Hampshire & Wight Trust for MARITIME Archaeology

ENGLISH HERITAGE

Quantifying the Hazardous Threat: an assessment of site monitoring data and environmental data sets

Project Report

July 2006

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ii. Acknowledgements

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We would particularly like to acknowledge the help and support of the Hazardous Project Group who have provided data, information and their time and efforts in contributing to this project. Without the work of the Hazardous Project Group on the site for the past twenty-five years there would not be such an archive of material available for study.

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Research and data analysis has been carried out by Julian Jansen van Rensburg; this report has been written by Julian Jansen van Rensburg and Julie Satchell, with contributions from Iain Grant and Jan Gillespie.

iii. 2007 Addendum

Changes on the Hazardous site over the winter of 2006/07 have been some of the most extensive witnessed by the Group. Loss of sediment has uncovered a wide range of artefacts and freshly exposed features which have not previously been seen. These changes have occurred despite a relatively low level of storms.

This new evidence does not affect the results outlined in this report, however, it does reinforce the effect that the net sediment loss in the Bracklesham Bay area combined with the position of the site at the junction of sediment pathways are a major threat to the site.

iv. Glossary

Accretion: The accumulation of sediment by natural processes.

Scouring: The erosion of sediments caused by water moving at a velocity higher than the equilibrium.

Coastal processes: Collective term covering the action of natural forces on the shoreline and nearshore seabed.

Hold the line: Holding the existing coastal defence line involves taking action to maintain its position. This line may or may not be artificially defended (e.g. by structures). In other words the "defence line" may currently comprise sand dunes, mud flats or cliffs. Holding the line means that that the stretch of coast in question could be the subject of works, as necessary, in the future.

Groynes: Cross-shore coastal structures connected to the shore, designed to reduce longshore transport by causing beach reorientation. They may be constructed from timber, concrete, steel sheet piles or rock.

Littoral drift, littoral transport: The movement of beach material in the littoral zone by waves and currents

Longshore: Parallel and close to the coastline.

Longshore transport: Movement of beach sediments approximately parallel to the shoreline, also known as longshore drift.

Management unit: A length of shoreline with similar characteristics in terms of both natural coastal processes and land use.

Nearshore: Area over which seabed transport can be caused by storm waves, including the intertidal zone.

Offshore: Area seaward of nearshore zone where seabed transport is not normally driven by waves.

Plan shape: The shape of the beach in plan; usually shown as a contour line, or a combination of contour lines or recognisable features such as beach crest and/or still water line.

Sea defence: A structure or scheme designed to prevent flooding of coastal regions by the sea under extreme wind and tidal conditions.

Sediment source: Point or area on a coast from which beach material arises, such as an eroding cliff, or river mouth.

Shoreline Management: The development of a strategic, long-term and sustainable coastal policy, often related to coastal defence.

Shoreline Management Plan: A document that sets out a strategy for coastal defences for a specified length of coast.

Swash aligned: Beaches where waves approach at 90 degrees are called Swash Aligned Beaches and therefore there will not be much of longshore drift. Instead sediments are transported up and down the beach.

Tidal current: The movement of water associated with the rise and fall of the tides.

1. Project Introduction

This project has been undertaken in response to the urgent need for work on the protected wreck site of Warship *Hazardous*. The site has been under archaeological investigation for over twenty years. The work on site has been undertaken by the *Hazardous* Project team (308 Sub Aqua Association) with the support of a range of archaeological advisors and organisations.

Hazardous is one of only 42 Protected Wrecks around the coast of England. It is designated under the Protection of Wrecks Act 1973 and all diving and archaeological investigation must be licensed.

This project addresses the need to quantify the extent and rates of erosion that are occurring on the site to aid future management of the wreck remains. This task has been undertaken using data from two principle scales:

- The wreck site, including data from sources - archaeological, photographic, monitoring, distribution studies and diver observation.
- The coastal environment of the on, near and off shore zones – including data on sediment transport, coastal response, aerial photographs, beach monitoring, charts.

This data has been analysed to identify particular areas of the site at risk from erosion in relation to areas with high archaeological potential. The result is an assessment of past and current environmental factors affecting the stability of the wreck site, and the implications for the long-term future of the archaeological archive. The report concludes with proposals for active archaeological investigation of selected areas of the site aimed at providing preservation by record of this highly dynamic site.

2. Site Background

2.1 The wreck and its environmental history

2.1.1 Vessel history and wrecking

Le Hazardeux was built in 1698 in France. The vessel was a 3rd rate ship of the line in the Navy of Louis XIV. The ship carried a crew of 350 and 50 guns. In 1703 the ship was captured by the English and refitted as a 4th rate ship of the line with 54 guns.

This capture and refit is an important aspect in the archaeological significance of *Hazardous*. Techniques of ship design and construction developed by the French are present on *Hazardous*. When captured the English studied these technological developments and some were eventually incorporated into English naval ship construction.

The ship was re-commissioned as *Hazardous* in 1704 but was to be wrecked only two years later after returning from escorting a convoy from Chesapeake Bay, Virginia, USA to England.

Due to poor weather *Hazardous*, following the lead of another naval vessel - Warship *Advice*, was forced to head for shelter in the Eastern Solent. Due to failure to signal *Hazardous* was driven into shoal waters in Bracklesham Bay.

There is evidence that some limited salvage work was undertaken on the wreck just after wrecking this was primarily aimed at recovering the arms on board. Due to the highly dynamic environment in which the site lies it is assumed that the wreck's upper structure would have broken up relatively quickly. However, no contemporary evidence has yet been discovered to support this claim. After the wrecking the remains would have slipped beneath the waves and became entombed within the seabed.

2.1.2 Discovery and protection

Hazardous was originally discovered in 1977 by sport divers. The wreck was designated in 1986 under the Protection of Wrecks Act 1973 and is now managed by English Heritage. Archaeological investigation of the wreck began in earnest in the mid 1980s, and has continued for the past twenty years. This work has been undertaken, with little financial support, by the avocational 308 SAA *Hazardous* Project group.

2.1.3 Summary of archaeological work 1986 - 2006

During the late 1980s numerous individual artefacts and concretions were raised and examined. Cannon were also surveyed *in situ* and a full pre-disturbance plan of the wreck site was completed. Artefacts were found to date to the late 17th to early 18th century. This pointed towards the wreck being that of *Hazardous.*

It was established that the remains of *Hazardous* were comprised principally of the lower hull. There appeared to have been a transverse breach of the hull at the amidships section. Forward of this the bow section had become buried within the seabed; the port side appears to survive to a slightly higher level than the starboard side. Aft of the amidships breach the stern has faired less well due to shallower sediments.

During the late 1980s changes in erosion patterns were noticed. Timbers, concretions and artefacts were being freshly exposed. Due to the excellent state of preservation of the timbers it was assumed that the wreck had remained relatively stable from the time of wrecking until the early 1980s.

Due to the increased erosion, intrusive excavation was carried out in 1988 and 1989. A trench forward on the port side established the extent of the remains buried towards the bow of the ship. Relatively undisturbed stratigraphy was encountered along with features and artefacts in secure context. Due to a move away from the granting of excavation licenses on protected wrecks, financial constraints and a backlog of work on artefacts raised, excavation was not continued after 1989.

Monitoring of the site continued into the early and mid 1990s. Artefacts and concretions at threat continued to be recovered. A detailed survey of a recently exposed gun carriage was carried out with the hope of recovery and conservation, however, as conservation could not be arranged this was not possible. Sand bagging to protect this feature was undertaken as a temporary measure.

Since 1998 annual survey and investigation has been ongoing. Particular focus has been on the central area of the wreck where the most active erosion is occurring. A Diver Trail has also been set up which explores the wreck and the surrounding natural environment. The 2003 diver trail season and the production of a popular booklet on *Hazardous* was part funded by English Heritage.

Specific initiatives to monitor the erosion were set up early in the 2002 season with a system of datums to monitor bed levels and timber erosion. The main focus of work on site continues to be recording the effects of erosion. The *Hazardous* team remain highly concerned that they are watching one of the Nation’s important wreck sites, and the potential information held within disappear at the hands of the dynamic environment.

3. Evidence for site changes

Evidence for chronological changes occurring on site have been identified through a variety of methods of investigation each of which has helped to build a picture of the site formation and transformation processes that have, and are, affecting the site. Each of the different types of data that demonstrate environmental change on the wreck site are presented below.

3.1 Sediment monitoring points

The monitoring of sediments was undertaken during two separate periods, the first being from 1987 to 1988 and the second from 2002 and is ongoing.

3.1.1 Monitoring 1987 to 1988

During 1987 and 1988 sediment levels were taken for the northern, central and southern parts of the site at datum points D6 (southern), D7 (central) and D4 (northern).

Sediment level changes during this period show an approximate 400cm accretion occurring along the northern and central parts of the site and approximately 300cm accretion occurring in the southern end of the site, figure 1. During the period October 1987 and April 1988 strong winds and storms were noted, which seem to be related to an increase in sediment levels throughout the site during this time.

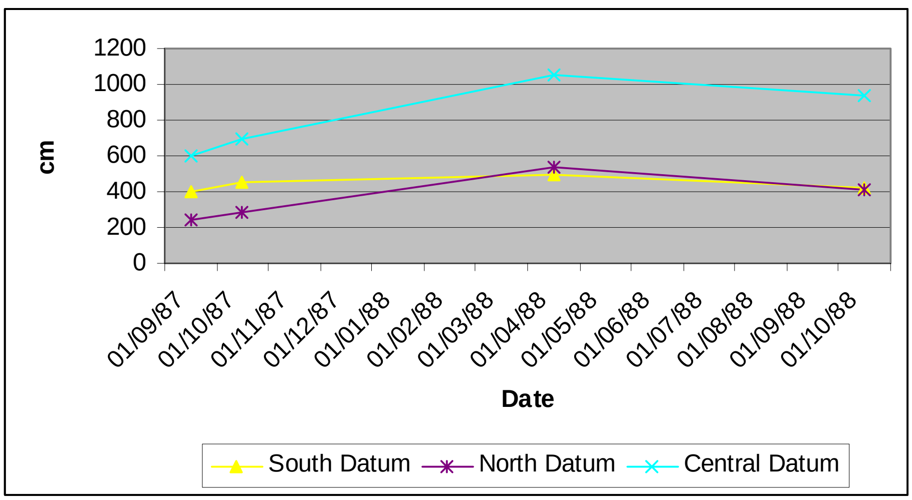

Figure 1 - Monitoring 1987 to 1988

3.1.2 Monitoring 2002 to 2006

In the summer of 2002 a series of sediment monitoring points were set up around the forward end of the site. These were put in place to gather evidence of sediment movements and to measure the degree of change occurring in the specific areas where they were situated. An overview of change throughout the site is obtained in the graphs below (figure 2) showing large sediment movements measured during the period from 2002 to 2005. The general trend appears to be accretion occurring mid way through each year with a slow decline in sediment levels towards the end of the diving season. This pattern of accretion and scouring appears to be cyclical, although the degree of change occurring seems to alter yearly with sediment movements being in the range of 100mm for certain years (2004) to in excess of 200mm for other years (2003 and 2005). When viewing the graph of sediment movements in figure 2 it is important to note that measurements are not obtained during the winter months, this is due to environmental conditions which preclude diving during this period. However, when comparing sediment levels at the end of one season and the beginning of the next it is possible to see changes occurring, these reflect scouring and accretion events that are not recorded in such frequency as those occurring over the summer season.

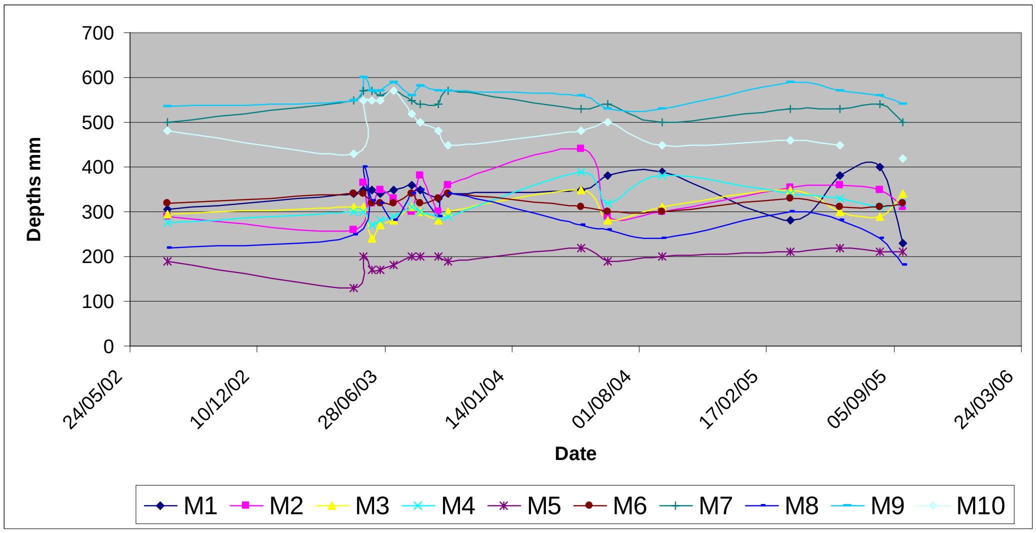

Figure 2 – Data from all sediment monitoring points

Figure 3 includes graphs which reflect the sediment movement recorded at each Monitoring Point (M) from 2002 to 2005. It is apparent that along the western side of the site (M1 to M5) and the northern edge of the site (M10) there are small degrees of sediment movement occurring, although localised scouring does occur. Along the eastern side of the site (M9 to M6) the sediment processes are more dynamic with large changes of accretion and scouring. These dynamic changes also affect the amidships section of the site (M6) and to a lesser extent (M5).

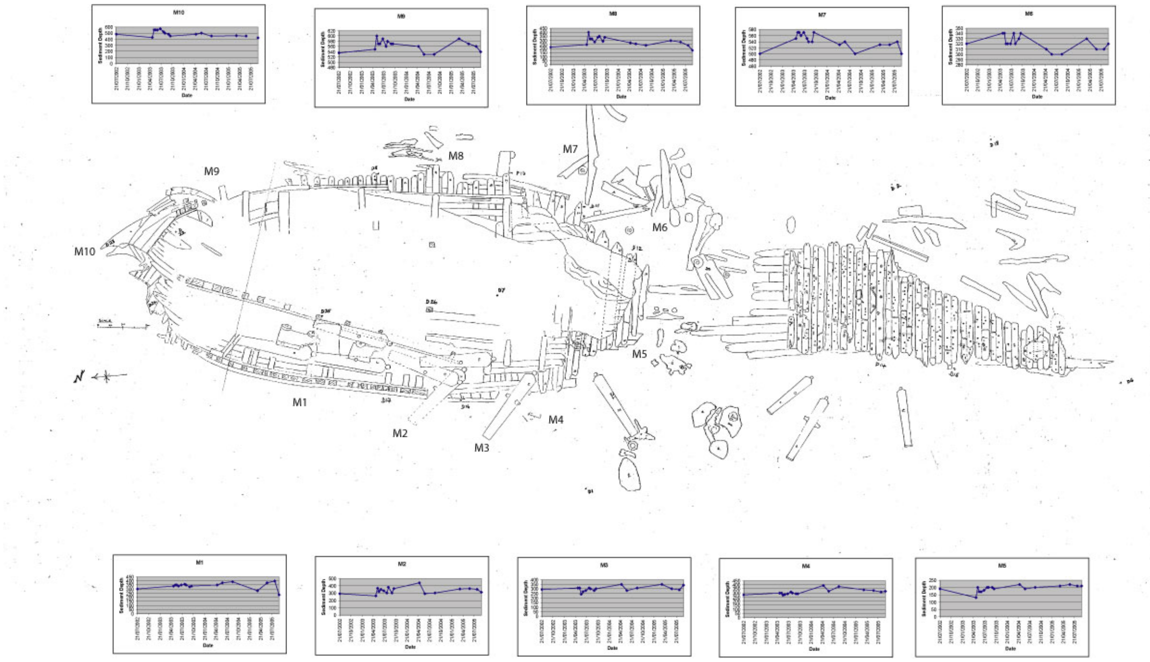

Figure 3 – Location of the *Hazardous* monitoring points

Annual change for each area is reflected through a graph displaying sediment movements, 2002 has been left out as there is only a single measurement for this period.

2003 - North (M10)

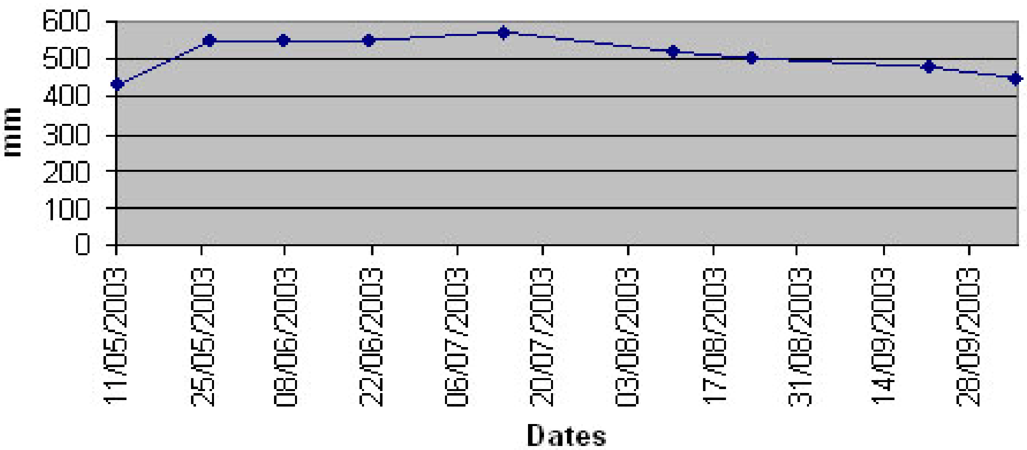

Figure 4 – Monitoring point 10 - 2003

The northern end of the site shows an increase in sediment up to 100mm during the first part of the year with a subsequent drop in sediments toward the end of the year. This profile of sediment movements in figure 4 shows a roughly cyclical movement.

2003 – East (M7, M8 and M9)

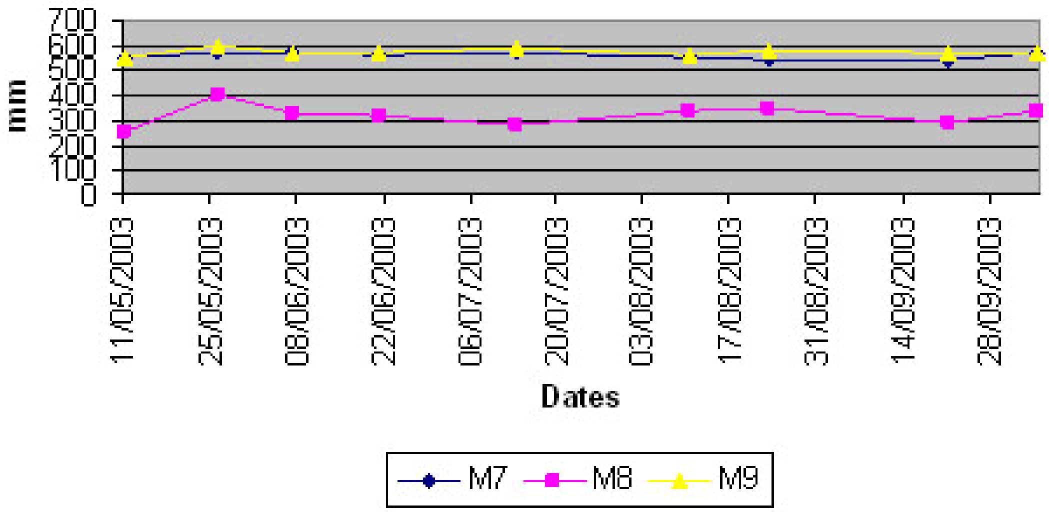

Figure 5 – Eastern monitoring point - 2003

The greatest change during the 2003 season occurred during May and July with an accretion of over 200mm taking place. Later during the year as can be seen in figure 5, the sediment levels stabilise and remain fairly constant with localised exceptions around M8 which shows a cyclical accretion and scouring cycle taking place throughout the year.

2003 – Amidships (M5 and M6)

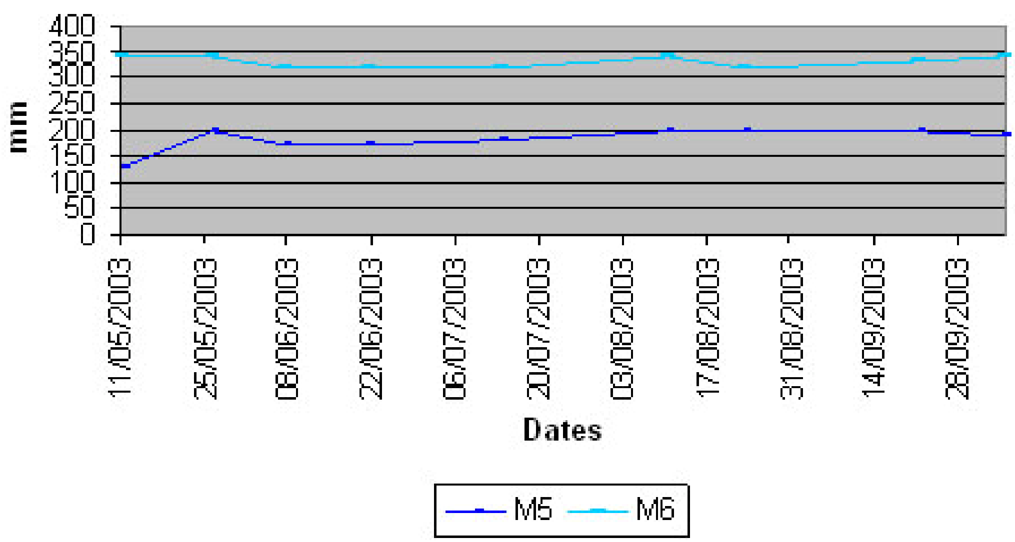

Figure 6 – Amidships monitoring points - 2003

Amidships the greatest change occurs during May 2003 with an accretion of 70mm followed by a general scouring effect from June after which levels remain fairly constant over the year as can be seen in figure 6.

