ENVIRONMENTAL IMPACT OF FAST FERRY WASH IN SHALLOW WATER

Mr. A Bell BSc CEng FIEI MICE MIStructE,
Senior Partner, Kirk McClure Morton

Mr. B Elsaesser Dipl. Ing.
Research assistant The Queen’s University of Belfast

Professor T Whittaker PhD CEng MRINA,
Professor of Coastal Engineering, The Queen’s University of Belfast

SUMMARY

The initial findings of a study of the environmental impact of ship wash in Loch Ryan is presented, which has application to other estuaries and provides information which may have to be included in future environmental impact assessments. The work has involved a combination of mathematical modelling, physical modelling and field measurement. The wash waves from conventional ferries, the naturally occurring wind seas and tidal flows have been studied. From historic records, it has been possible to ascertain movements in the shoreline and variations in the sea bed profile. The effect of fast ferry wash on the physical environment has been observed.

It is concluded that fast ferry wash does not necessarily have a greater effect on the mass transport of sediment in comparison to natural phenomenon such as wind waves and tidal currents. A case study presented shows that erosion of the coastal zone is dependant on many factors such as sediment size and size distribution. Therefore each shoreline needs to be modelled individually and it is not possible to generalise on the environmental impact of fast ferry wash.

AUTHORS BIOGRAPHIES

Adrian Bell is a partner in the firm of consulting engineers, Kirk McClure Morton. During the past twenty-five years he has specialised in numerically modelling the physical processes in the coastal environment. He has undertaken the mathematical modelling of the wave transformation and sediment transport processes.

Bjorn Elsaesser is a research assistant at the Queen’s University of Belfast working on fast ferry wash. He is responsible for fundamental research, model testing and field measurements to establish the wash wave characteristics of ships and their environmental impact.

Trevor Whittaker is Professor of Coastal Engineering at the Queen's University of Belfast. He is a chartered naval architect and head of both the Wave Power and Fast Ferry Wash Research Group. He is the author of over 90 technical publications.

1. INTRODUCTION

In January 2000 Kirk McClure Morton in collaboration with the Queen's University of Belfast was engaged by the Loch Ryan Advisory Management Forum to carry out an investigation of the coastal processes in Loch Ryan in Scotland. The aim of the project was to provide baseline information on the natural processes that occur in Loch Ryan and to evaluate the impact which human activities, particular those related to ferries, are having on the natural systems.

1.1 BACKGROUND

To date the majority of the work relating to ferries in general has concentrated on the physical properties of the wash waves produced by fast ferries. This work has identified wave characteristics which would not naturally occur in many locations. In particular, ships operating at speed in shallow water produce a 'super-critical' wash wave pattern with leading waves, which are non-dispersive. This results in energy being contained in individual waves. In addition ***Whittaker et al (1 & 2)***, has shown that the two leading waves diverge at an angle which is maintained with distance from the sailing line resulting in wave periods of up to 40s, 3,000m from the track of the ship. These very long period shallow water waves produce considerable horizontal fluid particle motion at the seabed.

A further influence is the effect of water jet propulsion, which produces a different pressure field beneath the hull or hulls compared to propellers. For example four water jets at full power in a vessel such as Stena HSS pump 112m^3 of water per second in the northern part of the loch when the vessel is at full speed. When operating at speed the clearance between the jet intakes and the seabed can be as little as 4m. In Loch Ryan to the south of Cairn Point, when the vessel is operating at a slow speed of 12 knots, the clearance can be as little as 2m. Additionally, catamarans are wide overall in relation to their length compared to a conventional ferry and consequently the pressure field is different. However, the heavier longer conventional ferry may create more sea bed disturbance than the wider, shorter and lighter catamaran.

1.2 SCOPE OF THE STUDY

Currently the environmental impact of the wash from both conventional and fast ferries is being studied in Loch Ryan. The work involves a combination of mathematical modelling, physical modelling and field measurement. The scope of the study is as follows,

- provide data on natural coastal processes such as wind waves, tidal movements, sediment transport pathways (littoral and nearshore) and shoreline changes,
- identify and quantify the effects of man-made disturbances such as wash waves produced by both conventional and fast ferries with particular emphasis on sediment transport and the effect of different propulsion systems,

- study the effect of coastal defence and other structures on the natural movement of sediments,
- provide guidance on future management of the area.

1.3 SCOPE OF THIS PAPER

This paper concentrates on wash waves produced by both conventional and fast ferries and looks at any resulting sediment movement along the shoreline and in the vicinity of the dredged channel. In particular the relative magnitude of natural and man-made disturbances is discussed.

1.4 LOCH RYAN

Loch Ryan, shown in ***figure 1***, is 13km long and between 1.5 and 4km wide. It is open to the North and exposed to swell waves from the North Atlantic in a general direction of 340^0. The nature of the coastline around the loch is also displayed in ***figure 1***.Therange of hatched patterns indicate the different geological formations at the surface as specified in the key. The entrance is flanked by rocky cliffs rising in the north east to over 300m above sea level. The east coast from Glen App to Cairnryan is formed mainly by hills. At the south or inner end of the loch the land is flat and there is a 700m wide muddy inter-tidal zone in the vicinity of Stranraer. The western coast from Stranraer to Kirkcolm mainly comprises sand and gravel beaches with finer deposits resulting from the sheltered position. The tide ranges between +0.2m at MLWS and +3.0 at MHWS.

Loch Ryan is an ideal location for this type of study for several reasons. These are as follows:

- there is sufficient historical data over 100 years on the movement of shorelines due to both natural processes and the operation of conventional ferries,
- there is a wide variety of types of shoreline and sea bed material,
- parts of the loch are sheltered from the prevailing wind seas and are only subject to waves from ferries,
- the northern part of the loch is subject to naturally occurring long period swells,
- the loch is fairly shallow ranging in depth from 20m near the entrance to 3 and 4m in the upper reaches.
- up to 3 fast ferries and 5 conventional ferries operate in the area and there is no other shipping.

1.5 MORPHOLOGICAL DESCRIPTION OF THE STUDY AREA

In this paper two areas have been selected for detailed study, Kirkcolm Bay and the navigation channel to Stranraer. Around Clachan Heughs benches of red sandstone and coves form cliffs with 3-6m wide beaches towards the sea. In some coves the sandstone is hollowed out creating overhanging sections of soil fixed by roots.

At Kirkcolm Bay gravel is partially thrown in tong like formations into the adjacent fields. A river (Corsewall Burn) flowing out from the forest east of Kirkcolm and draining the land has been moved and straightened with an artificial outlet to sea formed by large stones. Around the Scar, brick and concrete slabs have been dumped along the foreshore forming an embankment to protect the low lying land beyond. The beach shows no significant vegetation. Around the outlet of the river the topsoil layer has been eroded to a 0.2-0.5m high edge. At one point gravel and pebbles are thrown up against a fence by wave action.

The seabed consists mainly of a mix of mud and fine sands. Near the shoreline gravel and pebbles are deposited. The deeper areas below the 5m contour line consist of sands with gravel and broken shells. In some places single rocks break through the sediment layer.

The water depth south of The Wig and south of Beacon No.1 is generally less than 5m. Around the navigation channel there are areas where the depth exceeds 5m. The bed material is mainly fine sand with mud. In some parts the bed is covered with broken shells, especially near the coastline, but in other areas there is a higher proportion of mud.

