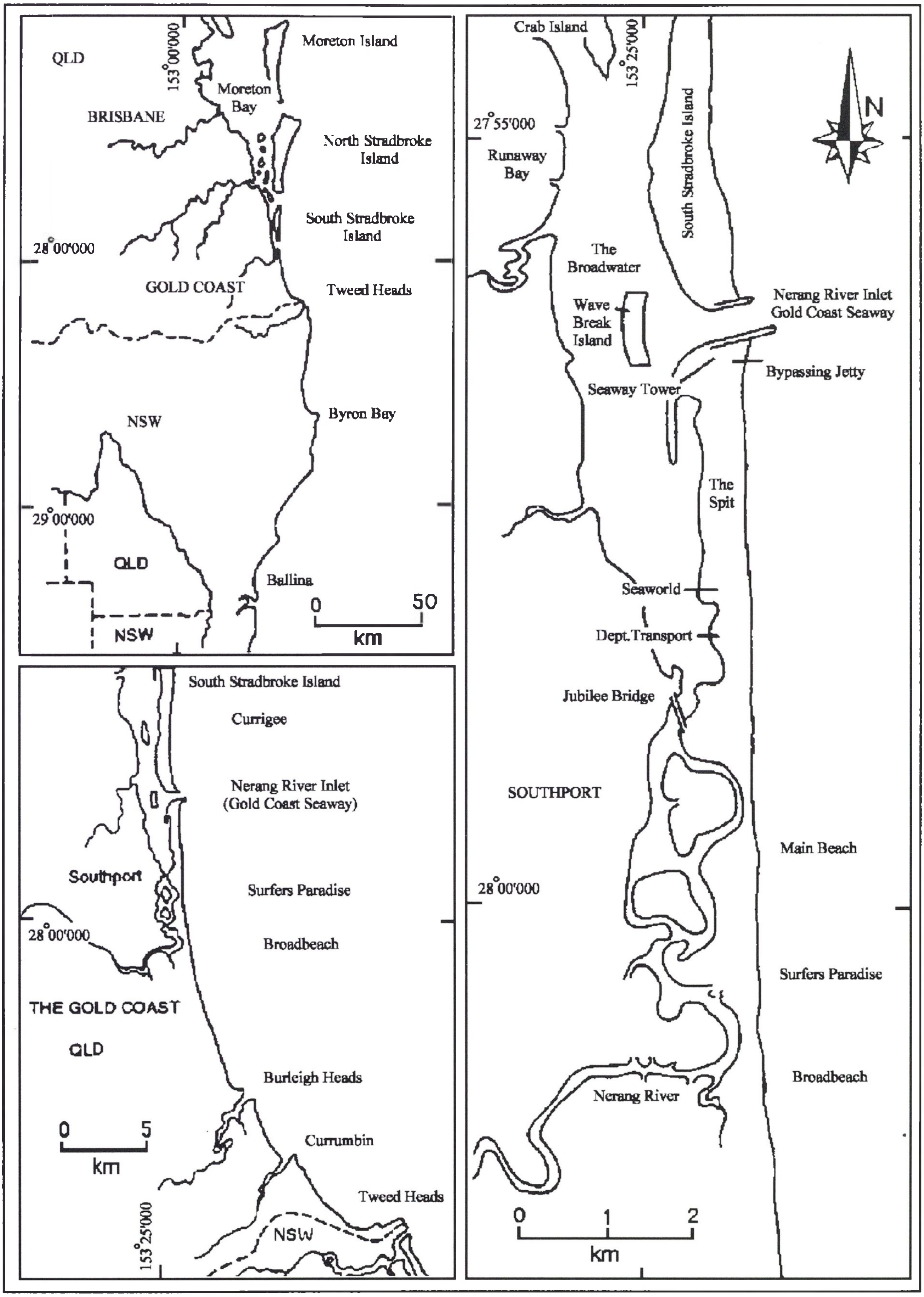
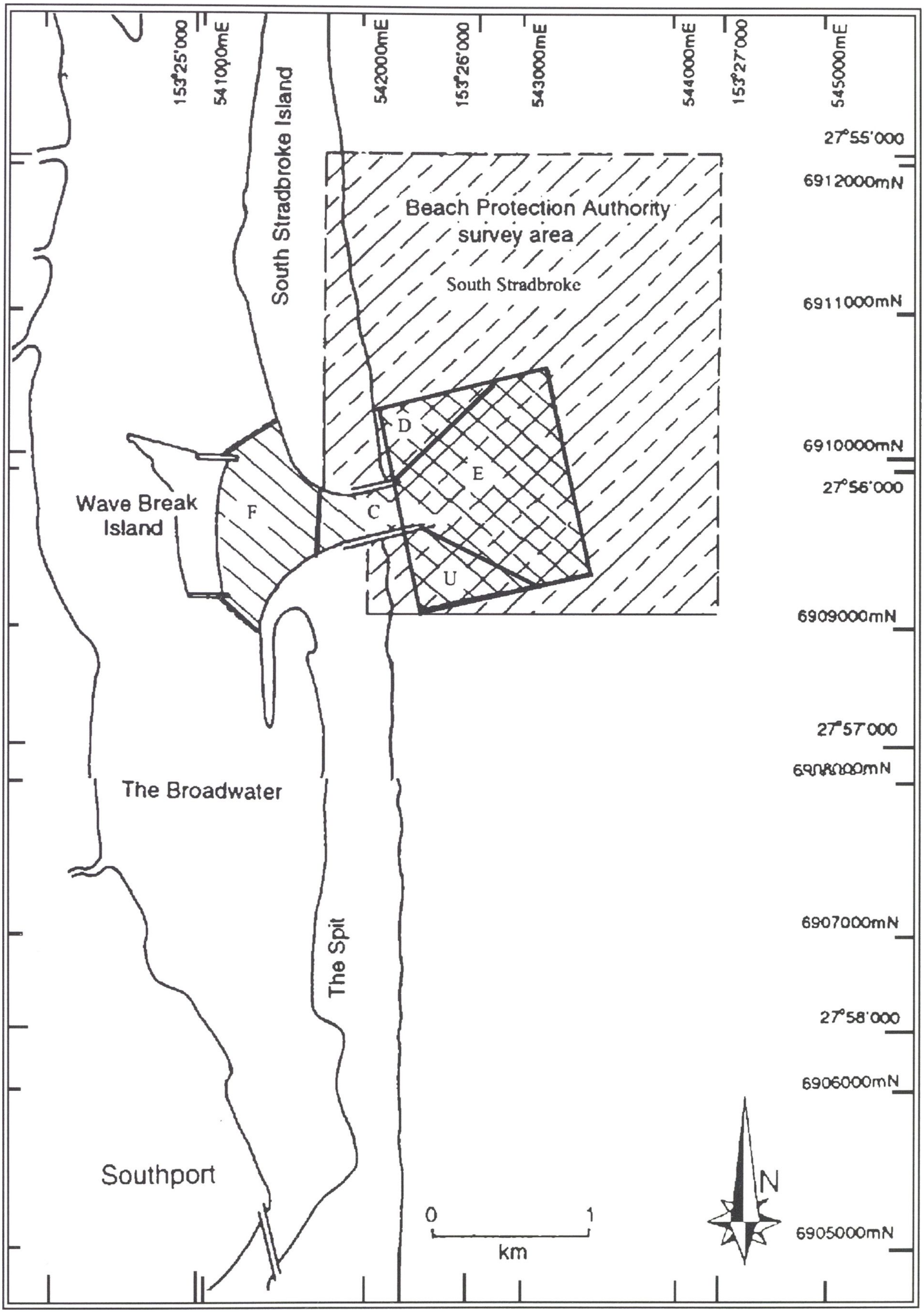
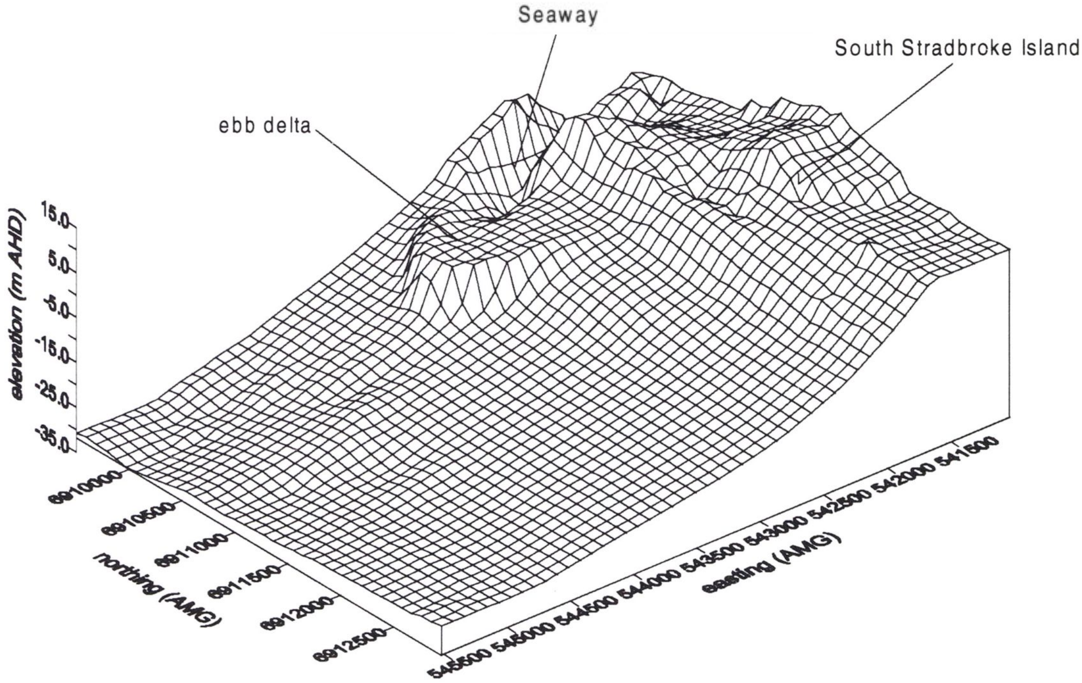


UNISEARCH Report No. 98/08	Location	Figure 1.1



Definition of regions adjacent to, and within, the Seaway

Figure 2.1



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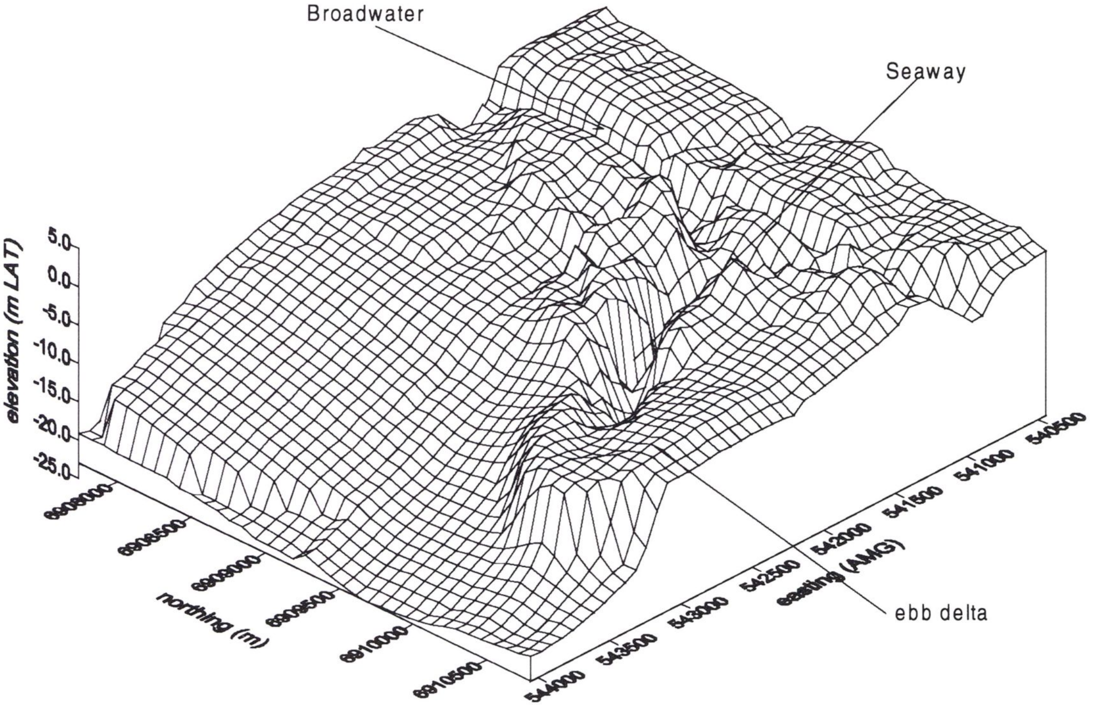
Digital Terrain Model DoE (1992)

Figure 2.2



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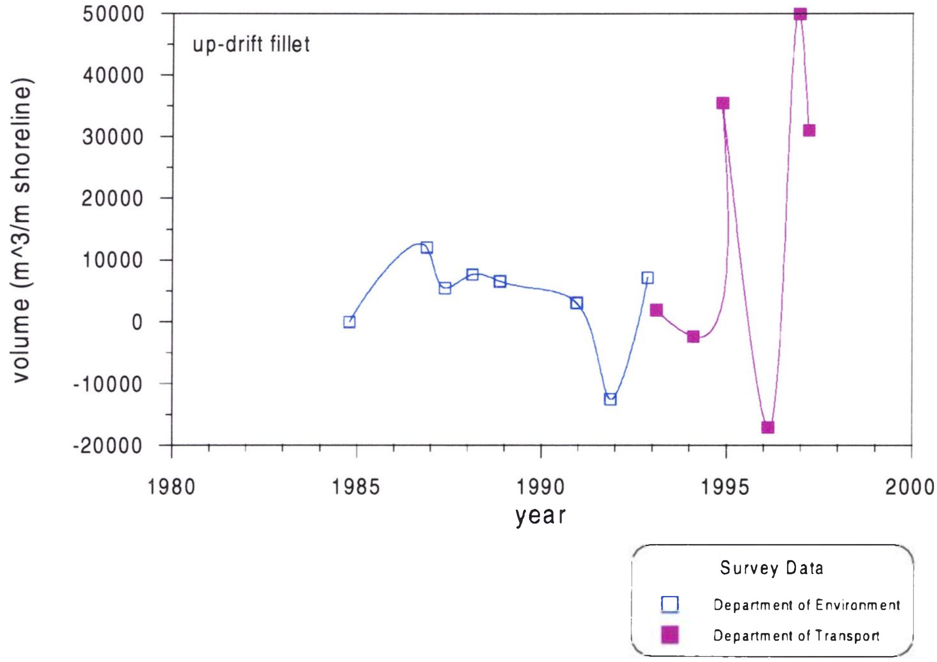
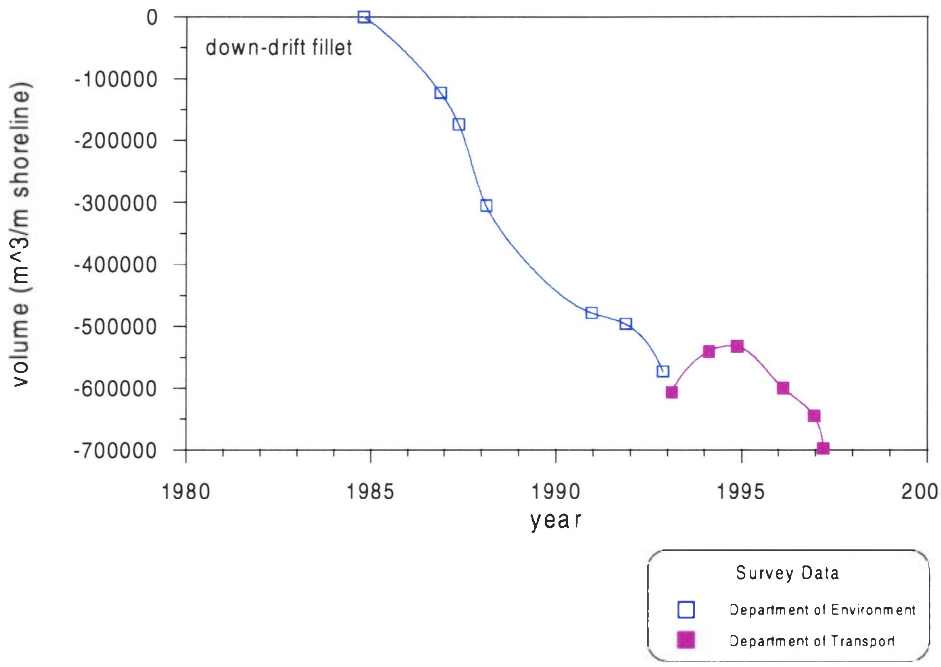
Digital Terrain Model DoT (1996)