2003 – West (M1, M2, M3 and M4)

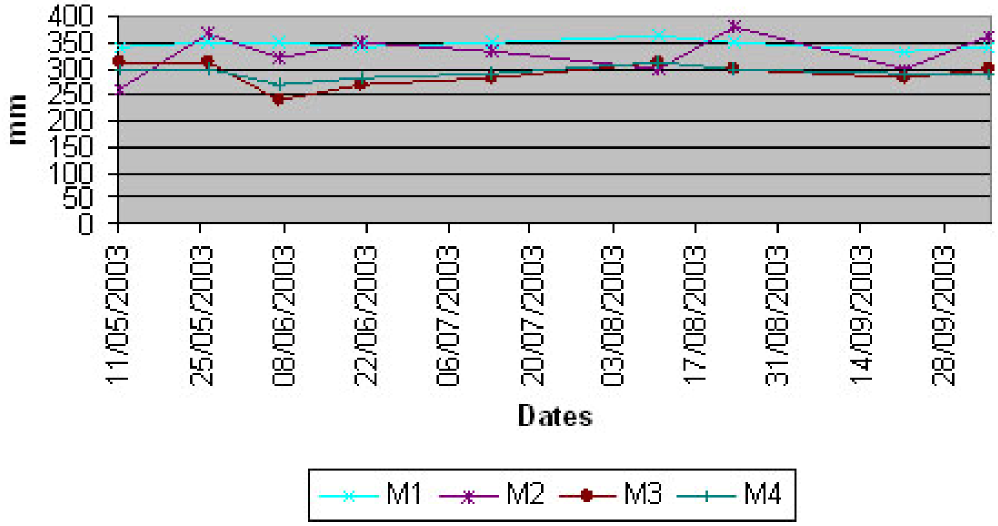

Figure 7 – Western monitoring points - 2003

The western section monitoring points provide evidence for the most dynamic section of the site with periods of both accretion and scouring occurring within months of each other throughout the year. These changes (seen in figure 7) are in the range of approximately 100mm with singular exceptions being M1 where only minor changes are occurring.

2004 – North (M10)

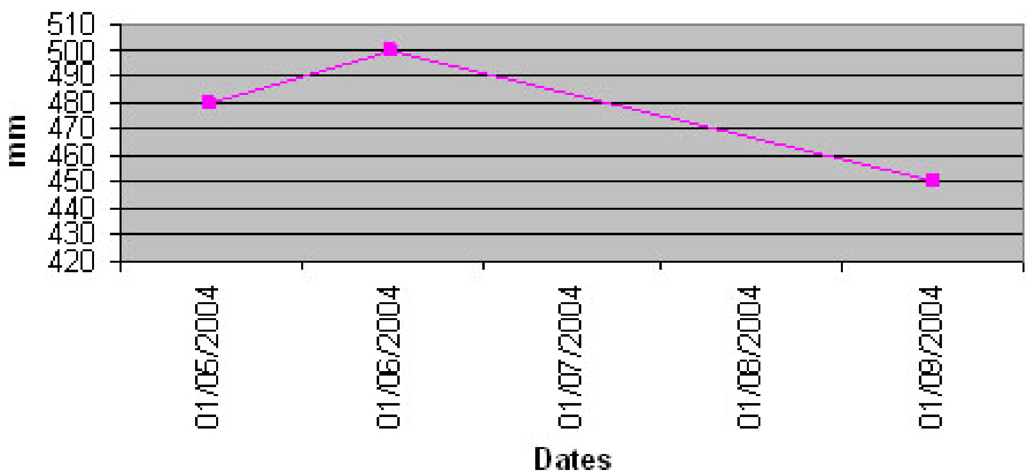

Figure 8 – Monitoring point 10 - 2004

During 2004 the northern part of the site shows a small level of accretion occurring from May to June with a subsequent slight drop in levels in the range of approximately 50mm towards September, shown in figure 8.

2004 – East (M7, M8 and M9)

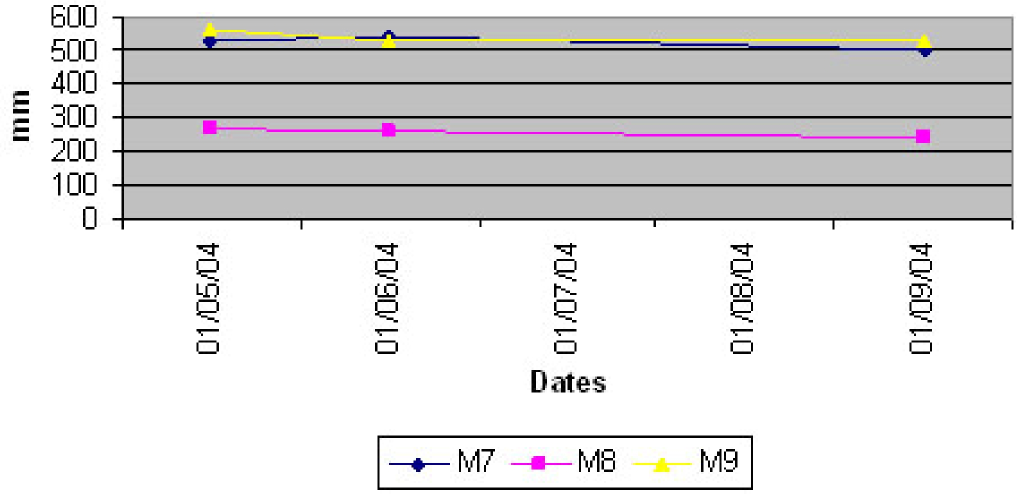

Figure 9 – Eastern monitoring points - 2004

Throughout the 2004 season the eastern monitoring points show that there is very little change in sediment movements with an approximate 50mm drop starting to occur midway through the year (figure 9).

2004 – Amidships (M5 and M6)

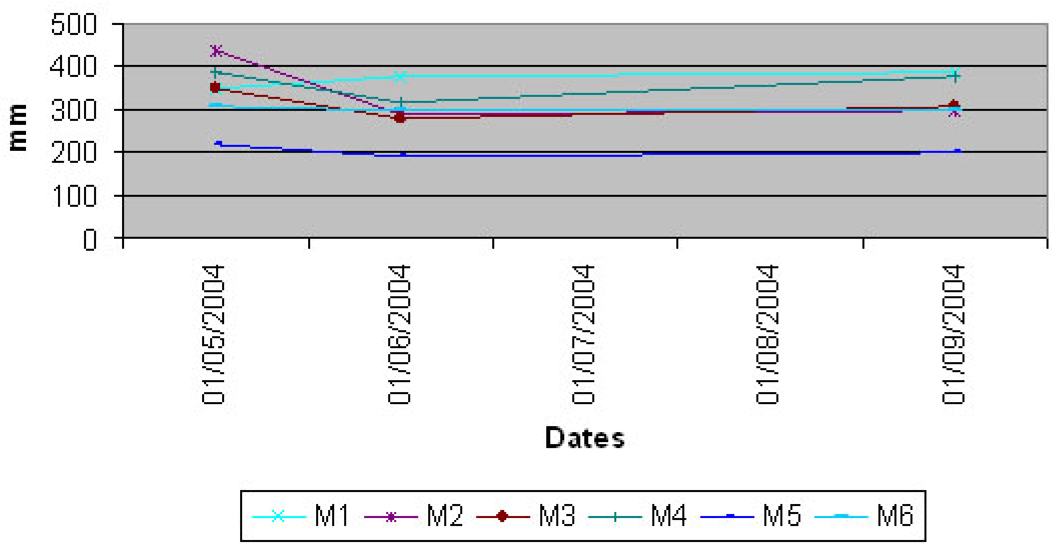

Figure 10 – Amidships monitoring points - 2004

In the beginning of 2004 the amidships monitoring points show an initial drop in sediment levels with scouring removing in excess of 100mm. Thereafter sediment levels show a slight accretion in some areas but generally remain static throughout the rest of the year, as can be seen in figure 10.

2004 – West (M1, M2, M3 and M4)

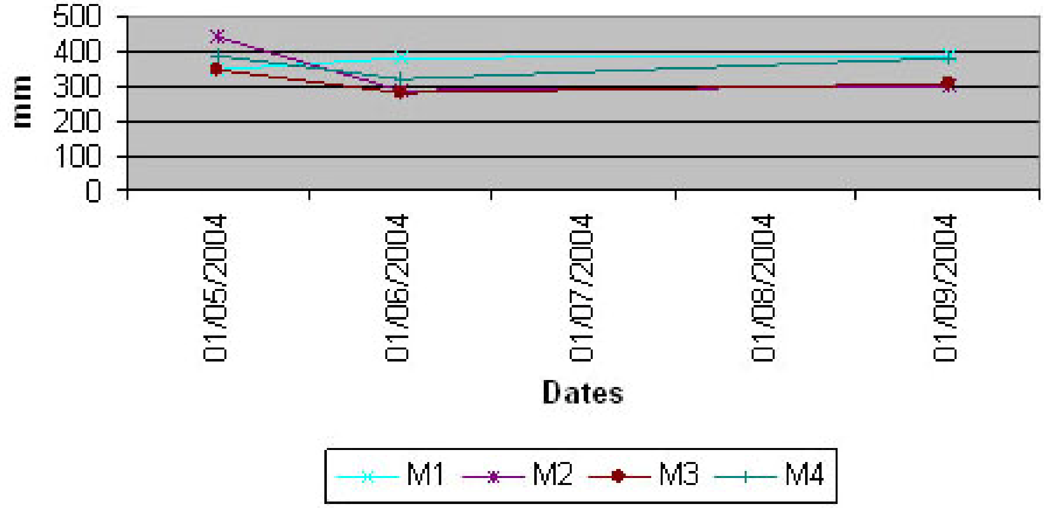

Figure 11 – Western monitoring points – 2004

The western monitoring points reflect a similar situation to the amidships area with a substantial drop in sediments from May to June, especially in the vicinity of M2 which shows over a 100mm drop in sediment levels. After this period sediment levels remain constant with some limited accretion occurring, figure 11.

2005 – North (M10)

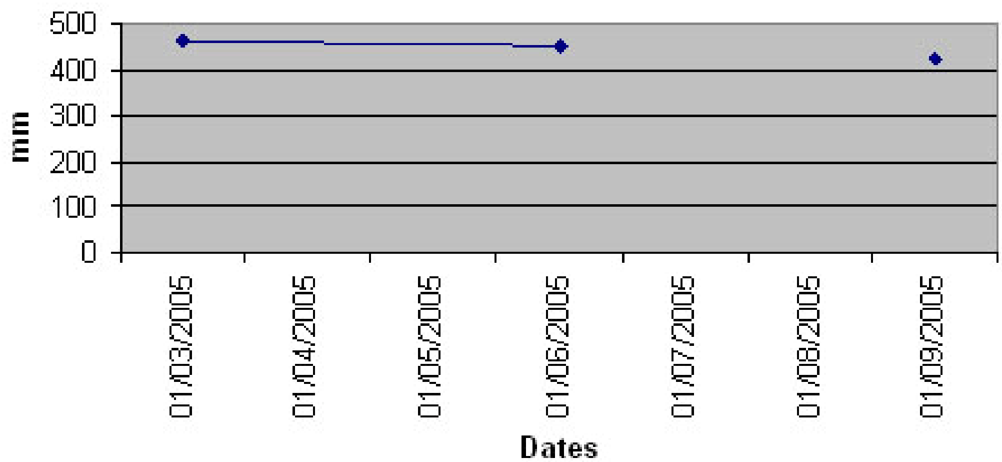

Figure 12 – Monitoring point 10 - 2005

The 2005 season for the northern section of the site (figure 12) shows a relatively stable sediment pattern with changes of only between 20-30mm being recorded. The temporary loss of the monitoring point at this position has influenced the latter half of the year with no records for this area being obtained, with the exception of September when the point was reinstated.

2005 – East (M7, M8 and M9)

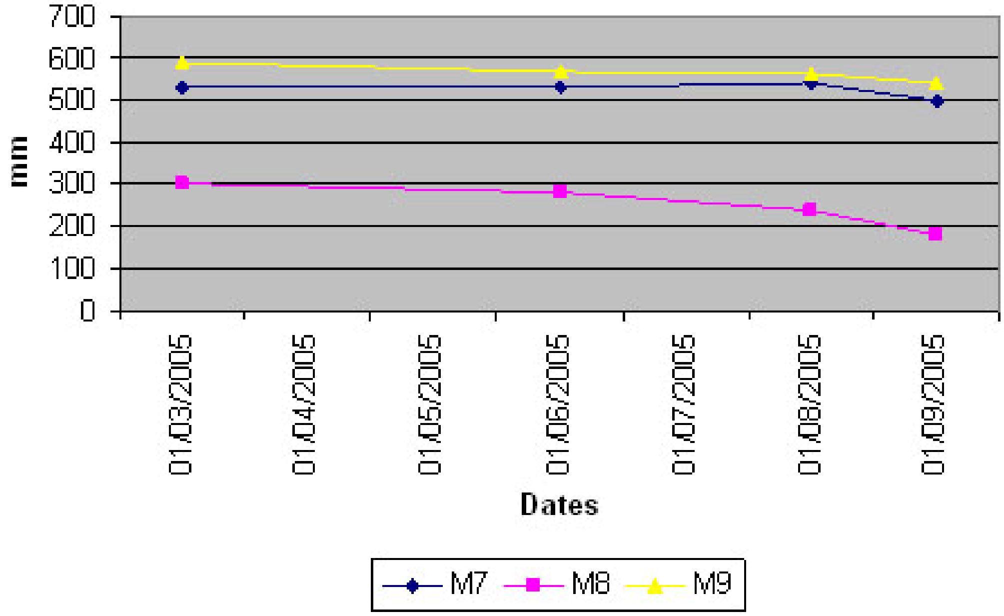

Figure 13 – Eastern monitoring points – 2005

Throughout the eastern section sediment patterns remained stable for the first half of the year after which a general drop in sediment levels occurs across the site. As seen in figure 13 localised scouring around M8 has caused sediments to drop in excess of 100mm.

2005 – Amidships (M5 and M6)

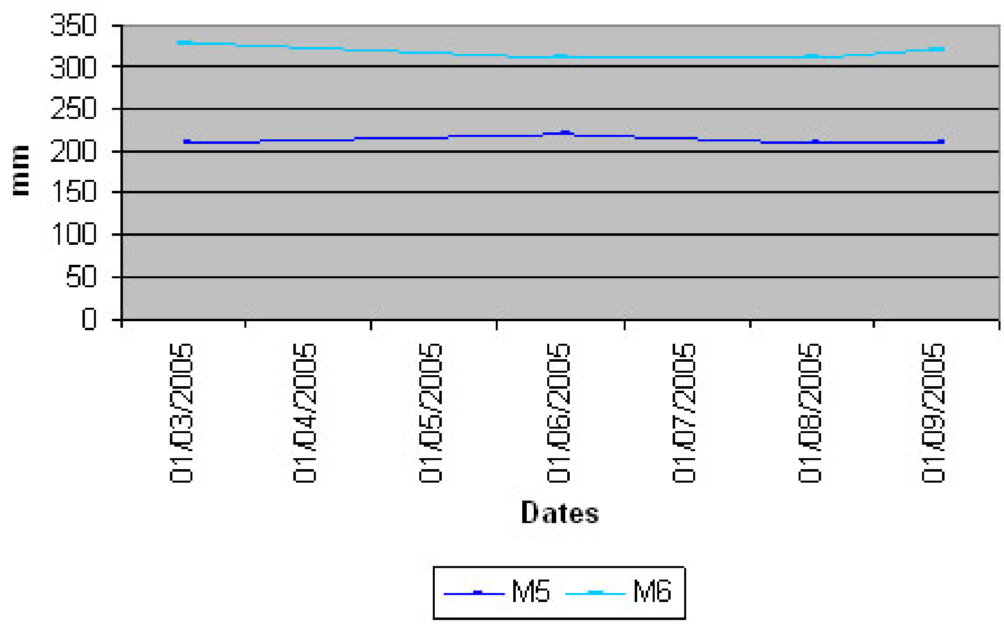

Figure 14 – Amidships monitoring points - 2005

Figure 14 shows the 2005 amidships monitoring point, this shows small changes with accretion at M5 and scour at M6. However, sediment level changes are relatively small, being in the region of 20-30mm.

2005 – West (M1, M2, M3 and M4)

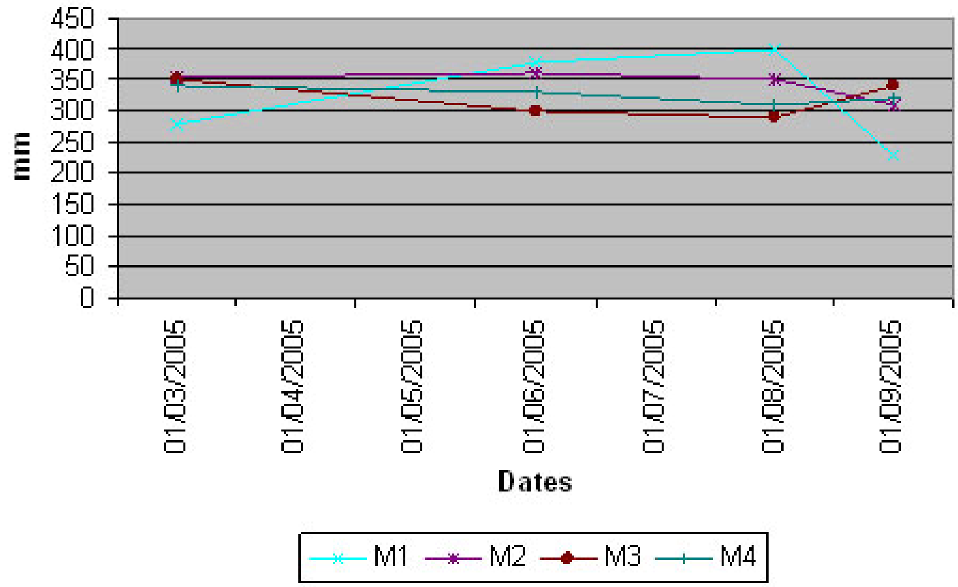

Figure 15 – Western monitoring points - 2005

Figure 15 shows the dynamic nature of the western section of the site with the western monitoring points showing localised patterns of scour and accretion with sediment movements around M1 being in the range of 200mm.

3.1.3 Conclusions

One of the general trends visible from the monitoring point data is an apparent cyclical scouring and accretion regime. While the lack of data for the winter months means there is no detailed information for this period it has been possible to analyse the movement of sediments on an annual basis. Whilst it is not certain what short term changes are occurring during the winter months it is still possible to show patterns of sediment movement.

Although there appears to be a general cyclical pattern of accretion and scouring occurring across the site, the monitoring points demonstrate some considerable localised differences in site changes. The western area and amidships section show a general loss of sediment while the northern and eastern sections show a more constant sediment pattern. Due to the lack of visible structure above the seabed in the southern area of the site there are no direct sediment monitoring points here, other data sources have been used to assess sediment changes in this area (see below sections 3.4 and 3.5).

In determining general trends for the site as shown through the sediment monitoring points it must be borne in mind that these are only representative of the years 2002 to the present. However, these changes in sediment levels follow a general trend, albeit to varying degrees each year; we can use these trends as being indicative of general sediment processes on the wreck site.

3.2 Timber degradation points

Timber degradation points were put in place during 2002, at the same time as the sediment monitoring points were established. These were all situated in the amidships area close to sediment monitoring point M5. Trends in the degradation of timbers in this amidships area can be seen, reflecting the significant sediment changes occurring in this area. During the 2004 and 2005 season changes of up to 173mm were recorded for H3. While at the end of 2005, a change of 260mm at H5 was recorded.

These changes reflect the degree of degradation suffered by the timbers through attack by marine organisms such as gribble worm, as when new structure becomes uncovered the gribble worm immediately attacks it, especially where end grain is present. These changes occurring to the timbers can be seen to be related to a substantial drop in sediment levels from the amidships section. This is evident when looking at the scouring that occurs at M5 and M6 during 2004 which is directly related to the increased exposure of timber and subsequent degradation of timbers through marine organism attack.

3.3 Cannon corrosion assessment

During 2000 a specialist cannon corrosion assessment was undertaken by Dr David Gregory from the National Museum of Denmark. Through plotting the corrosion potential (vs S.H.E) and pH of each cannon onto a Pourbaix diagram he found that the cannons could be located into three distinctive regions namely:-

- **Region 1**
  Cannon 3, 6, 7 and 8 fall into this region where ferrous iron, Fe^{2+}, is the thermodynamically favoured state of iron which indicates that not only is the metal corroding freely in the absence of any protective oxide coating but the microenvironment underneath the concretion is low in oxygen (i.e. reducing).

- **Region2**
  Cannon 1, 2 and 4 are located in this region where $FeOH^{+}$, is the favoured state of iron and indicates that these cannon are actively corroding but a hydroxide coating is being formed.

