Channel Deepening Project
Supplementary Environmental Effects Statement

Assessment of potential impacts to the long-term corrosion rates of shipwrecks in Port Phillip Bay

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Introduction

The Port of Melbourne Corporation (PoMC) proposes to deepen the shipping channels within Port Phillip Bay (the Bay) to allow for 14 metre draught vessels to access the Port. Figure 1 presents a map of the proposed works. An Environment Effects Statement (EES) for the Project was prepared and exhibited in July 2004. Following an Independent Panel Inquiry the Minister for Planning directed that a Supplementary Environment Effects Statement (SEES) be prepared for the Project.

This report provides supplementary information regarding the Non-Aboriginal Heritage Study conducted as part of the SEES, building on the findings of the EES by Terra Culture and Cosmos Archaeology who have been engaged to undertake the study. Findings from other relevant studies, in particular the modelling results from the Hydrodynamics study, have been used to determine potential impacts to heritage sites. The principal source of data pertaining to the projected changes in the microenvironment of the wrecks has come from the Cardno Lawson Teloar (CLT) report and overall environmental assessment. This report addresses the concerns of the Port of Melbourne Corporation regarding the potential impact on the wrecks of HMVS *Cerberus* (S117) and the *City of Launceston* (S124) and the J Class submarine J7 (S384).

Summary of analyses and conclusions

The existing data on the rates of deterioration of HMVS *Cerberus,* the *City of Launceston* and the *J-7* submarine comes from the experimental data base collected by the author on behalf of Heritage Victoria. The effects of the changes in the microenvironment of the wrecks has been assessed in terms of the impact of the channel deepening operations on the amount of water movement in and around the actual iron shipwrecks, since it is the flux of dissolved oxygen that has the major impact on the rates of deterioration of historic shipwrecks. The overall impact of the changes in water depth, in currents and in wave action attributable to the CDP are very minor and the effect of any changes in the amount of water movement would not be possible to discern, since estimation of the rate of corrosion of iron wrecks is limited to the errors associated with measuring corrosion potentials and the surface pH of the corroding metal underneath the concretion formed by interaction of the iron corrosion products and the encrusting marine organisms. It is not possible to determine the corrosion rate to better than ± 1.5% owing to the systematic errors associated with measurement having a range of ±0.002 volts. Errors associated with the determination of corrosion specific equations for each wreck site provide an additional source of error so that the best data has a typical error of ±5% in corrosion rate. Since the predicted changes in water volume of the Bay after the CDP amount to 2% and the predicted changes in salinity of an increase of 0.074 ‰ will bring about negligible change in the maximum dissolved oxygen content of the seawater these elements will not

provide sufficient impetus to materially affect the rates of deterioration of the vessels. It should be noted that owing to the date of sinking of the *City of Launceston* in 1865 the vessel is in an advanced state of decay (MacLeod 2002, 2006) and that it has begun to shed hull plates. The wreck of the HMVS *Cerberus* is in a much worse condition, owing to its exposure in a semi-submerged state and has already undergone major collapses which lead to the removal of the four massive guns to ease the weight bearing down on the extensively degraded substructure. The J class submarine J7 is similarly half in and half out of water at the Sandringham Yacht Club and when inspected in March 2006 was showing significant decay. Since the modelling has shown that storm surges are not going to be affected by the CDP it is important to note that it is likely that all vessels and HMVS *Cerberus* in particular, are very likely to undergo major collapse if the sites are subjected to a major storm. **The deepening of the shipping lanes cannot be held responsible for any such collapse since the control of the wind-born waves and major storms are outwith the control of the Port of Melbourne Corporation.**

Several degradation mitigation options are available for the three vessels but it is the responsibility of the owners or managers of the sites and the wrecks to undertake appropriate conservation measures. In the case of the *City of Launceston* addition of spoil debris to the silt mounds surrounding the wreck is considered to be beneficial and the HMVS *Cerberus* would respond to any measures that would reduce the impact of the waves on the structure. In a similar vein, it would be possible to apply cathodic protection, in the form of impressed direct current or sacrificial anodes, to the residual hull structure of J-7 since it is adjacent to power supplies inside the pens of the Sandringham Yacht Club. These forms of corrosion mitigation lie outside the scope of the Port of Melbourne Corporation and are provided for information only.