Figure 2.3



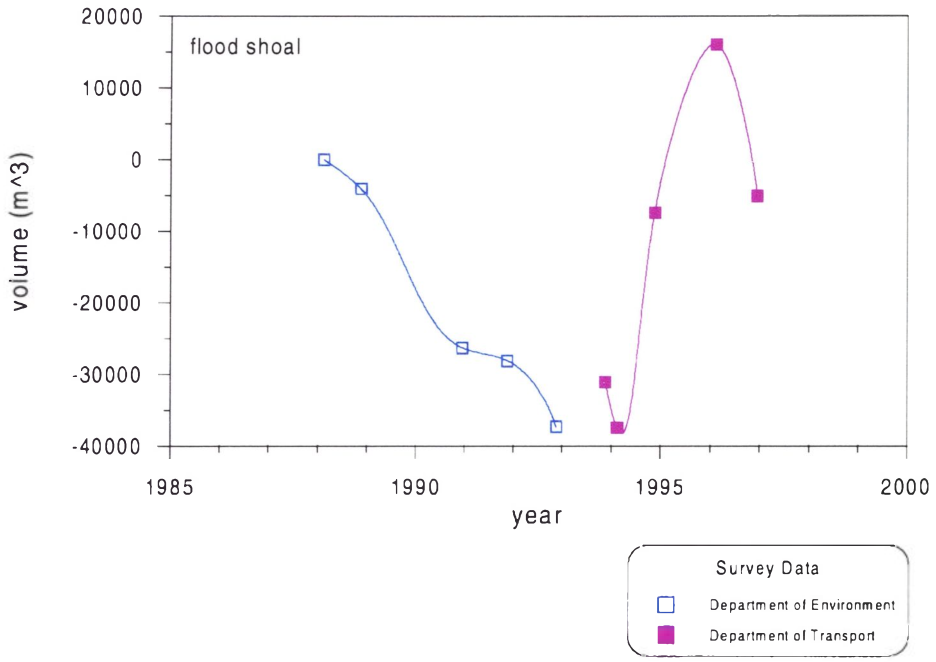
Change cumulative volume (relative to first survey date)
- Up-drift fillet

Figure
2.4



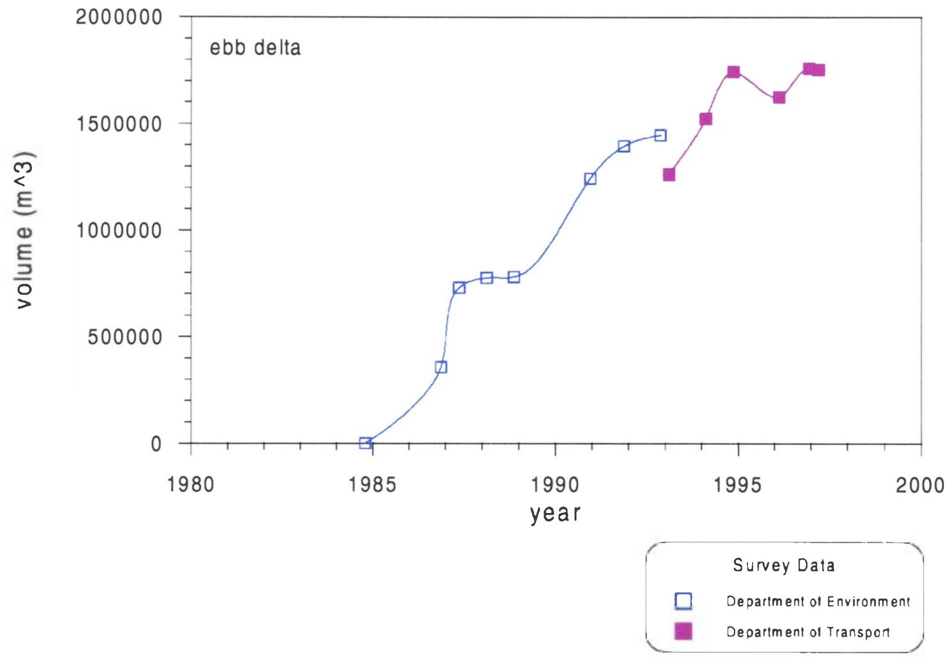
Change cumulative volume (relative to first survey date)
- Down-drift fillet

Figure
2.5

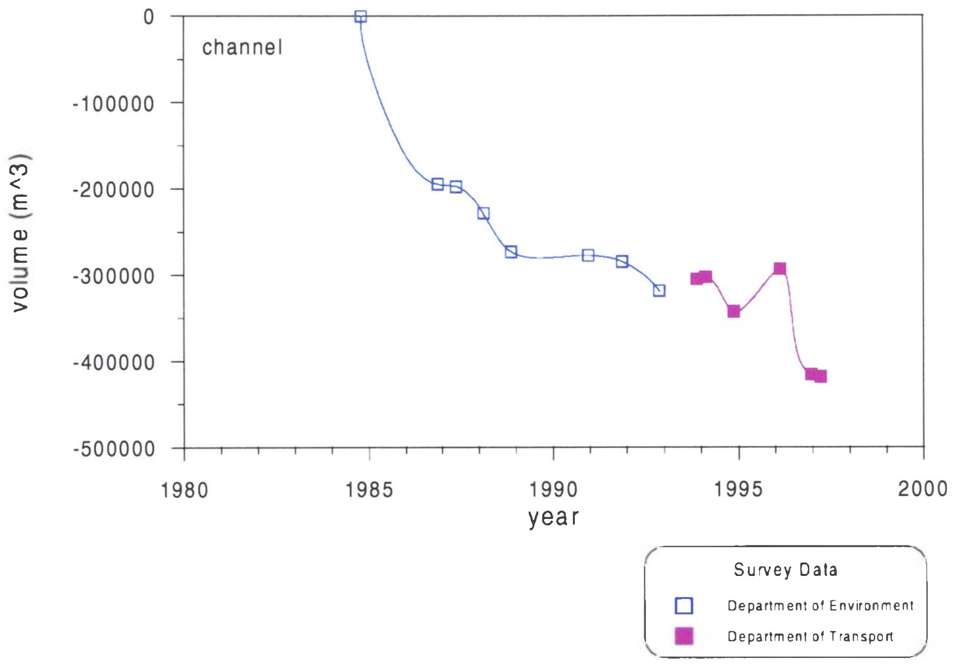


Change cumulative volume (relative to first survey date) - Flood Shoal

Figure 2.6



UNI SEARCH Report No. 98/08	Change cumulative volume (relative to first survey date) - Ebb Delta	**Figure** **2.7**



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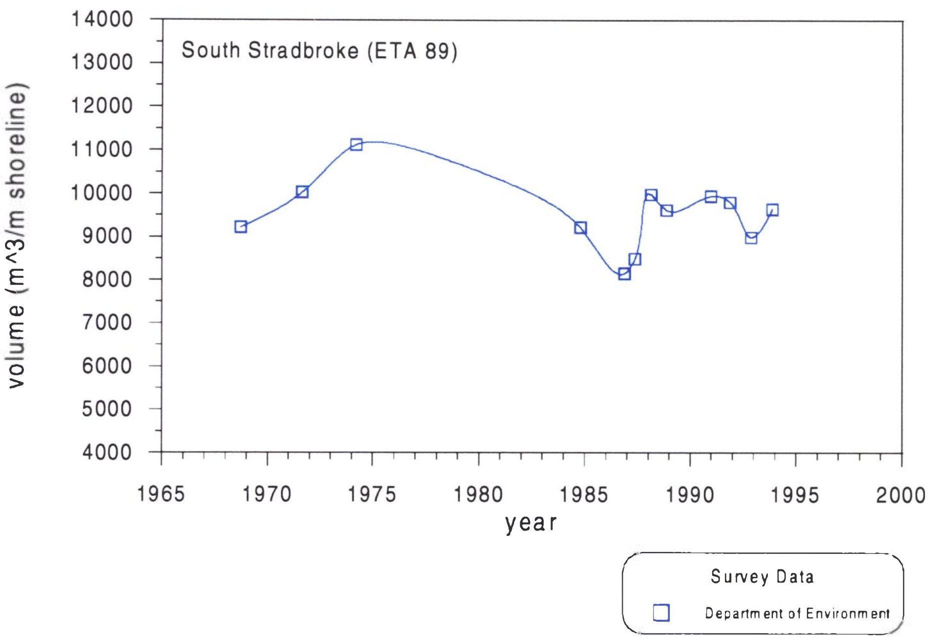
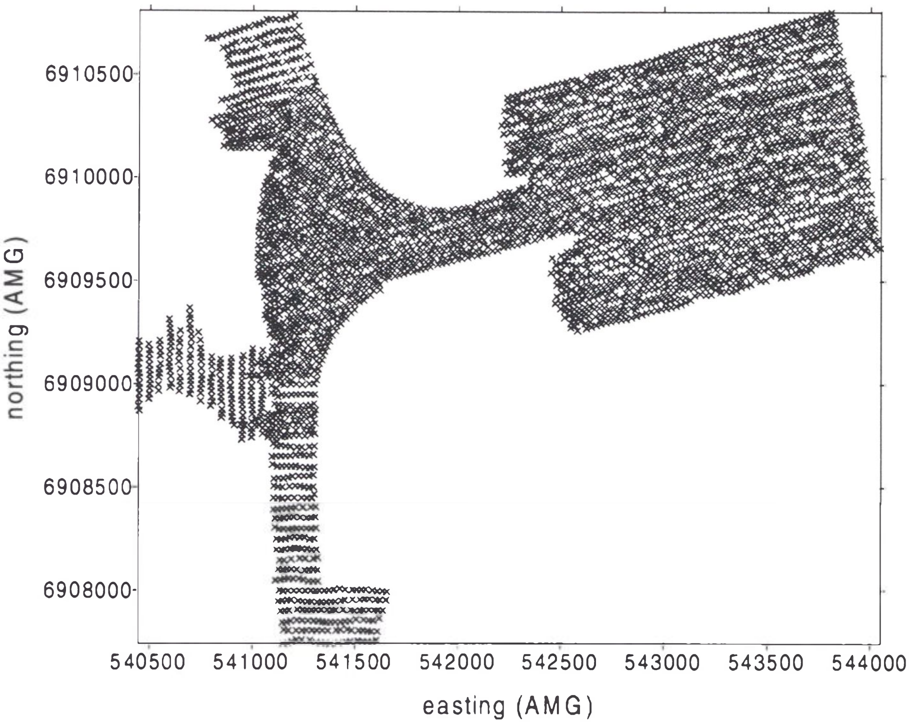
Change cumulative volume (relative to first survey date) - Channel

Figure 2.8

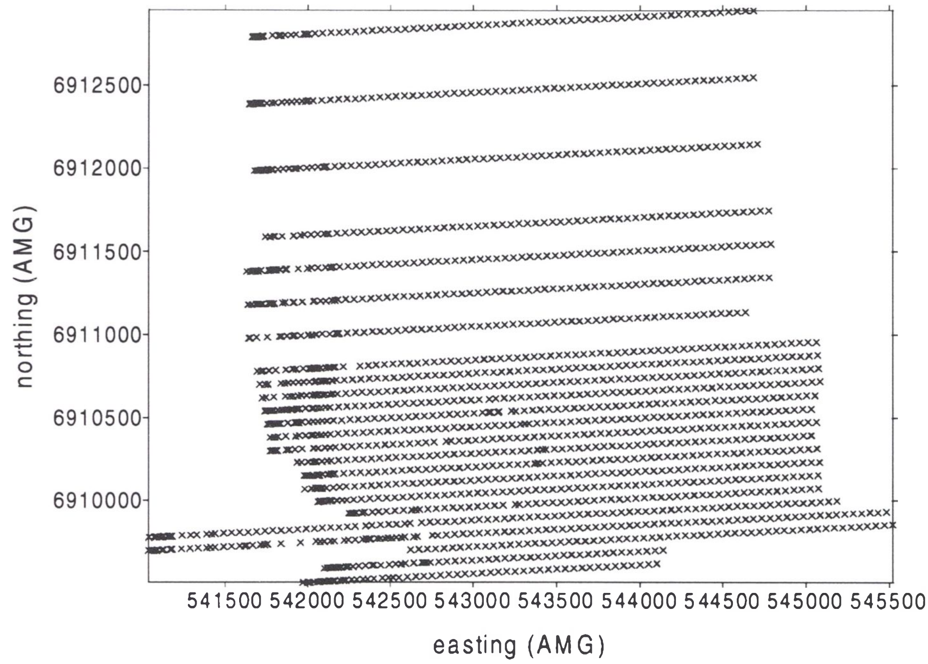


Change cumulative volume (relative to first survey date) - South Stradbroke

Figure 2.9



UNISEARCH Report No. 98/08	Survey data density - DoT (1996)	Figure 2.10



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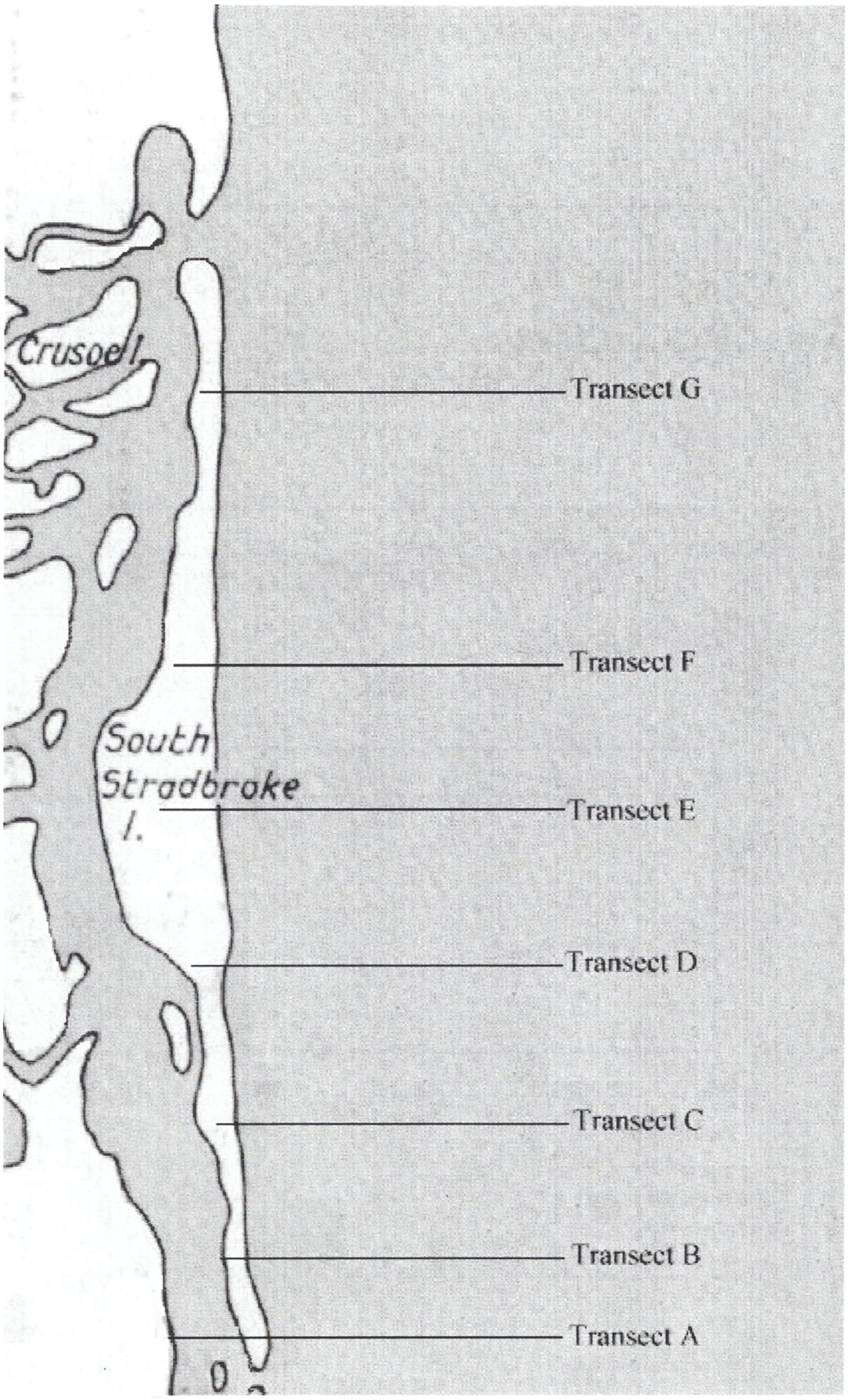
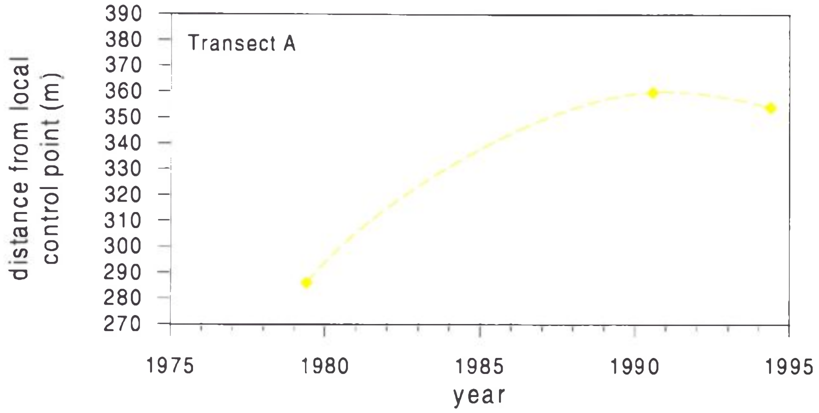
Survey density - DoE (1992)