- **Region3**
  Cannon 5, 9 and 10 are located in this region where magnetite, Fe_3O_4, is the thermodynamically favoured state of iron. Ferric ions, Fe^{3+}, as in magnetite, are much less soluble than ferrous ions in seawater and this oxidisation results in Fe (III) oxide and hydroxide formation. Under such conditions corrosion will continue, however, the formation of such oxides slows down the corrosion rate due to their passivating nature.

In order to determine further the corrosion rate of each cannon the corrosion potential was plotted against the logarithm of the corrosion rate (mm yr^{-1}).

This has shown that the cannons fall into two sets of corrosive environments namely:-

- **Corrosive Environment One**
  The data for cannon 1, 2, 4, 5, 9 and 10, coupled with seabed observations of sediment movements, indicate that they have been buried for the majority of the time since the wrecking and only recently became been uncovered, cannon 2 only having being discovered on 10th April 1988.

- **Corrosive Environment Two**
  The data for cannon 3, 6, 7 and 8 reflects a long term corrosion environment, indicating that these cannon have been exposed to the same environment since the wrecking of the ship.

These results have been represented in figure 16.

Conclusions

Through determining the depth of corrosion occurring in the cannons it became evident that cannon 3, 6, 7 and 8 have been exposed to seawater and remained relatively undisturbed since 1706, while cannon 1, 2, 4, 5, 9 and 10 were buried at this point and only later became exposed. Through determining the levels of corrosion and looking closer at sediment patterns noted on the wreck it could also be determined that a net sediment transport drift in a north-easterly direction appears to prevail, exposing cannon 5, 4, 2 and then 1 with cannon 9 and 10 only very recently being exposed through scouring. Through identifying this long-term trend in sediment movement it is possible to determine those areas that will have better preservation of archaeological material. Areas such as environment two show long-term loss of sediment and therefore would have low potential for preservation of archaeological material whereas area one would have a higher potential of preservation. Figure 16 shows those areas that have the greatest potential for relatively undisturbed archaeological deposits through the lack of significant sediment loss.

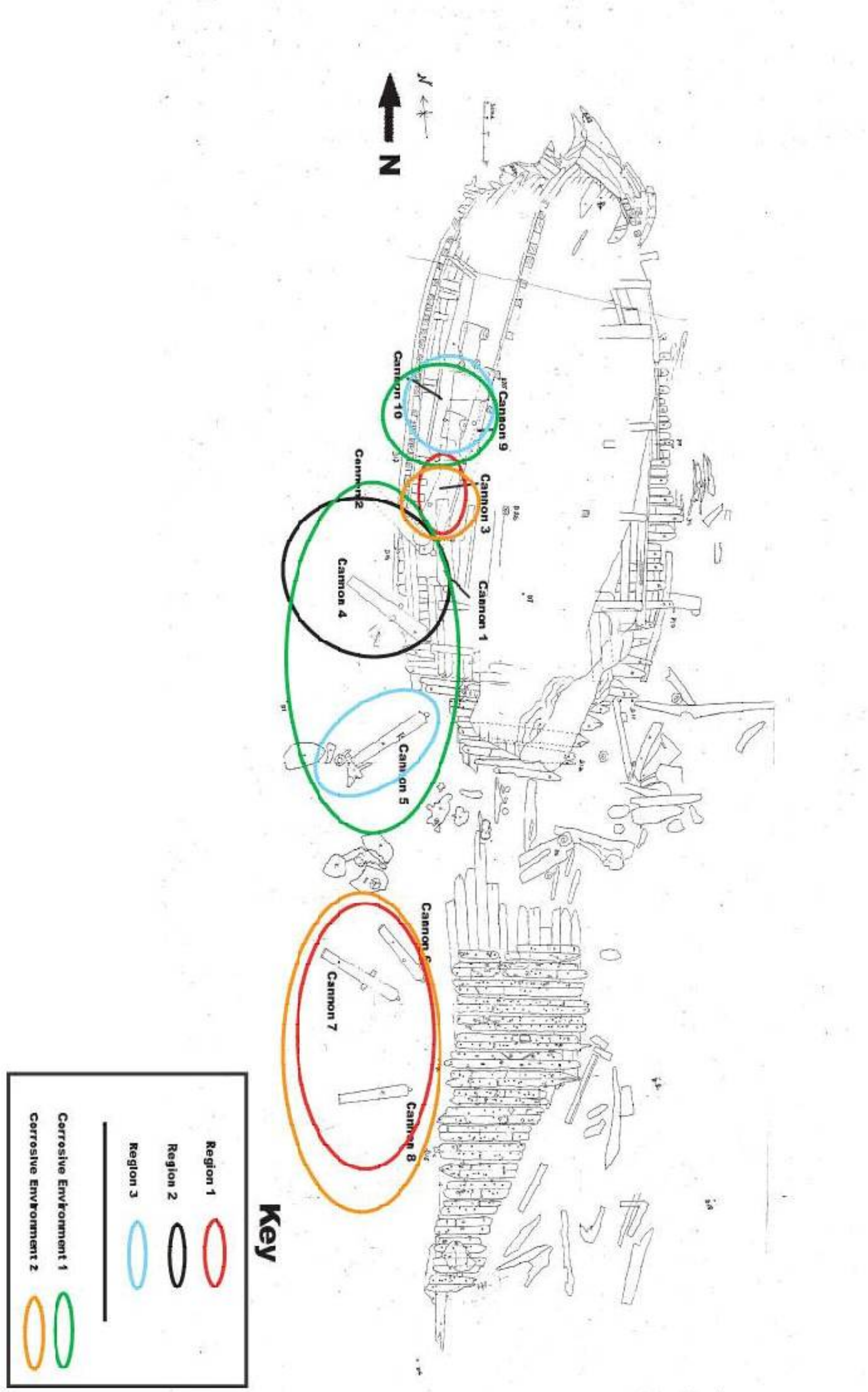

Figure 16 – Cannon corrosion assessment report – Regions and corrosive environments

3.4 Dive Logs

Through analysis of the dive logs, periods of site erosion and accretion can be grouped into year, area and quantity of sediment movement. These dive logs together with the site plans provide primary accounts of sediment movement on the *Hazardous* site as well as a good indication of the processes at work. A similar approach was adopted by the initial licensee of the *Hazardous* site, Norman Owen, who in an article entitled '*Hazardous* 1990-91 Interim Report' (IJNA 20:4) drew a summary diagram showing the extent of the scatter of artefacts from the site in relation to prevailing winds. The diagram pictured in figure 17, was derived from archaeological survey and diver observation of artefact scatters on the wreck site.

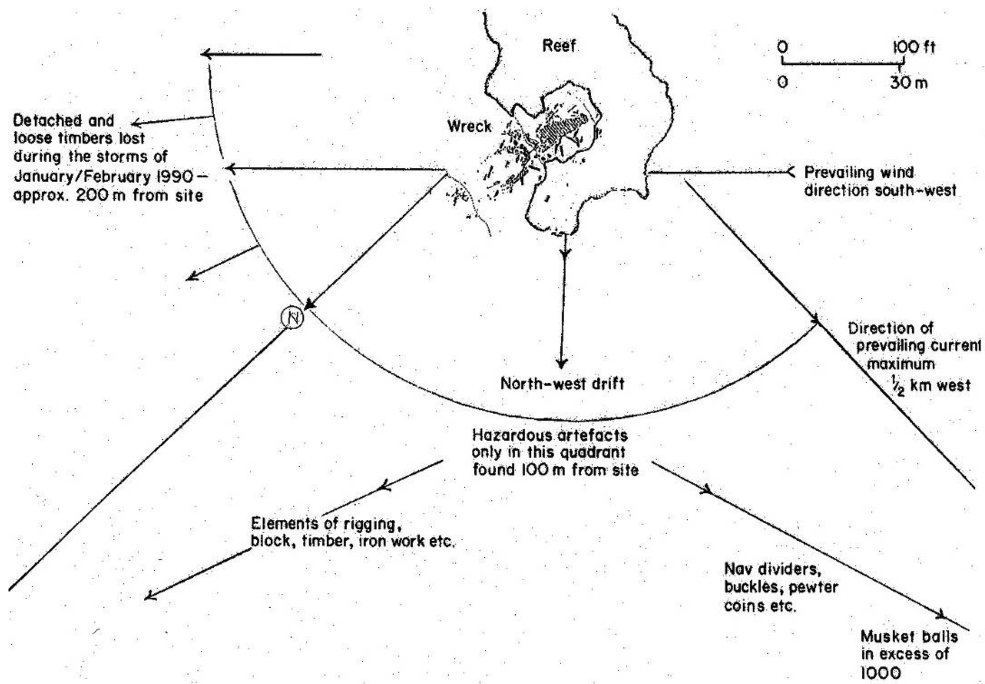

Figure 17 - Diagram demonstrating the observed pattern of distribution of artefacts from warship *Hazardous*

The first dive logs on the site are from the period 1977 to 1984 in which regular visits were made during the summer months. Through this initial period of diving scouring of the site is noticed with some of the cannons and timbers being exposed during 1977. Later from 1984 to 1986 a large drop in sediments around the site prompted a thorough investigation of the artefacts exposed in order to determine the identity of the shipwreck.

During 1986 to 1987 there was a large drop in sediments around the site with seabed levels reducing as much as 250mm in places. The dive logs report substantial scouring of the western section of the site around cannon 2 with seabed levels around the frames in the vicinity dropping. While in the north western part of the site substantial accretion occurred covering an iron plate found in the previous season some 100m off the main site.

During the 1988 season scouring had seriously affected central and western parts of the site exposing further cannon and additional timber components. In the western section cannon 4 was revealed while this drop in seabed levels also caused more timber frames to be eroded out. Scouring of the central area shows drops of 540mm at the northern end, 1050mm in the central area and 500mm at the southern end of the site. Off site changes to the seabed noted include areas to shoreward showing deep scouring revealing gullies cutting into the clay bedrock. These changes are believed, by the divers, to have been influenced by recent sea defence measures undertaken at Bracklesham Bay.

The site plans for 1987 and 1988 demonstrate the changes taking place. Figure 17 shows both site plans overlaid with the 1988 area of scouring and the ships structure that has been uncovered marked.

In the 1989 season scouring appears to be more localised to the north and south-western areas with new timbers being exposed and datum points 4, 6 and 7 having being lost. Through a comparison between the site plans from 1988 with the two from 1989, (figure 19) these areas affected by scouring become more evident.

Severe storms in January and February of 1990 show serious scouring which has affected all parts of the site. Erosion damage has occurred to datum points and timbers in the amidships section and areas to the south end of the site. Further damage was caused to the site by the movement of eroded timbers from the south-eastern side across to the northern edge of the site. Whilst in the northern part of the site some siltation occurred and the clay gullies shoreward have been completely covered with sand. The site plan for 1990 shows the most complete picture of extant remains for the *Hazardous* as can be seen in figure 22.

During 1991, 1992 and 1993 few dives were undertaken. The observations that were made during this period include some scouring along the western, southern and amidships sections of the wreck. Due to significant scouring amidships substantial amounts of timber were uncovered; this is reflected clearly in figure 23 where the exposed timbers were planned. Scouring effects at the south end of the site although not apparent in the site plan were also mentioned due to the undermining effect on the timbers in the area. Accretion occurring at the northern end of the site although not drawn was mentioned as several areas of timbers had been covered.

During 1994 and 1995 scouring occurred along the eastern side of the site progressing down to the southern end, in places this scouring was so severe that it had exposed the clay natural. Scouring in southern and eastern parts of the site caused new timbers to be exposed and exposed timbers to be moved off the site. According to dive logs the whole of the southern end structure of the site started to break up in the winter of 1994 with continued loss occurring through 1995. During the end of 1995 the dive logs also mention the near complete loss of the southern frames together with most of the timbers in this area. The dive logs for this period also mention areas within the centre of the main site in the vicinity of datum 7 where slight scouring had occurred. The northern section of the site demonstrates further siltation along both the north western and eastern edges. During this period further damage was sustained to the southern end of the site through trawling, with timbers being lost offsite. Figure 22 shows areas of scouring and loss of timber structure.

The 1996 season dive logs mention how the northern end of the site appears to be becoming more stable with little sediment movement evident, while at the southern end of the site further timbers appear to be disappearing. The amidships section appears to be continually eroding with timbers still being exposed but to a lesser extent, figure 23.

The 1997 diving season saw a continued accretion of sediments in the south end with large areas of timber loss being covered. Accretion also has occurred at the northern end of the site with areas amidships showing a build up of sand. However amidships in the vicinity of cannons 4 and 5 some localised scouring has taken place.

During the 1998 diving season further sediment accretion took place throughout the site with a build up of 400 mm taking place in the northern end while sediment levels amidships appear to have remained stable.

The 1999 season seems to show a general stabilisation occurring at the northern and southern ends of the site while amidships some localised scouring has exposed further timbers.

The 2000 and 2001 season dive logs reveal how the southern and northern ends of the site are showing an accretion of sand. During this period the amidships section appears to be showing a greater degree of stability with levels remaining constant throughout the area.

The diving seasons of 2002 and 2003 have little mention of on site sediment processes; this is due to the establishment of the sediment monitoring points which provide detailed and accurate sediment measurements. During the 2004 and 2005 dive season severe scouring is noted at the north western and amidships section of the wreck site with a gun carriage being uncovered from the western area. Along the eastern and western side within the hull scouring has also occurred with the cannon ball mound showing a localised scouring pattern. The northern section of the hull appears to be more stable showing further accretion of sediments. Recently a report on the first dives for the 2006 season allowed for further data to be obtained. This data provides evidence for scour that has severely affected large amounts of the site, with no noticeable sedimentation. According to the dive report almost all areas of the site have been affected with an area amidships showing a high degree of marine organism attack and the northern area showing a 330mm drop in sediment levels. This area of scour has formed a metre wide path along the eastern section of the site exposing new timbers and artefacts. While in the north-western and southern sectors of the site scouring has affected large areas with substantial drops in sediments. These processes from 1998 to 2006 are represented in figure 24.