Background to decay on historic iron shipwrecks

It should be noted that the general rate of deterioration of metals on shipwreck sites is very dependent on the water depth and the flux of oxygenated sea water over the objects lying proud of the sea-bed. The overall impression of an iron shipwreck site is often dominated by the remains of the boiler, the engine and the frames that once gave the vessel its form. In warm tropical to sub-tropical waters, corroding iron and steel in seawater rapidly becomes encapsulated by encrusting organisms such as coralline algae and bryozoans (North 1982). This encapsulation begins the process of separating the anodic and cathodic sites of the corrosion cell, with oxygen reduction generally occurring on the outer surface and oxidation of the metal occurring underneath the marine growth (MacLeod 1989). Under such conditions the anodic, or oxidation, reaction is not the rate determining step in the overall corrosion process. The corrosion process results in the inward diffusion of chloride ions from the sea, through the marine growth to the corroding metal, and the outward diffusion of the metal ions towards the seaward surface.

In the absence of calcareous colonising organisms, a corroding iron wreck will generally be covered with a matrix of corrosion products and marine organisms such as algae, barnacles and tunicates. Wrecks such as the *City of Launceston* (1865) in Port Philip Bay are typical of historic iron vessels that are corroding in deep water (22 metres) in the absence of calcareous concreting organisms (MacLeod, 1991). In-situ corrosion measurements on this vessel and others in Port Philip Bay confirmed that the same corrosion mechanism operates for wrecks in this type of environment as for material that is concreted with a matrix of calcareous materials. More recently corrosion studies on submerged and riparian sites on the River Murray have confirmed that the cathodic reduction of dissolved oxygen is the dominant process in determining the overall rate of corrosion (MacLeod, 1992).

Rates of corrosion are naturally dependent on a range of microenvironmental parameters. For iron materials lying proud of or on the seabed, the primary cathodic reaction is the reduction of dissolved oxygen. For metal that is totally buried in the sediment and is not electrically connected to iron that is exposed to oxygenated waters, the major cathodic reaction will be the reduction of water and the associated evolution of hydrogen. Under such circumstances, the corrosion process is often dominated by microbiological activity (Fischer, 1983) since the presence of dehydrogenase enzymes will often control the rate of hydrogen evolution (Sequeira and Tiller 1988 & Metals Society, 1983).

Since the concretion acts as a semi-permeable membrane, a hundred years of corrosion results in a substantially different micro-environment being established around the metal itself compared with the surrounding sea. For example, the chloride concentration can be increased by a factor of 3 above the mean seawater levels and the pH can fall from the normal value of 8.2 to as low as 4.2 (MacLeod 1989-2). If the matrix of corrosion products and calcareous deposits are accidentally removed the increased access to oxygen results in accelerated corrosion of iron in a chloride-rich, acidic micro-environment, and the loss of much of the archaeological values (MacLeod,1981 & 1987). On an iron wreck any non-ferrous materials that are electrically connected to metallic iron will be protected by galvanic coupling. One result of this interaction is that all the copper, brass and bronze fittings become covered with a thin, adherent white calcareous concretion (MacLeod 1982). Once the concretion has formed, the surface is no longer biologically toxic and so it is then subject to the normal colonisation mechanisms associated with the particular marine ecology of the area.

A novel form of corrosion has been observed on historic shipwrecks where the deleterious effects of galvanic coupling on the corrosion of iron materials is observed where there has been no direct physical contact. This phenomena is now known as **proximity corrosion** and has been observed on the historic shipwreck sites of the *Rapid* (1811) and the *Hadda* (1877). These wrecks are in shallow waters at depths of 7 metres and 4-6 metres respectively. The initial research into the nature of this type of corrosion and the implications for industrial and general marine structures has been reported by North (1989).