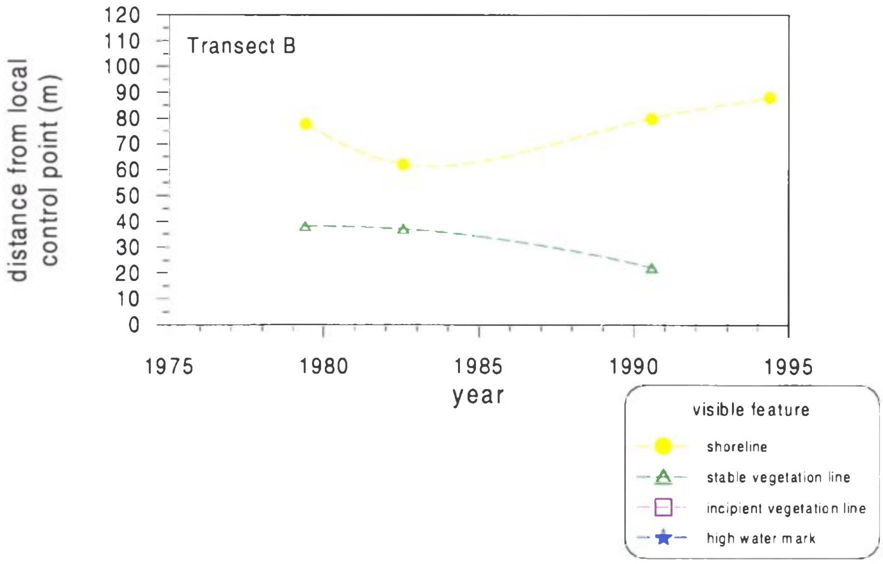
Figure 2.11



Transect locations for visual aerial photo interpretation

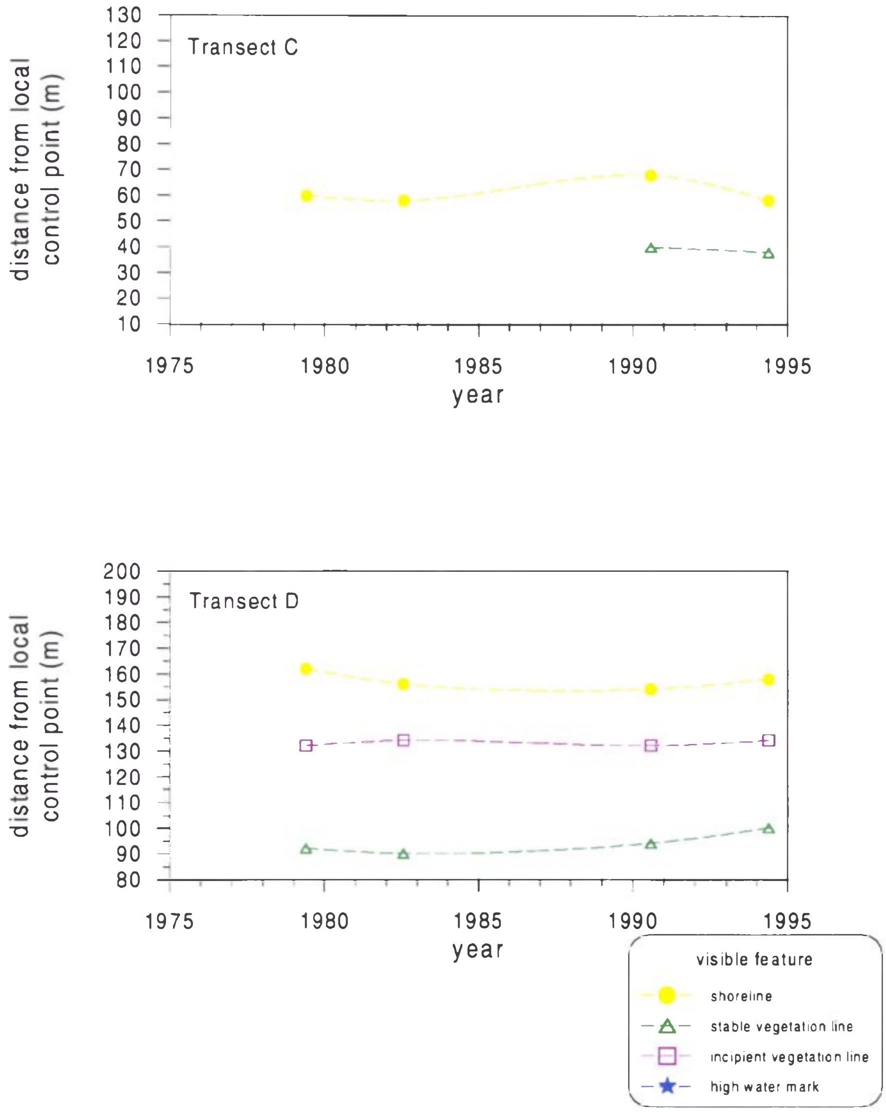
Figure 2.12





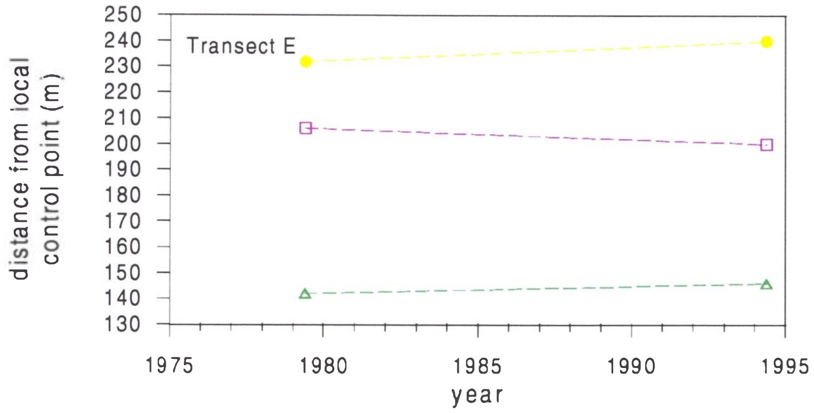
Results of photo interpretation - Transects A & B

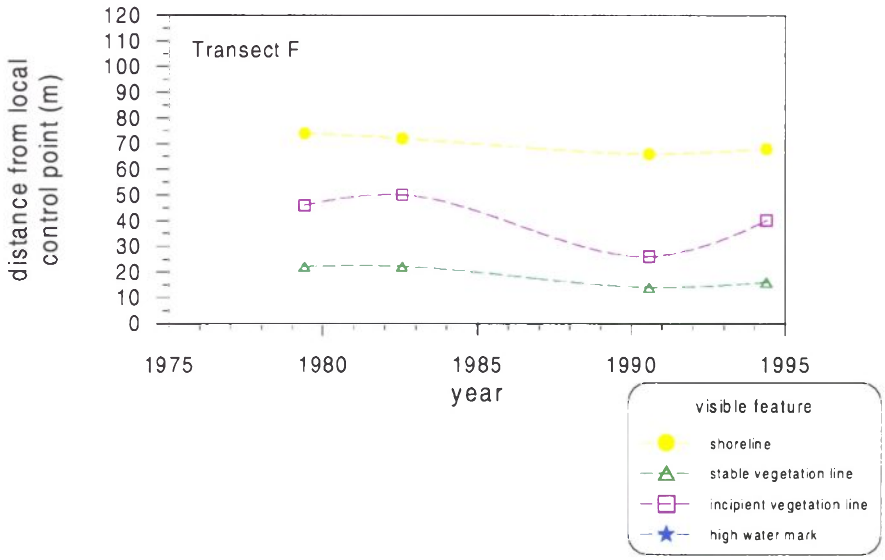
Figure 2.13



Results of photo interpretation - Transects C & D

Figure 2.14





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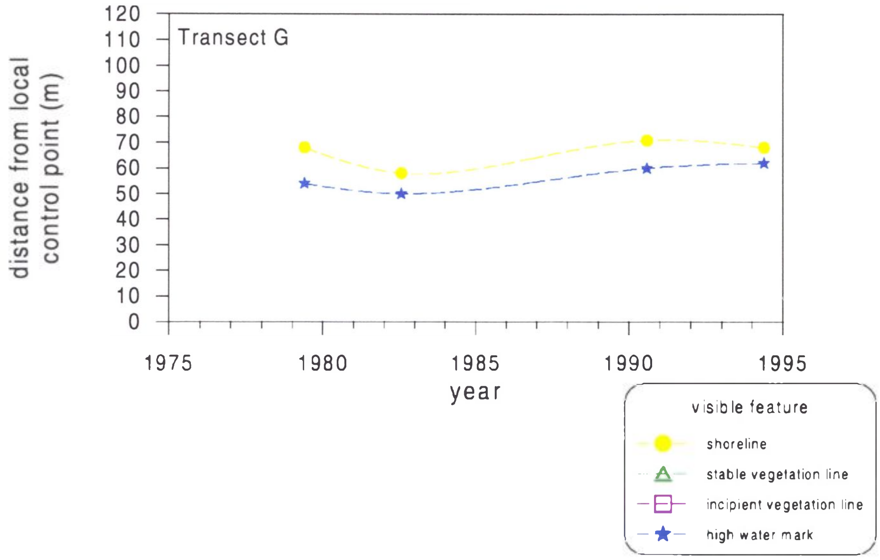
Results of photo interpretation - Transects E & F

Figure 2.15



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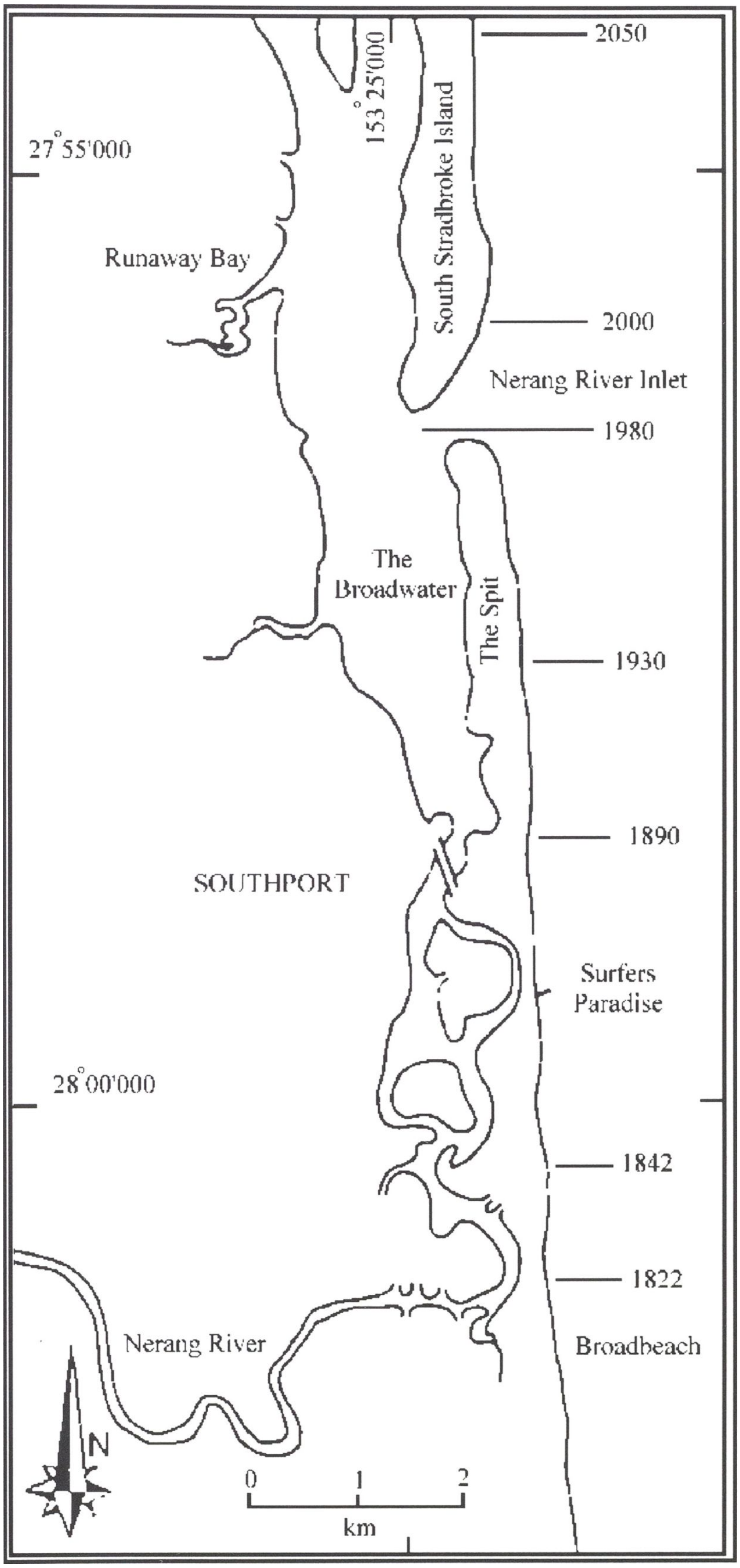
Results of photo interpretation - Transect G

Figure 2.16



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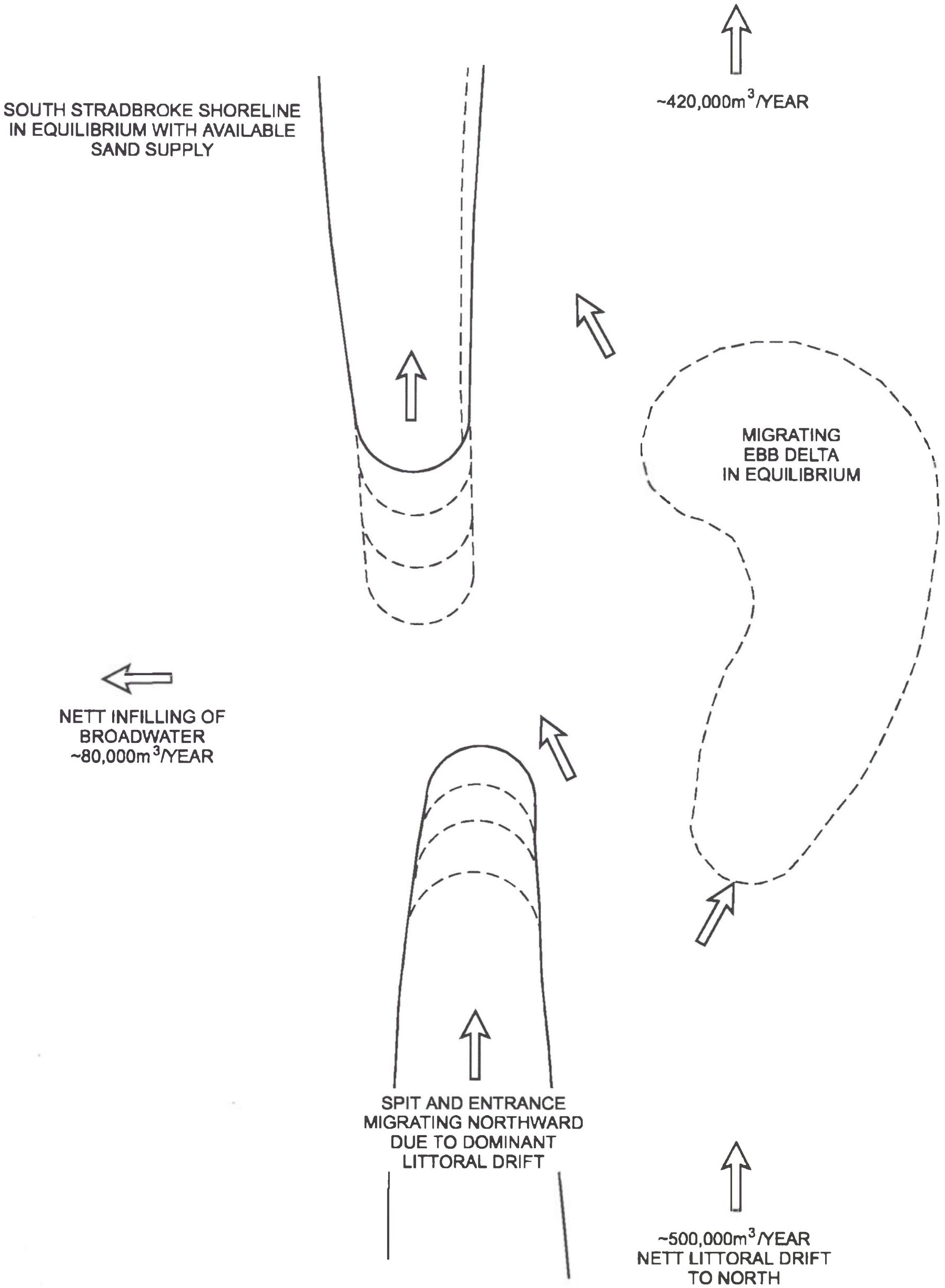
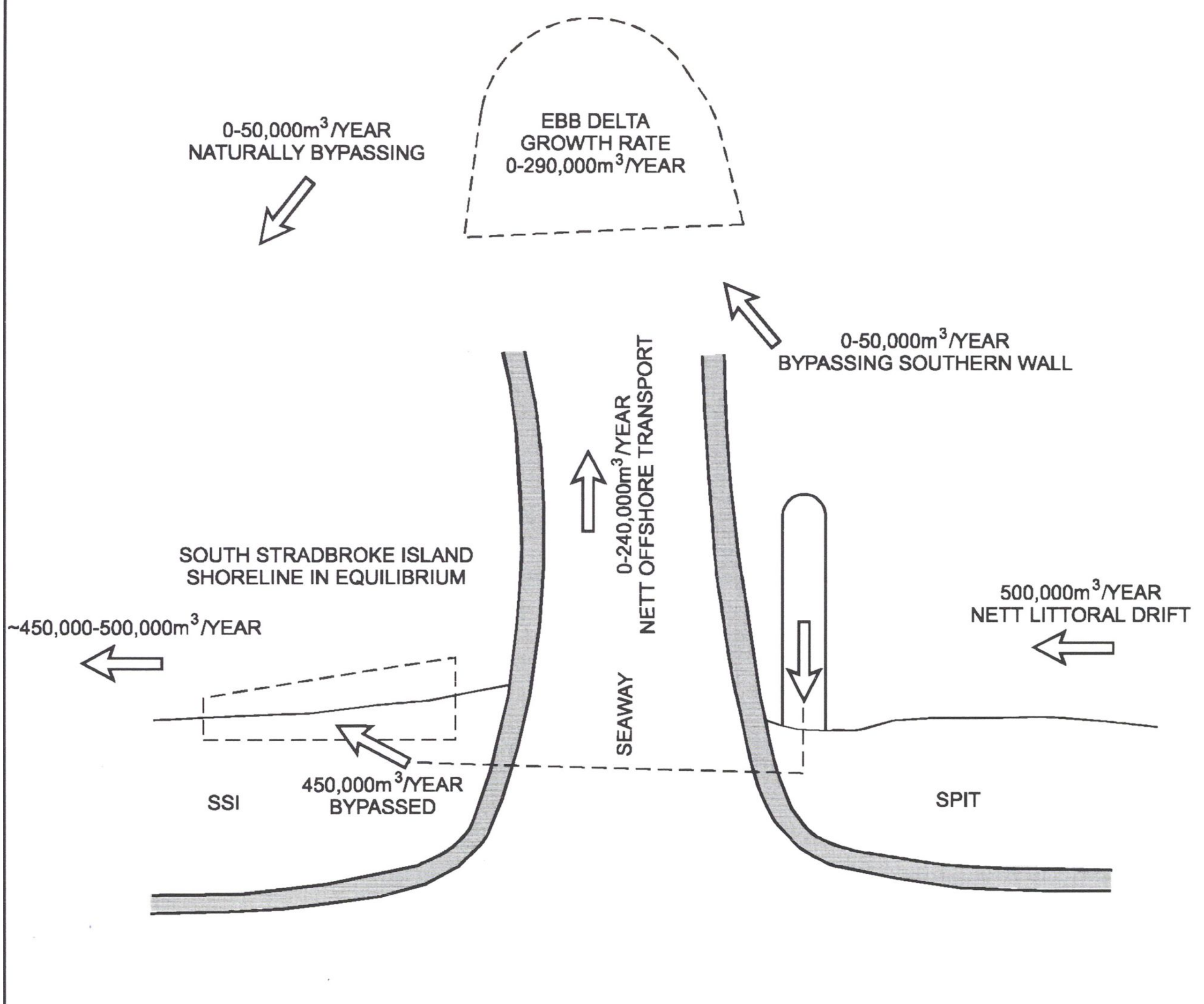
Inferred historical Nerang River entrance locations