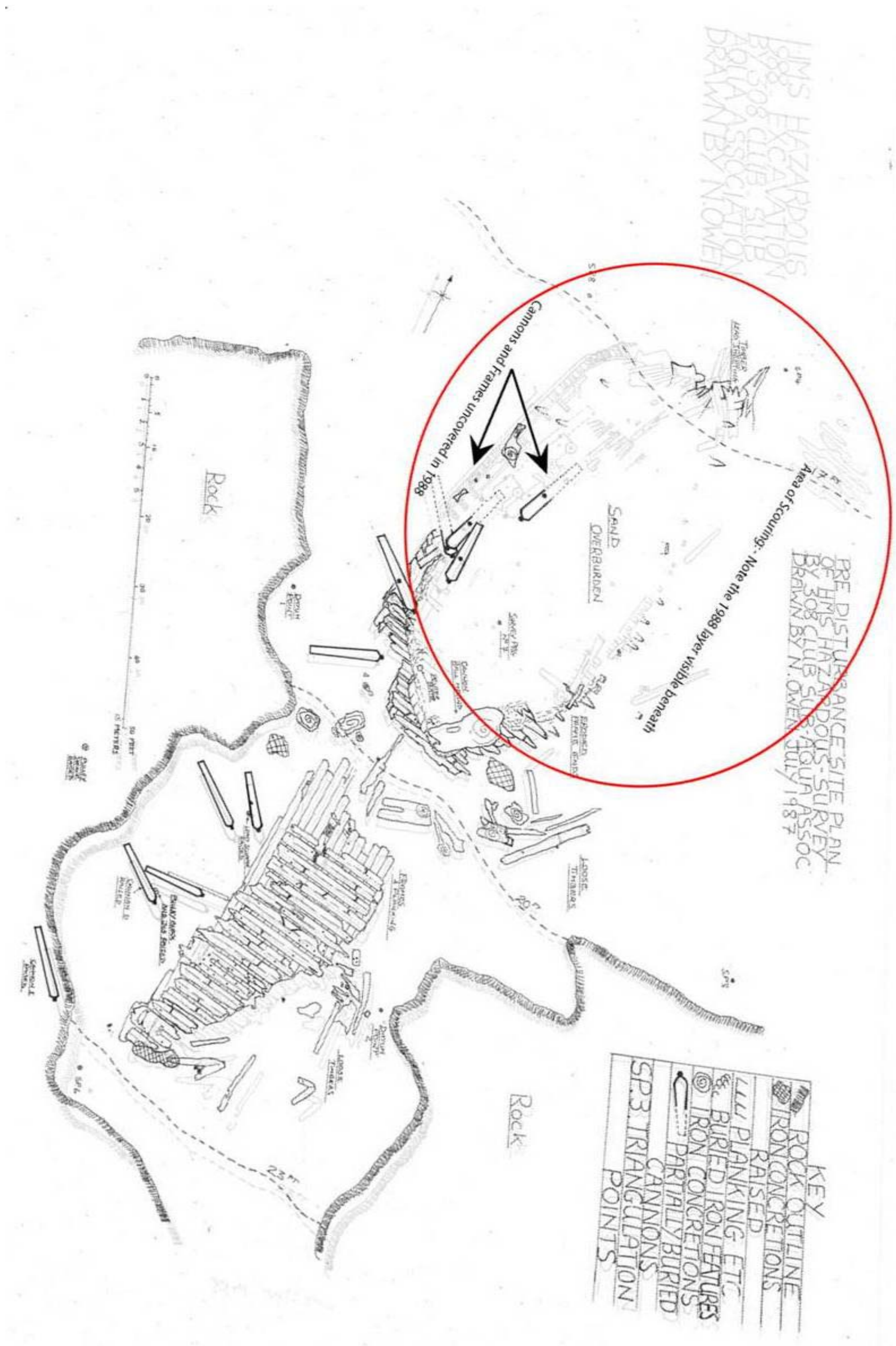

Figure 18 – The 1987 and 1988 site plans showing scouring

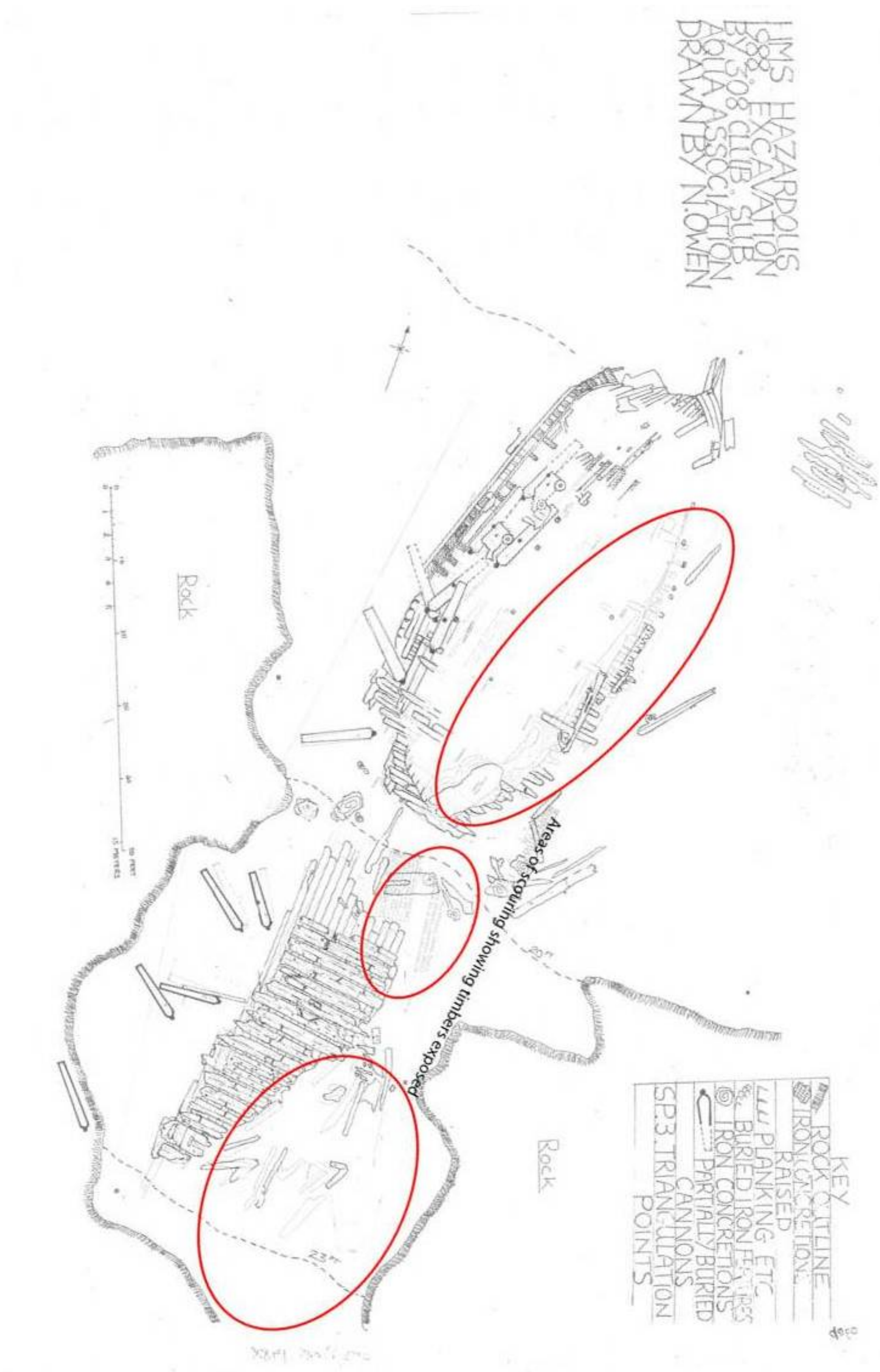

Figure 19 – The 1988 and 1989 site plans showing scouring areas

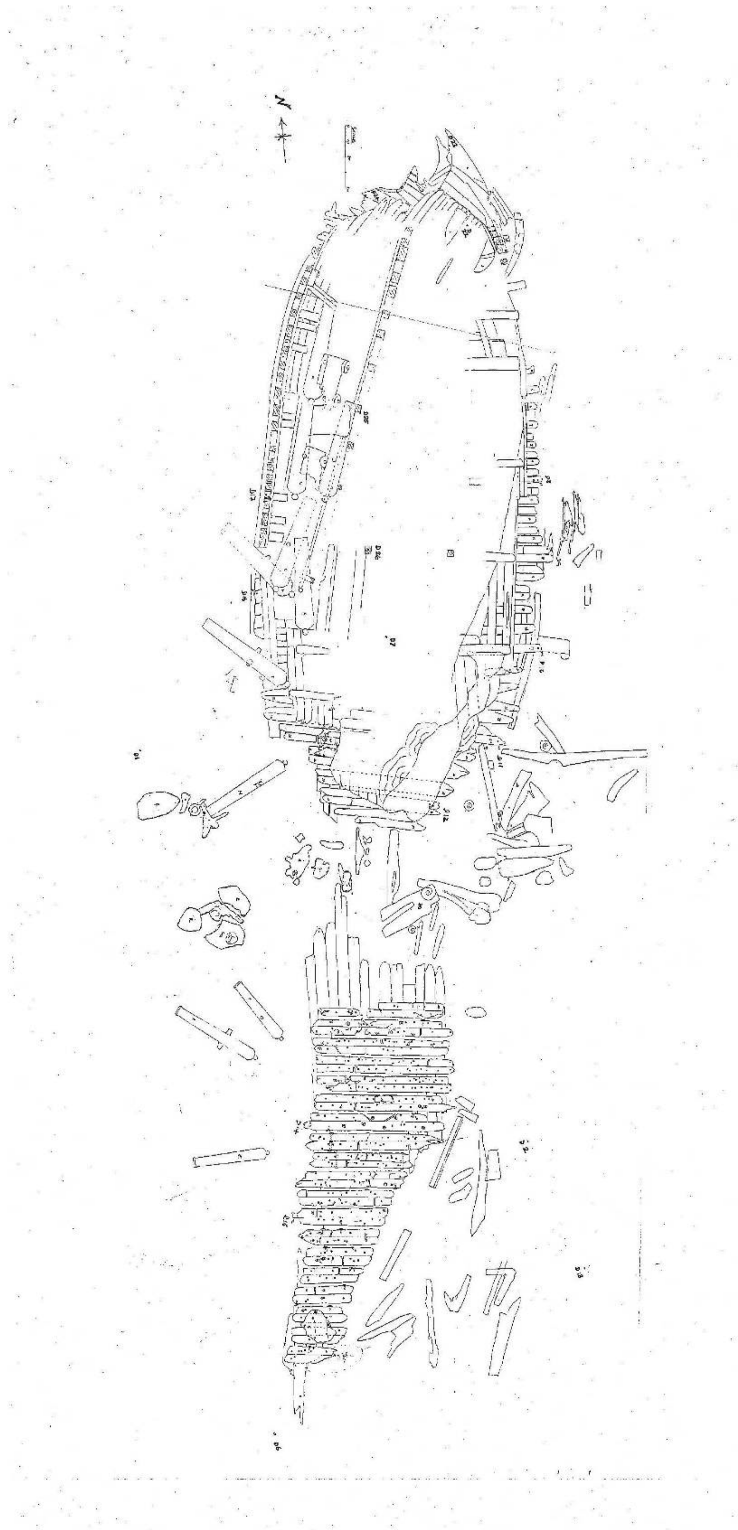

Figure 20 – The 1990 site plan

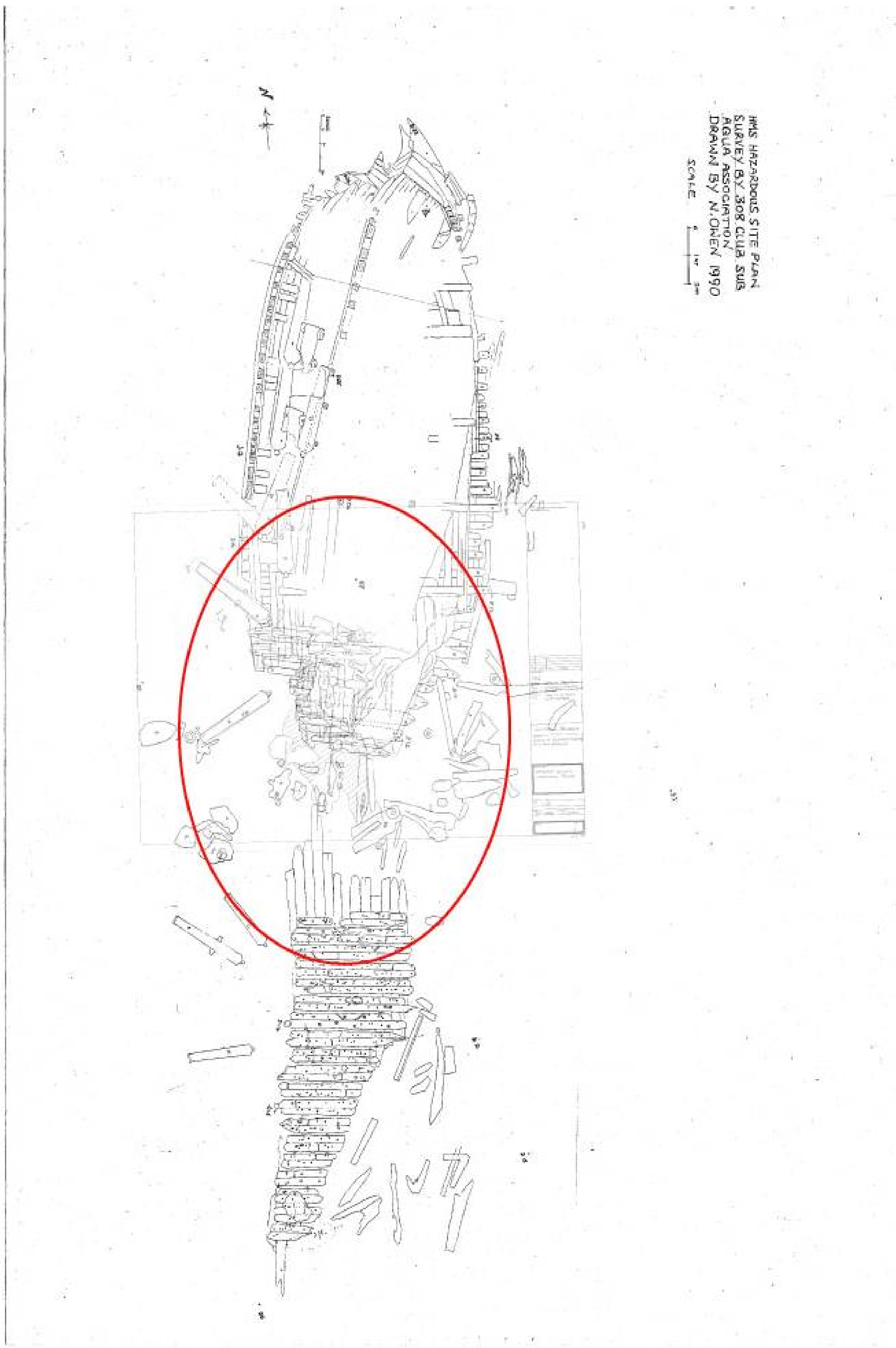

Figure 21 –The 1990 and 1993 site plan showing scouring

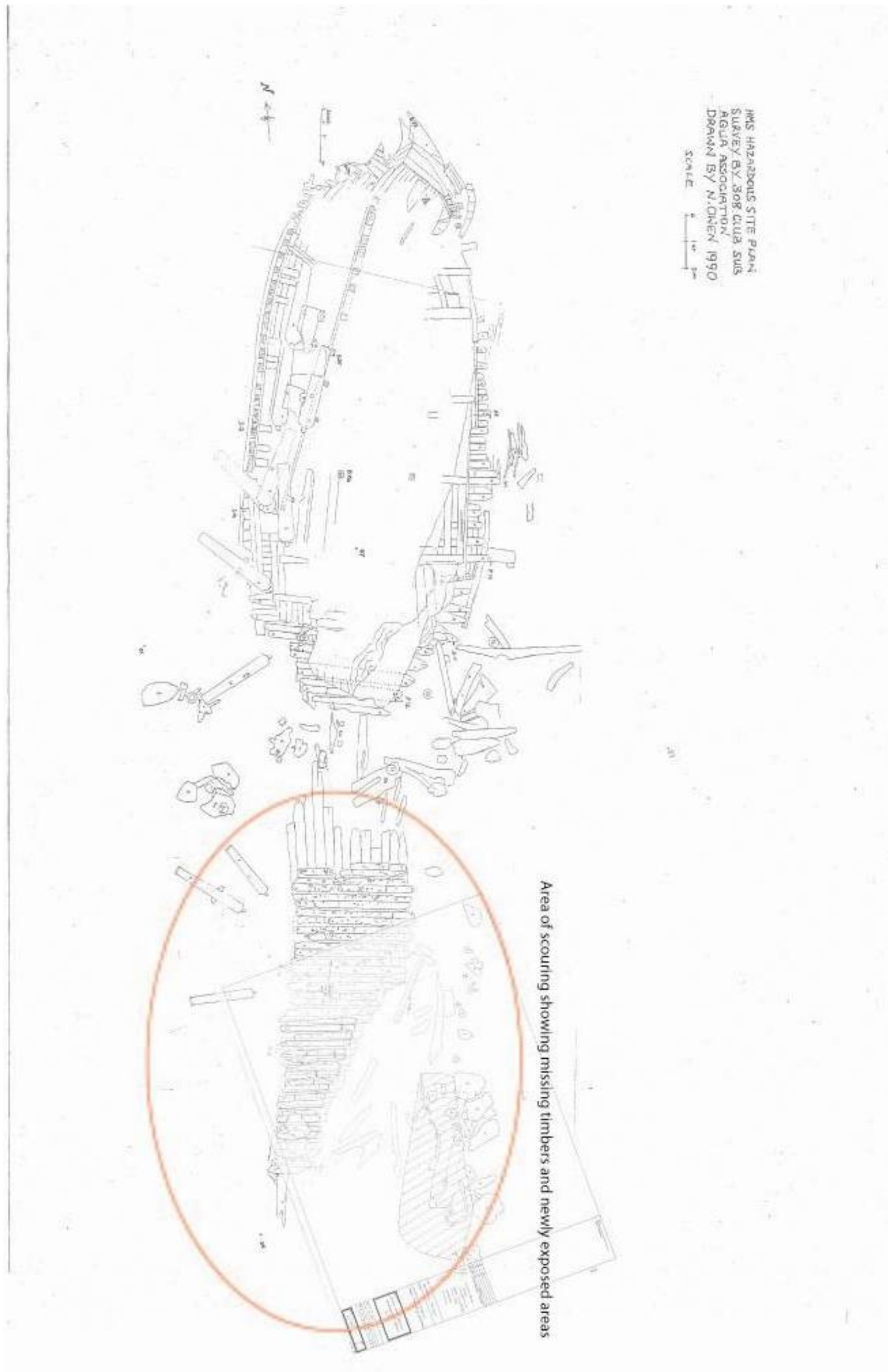

Figure 22 – The 1990 and 1994 site plan showing scouring area

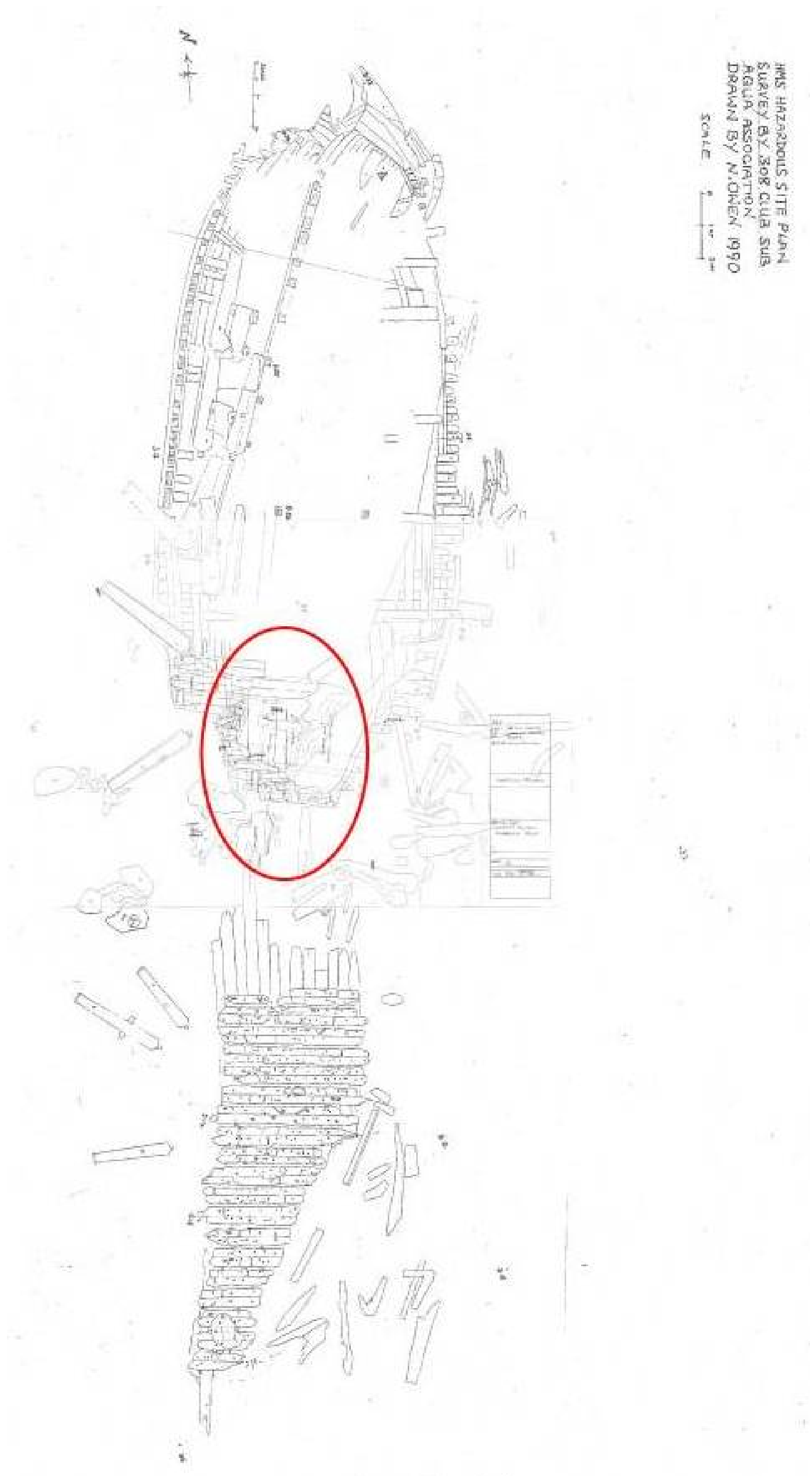

Figure 23 – The 1990 and 1996 site plan showing scouring area

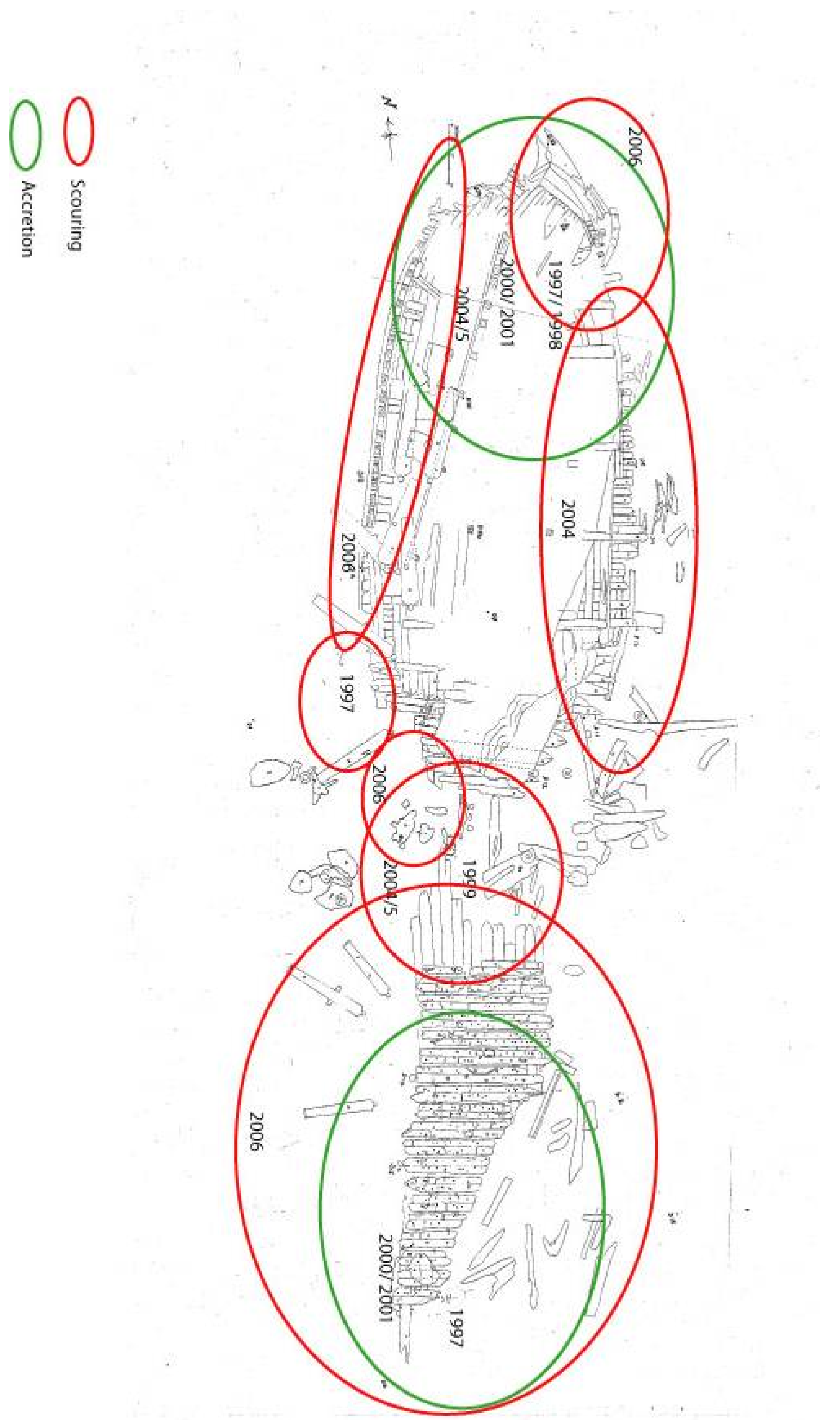

Figure 24 – Scouring and siltation occurrences

Conclusions

The dive logs represent the longest direct record of sediment changes on the wreck site with eyewitness accounts being the principle tool for interpreting sediment patterns. Using both the dive logs and the site plans it has been possible to determine both specific years in which significant change has occurred and the overall trend in site dynamics. As mentioned the first large change in sediment movement on the site was noticed from the mid 1980's with scouring uncovering large areas. While a storm event in 1990 caused even larger areas of the site to be uncovered, evidence of which comes from the 1990 site plan which is the most complete plan available and shows the extent of scouring that has occurred up to this period. Later changes to the site show scouring being more localised around the western edge, amidships and the southern end. The southern end however seems to show the most dramatic changes with scouring having caused almost complete loss of this section of the site. This degree of loss was further substantiated through probing of the sediments in this area with little evidence for any structure remaining.

The long term trend shows how scouring has initially caused an overall drop in sediment levels throughout the site which later seems to have become more localised around the western, amidships and southern areas. In more recent years this has localised to the western and amidships section with siltation concealing areas that were exposed previously. However, with the current data from early 2006 a change in this regime is noticed with new areas of scouring evident, especially in the north and east.

3.5 Artefact Distribution Studies

Studies into the analysis of artefact patterning and distribution within the wreck site between 1986 and 1999 have been undertaken by Sarah Holland as part of a Masters Dissertation, this project has extended this work through the addition of artefact scatters up to 2004. The artefacts positioned are those which have been recovered due to exposure through sediment movements. In mapping these exposures on a yearly basis further evidence for the effect of sediment processes on site can be gained. This analysis does not include artefacts that were recovered during excavation as these artefacts represent active intervention rather than the effects of erosion.