2. FERRY OPERATIONS IN LOCH RYAN

2.1 CURRENT AND HISTORICAL FERRY OPERATION IN LOCH RYAN

The ferry service from Loch Ryan to Northern Ireland is one of the most established and historical route in the Irish Sea. The first regular service commenced in 1861. At present Stenaline and P&O operate from Stranraer and Cairnryan respectively. Stenaline operates one fast ferry and two conventional ferries. The fast ferry, Stena Voyager, is an HSS 1500, a 120m long semi-swath catamaran. This is the largest fast ferry operating in the area.

P&O also operate one fast ferry and three conventional ferries. Their fast ferry Super Star Express is an Austal Auto Express 84, which is an 84m long catamaran. Up to this year they operated a 96m long fast monohull, Jetliner.

Seacontainers operated Seacat Scotland, a 74M Incat wave piercing catamaran, on the Belfast to Stranraer route between 1992 and 1999.

Table 1 gives an overview of the number of ferry sailings during the past 20 years in Loch Ryan.

Period	Departures per week		departures per year	
	Conventional	HSC	Conventional	HSC
1980-1992	94	-	4800	-
1992-1996	94	28	4800	1400
1996-1999	89	97	4600	5000
1999-2000	89	69	4600	3500

2.2 SHIP OPERATIONAL PROCEDURES

The course and locations of deceleration and acceleration of the various ships entering and leaving Loch Ryan are shown in ***figure 1***. All ships approaching Loch Ryan pass to the north of the cardinal buoy off Milleur Point and head into the Loch until passing Cairn Point. The ships bound for Stranraer alter their course passing Cairnryan and follow the navigation channel from Spit buoy via beacons 1, 3 & 5.

2.2.1 Conventional Ferries

The majority of the conventional ferries of both P&O and Stenaline arrive at the entrance to the loch at a speed of between 15 and 17knots. During 2000 P&O have introduced a new conventional ferry capable of operating at 23 knots. The ships slow to either enter or pass the port at Cairnryan. To the south of Cairnryan on route to Stranraer, the ships travel along the navigation channel at a maximum speed of 10 knots. The reverse process takes place on the outbound journey.

2.2.2 Fast Ferries

The Super Star Express arrives at a maximum speed of 37 knots (19m/s) and slows down near and to the south of Cairn Point. The vessel turns in front of the northern basin of Cairnryan ferry terminal and reverses into the harbour, mooring stern onto the link-span. On the outbound coarse Super Star Express accelerates immediately after turning to the north after leaving the harbour basin. The previous ship, Jetliner, had a similar operational procedure although the maximum speed was only 33 knots.

On the inbound passage, Stena Voyager slows from 40 knots to 17 knots off Old House Point and slows to 12 knots before the ferry terminal at Cairnryan and maintains this speed to Stranraer. On the outbound passage the reverse procedure is used with acceleration taking place off Cairn point. At high tide during the tern breading season Voyager slows at the Forbes Shoal Buoys to avoid the wash over topping the low banks which form the Scar.

When Seacat Scotland was operating on the Belfast Stranraer route, on both the inbound and outbound passages, the ship slowed in the vicinity of the Cairnryan ferry terminal but travelled at 36 knots both in the northern part of the loch and between Cairnryan and Stranraer.

2.3 WASH WAVE CHARACTERISTICS

All the fast ferries operating in the northern part of Loch Ryan generate wash waves in the super-critical depth Froude number range as a consequence of the limited water depth of between 20m and 8m. During deceleration from and acceleration to super-critical speeds either on inbound or outbound passages, the vessels transcend the trans-critical speed range. This is where they produce the maximum wave heights. These locations are highlighted as hatched areas in ***figure 1***.

Leaving Loch Ryan, HSS generates trans-critical waves after passing Cairn Point, which is their designated acceleration location. The waves approach the shoreline mainly along the cliffs at Clachan Heughs and the beaches at Old House Point.

The conventional ferries currently operating in Loch Ryan can reach a maximum speed of either 17 knots or 23 knots in open water. However when approaching shallow water the ships slow due to increased wave drag resulting from the reducing under keel clearance.

3. METHODOLOGY

3.1 WASH MONITORING

In November 1999 a number of physical measurements with two seabed pressure transducers were taken to quantify the size and characteristics of the wash produced by both fast and conventional ferries. The equipment was located east of Kirkcolm Bay at the 5m contour line to monitor the wash moving towards the cliffs at Clachan Hill, the beaches at Kirkcolm Bay, Kirkcolm Point and The Scar. The positions were 54°N58.25' 05°W02.34' (RSS) and 54°N59.00' 05°W03.46 (RNS), as shown in ***figure 1***. The distance of the northern location (RNS) to the track of the common navigation route was about 500m and on the southern location (RSS) about 800m. Results of these monitoring sessions were used for the numerical modelling, described in section 3.3.2.

3.2 FIELD OBSERVATIONS

During this study an investigation of the shoreline was carried out. Several sediment samples were taken from the beaches mainly in the inter-tidal zone to derive the erosion characteristics. On banks and beaches, where the particle size was excessive for normal sedimentary sample analysis, the grading of the material was determined using a line count analysis method. This gave a good approximation of the stone size and the distribution. As well, the shoreline morphodynamics were investigated and the main structures like ridges, bars, gravel cusps and overtopped beaches determined. Beach profiles along the shores all around Loch Ryan were surveyed to get an overview of the current state. In addition, pictures were taken to document the coastline.

3.3 MATHEMATICAL MODELLING

3.3.1 Numerical Simulation of Wind and Wash Waves

To obtain an overview of the wave climate in Loch Ryan representative wave data from outside the Loch was used. The annual wave climate for waves approaching from 270° to 60° from the North was modelled to determine the wave height, period and appearance along the shoreline of Kirkcolm Bay. In addition local wind seas from the south-east were determined, as this is the only direction with a fetch long enough to build up significant waves.

The wind wave characteristics were calculated from wind data for the area and data on swell waves in the North Atlantic produced by the Meteorological Office.

Having established the various wave characteristics for both wind seas and ferry wash the MIKE 21 suite of software was used to model the transformation processes taking place within the loch. Two types of mathematical model were used in order to produce information on different parts of the transformation process. A spectral wind wave model based on conservation of the energy density function was used to produce wave characteristics throughout the loch for the natural wave climate. Finally a breaking wave model was used to calculate the wave transformation processes which take place in very shallow water off beaches due to shoaling, refraction and bed friction.

With respect to ferry wash the same software was used. The time series were broken down into a series of characteristic frequencies to represent different parts of the wave train. The variation of direction of travel and height of the wash wave components was calculated along the track of the ship and this provided the input to the two models. This also provided input to the sediment transport model.

3.3.2 Numerical simulation of longshore sediment transport

Numerical modelling was undertaken using LITPACK/MIKE21, the integrated modelling system for littoral processes and coastline kinetics. This model uses data from the wave and tidal models together with bathymetry and sediment grading of the nearshore area. The model contains modules which enable the simulation of littoral currents, longshore sediment transport and coastline development.

Data derived from both the field measurements and the mathematical model were used as input for calculating the sediment transport at a range of sections across the shoreline around the loch. The simulation was carried out on an annual basis. The natural wave attack and the wave attack caused by the ferries on the inbound and outbound trips were distributed over five different tidal levels during flood and ebb tide cycles.