Burial and Exposure Phenomena on Iron Wrecks

The effects of the cyclical burial and exposure of wreck materials and the effects on corrosion mechanisms is best illustrated by analysis of the site of the SS *Xantho* which was an iron screw vessel that sank off Port Gregory, Western Australia in 1872. Analysis of the corrosion layers around a copper wire in a water cooling device from the engine room showed that there were a number of corrosion layers. When the logarithm of the spacing between the layers was plotted against the number of growth rings, the linear relationships showed that the corrosion phenomena on that site can be described in terms of the liesegang phenomena, i.e. of periodic precipitation (MacLeod 1986-2). The precipitation of the copper sulphides as the corrosion products occurs with the change of the micro-environment from being aerobic, when the object was exposed to the strongly flowing seawater, to anaerobic when two metres of sand were deposited on the site. During the periods of exposure to open seawater the fitting was in a passive corrosion state and suffered negligible corrosion. Under anaerobic conditions the passivating nature of the Cu_2O film was rendered inactive and so significant corrosion took place each time the site was reburied. This type of corrosion illustrates how the corrosion mechanism of materials can change as a function of burial conditions. During the time interval associated with historic shipwrecks it is probable that significant changes have occurred on the site.

The rapidly changing nature of the seabed at Port Gregory was noted in 1864 when the *Zephyr* found a discrepancy of 2.1m in the charted water depth and grounded (Henderson 1988). In the space of the last 110 years approximately 16 bands were found in the corrosion product layers on the artefact. These changes amount to approximately a seven year cycle and it seems not unlikely that the site has been buried and exposed at least that number of times. The "newness" of the biological environment on the wreck site compared with the surrounding reef is most probably due to the fact that the whole site is periodically buried under several metres of sand. It may be that such burials are due to the scouring of the upstream beaches during heavy winter storms.

In order to properly assess the impact of changes in the site conditions, it is important to have an understanding of the phenomena that are taking place underneath the essentially protective layer of concretion. The corrosion potentials ($E_{corr.}$) show that archaeological iron is often in strongly reducing conditions with E_h values at -0.290 ±0.015 volts at pH 4.8, i.e. just below the hydrogen evolution potential for the same pH. Hydrogen has been identified as a major component of the gases released when concretions are penetrated for the first time in centuries (MacLeod 1988). Amongst the other gases were carbon dioxide (from acid dissolution of calcite and aragonite as a result of hydrolysis reactions) and methane. Analysis of the carbon isotope ratios of $^{13}C/^{12}C$ in the methane gave an isotope shift of -4.7 ppt which showed that the methane was inorganically derived via reactions such as 1

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \quad \ldots\ldots\ldots 1$$

Since bacteria effectively fractionate carbon isotopes in favour of ^{12}C, an isotope shift ($\delta^{13}C$) with a value in the range of -55 to -75 ppt (relative to the standard limestone, PDB) would have been observed for bacterially produced methane (Hunt 1979). Inspection of the carbon Pourbaix diagram shows that methane is the thermodynamically stable form of carbon under the lower portion of the range of Eh and pH (Pourbaix 1974) that have been recorded on wreck sites at depths up to 22 metres.