3.5.1 Artefact exposure 1986

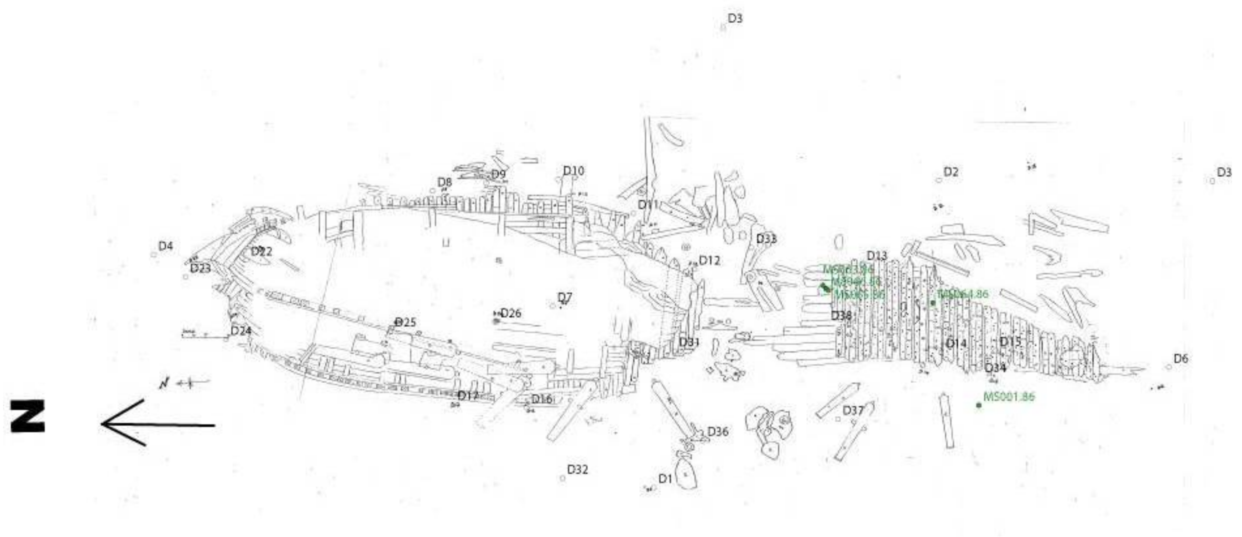

Figure 25 - Artefact exposure 1986

Sediment movements on site for 1986 were based primarily in the southern section with some finds made in the amidships area (figure 25). With the small quantities having been recovered scouring doesn't appear to have greatly affected the site.

3.5.2 Artefact exposure 1987

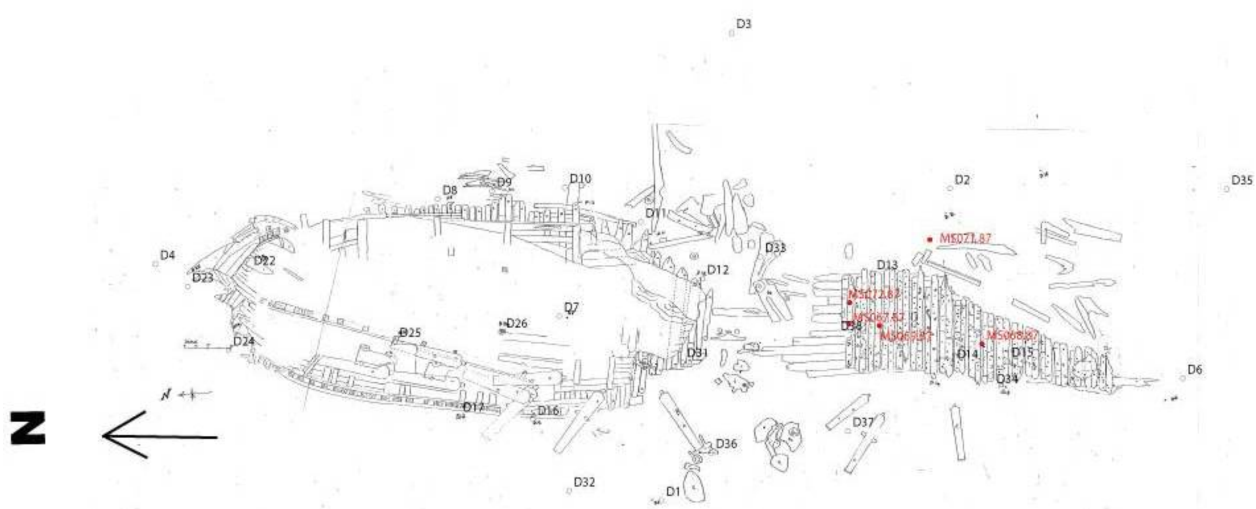

Figure 26 - Artefact exposure 1987

As seen in figure 26, during 1987 scouring continued to affect the southern part of the site, although again a relatively small number of artefacts have been uncovered.

3.5.3 Artefact exposure 1988

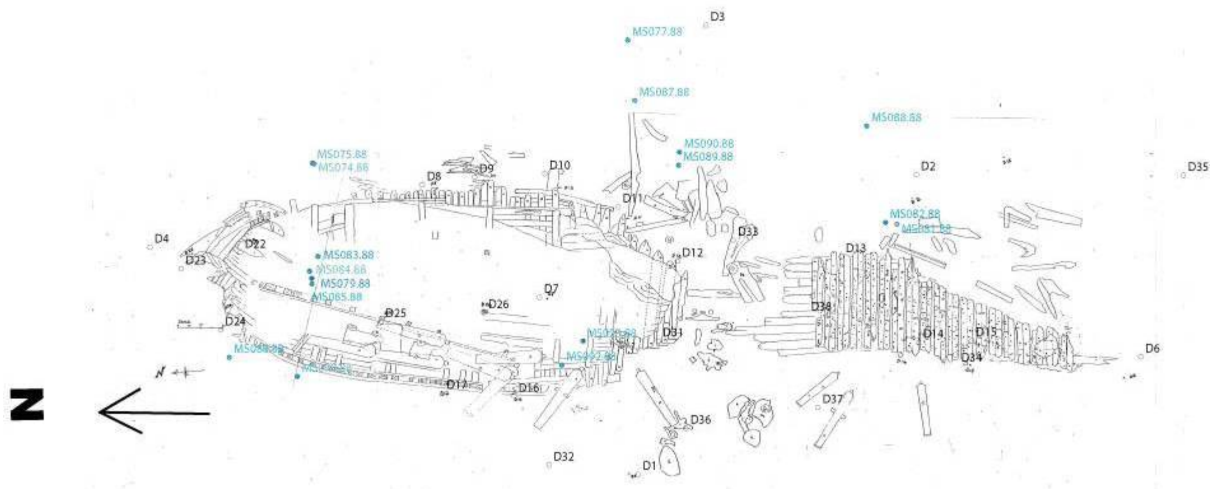

Figure 27 - Artefact exposure 1988

During the 1988 season larger quantities of artefacts were recovered from northern, western and south-eastern areas as can be seen in figure 27. Through the wide spread of artefact recovery we are able to determine that scouring has seriously affected the site with the general spread appearing to be in a north easterly direction.

3.5.4 Artefact exposure 1989

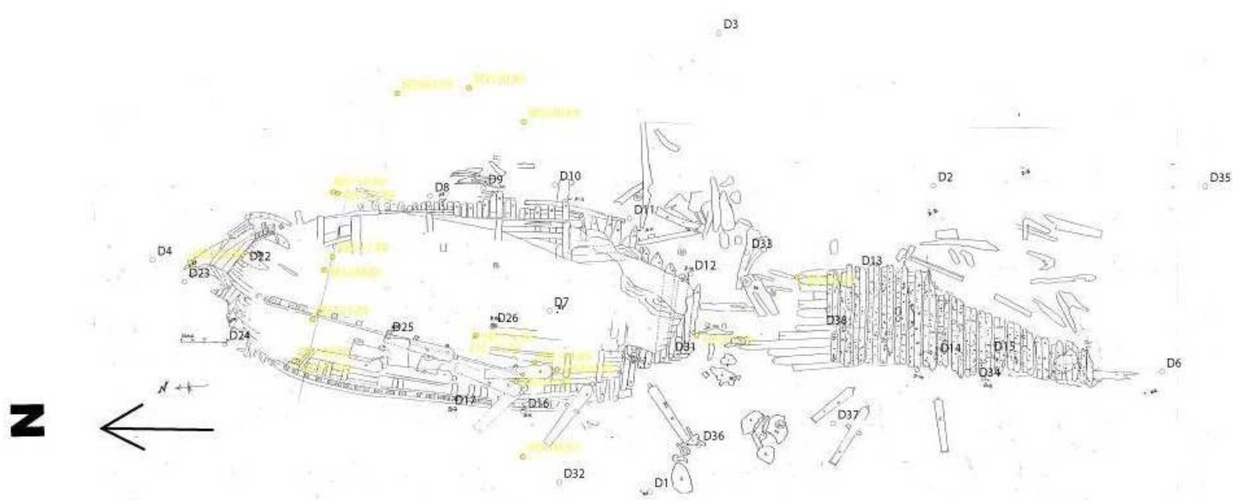

Figure 28 - Artefact exposure 1989

Figure 28 demonstrates significant scouring still occurring on site although due to the increase in artefacts recovered from the northern section of the site scouring appears to be more localised. As with figure 27 the positioning of the artefacts demonstrates again a north easterly spread of artefacts.

3.5.5 Artefact exposure 1990

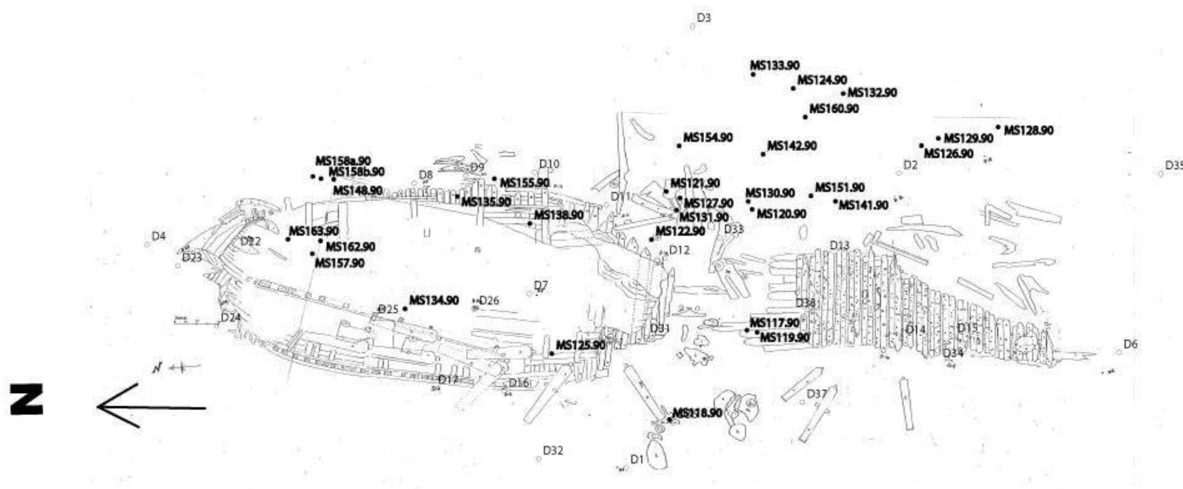

Figure 29 - Artefact exposure 1990

At the beginning of 1990 severe storms struck the south coast of England, this caused damage along the coastline. This damage is also reflected on the wreck site (figure 29) with 1990 being one of the years in which most artefacts were recovered. The spread of artefacts seems to be mainly concentrated towards the east and south east of the site. The scouring of artefacts has been influenced by particularly severe storms; this demonstrates the effect of such events and the vulnerability of the site.

3.5.6 Artefact exposure 1991

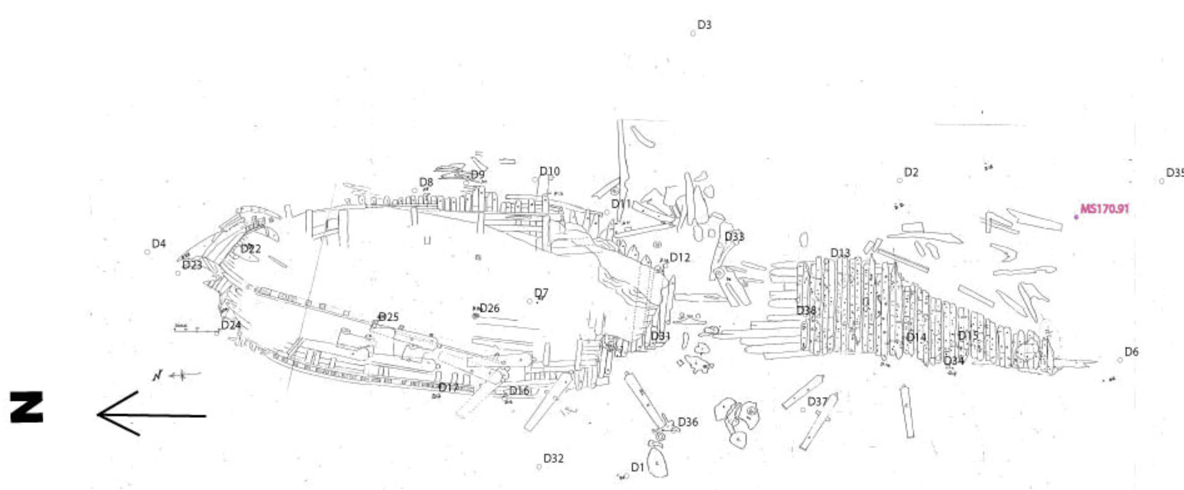

Figure 30 - Artefact exposure 1991

Through figure 30 it is possible to see that very little was recovered during this season, with only one artefact having been recovered from the southern end of the site. Due to this very little can be said about sediment movements for this period although it is likely that this area is still recovering from the scouring effects from 1990.

3.5.7 Artefact exposure 1996

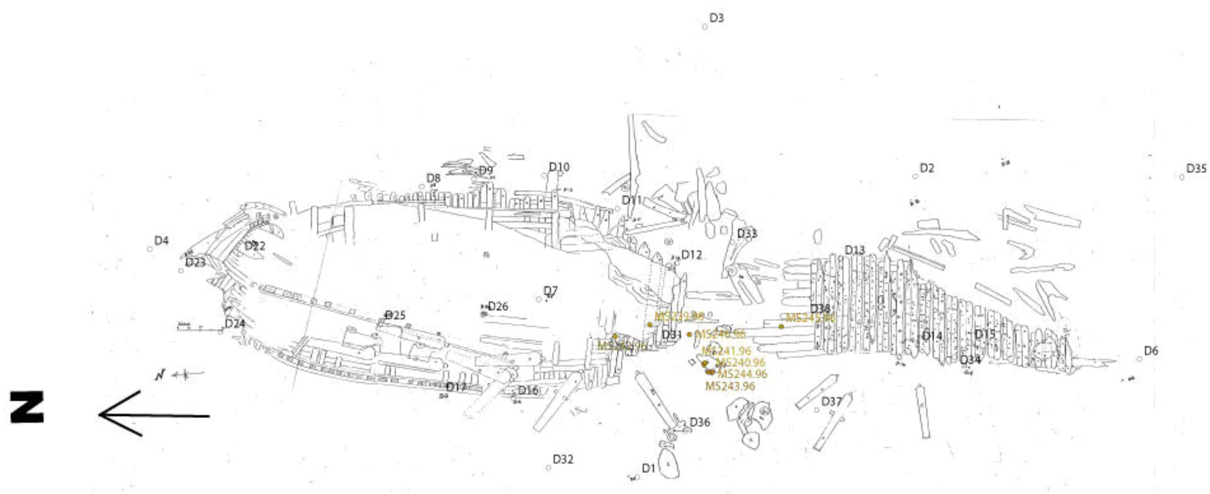

Figure 31 - Artefact exposure 1996

After several years with no artefacts being recovered figure 31 shows the general pattern of recoveries during 1996. The amidships section of the site is showing a concentrated pattern of recoveries from which it is possible to determine that scour is centred in this area.

3.5.8 Artefact exposure 1998

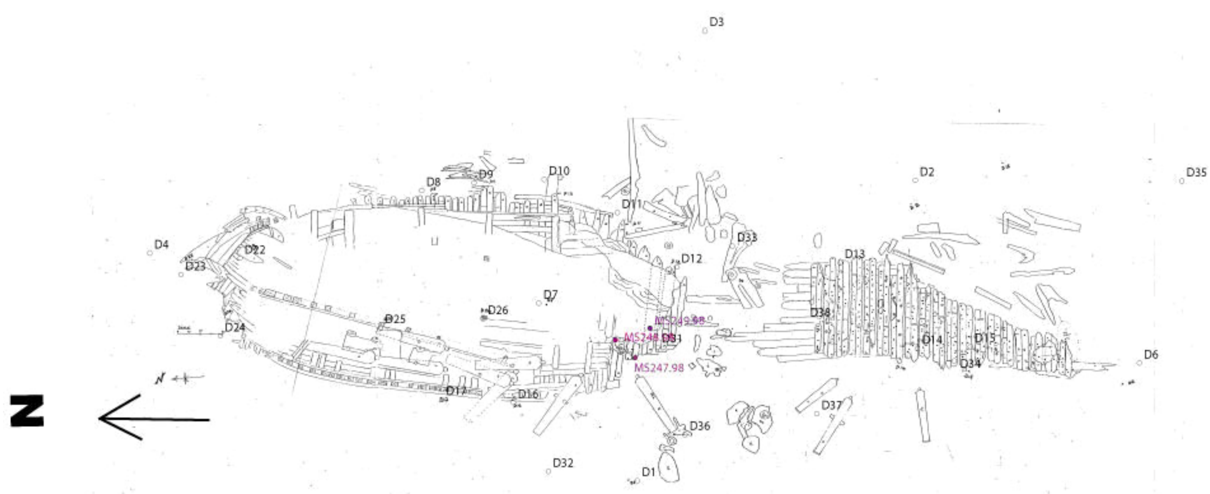

Figure 32 - Artefact exposure 1998

As demonstrated in figure 32, artefact exposure is occurring amidships in the same area as seen in figure 33. Although fewer artefacts are being recovered the scouring processes appear to be more centralised within this amidships section.

3.5.9 Artefact exposure 1999

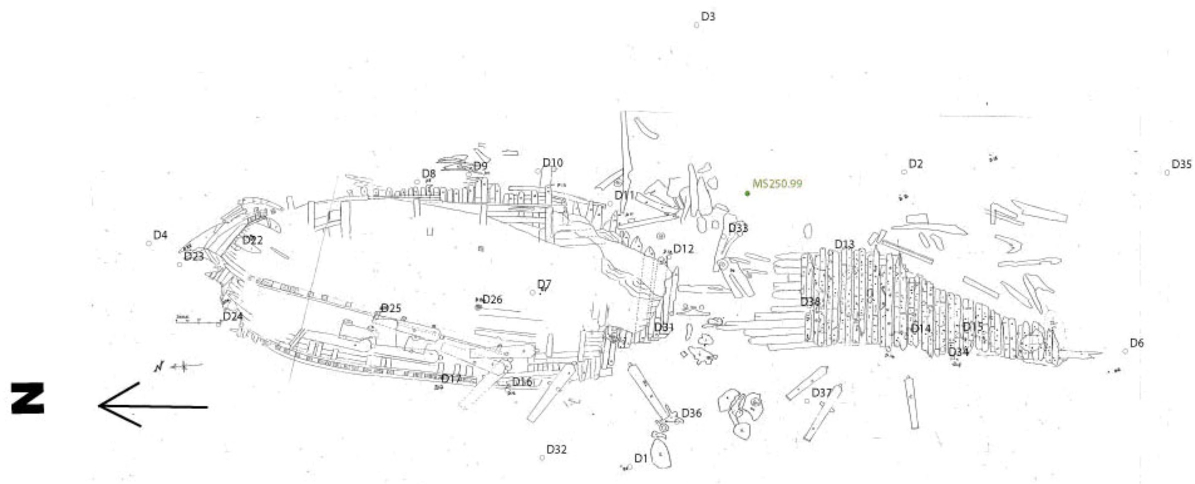

Figure 33 - Artefact exposure 1999

Whilst only a single find is made its location, as can be seen in figure 33, is also amidships although further east than in 1996 and 1998. Scouring again appears to be more centralised amidships.

3.5.10 Artefact exposure 2000

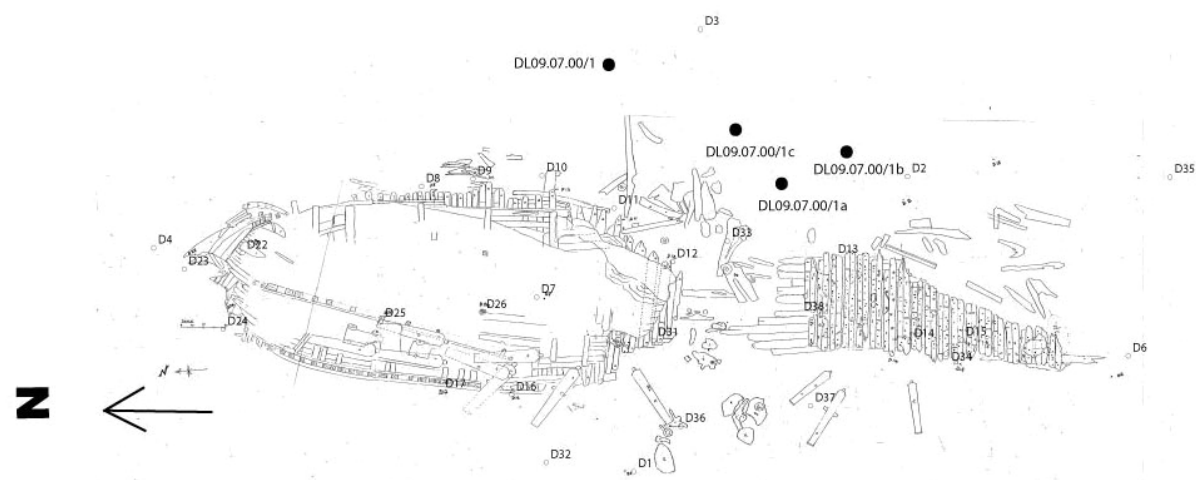

Figure 34 - Artefact exposure 2000

Figure 34 demonstrates that artefacts are still being uncovered in the amidships area albeit spreading eastwards. Being centred amidships these artefact recoveries demonstrate a scouring regime affecting the north east of the site although mainly being centred amidships.