Figure 2.17



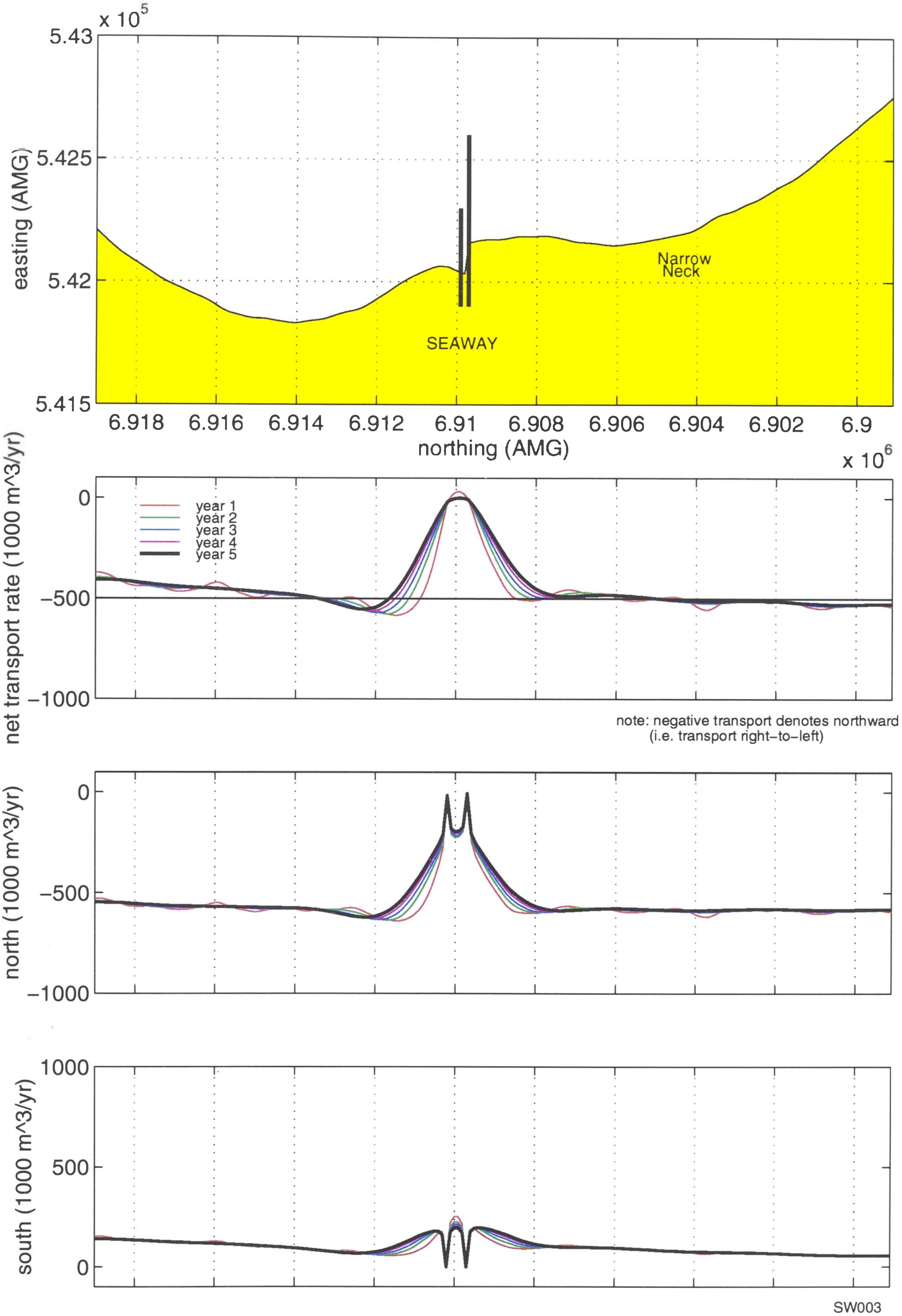
Conceptual Model - pre Seaway conditions

Figure 2.18



Conceptual Model - post Seaway conditions

Figure 2.19



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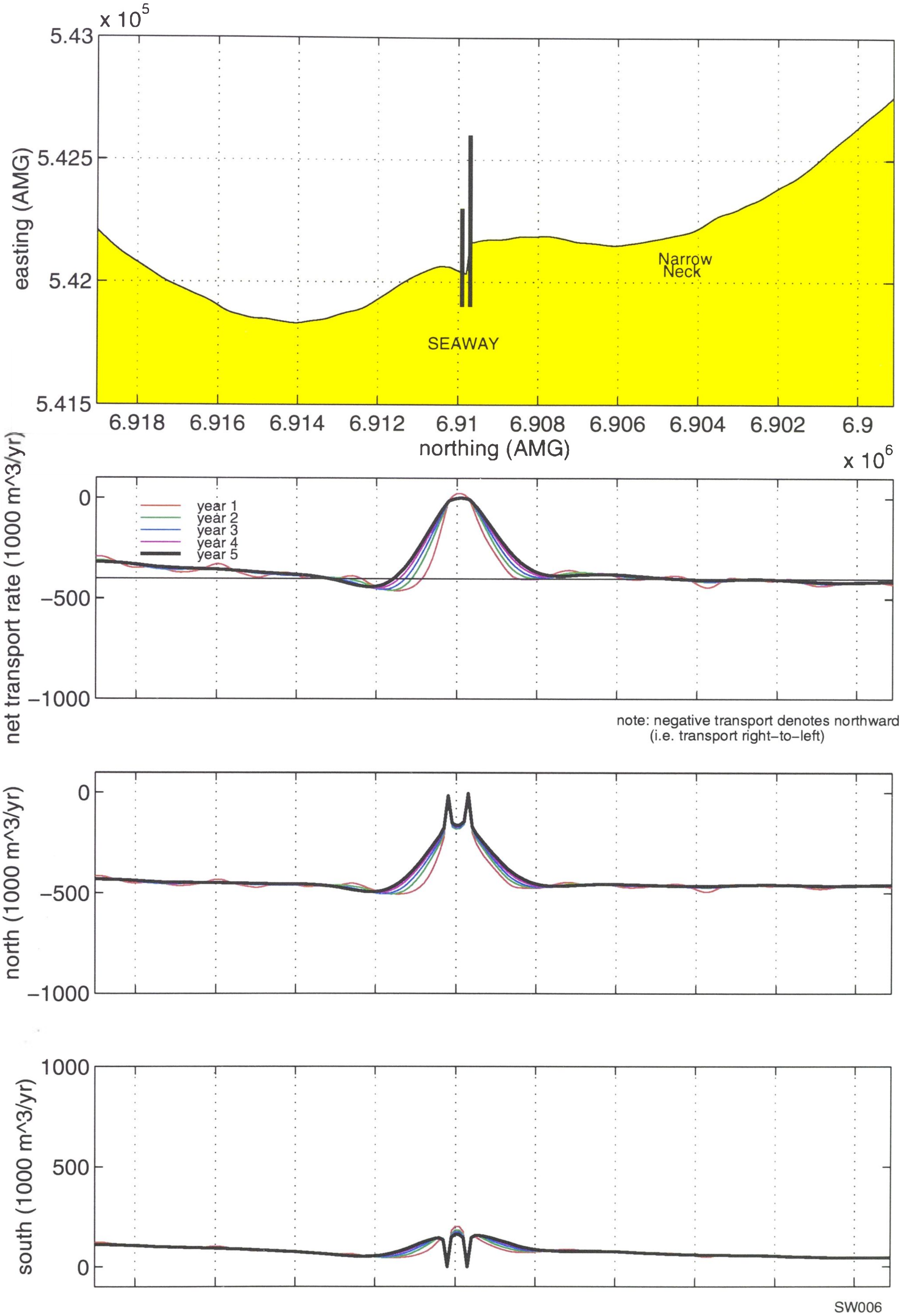
GENESIS - Model calibration
(net longshore transport rate ~500,000 m^3/yr.)

Figure 3.1



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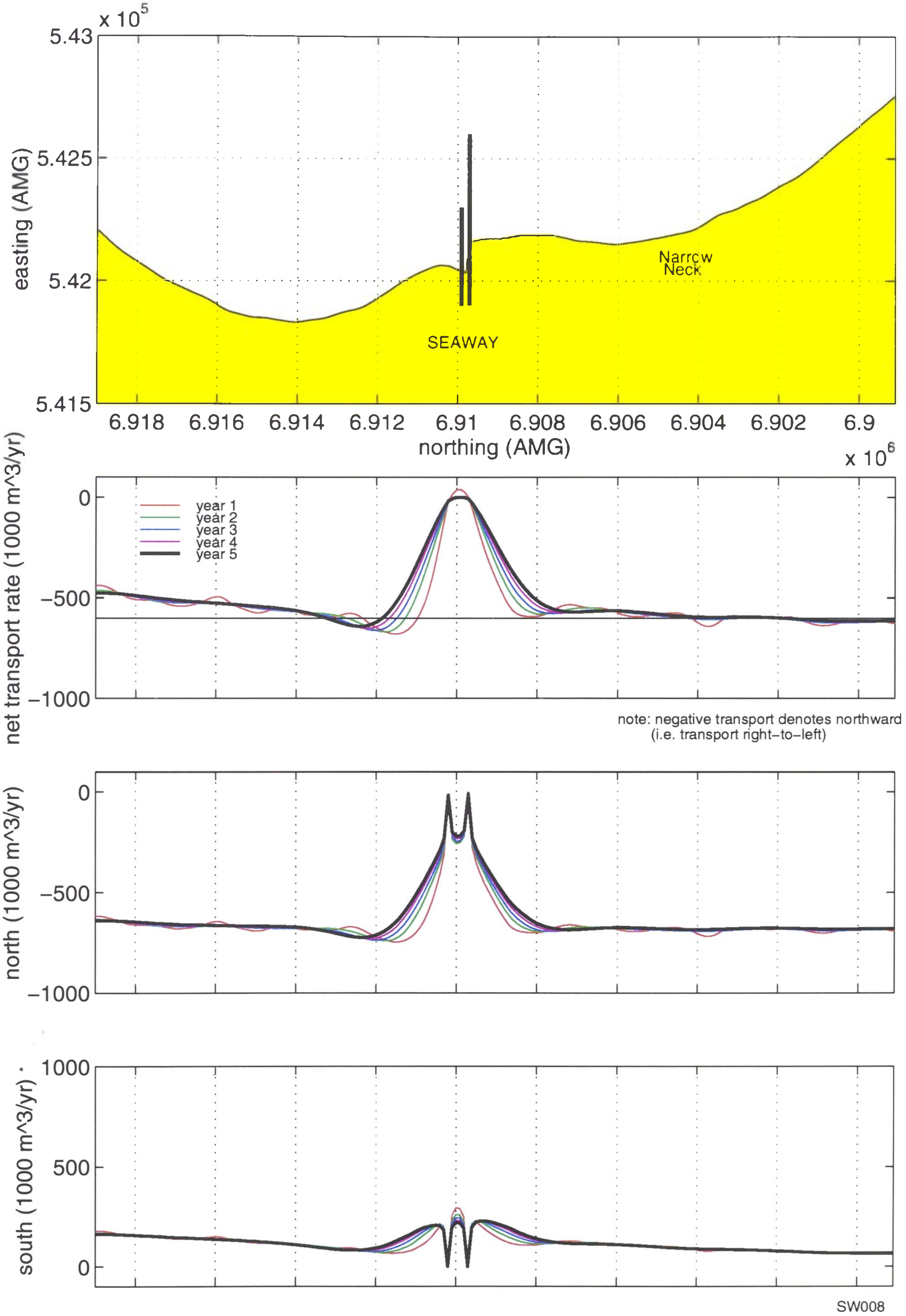
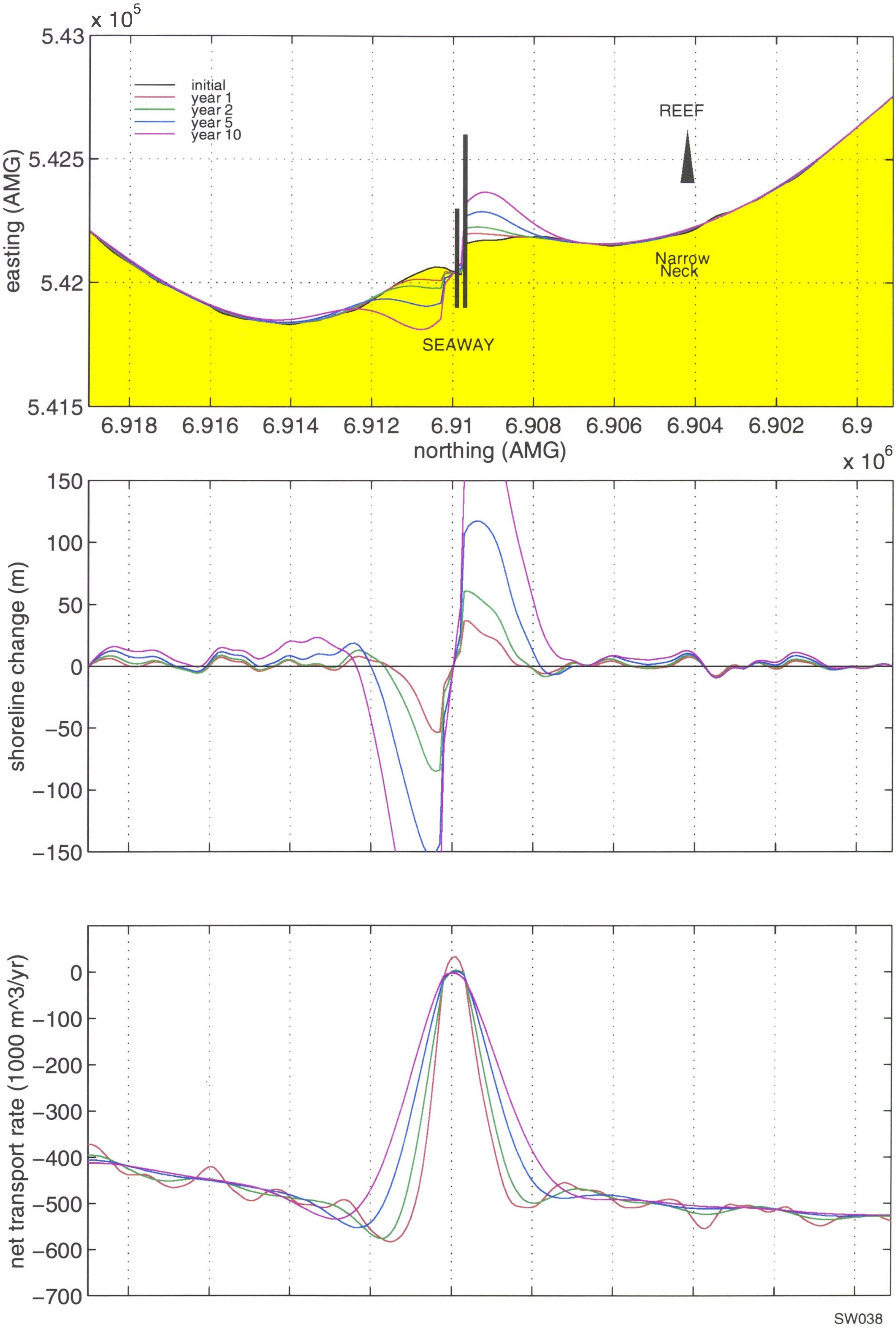
GENESIS - Model calibration
(net longshore transport rate ~400,000 m^3/yr)

Figure 3.2



UNISEARCH Report No. 98/08	GENESIS - Model calibration (net longshore transport rate ~600,000 m^3/yr)	**Figure** **3.3**