Effects of water movement on corrosion rates

The effects of the movement of water, and with it the changing flux of dissolved oxygen, on the corrosion rate of the iron materials was clarified in studies associated principally with the wrecks of the SS *Xantho* (1872) and HMS *Sirius* (1790) and from a longitudinal study on the *City of Launceston* in Port Phillip Bay. The water depth of these sites varies from average values of 2-21 metres. During the initial survey on the SS *Xantho* it was noted that the apparent extent of corrosion varied quite markedly. The windlass contained no solid metal and the E_{corr} values for the engine, boiler, etc. all seemed to be similar while the frames near the stern reflected lower corrosion rates. Subsequent work on the HMS *Sirius* showed systematic differences in E_{corr} between wrought and cast iron of approximately 70 mV for the same water depth (MacLeod 1989). The model also demonstrated that the corrosion rate is very dependent on water depth and the flux of dissolved oxygen. The SS *Xantho* data showed that the worst affected items such as the windlass were at a shallower depth and exposed to a localised eddying of current, while the engine was sheltered behind the boiler and was at a greater water depth. Armed with knowledge of water depth and site profiles and the way in which water moves over a wreck, it is possible to interpret the corrosion potentials on iron shipwrecks and to develop appropriate management strategies.

The temperature effects on corrosion potentials have not been directly determined, but repeated measurements of the *Xantho* boiler at Port Gregory (MacLeod 1988) over a period of four years gave an E_{corr} of -0.274±0.003 volts with the temperature at 4 metres depth ranging from 18.5-25.0°C. The small variation in E_{corr} values indicates that after more than 100 years immersion the objects are not as sensitive to temperature effects as objects at 30 days exposure (La Que 1975). It has been noted that the communities that exist around the shipwrecks are not those normally associated with the sandy bottom. This is a natural consequence of the wreck providing a different habitat for a wide variety of marine organisms. One effect of the formation of concretion on corroding iron materials is that the colonisation rate is strongly influenced by the iron. Recent work by this author (MacLeod, 1988) has shown that the average annual rate of colonisation by encrusting organisms is approximately doubled on iron substrates compared with inert wreck materials such as stone and ceramics. The anaerobic conditions that develop under the concretion result in the *activation* of microorganisms that convert inorganically bound phosphorus into a volatile phosphine (Microbial Corrosion, 1983). It appears that the encrusting organisms are able to capitalise on this source of phosphorus since there is a linear increase in the annual growth rate as the amount of phosphorus in the iron increases. An amount of 1.18 wt % phosphorus doubles the rate of concretion formation compared with the effects of iron by itself.

City of Launceston (1865)

A series of in-situ corrosion measurements were conducted on the wreck *City of Launceston* (1865) in Port Phillip Bay between 1991 and 2006 which have confirmed that the vessel is close to collapse. The apparent long-term corrosion rate is 0.119±0.014 mm/year which indicates that the average hull plate thickness will have fallen to less than 1mm of steel by the end of 2005. In this condition it is unlikely that the vessel will be able to withstand the impact of the strong storms that periodically dominate the weather patterns in Port Phillip Bay but the integrity of the site is partly assured through the retention of the concerted corrosion matrix across the hull, engine and fixtures. Interpretation of the *in-situ* corrosion parameters are at times complex, owing to the inter-connected nature of steel plates, frames and stanchions.