3.5.11 Artefact exposure 2003

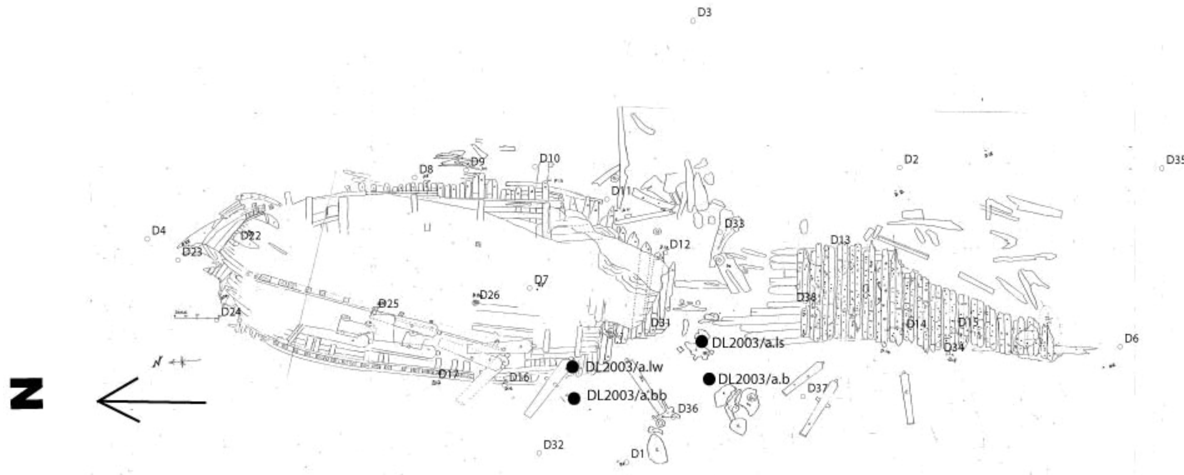

Figure 35 - Artefact exposure 2003

Artefact exposures appear to be again centred within the amidships section of the hull as can be seen in figure 35. As with previous years this information provides evidence for localised scouring.

Conclusions

The data derived from the artefact exposure studies provides important evidence for changes to the sites long-term sediment processes, and the effects of storm events. Figure 35 draws together all the annual data to enable further conclusions to be drawn.

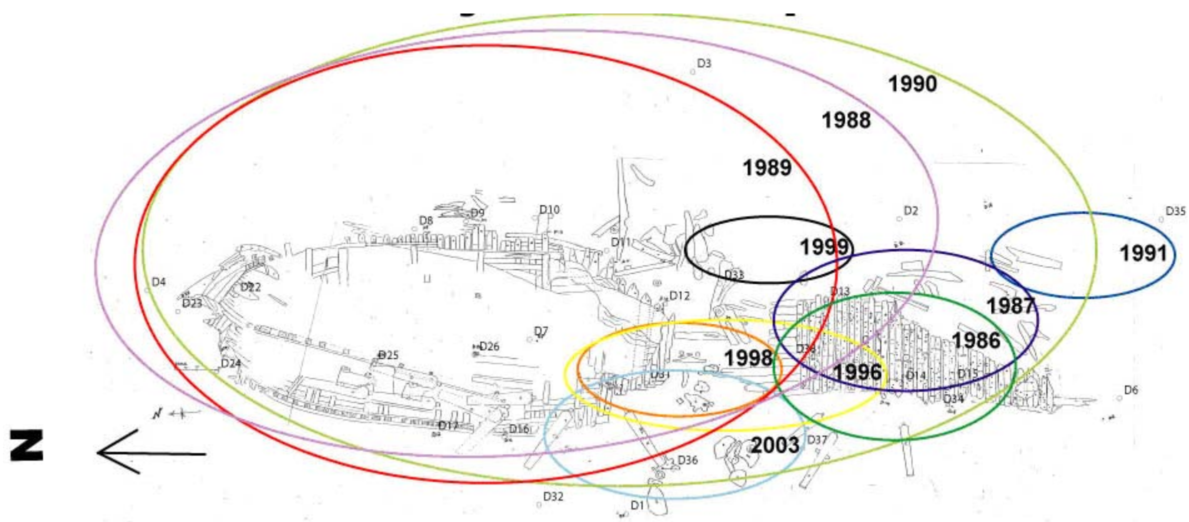

Figure 36 - Yearly artefact exposures

Figure 36 presents artefact exposures on an annual basis. In the early years of 1986 and 1987 there is a spread of artefact exposures at the southern end of the site. However for 1988, 1989 and 1990 this spread is much wider, with larger quantities of artefacts being recovered and a larger area being exposed. Through comparison with the dive logs it becomes apparent that the cause of this is storm events during these years. After these storm events the general spread of artefacts tends to centre more along the amidships section. It would appear that the general scouring effects on *Hazardous* were initially in the southern end of the site and have gradually progressed north into the amidships area where scouring is now having a significant effect.

3.6 Geophysics

Geophysical survey was undertaken on the *Hazardous* wreck site by the Archaeological Diving Unit in 2002 and Wessex Archaeology for English Heritage in 2003. These images have helped to provide both an image of the wreck site and information on the surrounding underwater landscape. These images demonstrate the effect the wreck site is having on the surrounding underwater topography and clearly show the reef which lies to the south of the *Hazardous*. The general movement of sediments is reflected in figure 38, it shows the scour pattern that extends to the west of the site and demonstrates the effect that the *Hazardous* has made on the seabed on which it came to rest. Through closer analysis the areas where scouring has occurred can be determined to be within and to the south of the wreck site as shown by the blue colour demonstrating the greater depth in these areas, figure 37.

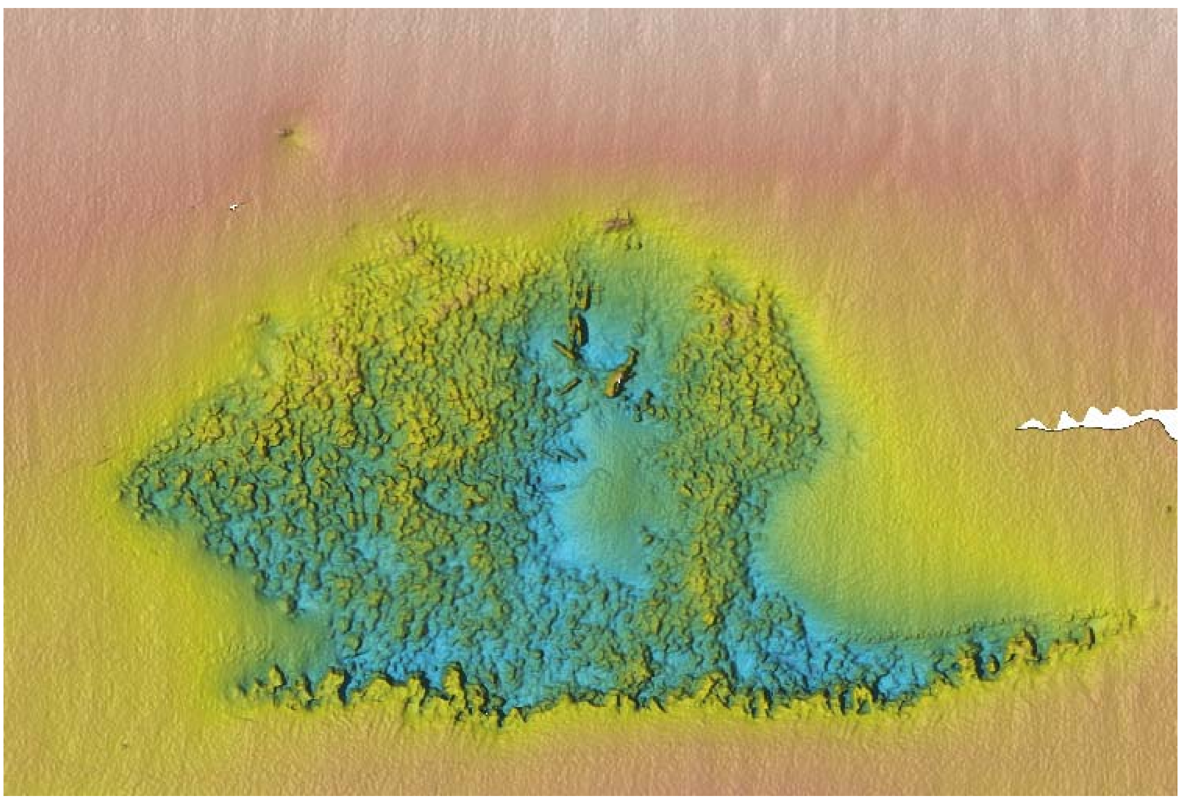

Figure 37 - Geophysical image of *Hazardous* (©Wessex Archaeology/ English Heritage)

It is clear that the *Hazardous* site is having an effect on the local scour patterns. The survey shows a relatively flat seabed surrounding the wider area, through diver observation it can be confirmed that this is area is made up of sand and clay. However, close to the site, particularly to the south and west an uneven surface has been exposed. To the south the linear edge is a small reef while the uneven surface around the wreck site is the exposed clay which is part of the Bracklesham beds.

The sediments directly within the wreck site in both the north and south sections are relatively flat; these sediments are covering cultural material. It is known from information gained during excavation on site that substantial amounts of hull structure are buried, particularly in the northern section of the site. These geophysical surveys have helped to demonstrate the extent to which the hull of the *Hazardous* has 'carved' a hollow within the relatively soft Bracklesham beds and also demonstrates the general scouring trend occurring up to this period.

3.7 Photographs

Throughout the period of diving on the *Hazardous* numerous photographs have been taken throughout the wreck site. In certain areas the photographs represent an important record of site degradation. Particular features of the site which can be compared include the cannon pile, cannon ball mound, timbers adjacent to cannon ball mound and the bow timbers. Whilst the quality of these photographs are not ideal due to environmental conditions sufficient detail can be obtained from which significant changes can be seen. As mentioned previously the cannon pile and cannon ball mound has undergone severe scouring and through comparison of photos from 1988 with those from 2003 these changes can be seen, figure 38 and 39. The processes at work on the wreck site is further augmented by photos of timbers from 1988 through to 2003 which show changes in the level of sediments, demonstrating both the scouring effects around the starboard or eastern timber frames. Figure 40 demonstrates the deterioration on site, seen from 1998 (right) to 2003 (left).

Figure 38 - Cannon ball mound

Figure 39- Cannon pile

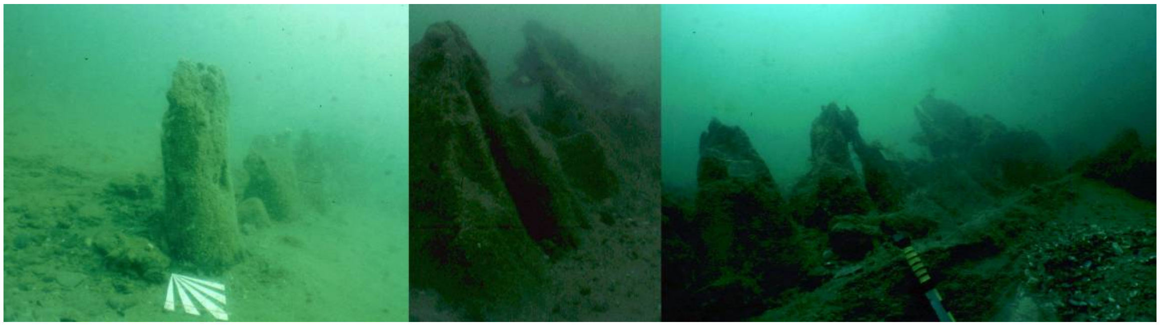

Figure 40 - Eastern timber frames

3.8 Interviews

Interviews with members from the *Hazardous* Project team provided an important source of data for both the localised changes taking place on site and more wide scale changes occurring along Bracklesham Bay and the Selsey peninsular.

3.8.1 Wreck site observations

General observations made regarding the wreck site were of ongoing degradation which has become most noticeable in the late 1980s. These changes were also witnessed through the uncovering of gullies to the north and east of the site. It is believed that these gullies were revealed in the winter of 1987 after a particularly severe storm where a large amount of destruction occurred at West Wittering and East Head. The gullies lie around 150m from the wreck site in a north westerly direction, while to the north of the site they are around 50 – 75m from site. The gullies were scoured to a depth of two metres in places.

The seabed to the east and west of the site consists of a flat clay bed with no artefacts having being recovered from the western end of this clay bed. Within the gullies a range of artefacts were discovered these included several pieces of ships timber, including what was believed to be the bowsprit. These artefacts were in the base of the gullies which indicates that they must have been exposed in the past when the wreck was still breaking up. The gullies appear to have a similar sediment regime to that of the wreck site in general, although there are more localised cyclical sediment movements within the wreck. However it was noticed that recent changes to the site show that there has been a general reduction of sediments.

An area particularly affected by scouring over the years has been the cannon pile on the western side of the wreck site (figure 41). This area has undergone severe scouring as noticed by Iain Grant with major changes having taken place around 1996. The cannons have gone from being partly exposed in the 1980s to now being undermined through scouring to such a degree that the cannons have become unstable and the concretion holding two of the cannon together has split causing one of the cannon to drop slightly. Elsewhere on site scouring around the cannons has been particularly noticeable especially in the amidships section where scouring action appears most dynamic. The most destructive site process is believed to be the winter storms which have affected the southern end of the site, removing timbers and sediments.

However through recent observations made in 2006 it would appear that these storm events are not the main cause in the destruction of the site as large changes were noticed even after the mild winter of 2005.

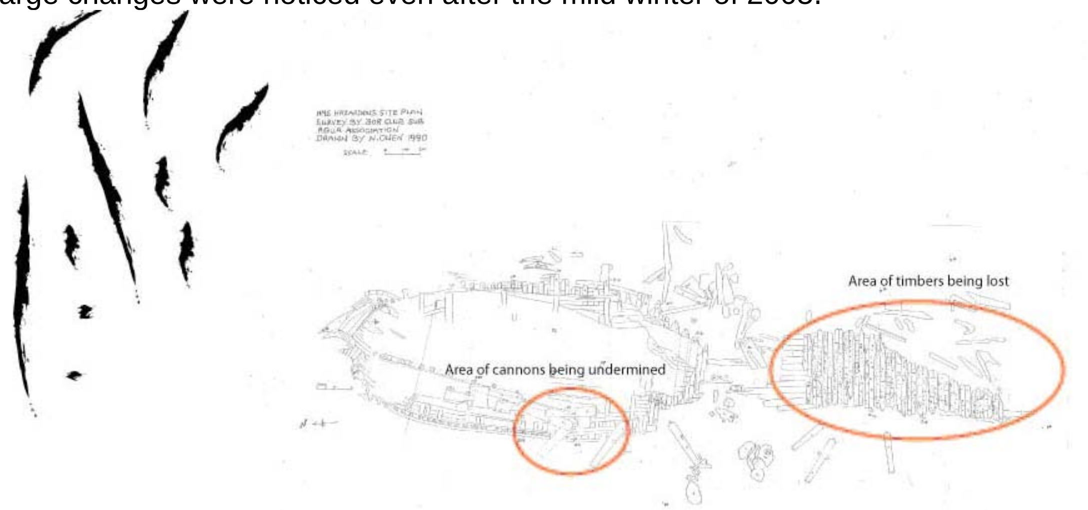

Figure 41 - Site plan with data from the interviews represented

3.9 Summary of site changes

In an effort to fully understand the changes occurring on site through the analysis of all available evidence it is necessary to firstly look at the broader seabed area in which the *Hazardous* lies and work toward smaller localised areas under threat. Figure 42 brings together data on areas affected by scouring and instability. The western edge and southern section of the site shows the most serious degree of scour with complete loss occurring in places, while recent changes have started to affect the northern and eastern part of the site, previously believed to have been areas of stability. This has been identified through dive logs and artefact movement studies and demonstrates the long term effect scouring has had on the site since 1987.

Through analysing the monitoring points, timber degradation points, artefact movement studies and dive logs the most threatened part of the site appears to be the amidships section. This area of the site has the timber degradation points and a number of monitoring points, and hence has a large amount of data available; this is now demonstrating the dynamic nature of this area. This data is reinforcing observations gained through artefact distribution studies and the dive logs. Scouring within the amidships section is shown to have been most prevalent from approximately 1989 although earlier scouring may have been masked through larger changes occurring on site through storm events. Recent observations made in 2006 have shown significant scouring occurring in the east and north and has demonstrates that scouring and associated damage to the site is still occurring during what has been a quiet winter in terms of storm events.

Further more localised small scale changes occurring around the cannons on site can be determined through both the interviews undertaken, the cannon corrosion assessment report and photographs, these are further reinforced by the artefact distribution studies and dive logs. This localised scouring around the cannons has occurred largely since the site was discovered, with the cannons (particularly those in the western part of the site) having become quickly scoured out. The cause of this scouring around the cannons is likely to be due to a number of complex factors related to the seabed geology, general sediment movement patterns and recent coastal defence measures.

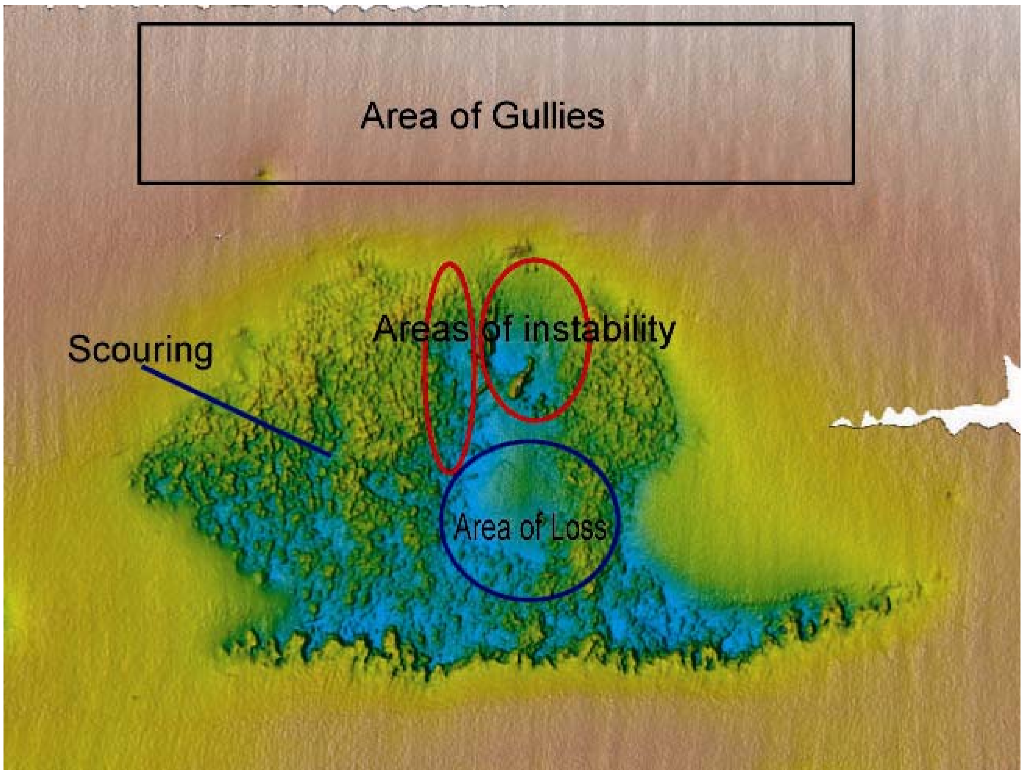

Figure 42 – Geophysical image with areas of loss and instability shown

Since the discovery of the wreck site ongoing survey work has shown the continual exposure of areas of the site with the greatest amount being revealed in 1990. Since this date scouring and accretion have both influenced the site to various extents in localised areas. In terms of quantifying the loss of cultural material the artefact exposures and recovery provide a gauge of material being lost each year. However, due to the infrequency of diving during the winter months, it is not known how much material is being exposed and potentially lost in this most severe part of the season.

As demonstrated, the long and short term losses at the south end of the site have resulted in almost complete loss of structure in this area, this has being determined through diver observation and probing of the sediments.

Through looking at these results and the various site plans that show long-term changes it can be seen that increased erosion is inevitable. This is reflected in more recent changes to the northern and eastern sections, areas originally believed to have been more stable. Additionally it is clear from the dive logs and artefact exposure study that single storm events can cause significant damage, the potential of which cannot be predicted but must be factored in to long-term management.

4. The influence of coastal processes

The coastal zone of the study area which ranges from Selsey Bill in the east to the entrance of Chichester harbour in the west is an exceptionally complex environment, affected by many factors, such as spatial variation in wave climate, and the effects of both planshape and seabed relief on the local tidal current systems. These factors affect the sediment movements offshore and influence the pattern of sediment movements on the wreck site of the *Hazardous*.

Additionally the presence of offshore and nearshore banks, bars, shoals and reefs tends to add other complications to sediment movements both along the whole of Bracklesham Bay and in the area of the wreck site. This is especially true with regards to the relationship between the site and the reef to the south, which may influence local sediment movements in ways that are at times contrary to general local sediment movements.