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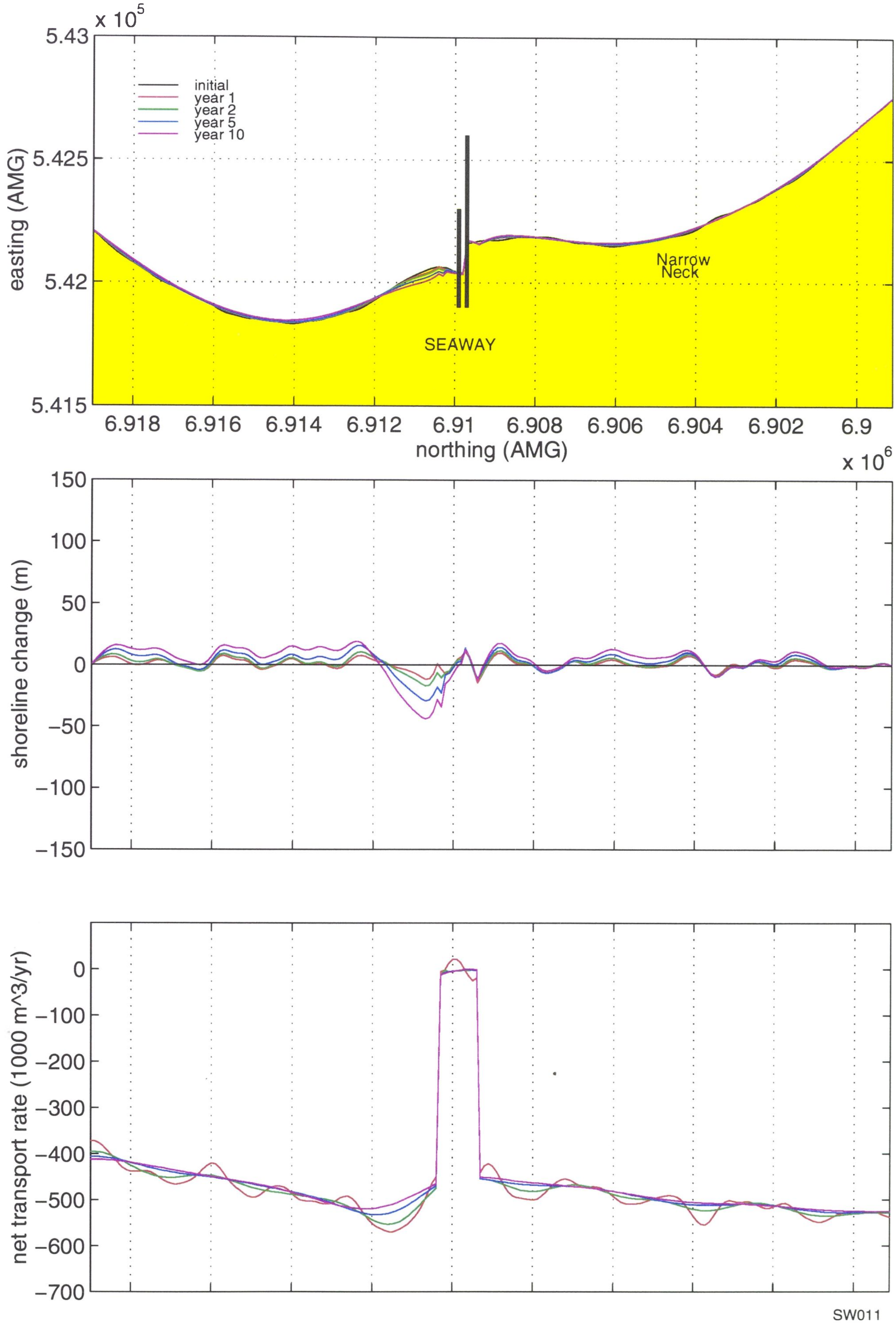
GENESIS - No mechanical by-passing at Seaway
(net longshore transport rate ~500,000 m^3/yr)

Figure 3.4



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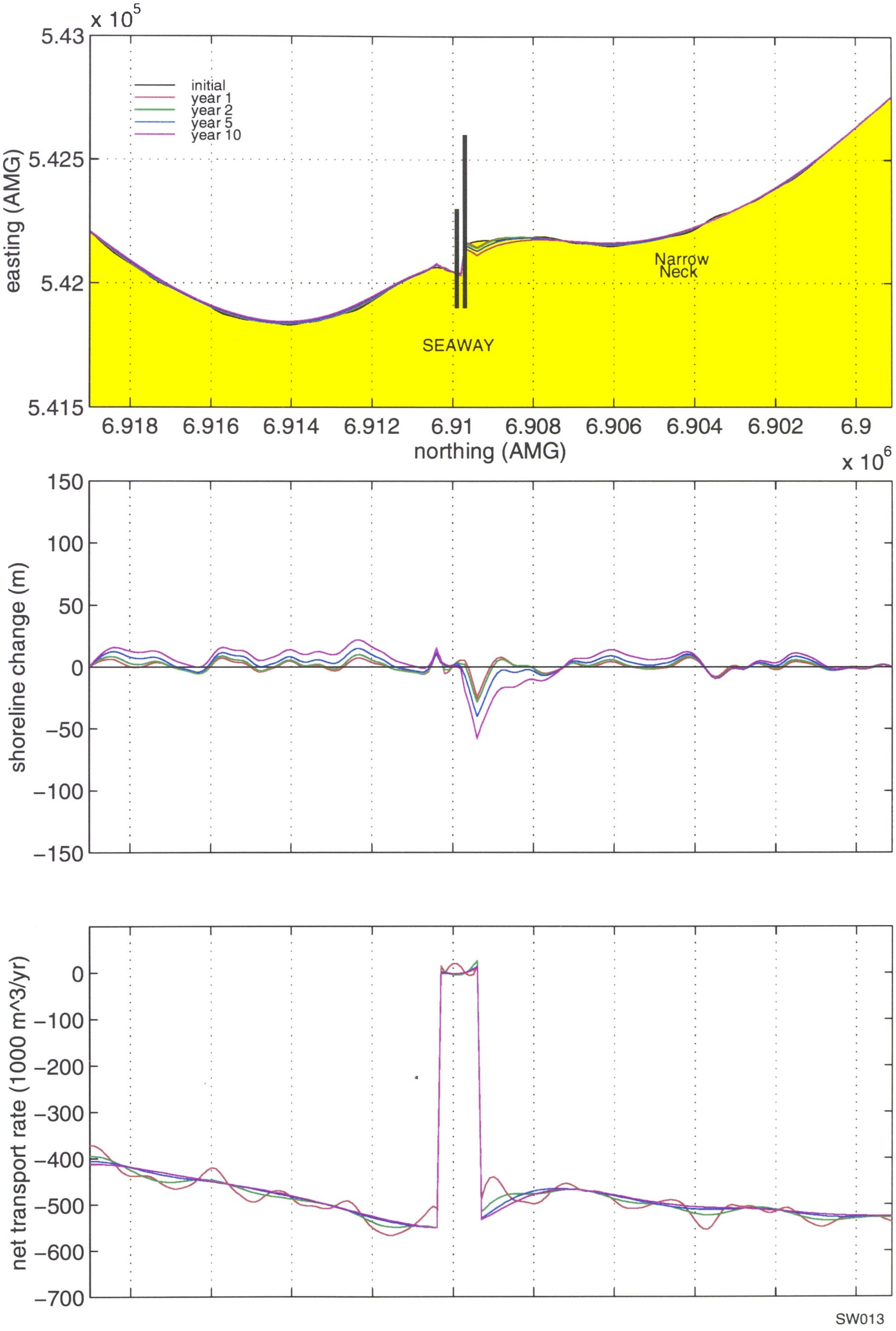
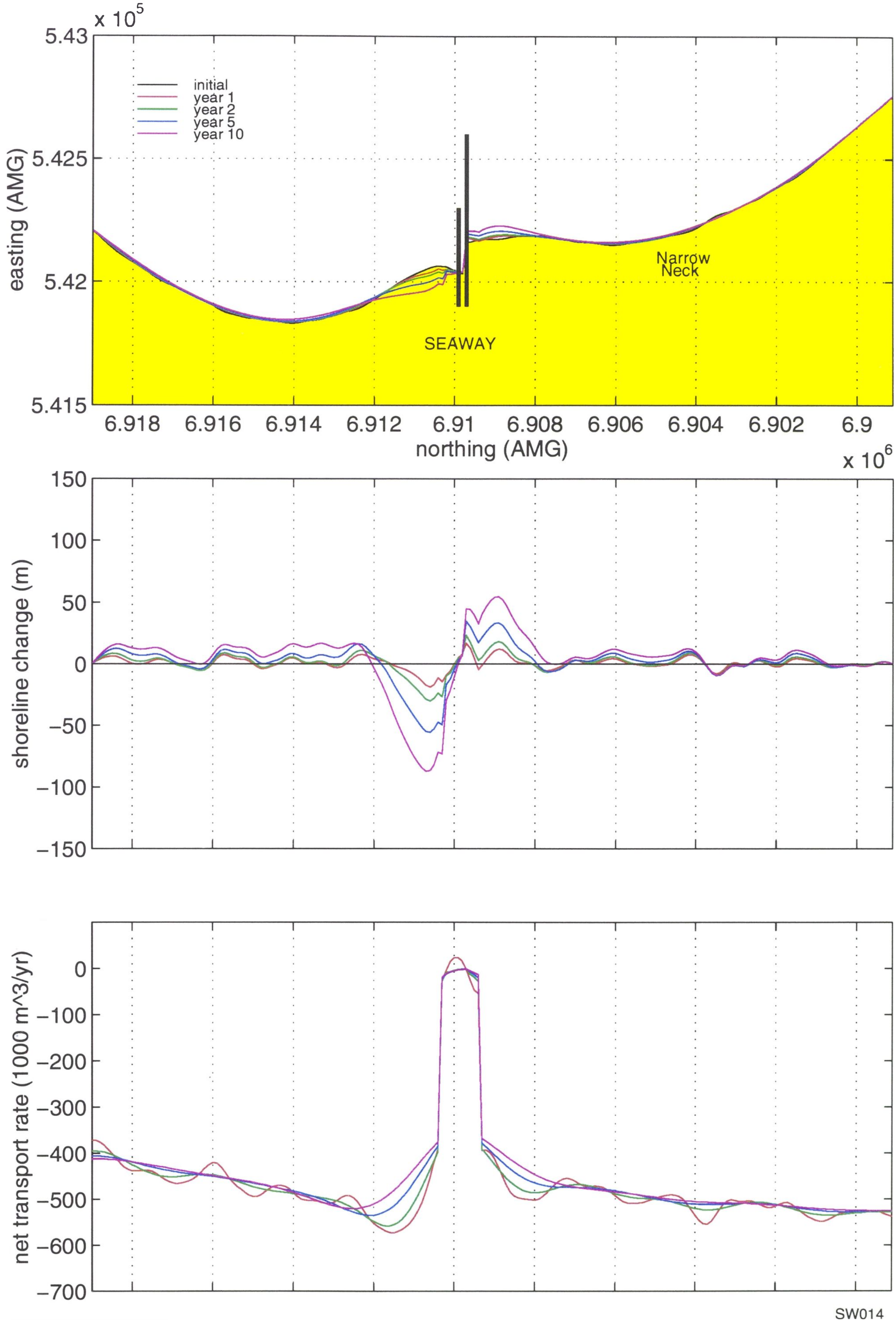
GENESIS - Mechanical by-passing at Seaway (450,000 m^3/ yr)
(net longshore transport rate ~500,000 m^3/yr)

Figure 3.5



UNISEARCH Report No. 98/08	GENESIS - Mechanical by-passing at Seaway (550,000 m^3/ yr) (net longshore transport rate ~500,000 m^3/yr)	**Figure** **3.6**



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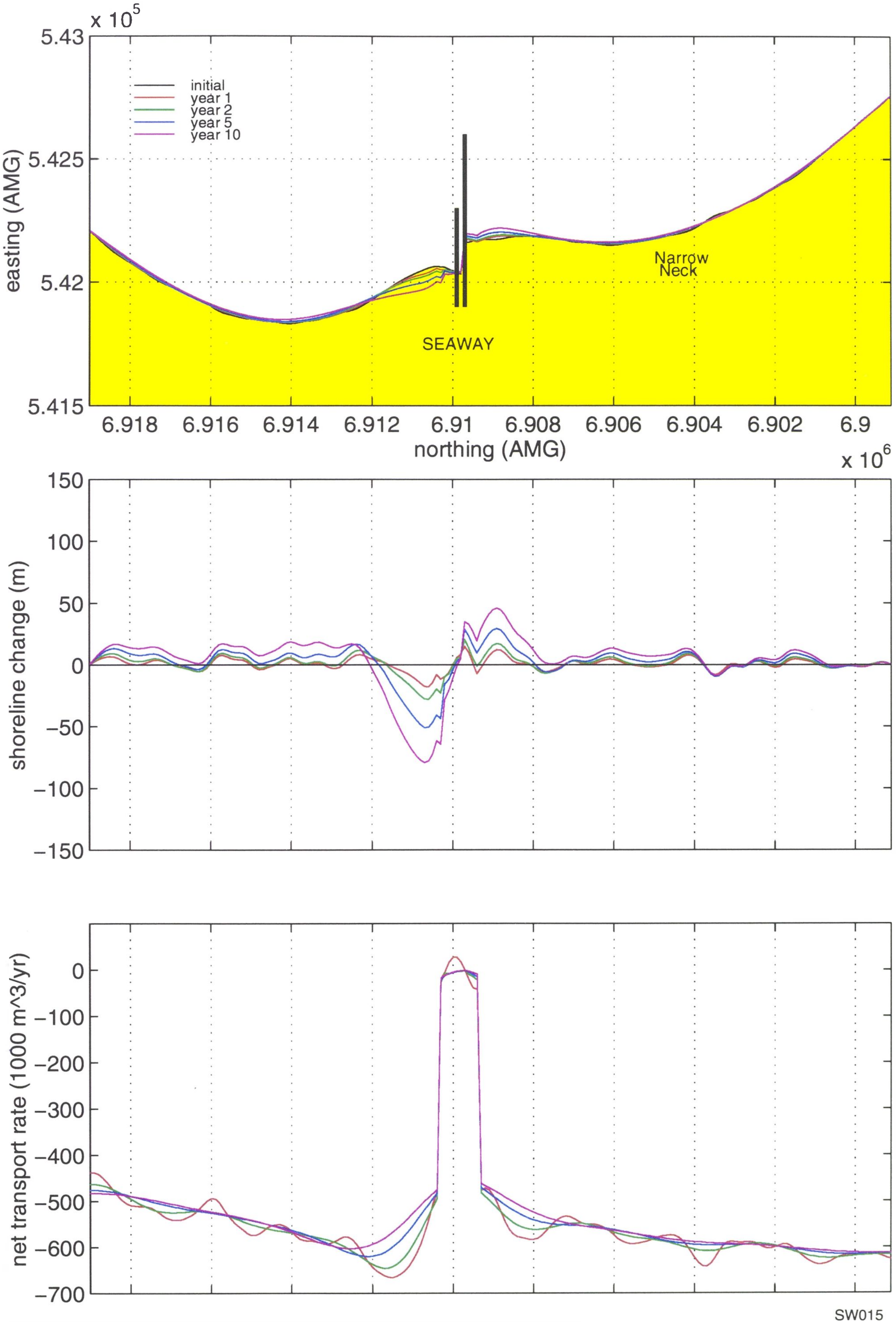
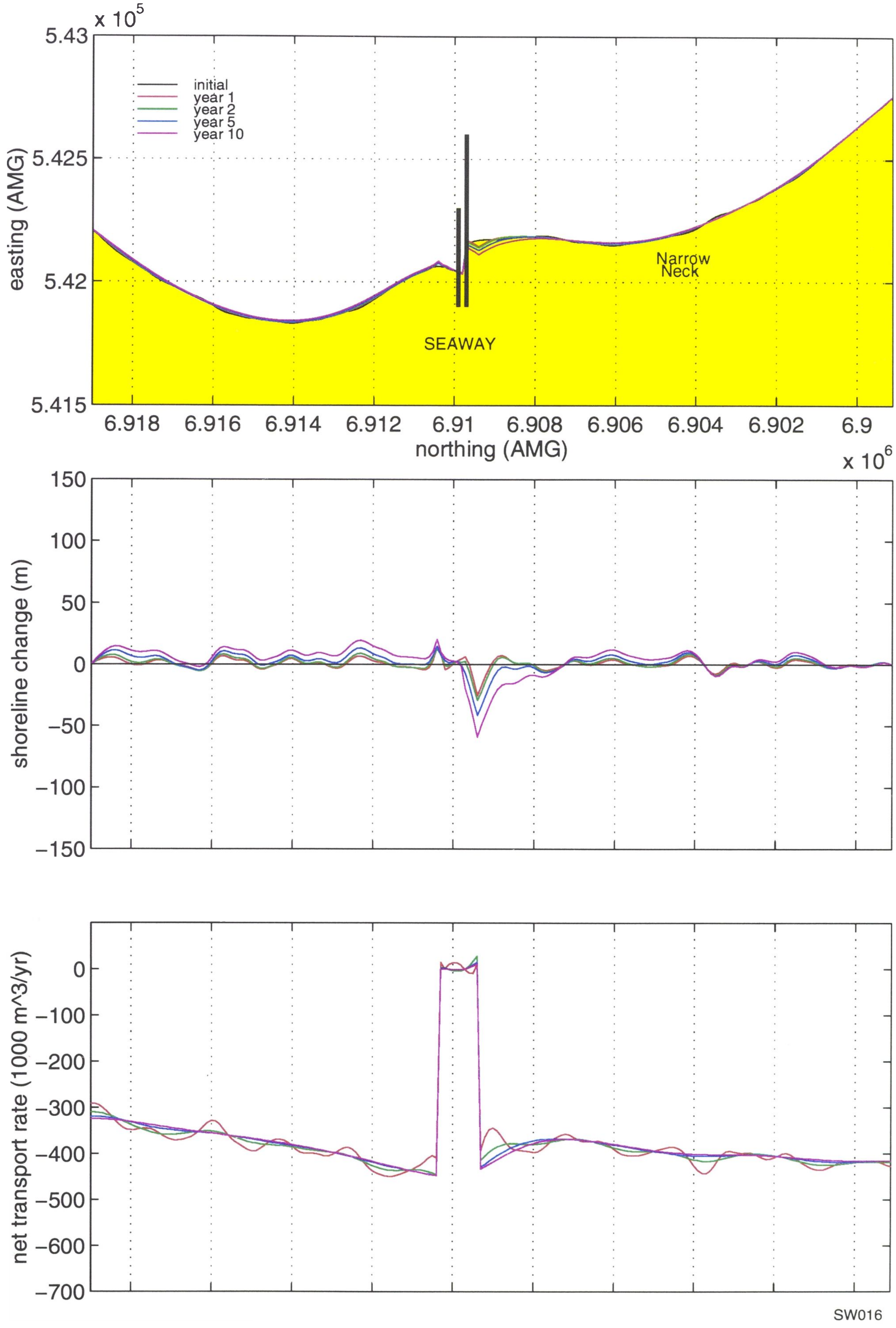
GENESIS - Mechanical by-passing at Seaway (350,000 m^3/ yr)
(net longshore transport rate ~500,000 m^3/yr)