4. HISTORIC RECORDS OF COASTAL CHANGES

4.1 SURVEY DATA 1898-1972

Major sediment transport along the shoreline can only occur south of the cliffs at Clachan Heughs. The cliffs supply a negligible quantity of sediment for longshore transport. Also the river reaching the sea at Kirkcolm Bay has not the capability to transport sediment. The training walls indicate that the mouth needs to be maintained to guarantee a free discharge of water. Any sediment transport processes occurring along this part of the shore are therefore nourished by the local sediment supply.

The admiralty charts surveyed in 1898/99 and 1972 were used to determine the natural changes in the coastline along Kirkcolm Bay. ***Figure 2*** shows the simplified charts with the older contour lines as doted lines and the survey of 1972 as shaded areas. The reference datum on both charts is similar as well as the tidal levels

In zone (1) the undulations have been filled and a straighter coastline can be found. The promontory at (2) has moved and a new promontory has formed further south (3). In zone (4) the shoal has moved landward to form a tongue and the 0m contour has changed to a combination of concave and convex shapes. The datum and 2m contour have moved out in zone (5) by about 150m to 300m within 75 years. In zone (6) the depth has also changed and the datum contour has moved about 200m to 250m to the south-east. The former shoals are a continuous area above the chart datum ending in a 80m wide and 275m long ridge. The shoal (7) has been divided into 3 smaller shoals at the Spit with less than half the area compared to the earlier years. As a counterbalance the 2m contour has moved out.

Along The Wig the shoreline has moved seaward in general. Near zone (8) the 2m contour has moved to the south-west. This indicates that material has been moved from the shallow area into this zone without changing the datum contour significant. Along (9) the entire bay has become shallower with the 2m contour depth moving out about 150m to 200m.

It is known that gravel removal took place around The Scar during the 1960's. Unfortunately the quantity is not known, therefore the change at Kirkcolm Point itself is both natural and created by human activity.

4.2 PHOTOGRAPHIC DATA 1940-1998

Aerial photographs of Kirkcolm Bay and The Wig were taken in 1940 for military purpose and in 1989 and 1998 for environmental purposes. Although the photographs of 1940 and 1989 were not rectified and information about the distortion was not available, the landmarks within the area of interest fitted very well. In this study the waterline was taken as a measure of the change in the coastline. As the tide level effects the waterline and precise tide levels were not available, only major changes could be identified.

Figure 3 shows the shoreline in 1940, 1988 and 1998 in the general area of Kirkcolm Bay and The Wig. The area has been divided into a series of zones.

- North of zone 1: No change could be established as this part is mainly composed of bedrock on the surface and major artificial or natural erosion is not possible.

- Zone 1: The change in waterline between 1989 and 2000 indicates long-shore or seaward cross-shore transport of material within the last year with no significant change in the years before.

- Zone 2: South of the current outlet of the river coming from Kirkcolm shows that slight erosion during the past 10 years has taken place.

- Zone 3: The eroded areas in zone 1 & 2 are compensated by a deposition area within this zone.
- Zone 4: There is also evidence of deposition in this zone during the last 10 years.
- Zone 5: The tongue reaching out at Kirkcolm Point has moved to the south-west and the area has increased significantly between 1940 to 1989.
- Zone 6: The scar has also moved in a south-westerly direction since 1940 and the area has changed as shown. It is reported that major gravel removal for commercial purposes took place in this area until 1962. After the gravel removal ceased the scar with a length of approximately 180m was breached by every high tide. The level of the seabed in the breach has deepened to 1.2m.

5. THE ENVIRONMENTAL IMPACT IN HARBOURS AND CHANNELS

5.1 SEA BED IN THE HARBOURS

Figure 4 shows a schematic view of Stranraer Harbour, the adjacent sea bed contours, the extent of the dredged area which forms the start of the channel, the turning area and three shaded areas where there is scour. In the harbour between the Mail Quay and Ross Pier 2 scour areas can be found. One is created by the conventional RoRo-ferries, which berth with their bows too the link span. The port operators have indicated that this situation has not changed in many years.

Stena Voyager berths stern to the link span next to the Mail Quay. The local scour area in front of the link span can be attributed to the action of the water jets. The port operators have indicated that this has occurred since the introduction of Voyager in 1996. It is interesting to note that a similar situation has occurred at Harwich where another HSS 1500 berths. Here the sea bed has been eroded in two parallel tracks in line with both hulls. It is thought that the water jets are particularly prone to cause sea bed erosion when the reversing buckets are down and the flow is being directed forward and down at an angle of about 40^0.

The above observations show that both conventional ferries and fast ferries with water jet propulsion generate local bed scour. Ideally the sea bed should be paved in order to prevent the problem and this has been done in some ports.

5.2 MANOEUVREING AREAS.

In front of the harbour basin is a dredged area, which is maintained to a minimum depth of 5m to provide space for ships to manoeuvre, as also shown in ***figure 4***. Within the basin there is evidence of a scoured area which coincides with the turning location for both the high speed and conventional ferries. Voyager enters the area bow first and reverses into the berth. There is a high degree of control with four steerable water jets and in conjunction with the computer controlled navigation system there is very little deviation in the location of the turning point. Consequently the scour area tends to be fairly concentrated.

The situation is partially redressed by the conventional ferry, which reverses from its berth and turns to travel along the channel. This manoeuvre is not as precise as with the high speed ferry and consequently the scouring action tends to be more distributed. It is thought that a dynamic equilibrium has been reached in the area. This means, that the fast and conventional ferries are eroding material due to the locally very high water velocities while turning but this material is deposed in the near field super-elevating the edge slopes, which causes slides and partially refills the scour area. The very low tidal currents contribute very little to this process, as the velocities are too low. In addition there are no significant rivers flowing into the loch at Stranraer and consequently sediment deposition is not an issue.

5.3 THE NAVIGATION CHANNEL TO STRANRAER HARBOUR

A channel linking the deeper water at Cairnryan with Stranraer Harbour has been dredged from the Spit buoy via Beacon 1 to Beacon 5 in 1979, as shown in ***figure 5***. The maintained depth is 5m below Chart Datum. The channel is 100m wide and has a length of 3750m.

Tidal current data has been calculated using the Mike21 Software. The tide induced current has been calculated at three points along the channel and a maximum value has been estimated as 0.4m/s close to the Spit buoy. The seabed consists mostly of a mix of mud and fine sands, therefore sediment movements must be assumed at currents above 0.25m/s. However, the mud fraction can stay as suspension at lower velocities. Movement of fine sand due to tidal currents is only possible during flooding at the position near Beacon 1.

Historic data indicates that in recent years the cross section of the channel has been relatively stable. However, it is thought that there is a net migration of sand from the Spit to the south-east and it is the presence of the ferries and in particular the fast ferries with water jet propulsion which clears the channel by forcing material into suspension. A further observation is the occurrence of sand waves on the sea bed to the east of the channel.

High speed craft with jet propulsion operating at sub-critical speed in a navigation channel or shallow water have very little effect on the seabed. There are several explanations for this: Firstly the flow through the jets is very little, the HSS for example pumps only 4% of the water through the jets at 12 knots compared to full speed. The highest velocities are reached at the water surface, were the jets plunge into the water and near the intakes of the jets. The under keel clearance, the shape and the direction of the intake are the determining factors for this. In contrast to this, a conventional propeller has a much higher secondary flow radial to the shaft due to the added mass effects and the flow around the propeller tips.