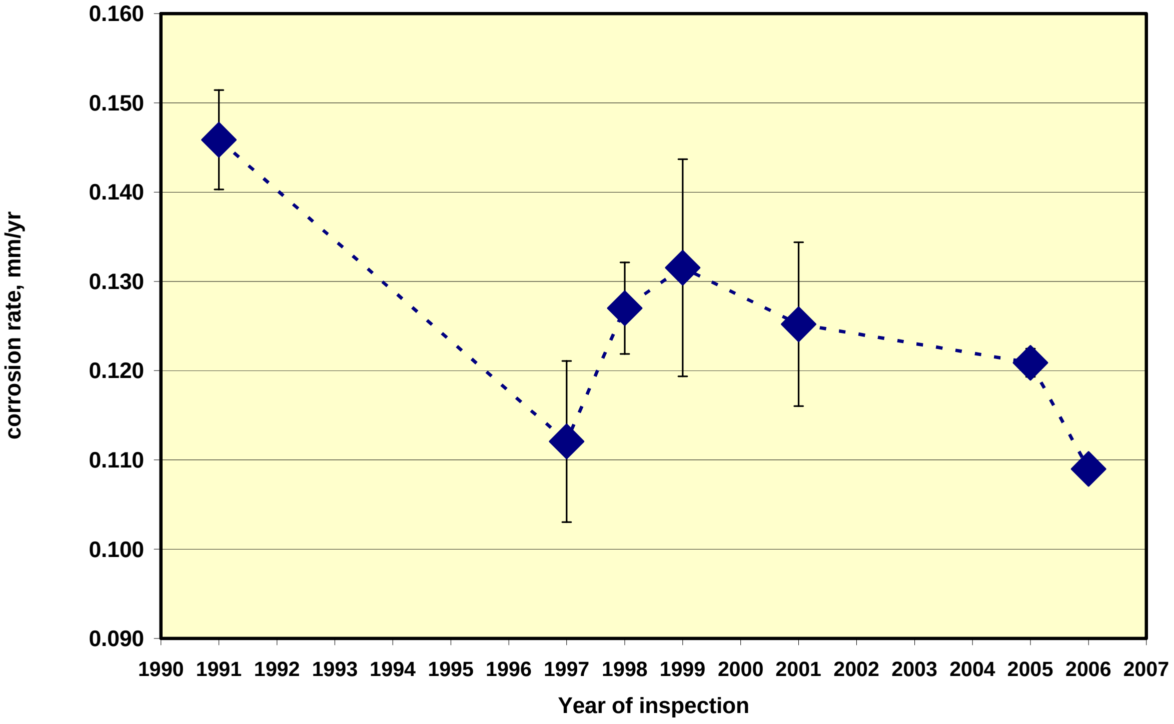

Figure 1: Plot of corrosion rate of the *City of Launceston* from 1990-2006

However, the surface pH of the corroding metal was found to be more representative of the local corrosion rate and can be used to establish the most likely sites for disintegration of the hull. Corrosion data has provided evidence of the detrimental impact of weed clearing (1997) but has also enabled the impact of re-colonisation to be determined and formed the basis for opening up the site to controlled diving tourism. The data shown in Figure 1 illustrate the beneficial effect of the cessation of scallop dredging after the 1991 inspection. Owing to the corrosion data indicating that the vessel had less than 7 years life as an intact iron wreck, the full archaeological survey and systematic excavation were undertaken. Although this work had a deleterious effect on the rate of corrosion, the recolonisation of the site and the decreased turbidity resulted in a significant decrease in the rate of decay of the wreck. Given the location of the *City of Launceston* with regard to the zones where channel dredging is planned, it is unlikely that any increased degradation will occur as a result of changes brought about by the Channel Deepening Project.

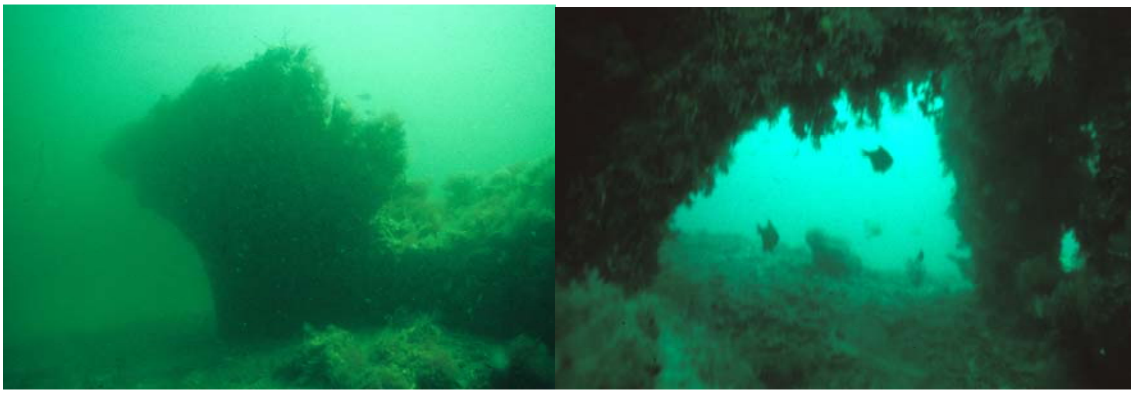

Figure 2: *City of Launceston* bow and stern sections showing concreted marine iron in 2002. © Heritage Victoria