Due to the extremely rapid erosion that has taken place along this coastline over the last five millennia there is the potential for an offshore archaeological legacy of submerged Romano-British, Saxon and early medieval landscape features, which have been partially recorded in documentary and archival records (Heron-Allen, 1911; Wallace, 1990). With such complex coastal processes operating it is important to fully understand the effects these are having on the Bracklesham Bay area in order to determine the effects these will and have had on the site of the *Hazardous*.

4.1 Geological data

The area of coastline from Selsey to Chichester Harbour was developed in the Eocene and comprises of principally the Bracklesham Beds overlain by Quaternary drift deposits. A generalised vertical section taken of the Bracklesham Beds series shows a formation within the study area comprising of sands, silts and underlying clays. Along much of the coastline the upper beaches comprise of marine deposits, undifferentiated silty clays, sands and storm gravel beach deposits, whilst the lower, shallow sloped foreshore comprises of medium and fine sand. These lower foreshore sands are frequently overlaid with patchy gravel, which in turn overlays the sandy clays of the Eocene Bracklesham Bed Series. The offshore area comprises predominately of sandy seabed sediment with some bedrock and reef outcrops, details of which can be seen in figure 43.

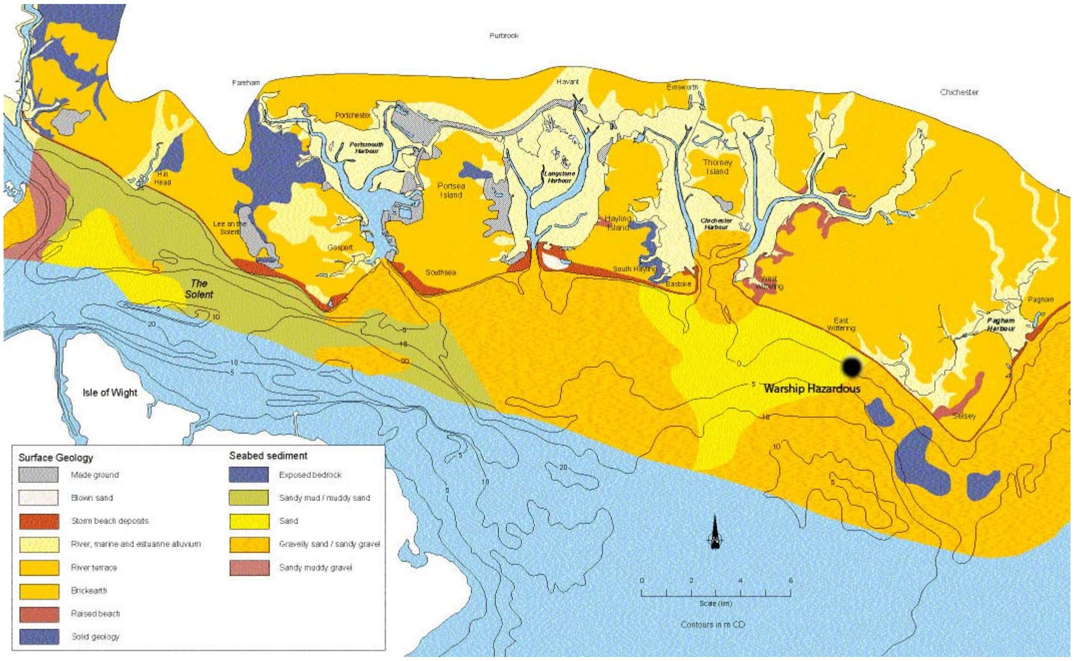

Figure 43 - Surface Geology and Seabed Sediment (Havant County Council ©)

Through the geophysical survey and dive logs it is possible to make out that the wreck of the *Hazardous* lies beneath the sandy, silty area of seabed and has penetrated down into the sandy clay of the Eocene Bracklesham Bed Series. Having penetrated into the sandy clay the burial conditions for the *Hazardous* would appear to have been stable and indeed according to the cannon corrosion assessment report some areas have remained so since 1706.

4.2 Sediment processes

The sediment processes within the study area are characterised by a net drift of sediments in a east to west littoral drift pathway with a less well defined west to east pathway operating within the swash aligned Bracklesham Bay area, this is clearly demonstrated in figure 44.

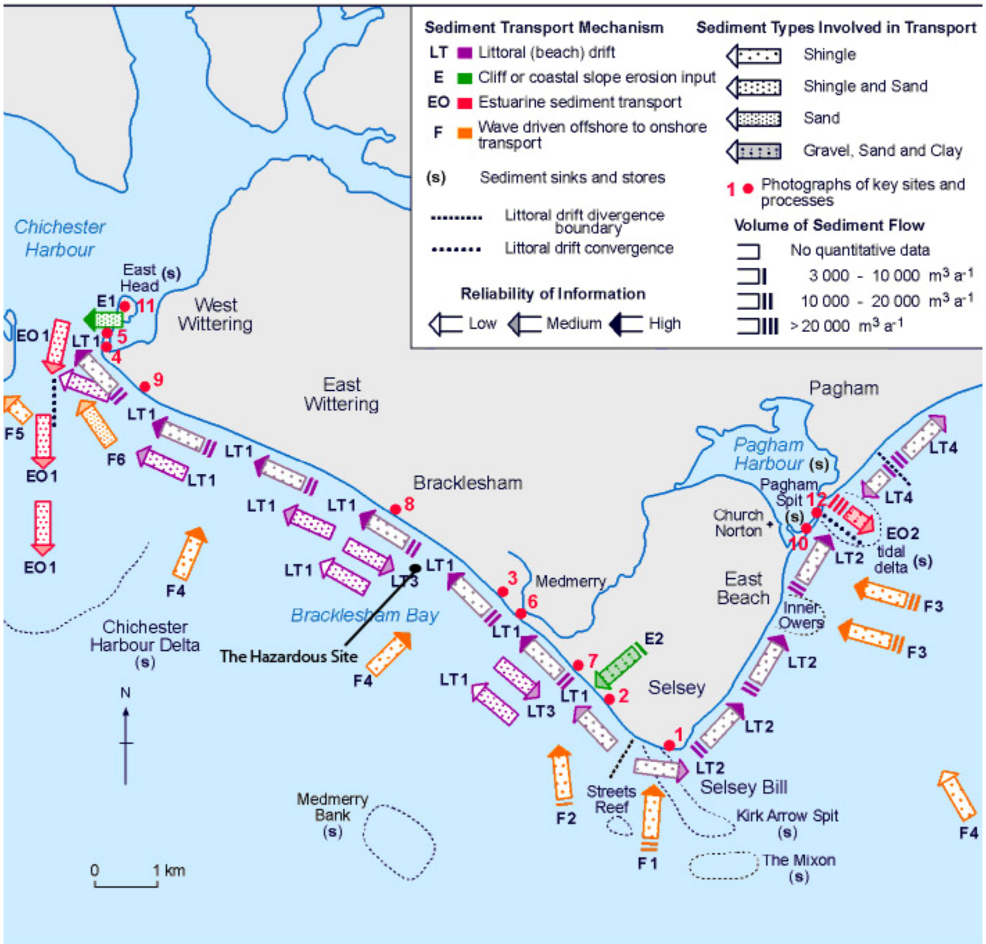

Figure 44 – SCOPAC map showing sediment transport patterns (SCOPAC ©)

Prior to the construction of more substantial sea defences between 1962 and 1969, much of the tip of the Selsey peninsula provided inputs of eroded sediment from wave-induced cliff and shoreface erosion. This erosive process has accounted for over 2 km of coastline retreat since the second or third centuries AD (Ballard, 1910; Brewerton, 1993; Wallace, 1996). The majority of sediment accumulation is derived from the rapid retreat of low cliffs around Selsey as well as the abrasional scour of the complementary, expanding, shoreface platform. Hydraulics Research (1974) estimated that rapid erosion between 1850 and 1950 could have released as much as 2 million cubic metres of gravel from raised beach deposits. Although currently this scour is somewhat diminished, this can be attributed to fluctuations in the volume of onshore sediments entering into the system at Selsey and the effects of progressively more substantial coastal protection structures.

The general trend of sediment movements along the shoreline of the study area are determined by sediment availability and the condition of groynes, as deteriorating or overflowing structures can locally increase sediment throughput for limited periods. Various experiments undertaken by Hydraulics Research (1974) and HR Wallingford (1995) into the sediment drift cycles occurring along Bracklesham Bay have indicated that sand transport may be reversed on the lower foreshore, seaward of groynes, due to strong eastward residual tidal currents. This reversal of sediment transport was considered to be occurring in the Bracklesham area due to the increase in the westward tidal current from Medmerry, inducing net sand transport westward to East Wittering.

The importance of this reversal, seen in figure 44, is that a transport divide may exist in the vicinity of Bracklesham and subsequently influence the sediment processes affecting the site of the *Hazardous* due to its position within this reversal area. These transport pathways in both a westerly and easterly direction could possibly account for the annual cyclical movement of sediments within the *Hazardous* as has been previously described in the sediment monitoring points.

Additionally the reduction of sediments entering this sediment transport system through the increasing of sea defences is very likely to have directly affected the site of the *Hazardous* by removing available sediments. Through interviews with members of the *Hazardous* diving team, most of who live locally this was seen to be the most likely cause. It was generally believed that after the storm of 1987 with the increase in groynes at West Wittering sand movement along the coastline was severely restricted. Evidence of which was the large build up of sand along the groynes at West Wittering with a subsequent reduction of sand levels elsewhere. Additional evidence was the increase in the amount of clay bed that has become visible between Bracklesham and Selsey especially between the high and low water marks during the summer months. This area of exposed clay beds lies directly in front of the wreck site and together with the reduction in sand may represent an additional cause for the loss of sediments on site.

4.3 Beach morphology and shoreline change

Much of the coastline within the study area consists of upper beaches which are steep and composed of flint gravel and a lower foreshore which has a relatively shallow slope and is composed of medium and fine sand (Harlow, 1980; Posford Duvivier, 2001). However, these underlying sedimentary processes have been complicated through numerous beach replenishments and beach scraping undertaken for coastal defence. An analysis of beach profiles has revealed that the upper gravel beach was narrow at Bracklesham and did not appear to derive much benefit from up-drift replenishment while towards Selsey the affect of this became more substantial. Site-specific variations in width and height tend to reflect more groyne trapping efficiency than sediment processes. The lower foreshore area appears to have maintained its form, but levels have dropped progressively, especially at East Wittering, Bracklesham and Medmerry.

Current studies by the South East Strategic Regional Coastal Monitoring Programme show that the general trend for coastal management units MU 3 (in which the *Hazardous* falls), 4 and 5 shows less than a 5% change in beach morphology. While a closer examination of each management unit shows much the same with certain exceptions. Bracklesham Bay and Selsey, MU3 demonstrates a mostly unchanged or accreting profile while East Wittering and Bracklesham, MU4 shows a slight accretion indicative of stable beach morphology. East Head and West Wittering, MU5 especially the area closest to the Chichester harbour entrance at East Head shows considerable sediment loss, yet the remainder of the management unit is generally accreting toward the central area. However it should be noted that these changes only reflect the annual cycle of change of beach morphology from 2004 to 2005, and for long term processes historical data is needed. See figure 47 for Management Unit boundaries.

This historical data of the coastline from Selsey to Chichester Harbour shows a rapid erosion taking place at the low cliffs and beach frontage. Through an analysis of historic charts at the UKHO and maps of Bracklesham Bay from the Chichester Records Office these changes in the shoreline were mapped from 1805 to the present day. Using GIS the historical coastline polylines, supplied by West Sussex County Council, were placed on the present day shoreline, data courtesy of Channel Coastal Observatory clearly showing shoreline regression (figure 45).

Figure 45 – Present day and historical coastlines showing the *Hazardous* wreck site (data courtesy of Channel Coastal Observatory and West Sussex County Council)

This regression in shoreline demonstrates the negative sediment transport system which is operating along Bracklesham Bay as well as providing evidence for the effectiveness of recent coastal defence measures in retaining sediments and reducing the scouring effect along the coastline. Through understanding the volume of sediments that were entering the sediment transport system it can be demonstrated that until relatively recently sediments entering the Bay were enough that the *Hazardous* site remained covered. This change in beach morphology and resultant shoreline change shows that the scouring occurring on the site of the *Hazardous* is partly due to this change in sediment volume. As the shoreline regression is unlikely to continue the amount of sediments entering the system will decrease and subsequently increase the scouring action offshore at sites like the *Hazardous*.

4.4 Hydrographic data

Through a range of detailed observations and transport modelling studies within the area undertaken as part of the DEFRA Futurecoast Study, various short-term and short distance reversals of the net sediment drift direction as a result of varying incident wave approach have been recorded (Halcrow 2002). Through this study an offshore wave climate was synthesised based on 1991-2000 data from the Met Office Wave Model and then transformed inshore to a prediction point in Bracklesham Bay. Results from this study suggested that a one to two degree variation in wave climate direction could result in a 2 - 4% variation in longshore energy and confirmed that the Bracklesham Bay was particularly sensitive to the offshore wave climate.

Wave climate for any one location on this coastline is a result of complex relationships between offshore to inshore transformation as a function of shoreface width and water depth; seabed relief; approach angles and interaction between wave and tidally induced currents in the breaker zone. As Bracklesham Bay is a swash-aligned shoreline it is particularly sensitive to wave approach direction, variations in this direction can cause drift reversals and variations in the longshore drift that runs along this area of coastline. Predominate wave direction and heights are given in figure 46.

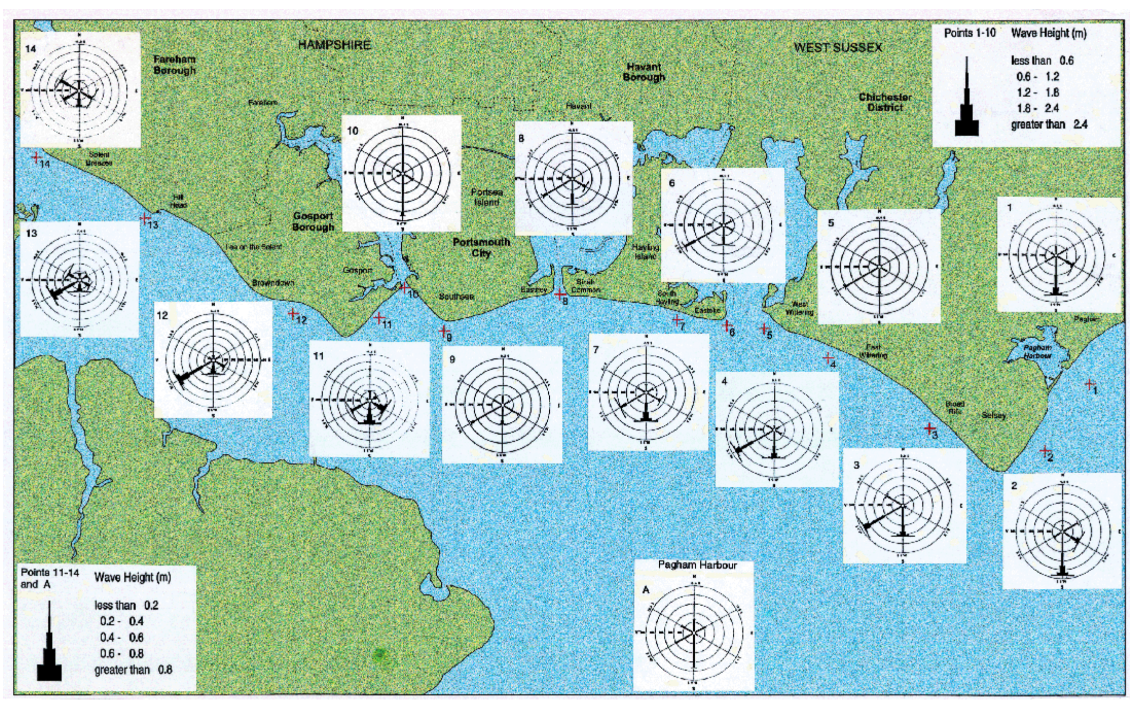

Figure 46 – Wave height and direction (Havant County Council ©)

The offshore wave climate is dominated by waves from the south and southwest with periodic episodes of less energetic waves from the southeast, figure 46. While further evidence of the annual wave climate offshore at Hayling Island for 2004 can be seen in table 1 below.

Hayling Island 2004							
Month	H_s	H_{max}	T_p	T_z	Direction	SST	**No. of days**
	(m)	(m)	(s)	(s)	(^{o})	(^{o}C)	
January	0.967	1.471	9.9	4.2	-	7.9	31
February	0.687	1.039	9.2	4.1	-	-	26
March	0.689	1.048	9.4	4.0	208	-	30
April	0.532	0.814	8.7	3.8	185	-	29
May	0.403	0.621	7.3	3.4	186	-	31
June	0.505	0.779	5.9	3.2	203	16.3	30
July	0.474	0.731	4.9	3.2	200	17.3	31
August	0.611	0.945	5.8	3.5	191	19.3	31
September	0.705	1.101	6.5	3.5	193	17.8	30
October	1.020	1.587	6.8	3.9	182	14.5	31
November	0.491	0.746	7.2	3.4	203	12.0	30
December	0.635	0.982	10.7	4.2	183	9.6	26

Table 1 – Hayling Island wave buoy showing the general trend for 2004

The effect that these wave climates have had on the *Hazardous* wreck site can be seen through the sensitivity that this swash aligned coastline has to the direction of these waves, with small changes affecting the sediment pathways. On the site of the *Hazardous* this influence can be seen to be affecting sediment movements on site through the changes to directional flow of sediments inducing a north-westerly scouring. Changes to the wave climate through seabed relief and changes in depth amongst other factors all play an important role in the changes to sediment patterns; these in turn affect scour patterns within the *Hazardous* site.

4.5 Exceptional conditions

According to interviews with the members of the *Hazardous* diving team and an analysis of dive logs the most damage occurring to the *Hazardous* wreck site is during storm events. Data for these storm events comes from the East Solent Management Plan where anticipated yearly exceptional storm events are given with a estimation of nearshore wave heights; storms expected to occur annually with 3.9m wave height, a one in ten year storm event with 4.6m wave height and a one in fifty year storm event with 5.0m wave height. Through recent studies into storm events the Southeast Strategic Regional Coastal Monitoring Programme Annual Report 2004/5 for the Eastern Solent has a set of data which recorded wave heights and periods in which they are most prevalent, table 2 and 3. Although only based over two years this does allow for an understanding, when taken together with dive log information, of events which have the greatest affect on the site.

5 Highest storm events in 2003	
Date/Time	Hs (m)
29-Nov-2003 10:00	2.68
26-Nov-2003 07:30	2.66
14-Nov-2003 01:30	2.64
20-Dec-2003 13:00	2.53
02-Nov-2003 09:30	2.47

Table 2 – Storm events for 2003

Highest storm events in 2004									
Date/Time	**H_s**	**T_p**	**T_z**	Dir.	**Water level elevation* (OD)**	**Tidal stage**	**Tidal range (m)**	**Tidal surge* (m)**	**Max. surge* (m)**
08-Jan-2004 10:30	3.64	8.3	6.3	-	1.75	HW -1	3.4	0.48	0.49
31-Jan-2004 11:00	3.19	9.1	6.1	-	0.19	HW -5	1.7	0.73	0.75
23-Jun-2004 15:30	2.99	11.8	6.3	186	1.36	HW -1	2.9	-0.06	-0.10

Table 3 – Storm events for 2004

Through the dive logs it is clear that these storm events cause severe changes to the site of the *Hazardous.* Predicting the probability of large storm events occurring and their frequency are elements which should be taken into account in the long-term management of the wreck site.

4.6 Coastal response

Historically there has been an awareness of the scouring effect the sea has been having on the coastline within the study area, with some of the earliest coastal defences seen on charts from the mid 1800s. Presently the system of coastal defence measures for the study area is managed under the East Solent Shoreline Management Plan and is represented by three management units namely, Management Unit (MU) 3, MU4 and MU5 as can be seen in figure 47. For all of these Management Units the strategy for coastal defence is hold the line, which has been defined by DEFRA as maintaining or improving the existing shoreline or line of built defences. Whilst the East Solent Shoreline management plan is currently being reviewed it is likely that this option of hold the line will remain. In retaining this form of defence it is envisaged that there could be a potential lowering of the foreshore through erosion, with a resultant increase in wave energy at the shoreline.