From 1992 to 1999 Seacat Scotland operated to the east of the dredged channel. This small fast ferry navigated at full speed, 36 knots, up to the boundary of Stranraer harbour. This resulted in a partial second channel being formed to the east of the main channel. There was also a tendency to move the eastern edge of the main channel inwards. During the past year this second channel has largely disappeared and the main channel has returned to the post dredging state.

6. WAVE EFFECTS KIRKCOLM BAY

Although several areas around the loch have been modelled, only the area at Kirkcolm Bay is presented. At this location there is substantial wind wave action. In addition, all the fast ferries pass this location at speed and the resulting wash is well within the super-critical depth Froude range. Ferry wash has been monitored at the 5m contour close to this site, (location RNS).

6.1 WIND SEAS

Only the eastern and the western coastlines of the northern half of the loch are subject to long period swell waves. These primarily originate in the North Atlantic and in the North Channel between Scotland and Ireland. Swell waves with a period of 12s to 15s are common and these are supplemented by shorter waves generated in the Firth of Clyde and the North Channel. There is also some local wind seas from south-easterly winds with a typical period of 4 to 5 seconds. ***Figure 6*** shows the relative heights and directions of the swell waves entering the loch from the north. This wave climate was used in conjunction with information on occurrence and duration as input to the sediment transport calculations which provided an insight into the natural processes taking place.

6.2 FERRY WASH

During a five day monitoring period wash was monitored for both conventional and fast ferries. This included inbound and outbound passages. ***Figure 7*** shows two typical wash wave traces of two fast ferries inbound measured off Kirkcolm Bay at location RNS. The first trace is for Stena Voyager and the second is the P&O Jetliner. Each wash trace was categorised in terms of frequency bands, typical heights within each band and number of waves resulting from each passage. The total number of passages per year for each vessel was also calculated.

6.3 NUMERICAL SIMULATION OF LONGSHORE DRIFT

A range of particle sizes was used in the sediment transport calculations**. *Figures 8a to d*** show the output from the longshore drift calculations using a particle size of 5mm. The figures show the longshore drift resulting from the naturally occurring swell waves, the combined effect of conventional ferry wash waves, the combined effect of the wash from fast ferries and the total effect of all three combined.

The values calculated are only potential transport rates and provide a relative measure of the longshore drift caused by the three different sources. The total process taking place in the field is very difficult to model as the particle size grading ranges from gravel to very fine sand. The fine material is eroded first leaving a top layer of gravel and pebbles. This top layer armours the sediment and even though a potential transport rate exists only a small amount of material is actually transported.

The results of the calculation are shown in ***figure 8*** for cross section 3 at Kirkcolm Bay (the location of cross section 3 is shown in ***figure 1***). Natural sediment transport shown in ***figure 8a*** occurs only in the southern direction as the natural swell approaches with a period of about 13 seconds from the mouth of Loch Ryan. A lower level of wave attack occurs further out with another peak at a depth of 1.3 meters 600m off the coast. The largest transport rate appears in the inter-tidal zone and just below the chart datum in a zone 50m wide from the beach seaward. This is due to the waves breaking at this water depth.

The mass transport rate due to conventional ferries, Shown in ***figure 8b***, is much smaller than the natural rate due to wind seas. The fundamental difference is that the ferry wash causes a reversal of the transport direction depending on whether the vessels are inbound or outbound. Due to this cancellation effect the net movement of material in one direction is very small.

The fast ferries also produce a variation in mass transport direction depending on the direction of travel of the vessel. This is shown in ***figure 8c***. However, the mass transport rate in the southern direction is about twice that in the northern direction. This is due to the super-critical wash being more developed in the inbound passage with a larger number of longer period waves compared to the outbound passage. On the outbound passage the near-critical wash, which is the largest, dissipates very quickly with distance from the sailing line. This is because the ships accelerate quickly and energy is pumped into these waves for a very short time. When both these effects are added together, the net mass transport in a southern direction is similar to that caused by the wind seas.

Figure 8d shows the combined effect of both wind seas and all ferry wash. This shows that the peak sediment transport in a southern direction close to the shoreline is similar for both the ferry wash and the wind seas. However, the transport of material further offshore is greater for the wind seas.

A similar set of calculations were performed for a 1mm particle size at the same location. This produced a different effect with the sediment transport due to wind seas being substantially greater than that produced by the ferry wash. This demonstrates that any conclusions reached about the relative environmental impact of ferry wash compared to natural processes is highly dependant on the particle size of the sea bed materials. In general the fast ferry wash with its very long wave periods is capable of moving larger material than the naturally occurring wind seas.

7. CONCLUSIONS

The preliminary conclusions from this study are as follows;

- Compared to conventional ferries, fast ferries with water jet propulsion tend to produce more sea bed scour in harbours and manoeuvring areas but do so in a more localised position.

- Fast ferries operating at comparable speeds to conventional ferries in very shallow water tend to disturb less sediment due to their lower displacement and more streamlined hulls. However, the wider beam of catamarans in conjunction with water jet propulsion tends to move more sediment at the sides of the channel as the ship occupies a greater proportion of the channel width.

- Fast ferries operating outside the main channel in very shallow water tend to scour their own channel. In addition damage to the side slopes of the main channel occurs if the track of the new channel is too close or the vessel crosses back into the main channel.

- Historic records have shown that in areas such as Kirkcolm Bay and south to the Scar, there has been a southern migration of material over the past 100 years prior to the introduction of fast ferries. This process has been accelerated by the physical removal of material from the beach.

- Numerical models of longshore drift have shown that the erosion produced by fast ferries is greater than conventional ferries but is of a similar level to the natural processes resulting from wind seas from the north.

- The vulnerability of a coastal zone to wave attack is dependant on the typical particle size and the grading of the material. If fine sediments are interspersed with gravel and small stones, then armouring takes place and the mass transport rate is significantly reduced.

- The leading long period waves in fast ferry wash tend to move larger material than the shorter wind seas particularly further from the shore. In comparison the short steep waves produced by conventional ferries tend to move material closer to the shoreline.

- Each shoreline needs to be modelled individually and it is not possible to generalise on the environmental impact of fast ferry wash.