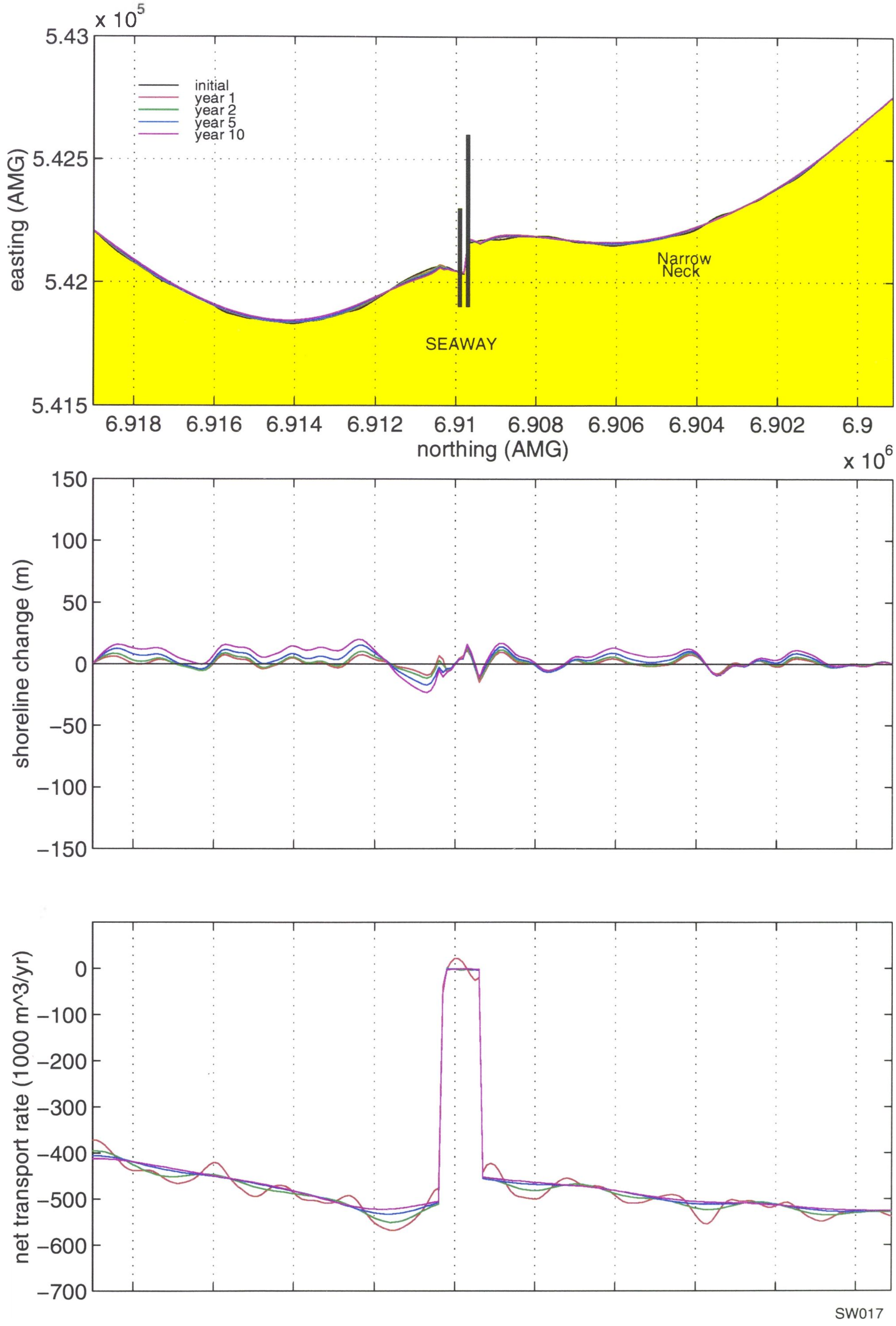
Figure 3.7



UNISEARCH Report No. 98/08	GENESIS - Mechanical by-passing at Seaway (450,000 m^3/ yr) (net longshore transport rate ~600,000 m^3/yr)	**Figure** **3.8**



UNISEARCH Report No. 98/08	GENESIS - Mechanical by-passing at Seaway (450,000 m^3/ yr) (net longshore transport rate ~400,000 m^3/yr)	**Figure** **3.9**



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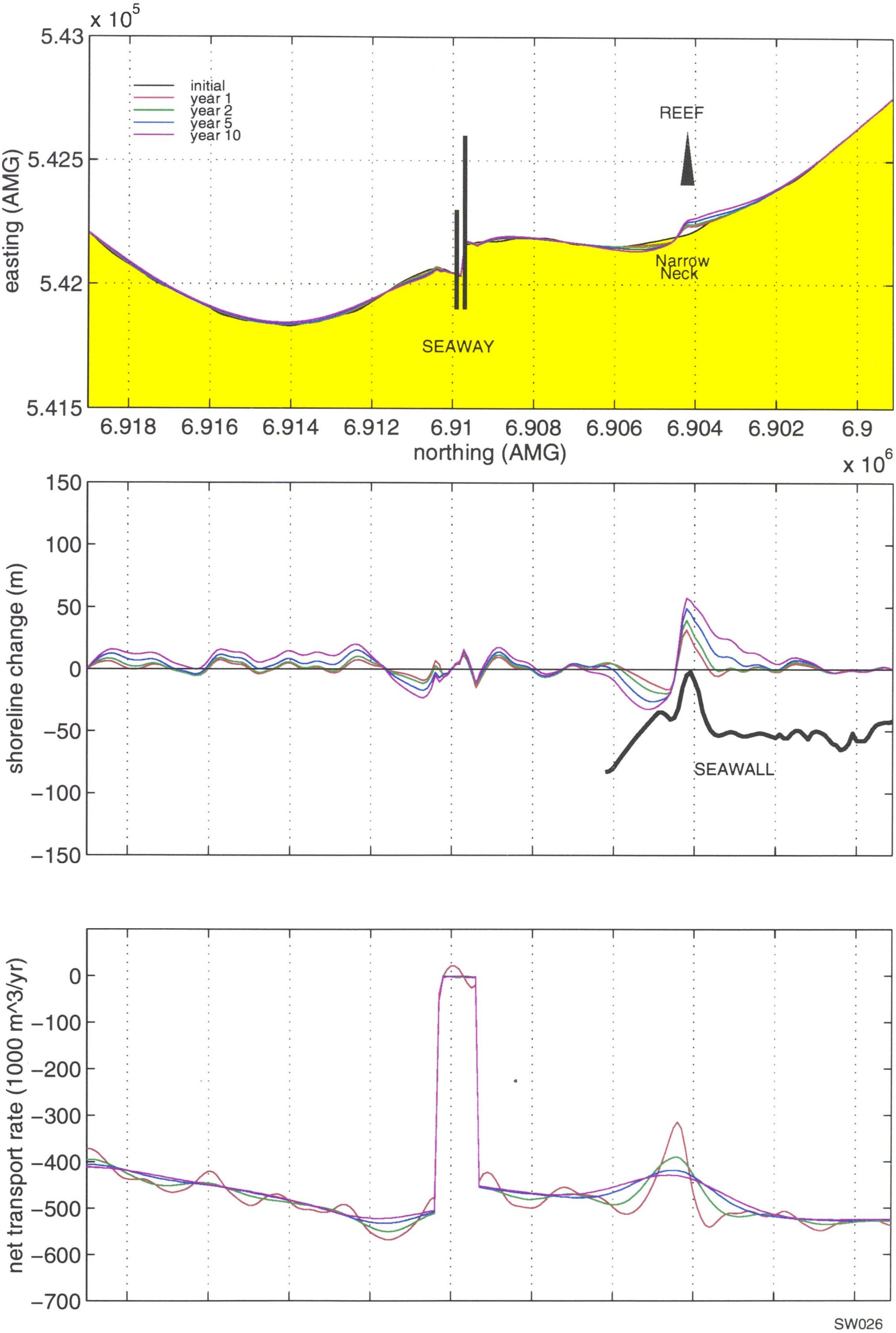
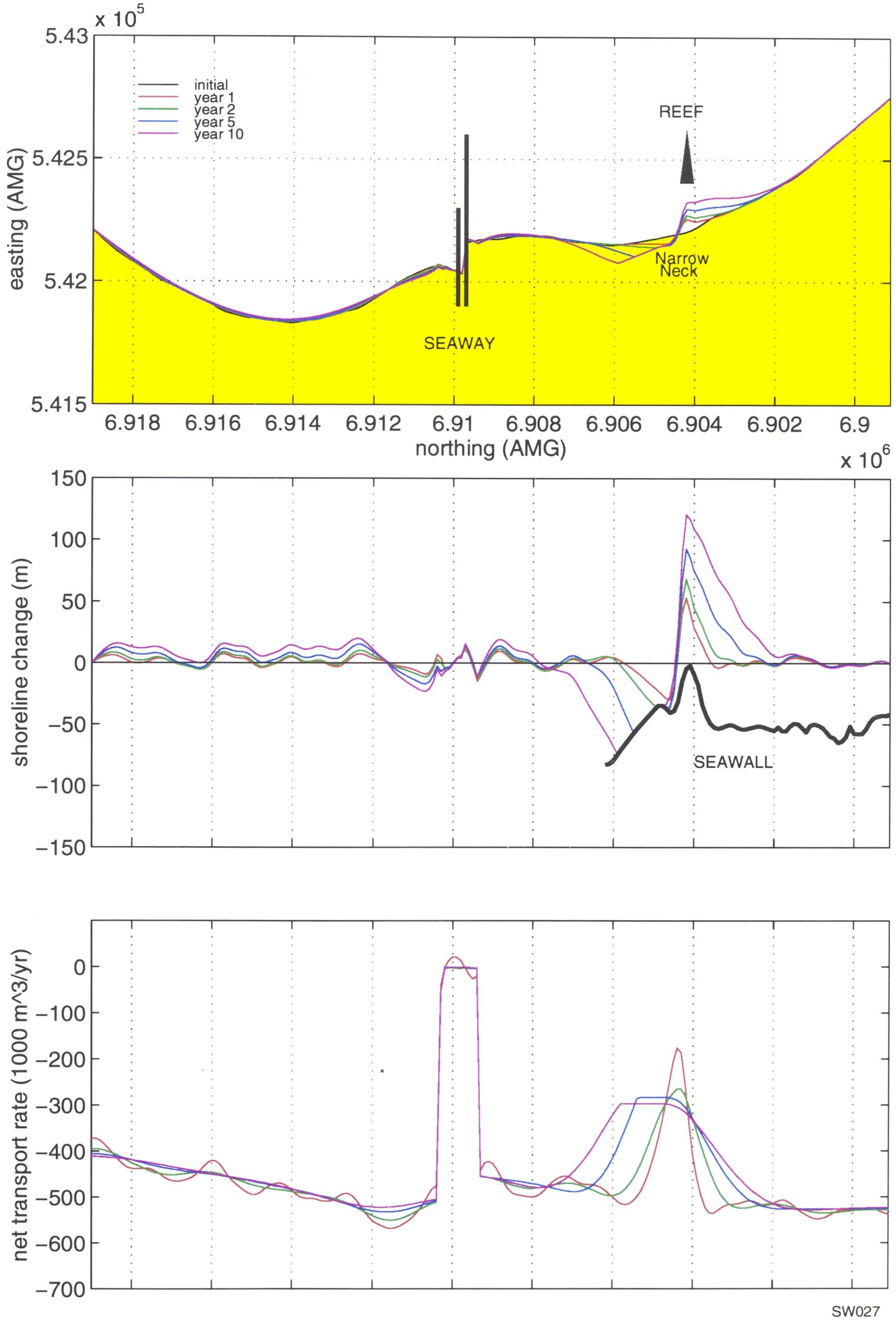
GENESIS - Mechanical by-passing (450,000 m^3/ yr) plus natural by-passing (50,000 m^3/yr) from ebb delta (net longshore transport rate ~500,000 m^3/yr)

Figure 3.10



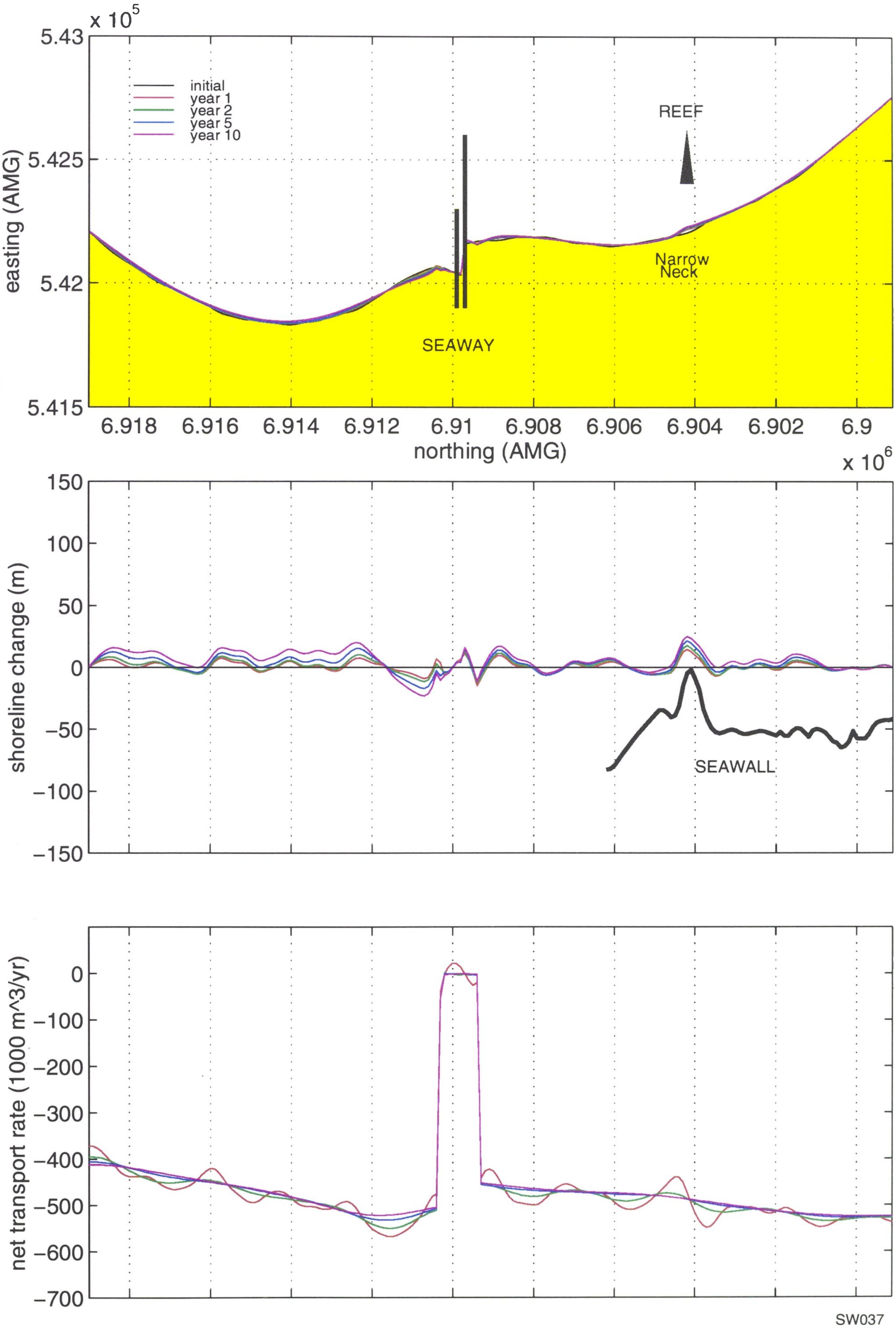
UNISEARCH Report No. 98/08	GENESIS - Artificial reef (wave transmission: 70%) (net longshore transport rate ~500,000 m^3/yr)	**Figure** **3.11**