If there is any report of major changes to the nature of the stability of the wreck after the channel deepening project has been concluded, the most likely cause of such changes will be due to the age of the wreck and that fact that it is ready to undergo a significant change in its profile on the seabed i.e. it is an impending state of advanced decay.

HMVS *Cerberus*

In 1999 the author of this report prepared an assessment of the last remaining *Monitor* style warship five years after the initial survey in 1994 concluded that unless some form of active site management was undertaken, the vessel would suffer major collapse within five years (MacLeod, 1996). The 1872 vessel was sunk as a breakwater in Half Moon Bay in 1926. A site inspection in April 1999 showed that the iron wreck was in a deceptively stable condition. The bow has been split in two and the stem post is now in two sections, which are approximately 80 cm apart. This will have made the vessel more stable in terms of providing a secondary form of bracing against wave action. The split does however indicate that the vessel is in the first stages of final collapse. Along both sides of the vessel the frames, which were supporting it when the site was inspected in 1994, have all collapsed and been flattened. The heavy sheet steel, which had been attached to the armour belt as a further protection, has been peeled off in large sections and it now lays in heaps along side the wreck. That the vessel has collapsed further on the seaward side is due to the more rapid rate of corrosion on the starboard side due to greater water movement. Over the period since it was sunk, the net effect of the differential rates of corrosion has lead to a greater reduction in residual metal thickness on the starboard side. It is not likely that the vessel will topple right over but it is probable that it will become canted at a greater angle.

Of great concern is the scouring around the stern of the wreck which has seen a large hole, about 2 metres deep, develop around the counter stern. This has exposed the wreck almost to the keel, which is lying directly on the bedrock of the ocean floor. One advantage of this scouring is that it is possible to determine that the average amount of sand cover around the wreck is about two metres and this can have important implications for the erection of any protective devices such as sea walls or cofferdams. The scouring did allow much better viewing of the remaining structural elements which are supporting the vessel and these look very thin and it is unlikely that the vessel will continue to be stable in another heavy storm. With the lack of support around the stern it is likely that another surge will see the rear of the *Cerberus* break off around the line of the aft turret. If this occurs the only realistic option is to let the vessel gradually collapse and become a managed dive site. Once the collapse has been completed, the wreck could be filled with sand, to prevent penetration diving, and the site managed with glass-bottomed boats having rights to take tourists to the site and to view it from above.

It is not possible at this point to determine which options are the best to follow since we do not have data on residual metal thickness of the supporting frames and deck beams under the turrets. If the original specifications can be found it is possible to do an estimate of the residual thickness. Present indications are that the steel was ½" thick and if this is the case, it is likely that there will be only a few mm of sound metal left in this structure. It would be wise to perform some detailed review of this issue since if there is essentially little material to support the overall integrity of the deck, then any attempts to support one section and to raise the profile back to the pre-collapse levels could result in the vessel breaking its back and good money being wasted. Engineering calculations need to be made to see if the stabilisation option is realisable. This work should be done prior to commissioning any work on building a cofferdam or any other such stabilisation works around the wreck. There seems to be little point in pursuing a major engineering works program of building a protective wall or barrier around the wreck if it is not going to be able to lead to the overall desired outcome of preservation of the original profile of the wreck.