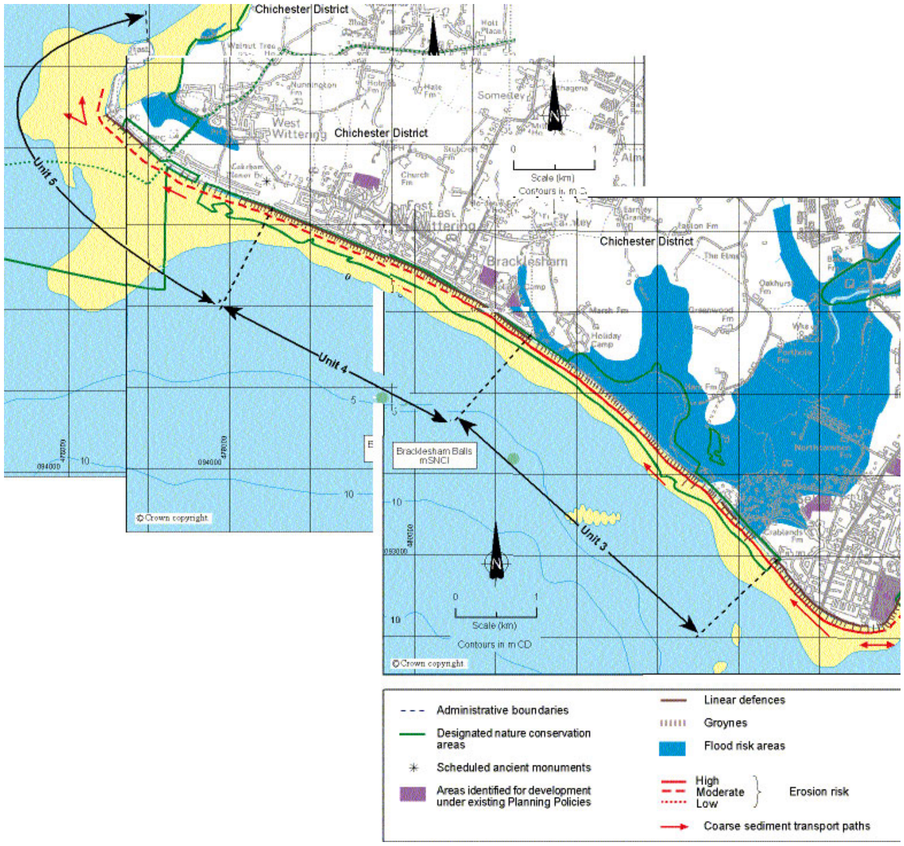

Figure 47 - Management units within the study area

The increase in wave energy and lowering of the foreshore are related to the changes occurring to the sediment patterns along the whole area of coastline from Selsey to Chichester. The long-term effects of these changes are likely to have further adverse effects on the *Hazardous* through increased scouring due to the lack of sediments within the sediment transport system. The envisaged increased wave energy is likely to cause further sediment movements within the site and cause changes to the apparent cyclical movement of sediments.

4.7 Summary of coastal processes

Understanding coastal processes operating along the coastline from Selsey to Chichester Harbour allows for wider large-scale changes to be identified. These changes are the result of a series of long term processes the study of which allows for future coastal processes to be determined. Understanding these large-scale changes and the effects they are having on the small-scale processes of the *Hazardous* is necessary for site management.

Looking at the local geology of the area in which the *Hazardous* lies and specific data concerning the sediments in which the structure and artefacts have been found, it is possible to determine that the site rests within the clays of the Bracklesham Beds and the more mobile upper sandy seabed layer. Through time the Bracklesham clays have become more exposed through the removal of overlying sand by scouring processes, a process which has also exposed more of the structure of the wreck. This exposure is due to the negative sediment regime which operates in the Bay which is likely to have been aggravated as a result of sea defences. However, while this is the major contributing factor in sediment movements and will remain so in the future other factors such as storm events need to be taken into account. As shown through the East Solent Management Plan the one in five and one in ten storm events proposed are of greater magnitude than the winter storms occurring. As has been shown these storm events play a large role in site degradation and with more structure becoming exposed these storm events and the predicted larger future storm events will play a major role in site destruction.

The SCOPAC sediment transport pattern map shows the long-term sediment movements along the coastline, demonstrating the contrary and complex sediment transport pattern within which the *Hazardous* lies. The sediment transport system shows the flow of sand and shingle over the wreck site in contrary directions and gives some indication for the reason of the cyclical flow of sediments around and within the site. Predictions for the long-term cycle of sediment movement within the wreck site must take account of a potential reduction in the volume of sediment entering the bay as this is likely to promote a further reduction in seabed levels.

Whilst sediment transport pathways provide an overview for sediment movements, other factors such as waves play an important role in altering local conditions. This is especially true around the *Hazardous* wreck site and the adjacent reef, which is affected by wave-driven sediment movement. During storm events these wave-driven sediments are particularly mobile especially during periods of exceptional storm events with anticipated nearshore wave heights of 4.6m in every ten years and 5.0m in every fifty years causing particularly severe sediment movements.

Along Bracklesham Bay the sediment movements mostly affected by the wave climate are those on the shoreline, these conditions onshore provide evidence for the degree of sediment movement occurring further offshore. The shoreline regression has resulted in an increase in distance between the *Hazardous* site and the shoreline over time which in turn may have afforded it some protection before sea defences were put in. The waves also play a role on the wreck site causing sediments to move in a shoreward direction as occurs with a swash aligned coastline which, due to the forecast increase in wave activity will result in more sediment movement.

5. Implications for the future

This section considers the implications of the data presented in section 3 and 4 on the long-term future of the wreck site and reviews options for investigation and management.

5.1 Quantifying site degradation

As previously mentioned an attempt to quantify the loss of cultural material from the *Hazardous* is particularly difficult and it is more reasonable to determine exposure rates based on artefact movement studies, dive logs, site plans and interviews. This provides evidence of long-term general trends which can be supplemented with data from the monitoring points (figure 1) in order to provide a more exact representation of the degree of exposure of structure on site. Although these monitoring points provide a short term view, when taken in conjunction with the long term coastal processes operating in the area of the site, they provide evidence for the cyclical movement of sediments. It is these cyclical movements which have made it particularly difficult to quantify any loss of cultural material as they can mask degradation by the build up of sediments. Whilst some masking of degradation has occurred, changes to larger cultural features such as the cannon pile and cannon ball mound provide a more representative gauge on the damage occurring on site.

Overall loss of sediments occurring within the wreck site as mentioned in the dive logs and artefact studies together with the evidence of a negative sediment budget in the Bracklesham Bay area (Section 4) demonstrates that sediment loss poses a major threat. The figures representing site change in sections 3 and 4 show this situation will progressively worsen as sediments are lost due to the lack of further sediment input.

Other major factors in site degradation are storm events which, as seen in section 3, can cause large scale changes throughout the wreck site. Storms can cause the loss of large amounts of sediment and associated cultural material which results in loss of the archaeological archive. It can be reasonably determined that storms are causing periodic loss of large amounts of sediments, which in a negative sediment budget leads to further, potentially more rapid, site degradation after each event.

5.2 Long term site stability

The coastal processes influencing the area in and around the *Hazardous* together with the effects of past events result in serious questions over the long-term stability of the site. The stability of sediments covering and protecting cultural material is undermined through various factors, the main threat being that of storm events. The destruction caused by three main episodes of storm events has been documented, the most severe being the event of 1990 which resulted in large areas of the site and a large number of artefacts being uncovered.

The other major threat to long-term site stability is the negative sediment regime within Bracklesham Bay that results in the continual loss of sediment. Whilst the shoreline sediments have been protected through the construction of defensive structures, offshore this negative sediment budget continues to remove sediments from the wreck site. The loss of sediment input from shoreline erosion is having a greater effect on the sediments offshore. The *Hazardous* wreck site lies in an area where there is a reversal of the sediment transport pathways (Section 4). It is this reversal which is potentially providing a small degree of protection from the general negative sediment regime and maybe lessening the effects on the *Hazardous* in certain seasonal conditions.

Due to the predicted increase in the severity of storm events, sediments are likely to undergo periodic disruption with large-scale changes of scouring and silting occurring within the wreck site. This dynamic sediment process has a negative effect on the survival of cultural material, causing on-going degradation and loss of material.

5.3 Assessment of options for future of the site

This report has demonstrated the long term future of the Hazardous site is currently extremely bleak. The site is being degraded through two principle mechanisms: long-term net sediment loss across the whole of Bracklesham Bay and isolated storm events. These factors combine to equal a site which is under extreme pressure and at high risk. Inevitable loss of the cultural heritage archive on the seabed means that there is an urgent need to consider the possible management options for the site and put in place a strategy which is agreed between all stakeholders.

Based on the results of the assessment of environmental conditions there are four possible management options for the site:

- Allow unrecorded loss of historic wreck site
- Continue to record the loss of the site
- Attempt site stabilization for *in-situ* preservation
- Undertake active intervention and achieve preservation by record

Each of these options have implications in terms of the seabed archive and resources required.

5.3.1 Unrecorded loss of historic wreck site

This option assumes that no further recording work is undertaken on the site. At present rate this would mean that any remaining archaeological material and associated stratigraphy is lost, potentially within a short space of time. Taking this option raises a number of issues.

Allowing the unrecorded loss of the site would be highly unfavourable for the Hazardous Project Group who have spent the past thirty years investigating and recording the site which has included substantial contributions of time, money and resources of group members. It must be recognised that without the work of the group this is the fate that would have befallen the site; little would be known about the site, there would not be artefacts on display to the public and the collection would not be available for study. The Group would not support this option as it has continuously strived to record as much of the site as possible.

This option also raises ethical and management issues. Should one of Britain's most important historic wrecks be allowed to disintegrate? This would mean the loss to the public of one of their most significant marine heritage assets.

This option would go against the national and international preferred option of preservation *in-situ*. However, when historic assets are faced with such a dynamic environment *in-situ* preservation is not always possible.

5.3.2 Continue to record the loss of the site

The work of the Hazardous Project Group over the last 15 years has involved the recording of artefacts and structure as they become uncovered. Mobile artefacts are raised when they are under threat of loss. Due to this mobility the archaeological context of this material has often been disrupted or destroyed prior to recording. While this approach enables some data retrieval it is essentially a method of recording site degradation and decay. While recognising that without such important recording work very little would be known about the Hazardous site, it must be questioned how much cultural information derived from the association of artefacts, features and deposits is being lost.

This management option should be seen as essentially the 'do nothing' approach. It would be a continuation of the current situation where rates of loss are recorded and a number of artefacts rescued. In the face of the option of unrecorded loss, is at least an improvement. In adopting this approach there is a risk of the project group becoming disengaged with the site, the effect of seeing such an important site disintegrating, especially with recent rapid changes, is becoming very disheartening to team members. The group currently input thousands of pounds worth of volunteer time and resources into the site, should lack of action to save the seabed remains result in their disengagement there would be a substantial resource implication for the heritage agency to continue this basic level of recording.

5.3.3 Site stabilisation and *in-situ* preservation

Despite the recognition of the highly dynamic environmental conditions on site the option to attempt to stabilise the site must be considered. To effectively stabilise the site would require significant hard engineering works. The most analogous example to the *Hazardous* site where stabilisation has been undertaken is that of the Dutch East India Trading Vessel *Amsterdam* on Hastings beach. Here a coffer dam has been constructed around the remains of this 18th century wreck site (Gawronski 1990).

This approach could be attempted at the *Hazardous* site, however, the financial cost of such an exercise is likely to be considerable as it would involve the use of marine barges and piling equipment. The addition of such a structure in the relatively shallow waters would also create a hazard for navigation and would require appropriate buoyage. The level of resources required for such an operation must be weighed up against the cost of preservation by record (see 5.3.4).

Additional factors that should be considered in relation to this approach is the potential for a coffer dam to actually increase localised erosion both inside and outside of such a hard structure, especially due to the local tidal and sedimentary regime. Further environmental impact studies are likely to be required to gauge the full potential effects of such a hard structure on the dynamic local coastal zone. Such a structure could cause erosion problems in other areas.

This option would also impact the site in terms of visitor access and the successful diver trail scheme which is in operation. Ceasing this trail would effectively prevent further public access.

In order to install such an intrusive structure archaeological investigation of the areas to be impacted would be required. This would depend on the proximity to the remains and depth of overlying sediment, but would be a further budgetary factor.

As a remedial measure the installation of smaller scale *in-situ* preservation options could be considered. To date the only previous stabilisation on the *Hazardous* site occurred after the excavation in 1989. This involved filling the excavation trench and covering and stabilising the cannon on its carriage which had been encountered during excavation. This was achieved using heavy duty plastic and sand bags. As this feature was located lower than the seabed level this was successful until recently when the plastic was exposed and has now degraded, although, this was more of a 'reinstatement' measure rather than stabilisation.

It is acknowledged that preservation *in-situ* in the marine zone has developed over the past 15 years. In Britain this has included the stabilisation trials on the site of HMS Colossus (Camidge 2005) and input into scientific aspects of the European MOSS project (Palma 2005). However, it has not been possible to locate examples of trials or successful good practice within such dynamic environments as the *Hazardous* site. With funding trials to stabilise specific features could be developed, however, in light of the pace of recent erosion this risks large amounts of cultural heritage being damaged should trials be unsuccessful. Additionally the protection of localised areas of the site may induce erosion in other areas.

If localised stabilisation measures were able to be successfully undertaken covering of some of the most prominent site features would affect the operation of the diver trail which uses some of these key locations for information points.

5.3.4 Active intervention and preservation by record

The fourth option for consideration is active intervention and preservation by record. As with option three this situation should not be taken forward without careful consideration of all possible eventualities.

Environmental data and evidence from site acknowledges a situation of long term loss. To ensure maximum retrieval of data and creation of the archive for the public the most effective option would be active intervention and preservation by record.

This report has highlighted that the forward half of the vessel contains the most intact seabed archive. To date only a single trench has been excavated within this area. The results of this excavation have demonstrated the potential of these deposits and the artefacts held within. It is this material which is now becoming exposed and degrading through erosion. Active intervention should be targeted at excavation, recording and recovery from this area. While not advocating the raising of large hull sections at this stage a programme of recording after the excavation of material within the hull should be undertaken. This is particularly important in light of the significance of the technological aspects of the construction of the vessel – one of the key features which make it so historically significant. Options for the removal of sections of the hull to a facility such as the recent storage of the Princes Channel Wreck hull sections in Horsea Island (Wessex Archaeology) could be considered as a future option.

Without undertaking active intervention and preservation by record there is a real chance that the opportunity to answer a range of research questions regarding the site, the ship and its related historical context will be lost. This option would require resources to undertake the excavation and analysis of recovered material, ensure the archive is collected, maintained and curated to accepted standards and that the results are made fully accessible through publication.

The Hazardous Project Group recognises that the site archive is not currently held within a public repository, however, on-going initiatives are striving to ensure that the collection is housed together in a public facility for the long-term. The Group recognises the importance of the collection as a whole and in its constitution has made provision that:

> "The principle asset of the Warship Hazardous Project is the site archive (comprising the paper and object record from the site). The value of this asset is historic rather than economic. In the event that the group no longer exists the whole site archive should be kept together and donated to the local public museum (Chichester District Museum). The group would like all efforts to be made to maintain a local display of artefacts from the site. If there are funds within the Group account at the time of disbandment this money should be donated to the Chichester District Museum to aid long term maintenance of the collection." (Hazardous Group Constitution Dec 2005).

While active intervention will require input of resources from the heritage agency, the level of funding required is likely to be less that that for large scale stabilisation works. The Hazardous Project team are a highly skilled group who will bring their experience to the excavation and recording of the site. Undertaking this work will ensure public access to their heritage through the availability of material for display and dissemination of results.

6. Archaeological investigation priorities

In determining the evidence for site changes three parts of the site showed the most damage and loss of material culture, that of the eastern, amidships and southern end of the site. Whilst the cannon ball mound and area of cannons on the western side of the wreck also show large amounts of localised damage and change. Through excavation of a trench in the forward section of the site a large amount of well preserved cultural material has been recovered. This demonstrates both the quantity and archaeological potential for the areas that have not been disturbed or severely affected by erosion.

In order to define areas to target for active archaeological investigation the areas of known high archaeological potential have been mapped against those sustaining degradation through erosion. The resulting figure 48 can now be used for developing priorities for intrusive investigation.

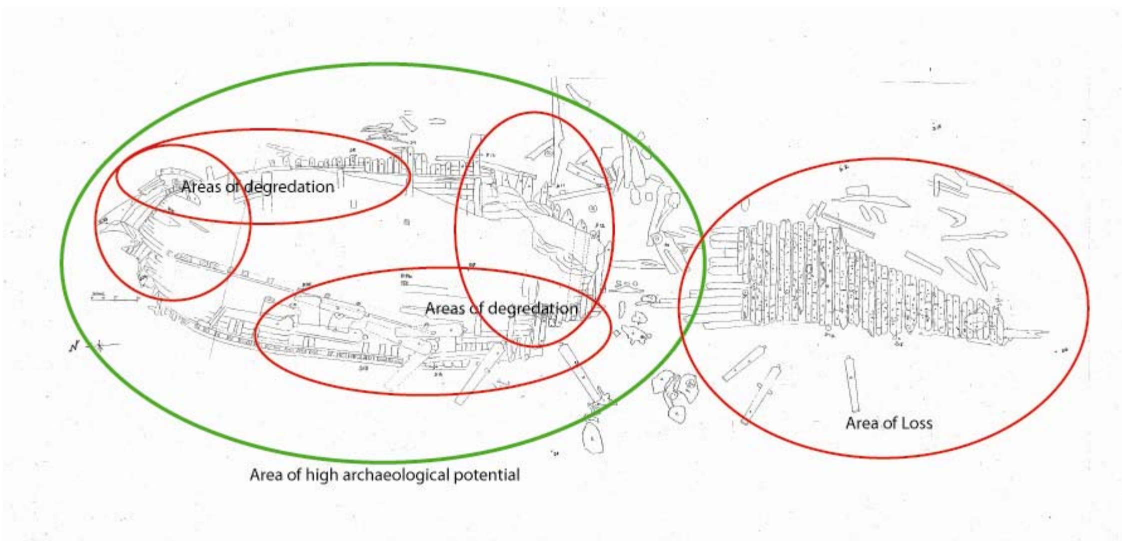

Figure 48 - Archaeological investigation priorties

These areas of high archaeological potential provide the possibility of recording areas of the site that have undergone little scouring up to the present and therefore would be able to provide most archaeological information in terms of wreck site assemblage and secure stratigraphic sediment sequences.

Using figure 48 it is possible to distinguish those areas of sustained degradation against those areas of high archaeological potential to determine which of these areas overlap. These areas must be given the highest priority for archaeological investigation due to the potential for recovery of cultural material and information on sediment sequences before they are lost through erosion. Stratigraphic recording could provide further evidence for sediment movement and on site processes and would help to further determine the effects of erosion.

7. Evaluation of project methodology

The project methodology was based on the collection and collation of multiple data sets and where possible incorporating these into a GIS programme.

7.1 Geographical Information System

GIS proved to be an extremely useful tool in manipulating and presenting the data for the chronological assessment of local environmental data obtained from the Channel Coastal Observatory and West Sussex County Council. The historic coastline polylines obtained from West Sussex were mapped onto a current base map together with the aerial photos from the Channel Coastal Observatory website. Through this it was possible to determine the degree of coastline regression obtaining approximate measurements for the rate of sediment loss occurring through time and determining the position of the shoreline in relation to the *Hazardous*.

7.2 Monitoring points

Sediment levels have played an important role in the preservation and protection of the *Hazardous*, therefore the setting out and recording of sediment monitoring points was seen as essential. The monitoring points were established directly on the wreck structure which forms the most stable base for monitoring the surrounding sediments. Copper nails provided the point from which measurements are taken vertically to the seabed. This system was established at negligible cost and has proved to be an extremely effective method of gathering data on changes around the wreck. The long-term process of on site sediment monitoring has helped provide a comparative dataset for detailed analysis of specific on site processes. While at the same time this has allowed for comparison to be made to the larger scale processes occurring.

Further monitoring was undertaken through situating timber degradation points on exposed timbers to gain an idea on the level of marine organism attack. These points were then also related to the degree of sediment loss and have provided data on the rate of degradation occurring within the area amidships.

7.3 Dive log data and interviews

The dive log data proved to be of inestimable use in mapping change on the site, through providing first hand observations on the changes occurring through time. The dive log data together with interviews undertaken provided a chronological series of observations made on sediment processes allowing long-term processes to be mapped and understood. Through using this data and the several site plans which had been created it was possible to identify specific areas affected by scouring and map these chronologically.

These site plans were overlaid in a drawing programme, Adobe Illustrator using the datum points to overlay the various site plans. This provided the most accurate and interpretative means by which chronological assessments of sediment movements between each site plan could be made.

7.4 Artefact distribution

Artefact distribution studies undertaken by Sarah Holland proved to be a useful tool in determining the chronological spread of artefacts and with the dive logs provided additional evidence for the sediment patterns occurring. However the data collected for the artefact distribution studies was more difficult to collate and interpret due to it being in a variety of versions of the 3H Consulting *Site Surveyor II* and *Site Recorder* software packages.

Without the most recent version of *Site Recorder* it proved difficult to extract data for inclusion within the project GIS which was held in ArcView 9.1. Therefore the data had to be converted into a DWG format and opened in AutoCAD, from where the points could be then separated and in order for them to be displayed and interpreted. This data was then transferred into Adobe Illustrator where it could be overlain onto a site plan using the datum points for accuracy.

7.5 Geophysical images

The swath bathymetric geophysical images provided a useful method for visualising sediment processes operating within the wreck site and the general vicinity. However, as the surveys were conducted within a year of each other it was not possible to gain sufficient data from which comparative analysis would display significant results.

It would be useful to have swath imagery of the site taken at intervals of around five years to use as a comparative monitoring tool. This interval would need revision if there had been particularly severe storms. This data could then be directly related to the high resolution detailed data gathered from the monitoring points established on site.

7.6 Coastal processes

The Bracklesham Bay area has undergone numerous studies relating to coastal processes and much data is available. Collating all this information has allowed for a further more in depth understanding of sediment patterns and influences of the dynamic regime in which the *Hazardous* lies. This data has also enabled the assessment of long-term management challenges for the wreck site.

7.7 Conclusions

Work on the environmental conditions affecting the wreck of *Hazardous* has been helped by the number and variety of data sets available, both for small scale on-site changes and wider coastal processes. The variety of formats in which this data is held has proved challenging. GIS has been used to successfully collate a number of data sets. Data already in standard digital formats has been readily incorporated into the GIS, some problems have occurred with digital data in non-standard formats. However, through analysis of the data sets it has been possible to determine the scale and nature of the effects of erosion on the site. This is an important step forward in understanding the threats to the site and for the formulation of plans for further archaeological intervention.

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