8.0 REFERENCES

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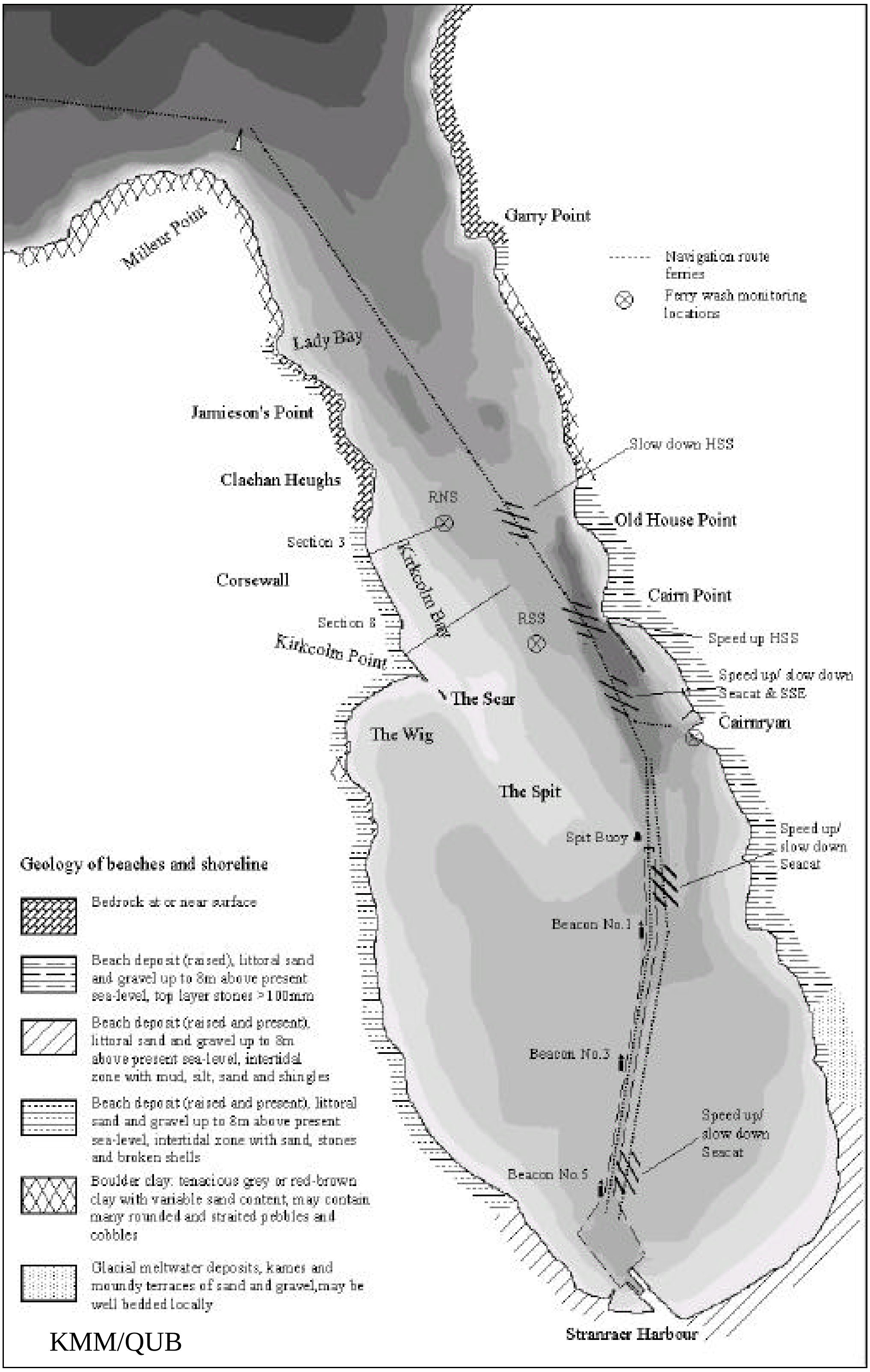


Figure 1: _Loch Ryan - Bathymetry, navigation routes and geological formations along the shoreline

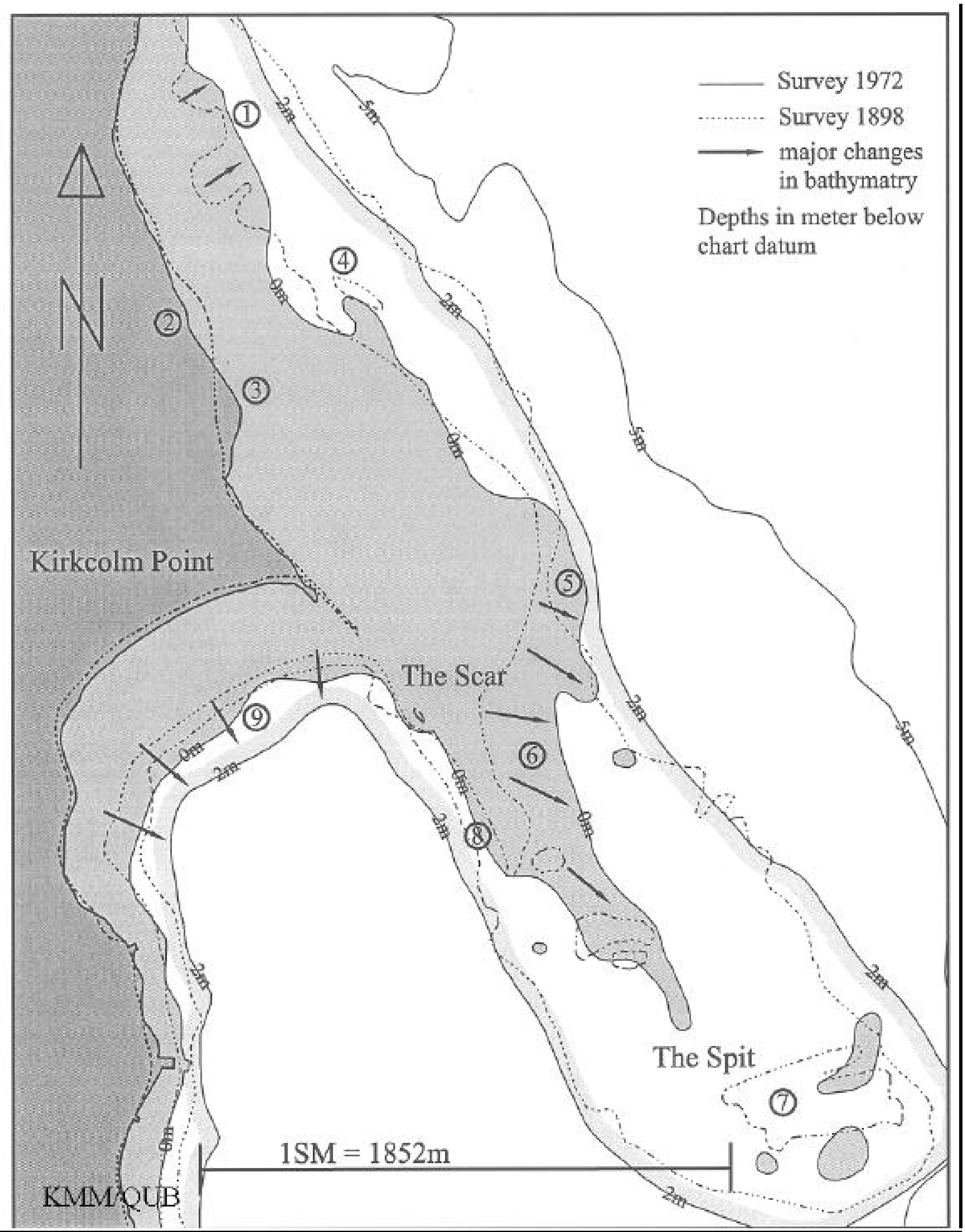


Figure 2: Bathymetric changes from 1898 until 1972 along Kirkcolm Bay and the Spit