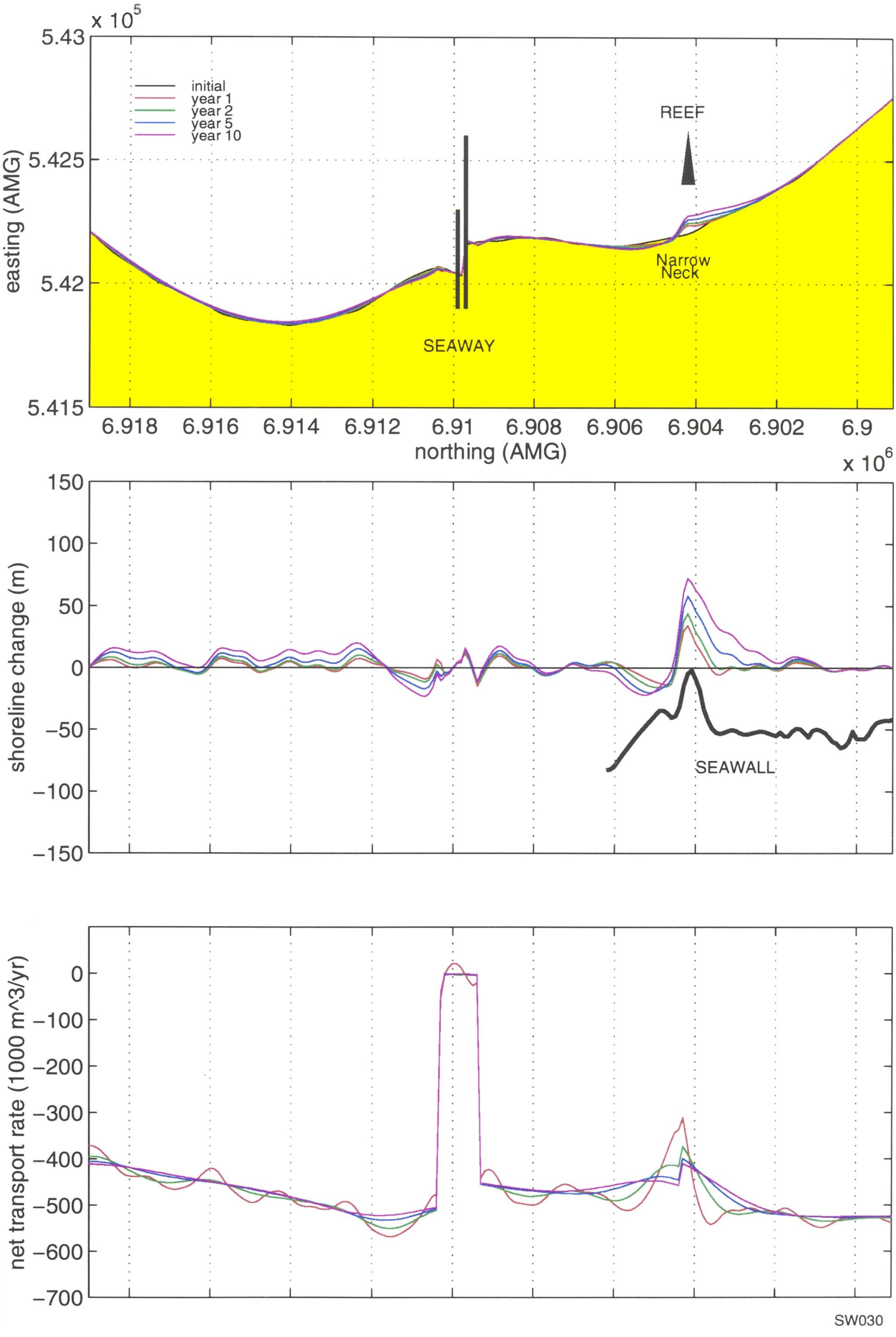
Report No. 98/08

GENESIS - Artificial reef (wave transmission: 50%)
(net longshore transport rate ~500,000 m^3/yr)

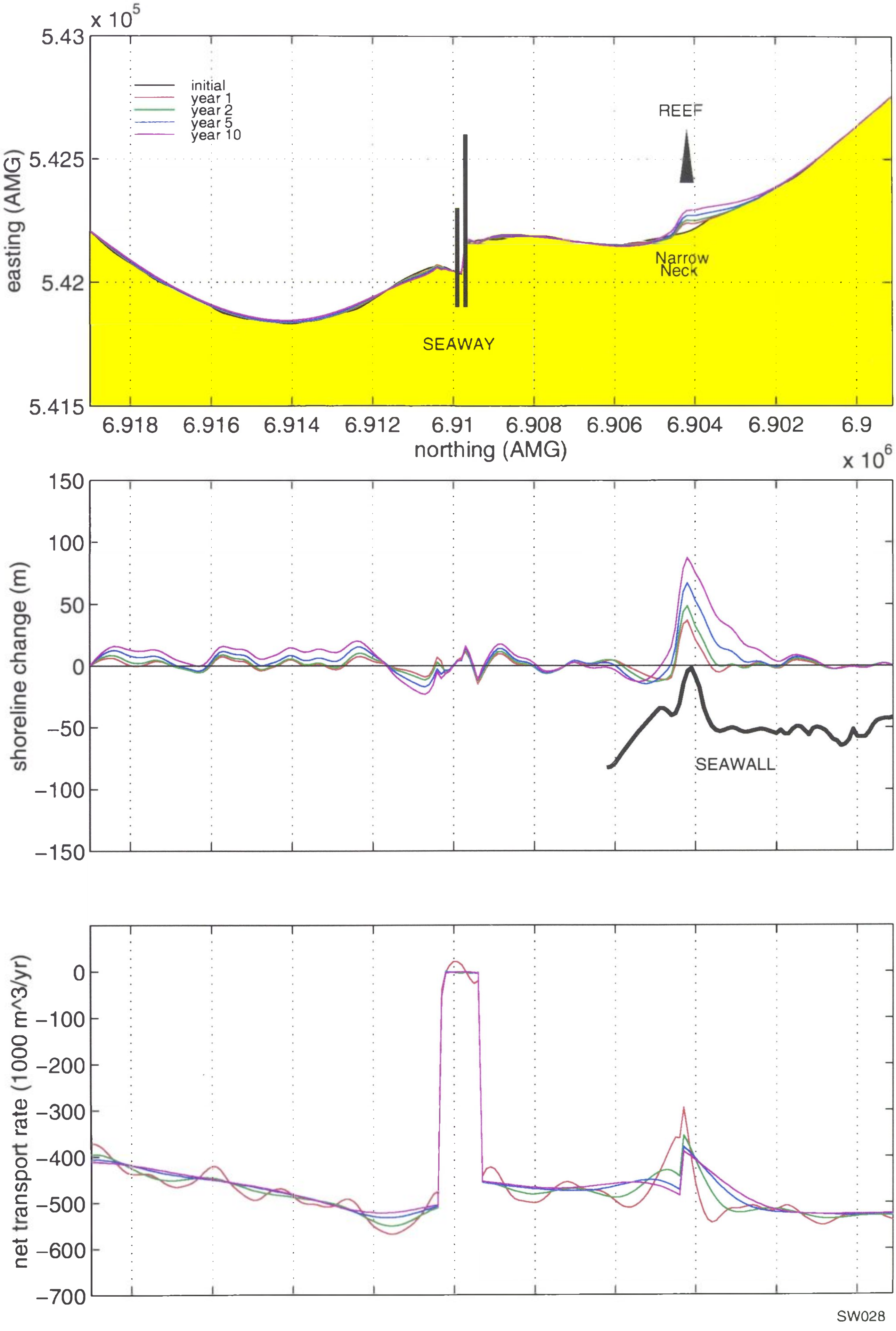
Figure 3.12



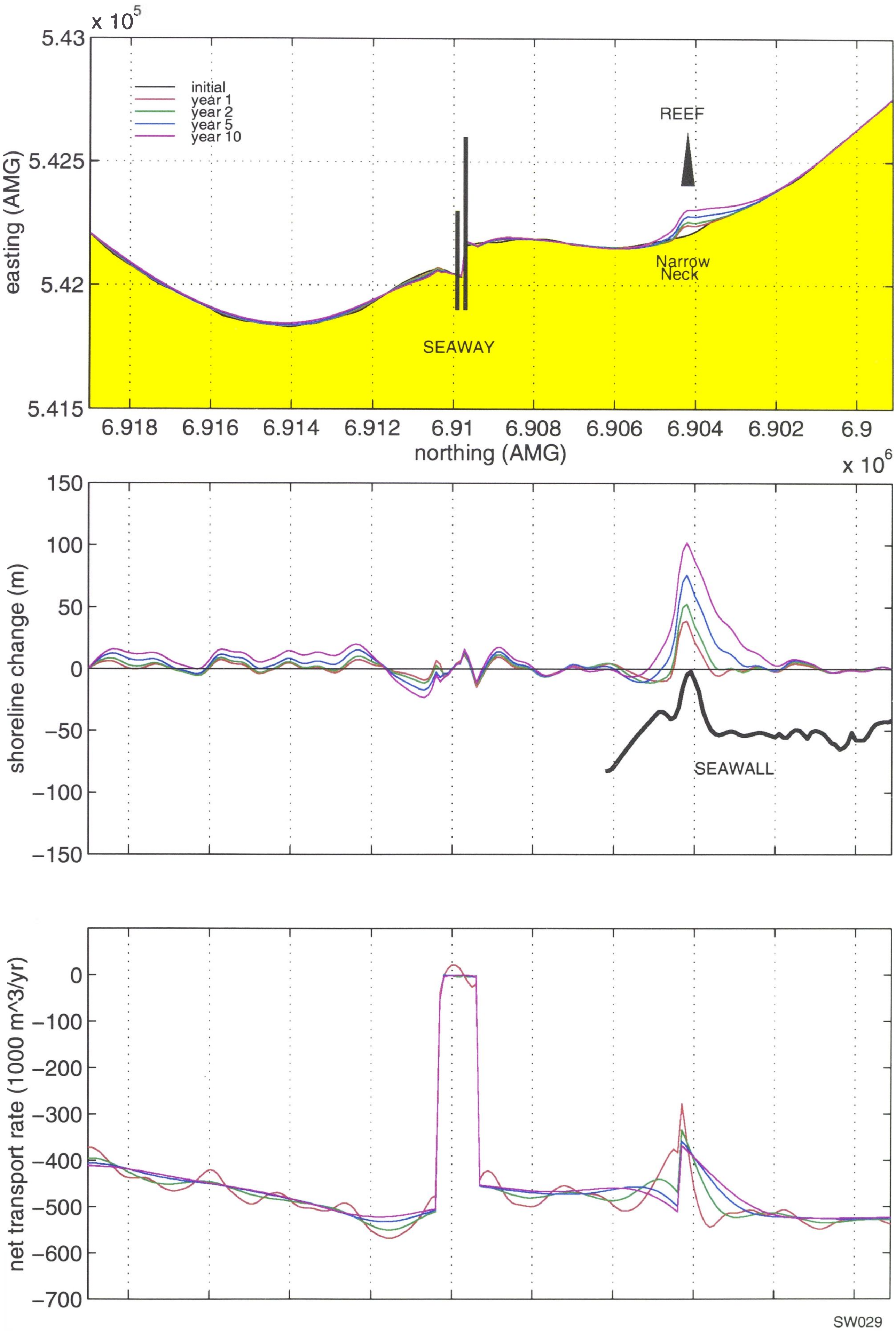
UNISEARCH Report No. 98/08	GENESIS - Artificial reef (wave transmission: 90%) (net longshore transport rate ~500,000 m^3/yr)	**Figure** **3.13**



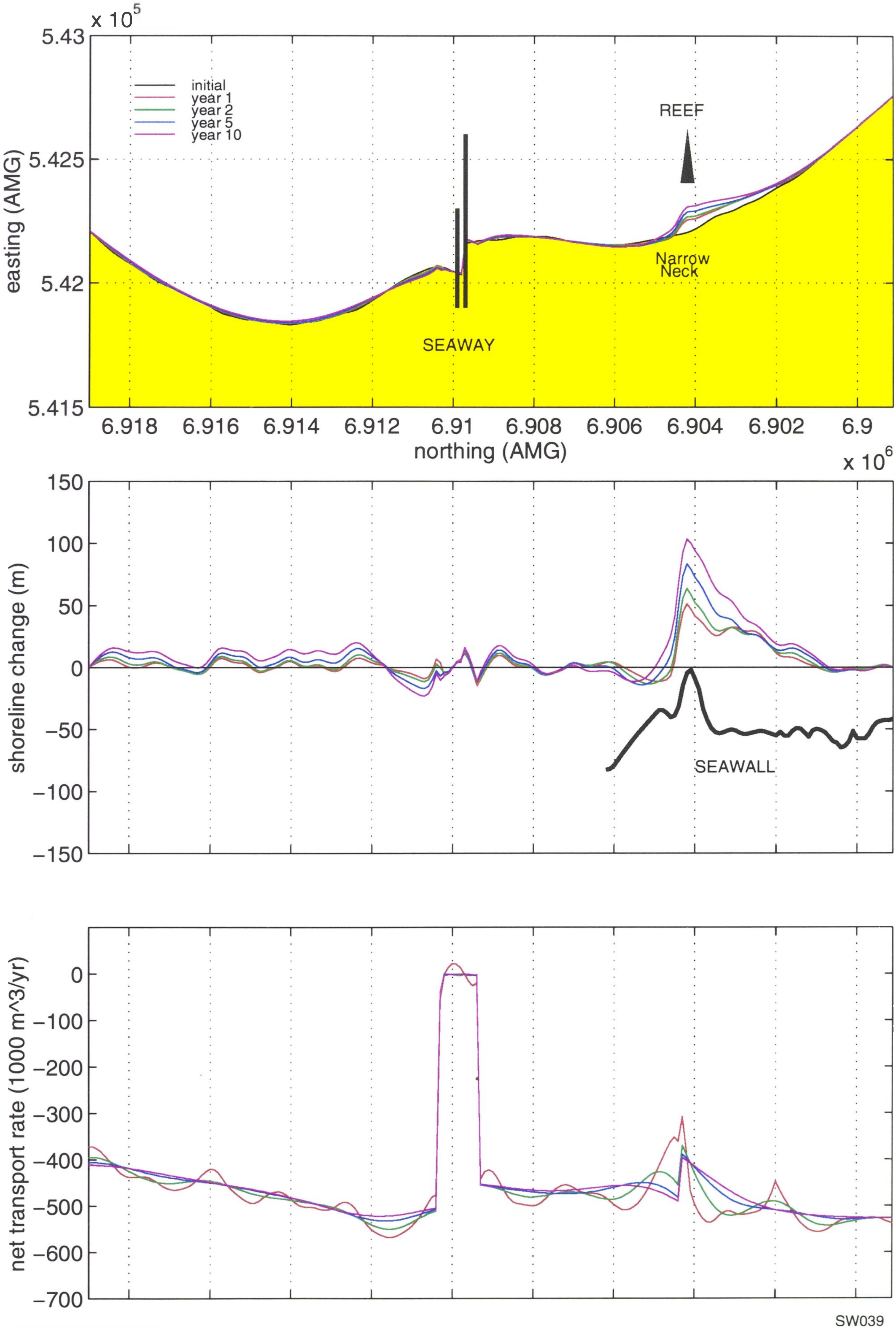
UNI SEARCH Report No. 98/08	GENESIS - Back-passing (50,000 m^3/yr) to nourish beach down-drift of reef (net longshore transport rate ~500,000 m^3/yr)	**Figure** **3.14**



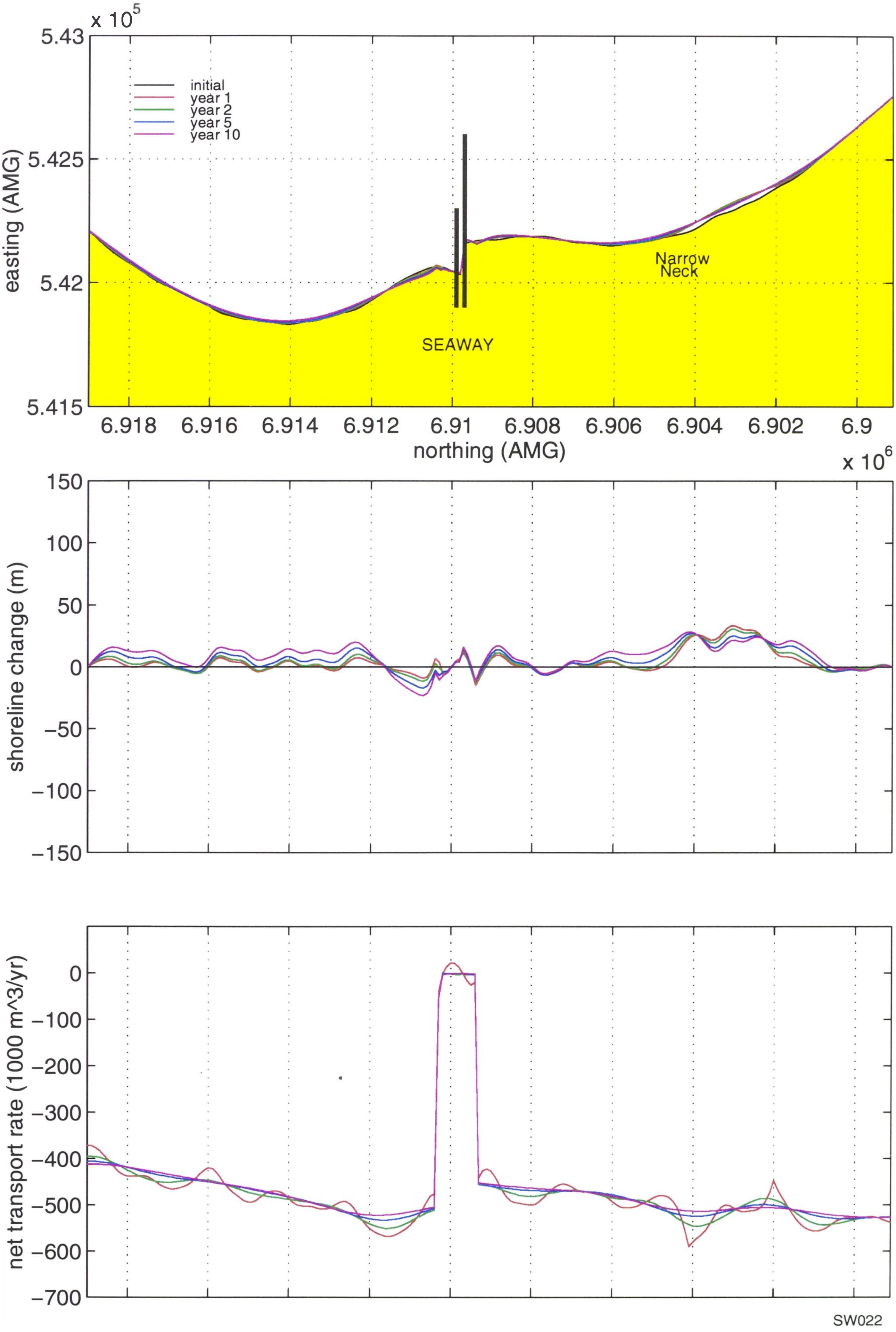
UNISEARCH Report No. 98/08	GENESIS - Back-passing (100,000 m^3/yr) to nourish beach down-drift of reef (net longshore transport rate ~500,000 m^3/yr)	Figure 3.15