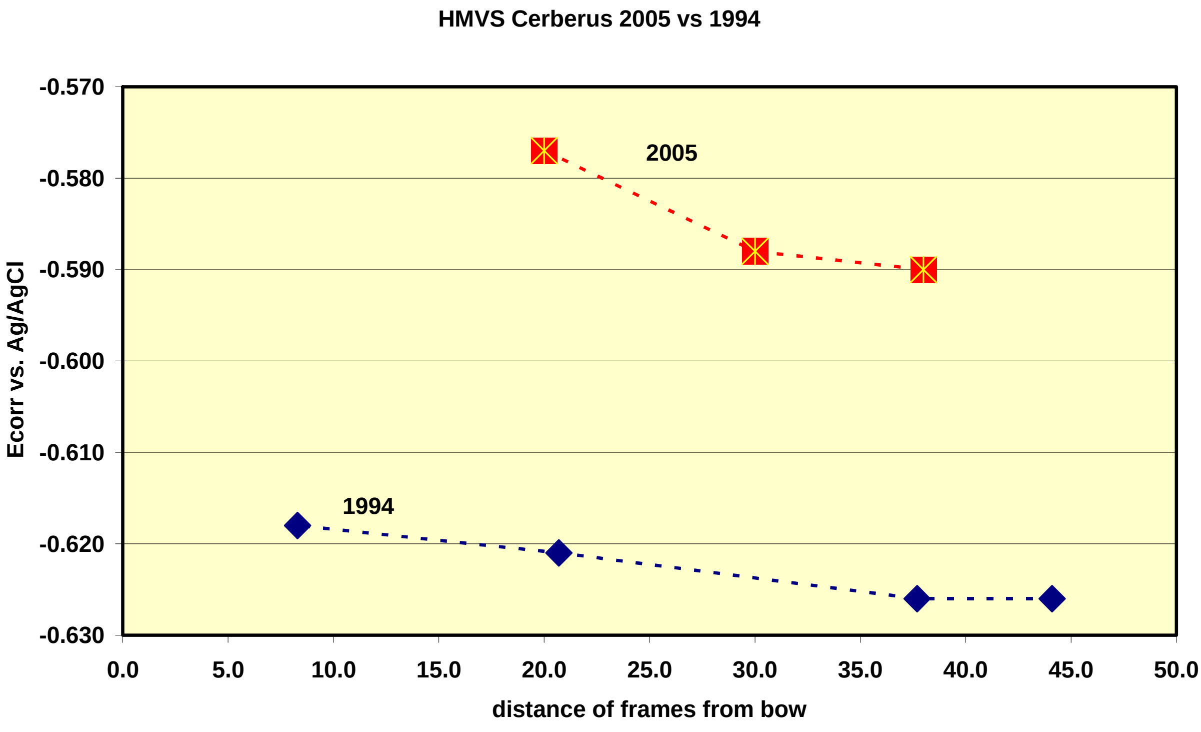

Figure 3: Plot of the Ecorr of the HMVS *Cerberus* frames as a function of time.

With concreted marine iron, a less negative E_{corr} value indicates that the object is corroding at a faster rate than those which have a more negative value. The data in Figure 3 clearly indicates that the HMVS *Cerberus* is in an advanced state of decay and that the rate of corrosion has increased between 1994 and 2005 by approximately 24%. Some work has been done to stabilise the structure and this has involved the removal of the four massive guns from the two turrets in the hope that the reduced weight will lessen the stress on the armour belt and deck.

Figure 4: HMVS Cerberus above and below water in 1999, with the author inspecting hull plates
© Heritage Victoria

Figure 5: HMVS Cerberus with guns removed from one turret and being extracted from another 2004
© The Age

Despite the good work done to stabilise the upper works of the HMVS *Cerberus*, the long exposure to the highly corrosive splash zone environment of being part in and part out of the water has meant that major decay of the ships internal structures has taken place since 1926. Given that there is no form of support for the vessel and that it is currently split at the bow, it is very likely that a naturally occurring storm will produce sufficient wave action to cause a further major collapse of the wreck. Such events are to be expected within the normal “once in ten years” storm cycle and should not be considered to have anything to do with the channel deepening project. The nature and the extent of the changes to the local marine environment caused by the channel deepening project mean that it will have a negligible effect on the fate of the HMVS *Cerberus*.