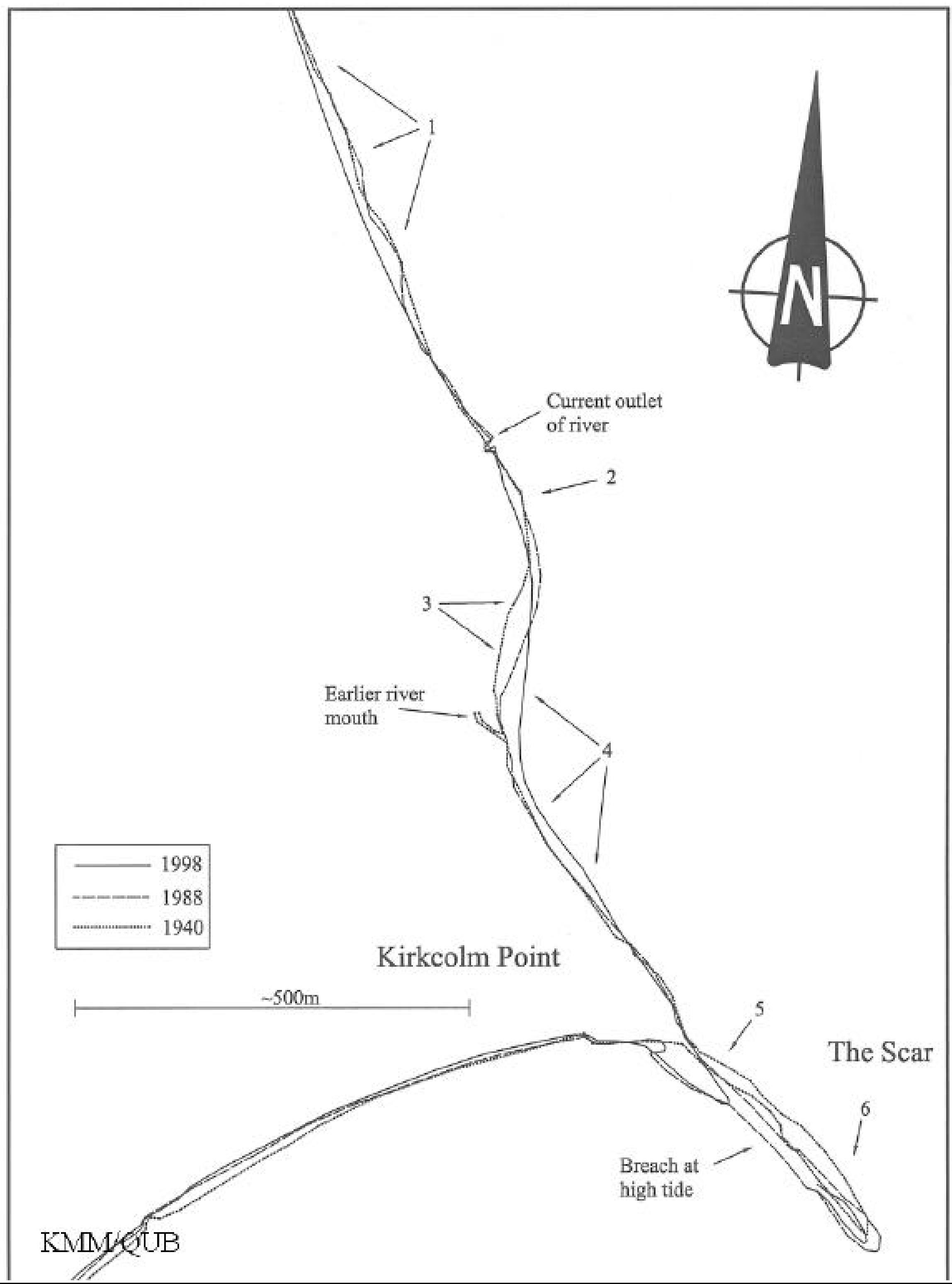


Figure 3: Comparison of the coastline taken from aerial photographs

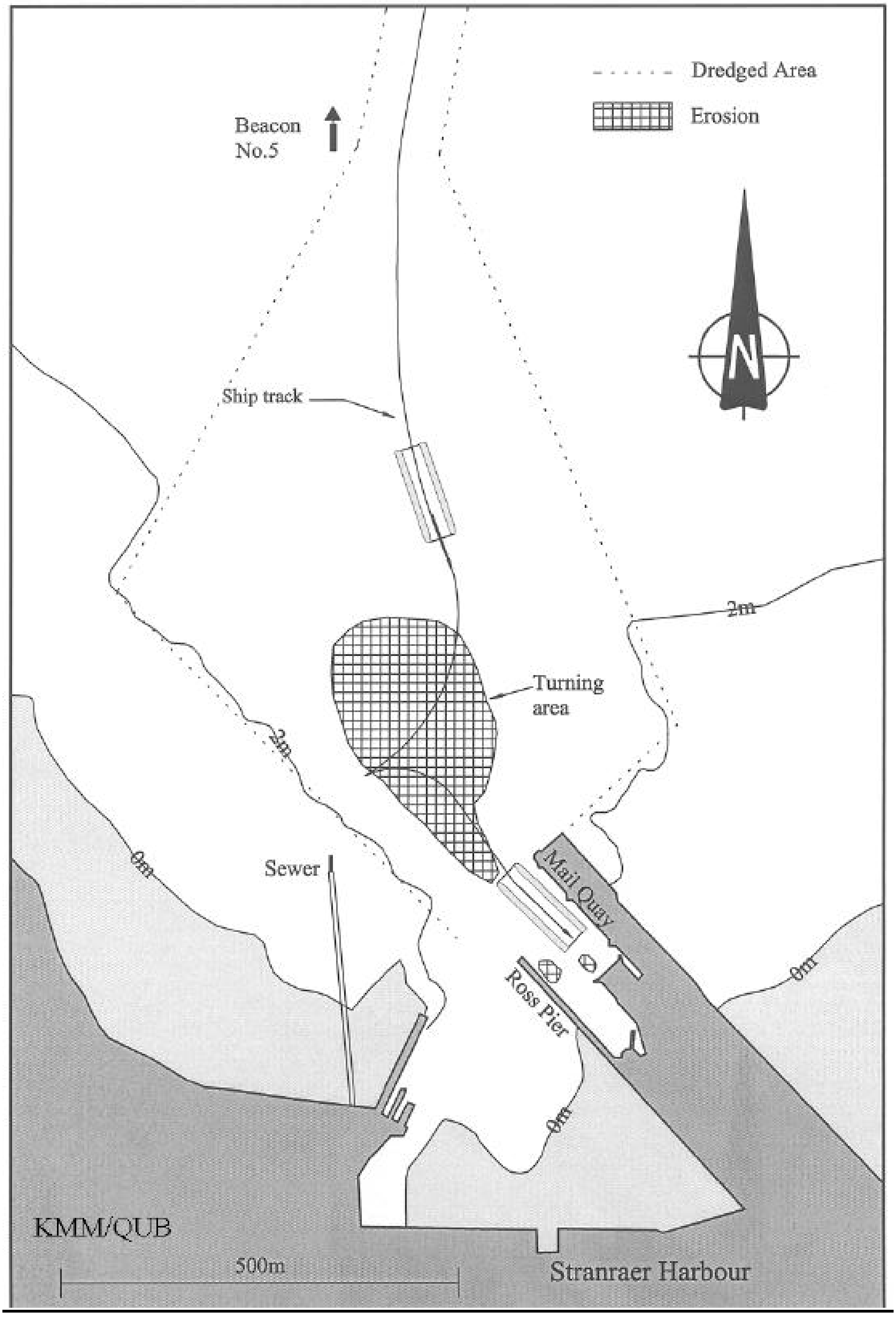
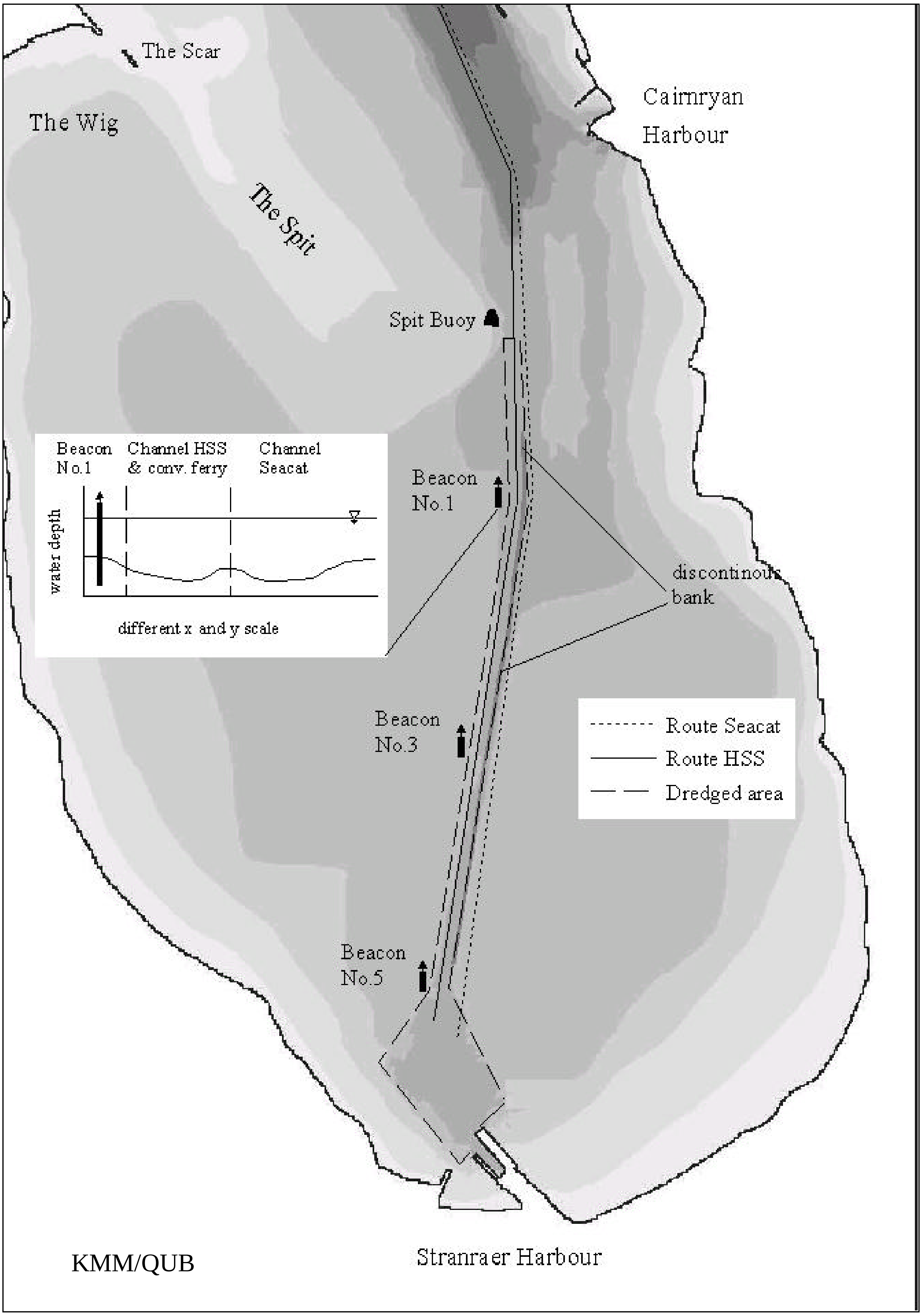