UNI SEARCH Report No. 98/08	GENESIS - Back-passing (150,000 m^3/yr) to nourish beach down-drift of reef (net longshore transport rate ~500,000 m^3/yr)	**Figure 3.16**



UNISEARCH Report No. 98/08	GENESIS - Reef plus nourishment to up-drift beach at Surfers Paradise (net longshore transport rate ~500,000 m^3/yr)	**Figure** **3.17**



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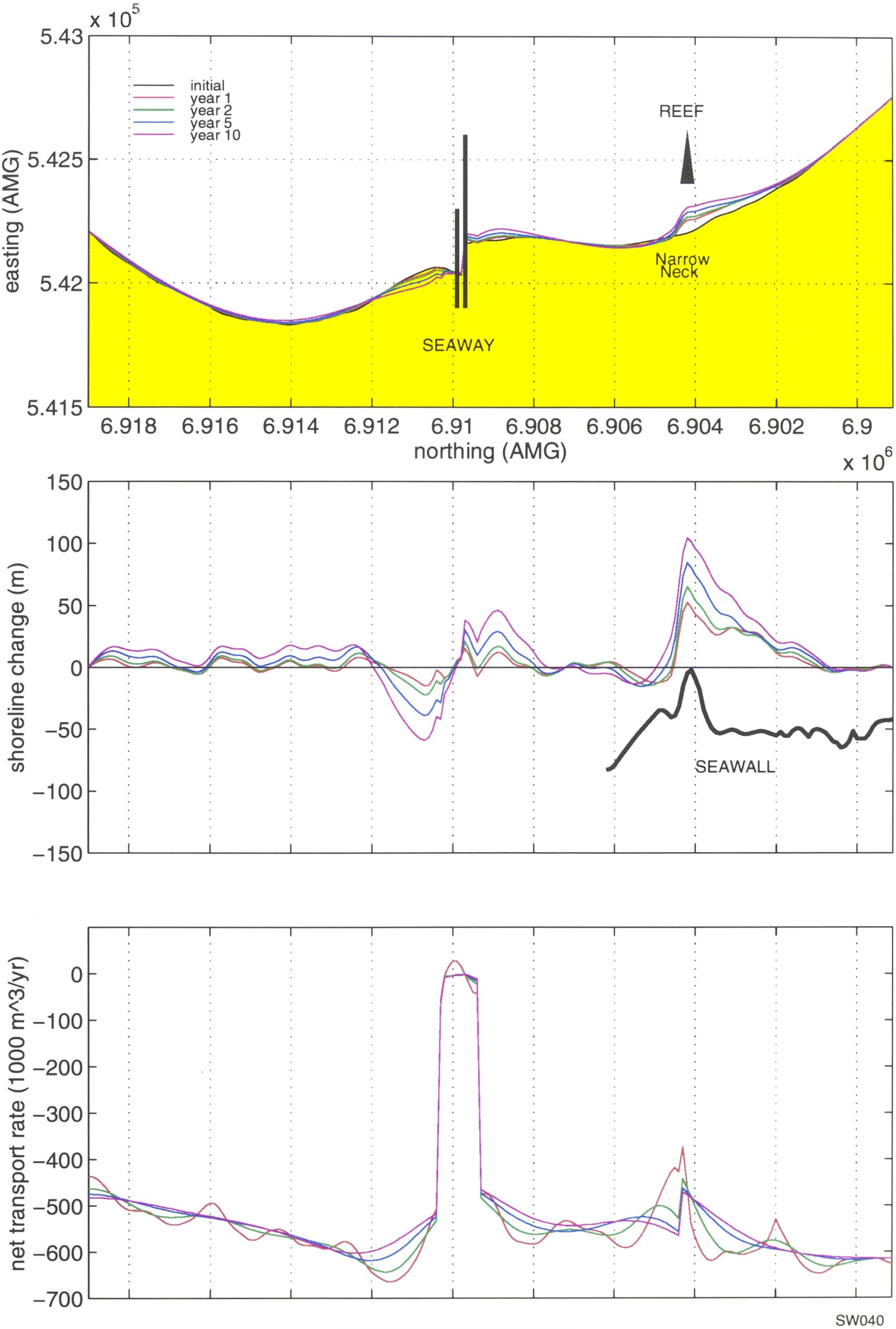
GENESIS - Nourishment to up-drift beach at Surfers Paradise (no reef) (net longshore transport rate ~500,000 m^3/yr)

Figure 3.18



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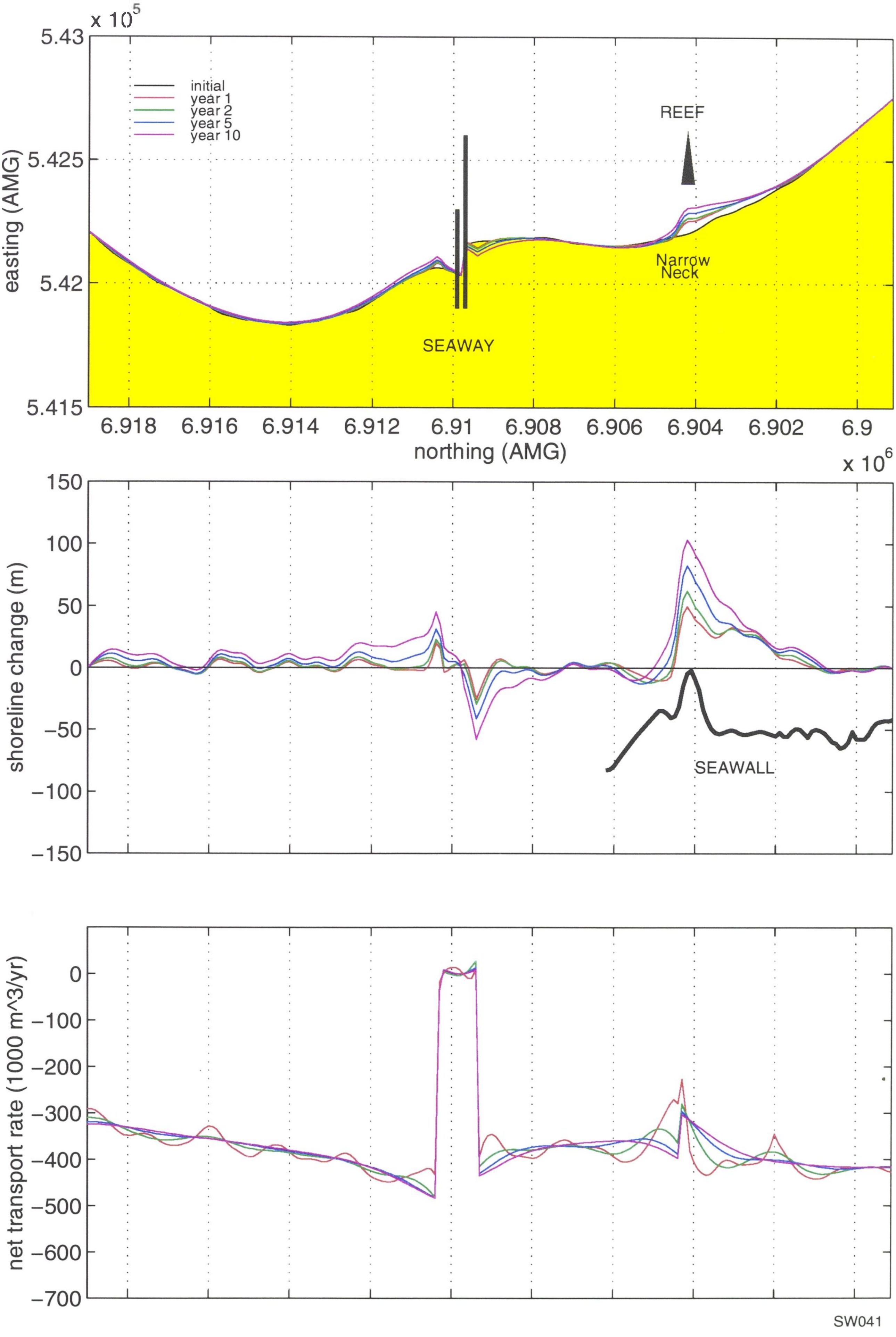
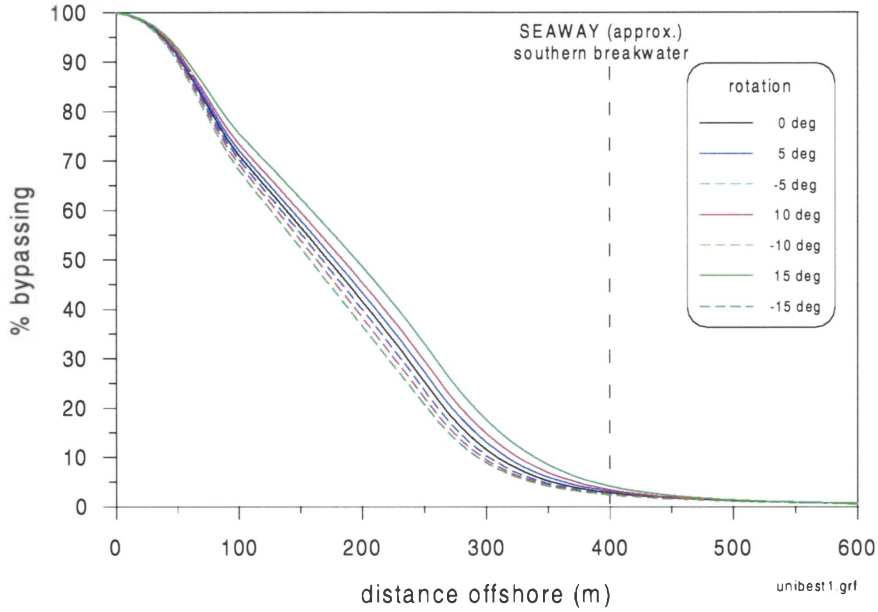
GENESIS - Reef plus nourishment to up-drift beach at Surfers Paradise
(net longshore transport rate ~600,000 m^3/yr)

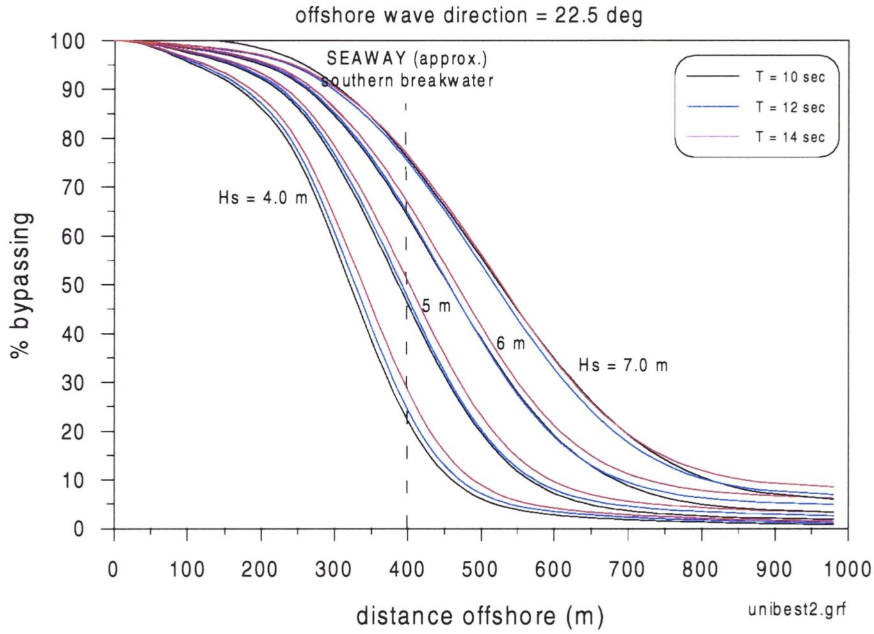
Figure 3.19



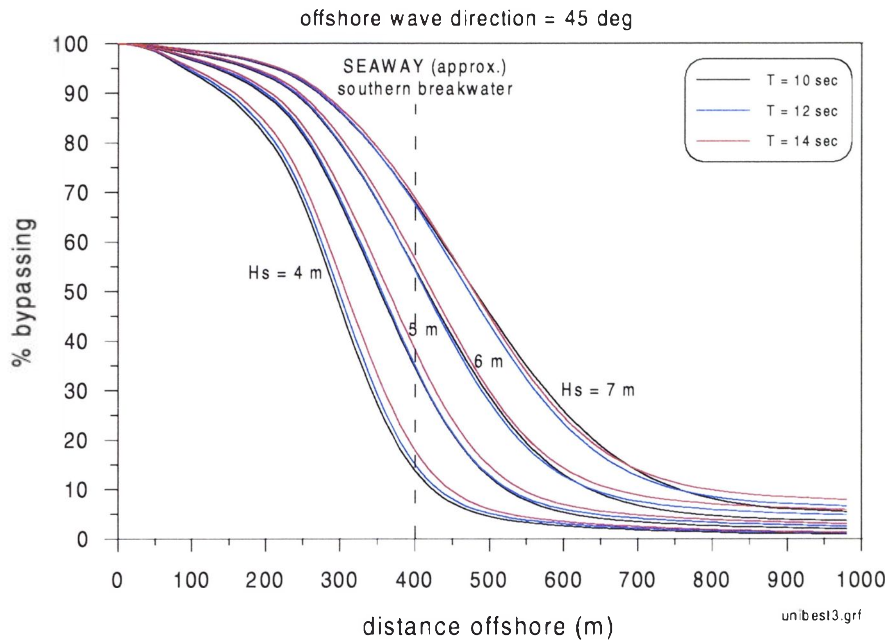
UNISEARCH Report No. 98/08	GENESIS - Reef plus nourishment to up-drift beach at Surfers Paradise (net longshore transport rate ~400,000 m^3/yr)	**Figure 3.20**



UNISEARCH Report No. 98/08	UNIBEST - Cross-shore distribution of longshore transport ('average' annual wave climate)	**Figure** **4.1**

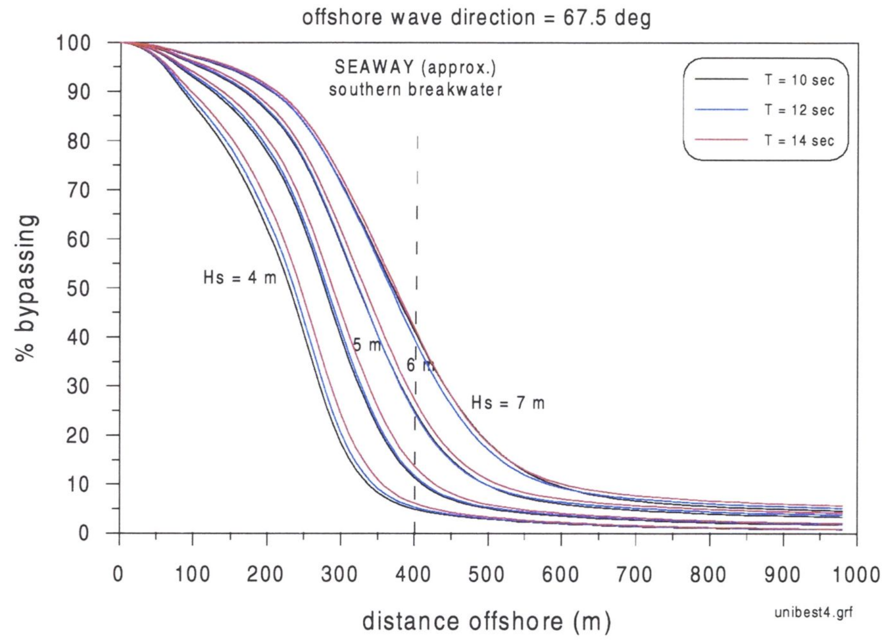


UNISEARCH Report No. 98/08	UNIBEST - Cross-shore distribution of longshore transport (offshore wave direction = 22.5°)	**Figure** **4.2**



UNIBEST - Cross-shore distribution of longshore transport
(offshore wave direction = 45°)

Figure
4.3



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UNIBEST - Cross-shore distribution of longshore transport (offshore wave direction = 67.5°)

Figure
4.4