Figure 4: Stranraer Harbour – Harbour basin and manoeuvering areas



<u>Figure 5: The navigation channel between the Spit buoy and Stranraer Harbour</u>

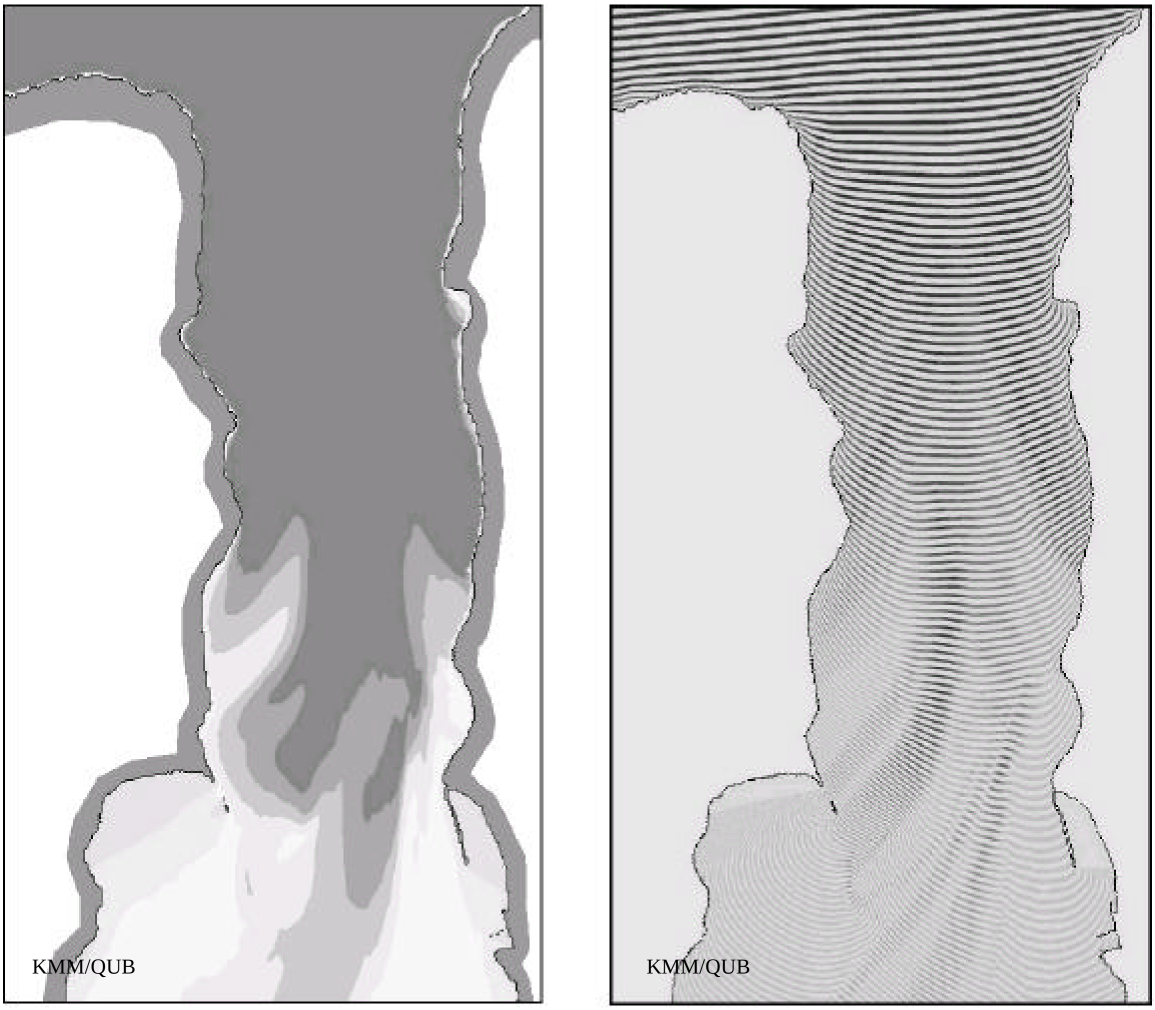


Figure 6: The natural wave heights and the refraction of waves penetrating into Loch Ryan from the Irish Sea

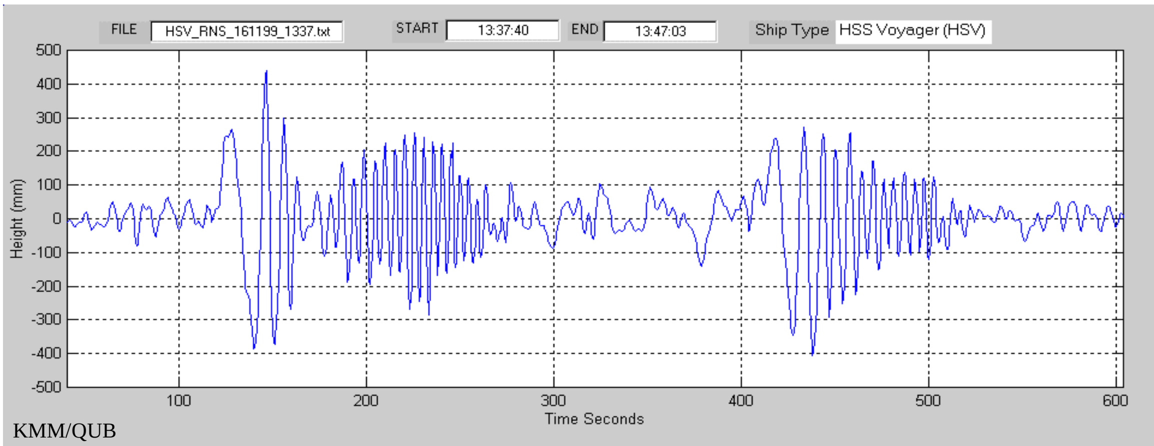


Figure 7: Fast Ferry wash @ RNS Stena Voyager followed by P&O Jetliner

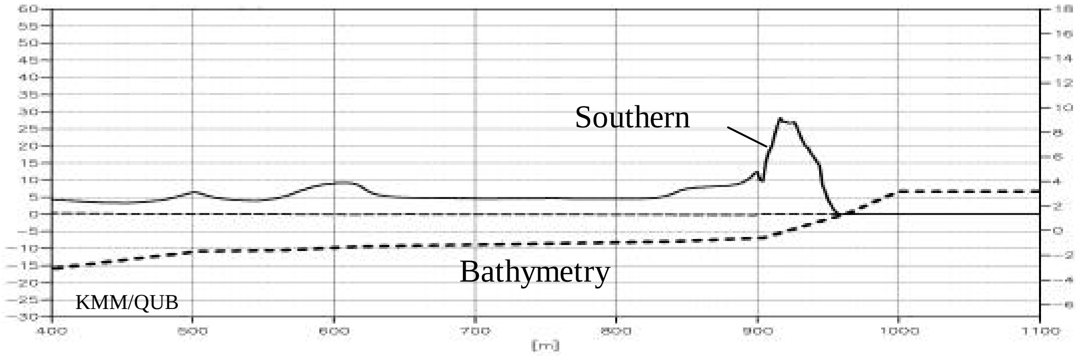


Figure 8a: potential sediment transport induced by natural waves

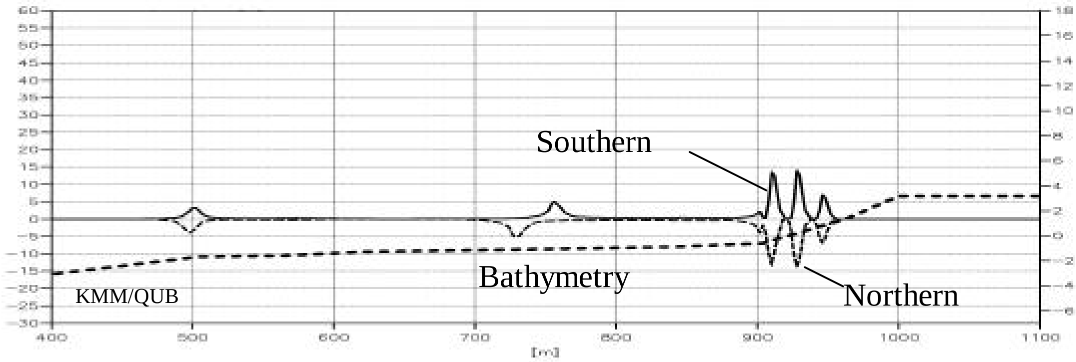


Figure 8b: potential sediment transport induced by waves due to conv. ferries

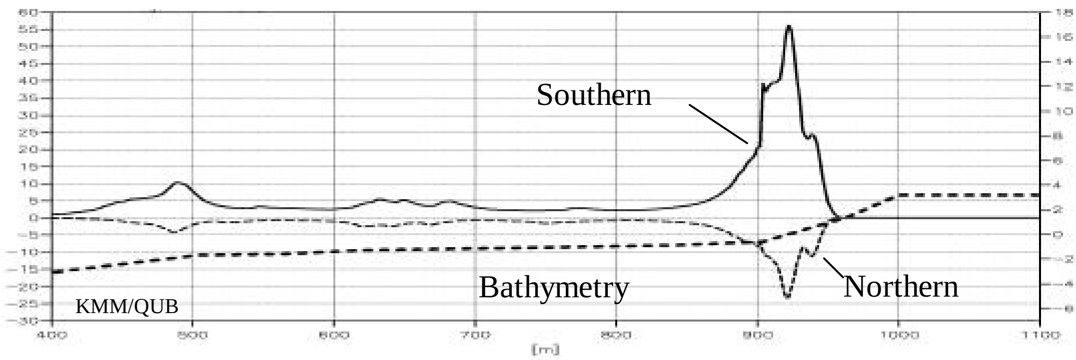


Figure 8c: potential sediment transport induced by waves due to fast ferries

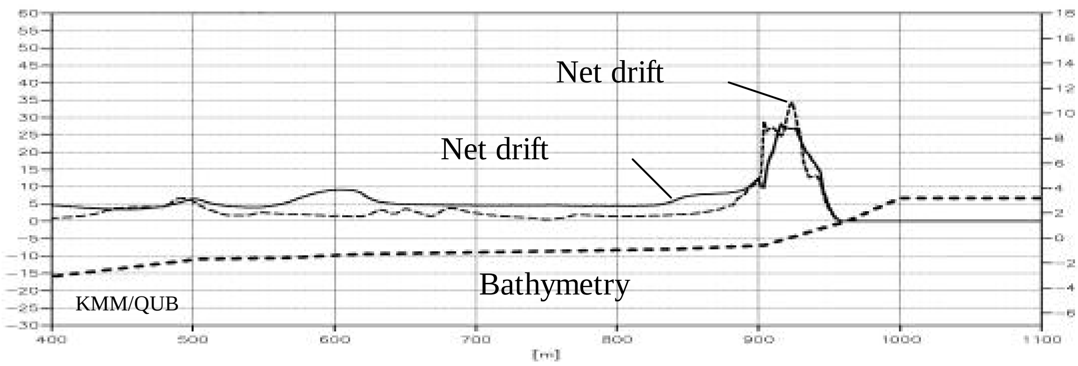


Figure 8d: net potential sediment transport induced by natural waves and waves due to fast ferries