J-Boat J7

The vessel was inspected in January 2005 and found to be in an advanced state of decay with significant elements such as the stem being loose to touch and several frames had become electrically disconnected from the remains of the submarine which lie deeply settled in a very fine silted bottom of the Sandringham Yacht Club (see Figure 6). The bow is completely corroded and the whole general degradation processes are similar to those of the HMVS *Cerberus* in that the vessel is part in and part out of the water The upper parts of the outer hull plating are significantly corroded and only the frames remain. The diving planes which are still in position. Owing to the fact that the submarine is in the lee of a number of pontoons it is relatively sheltered from the normal fetch and toss of wave action, unlike the HMVS Cerberus which is fully exposed to the corrosive forces unleashed by fully oxygenated seawater.

Figure 6: J Class submarine J7 at the Sandringham Yacht Club, © Heritage Victoria

Given the location of nearby 240 volt AC power it is a relatively simple process to purchase an appropriate DC rectifier unit and mixed metal oxide anodes and protect the submerged part of the submarine. The external and exposed upper works could be treated with a fish oil based product and this would prevent the ingress of moisture and greatly reduce the corrosion rate. Given that the wreck lies well within the yacht club boundaries the major environmental factor affecting its rate of deterioration is the increased water movement associated with recreational boating activities in the pens which are immediately adjacent to the wreck. It is most unlikely that the J7 submarine will suffer any adverse effect that could be ascribed to changes in current or physico-chemical changes brought about by the Channel Deepening Project.

Notes:

PDB PeeDeeBelemite. PDB is the acronym for the mineral which is a reference sample of a Cretaceous belemnite, *Belemnitella Americana*, from the Peedee formation in South Carolina, in the United States of America. The carbon dioxide evolved from the reaction of the limestone with 100% phosphoric acid at 25.2°C is used as a standard in carbon isotope measurements for determining the $^{13}C/^{12}C$ ratios. The details are found in Craig, 1957.

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Appendix I: Details of qualifications and experience of reviewer

Dr Ian Donald MacLeod

Executive Director, Collections Management and Conservation
Western Australian Museum

Ian MacLeod has been 28 years of experience in the corrosion and conservation of metals recovered from historic shipwrecks. He has published more than 110 papers on applied chemistry, corrosion and conservation science. His electrochemical studies began with polarography of metal fluorides in liquid anhydrous hydrogen fluoride and continue in shipwreck sites, car engines, boats, planes and deterioration mechanism in historic cemeteries. He has conducted in-situ research on corroding metals on shipwrecks around Australia, Scotland, Canada, USA, Portugal, Finland and Micronesia. He was a Senior Fulbright Fellow in 1993 studying at the Smithsonian Institution in Washington, D.C. and the Getty Conservation Institute in Los Angeles. He was elected a Fellow of the Australian Academy of Technological and Engineering Sciences (FTSE) in 2002. He is a Fellow of the Royal Australian Chemical Institute and a Fellow of the International Institute for Conservation of Historic and Artistic Works. He was awarded a Centenary Medal in 2003 for “For service to Australian Society in metallurgical science and engineering” by the Prime Minister.

Ian advises heritage managers on conservation options for underwater sites and for objects recovered from shipwrecks. He liaises with indigenous communities on conservation issues for rock art. He is a Board member of the Australian American Catalina Memorial Foundation and the Swan Bells Foundation. He was for six years a member of the Directory Board of the International Council of Museum’s Committee for Conservation. He is on the Editorial Board of *Reviews in Conservation.*

Shipwreck in-situ corrosion and conservation studies:

- Conservation of the US confederate submarine HL Hunley from Charleston in South Carolina, the world’s first submarine to sink an enemy warship.
- Corrosion studies on former HMAS’s Swan and Perth
- Isle of Mull, Scotland on a civil war frigate
- Portuguese shipwreck from 1786 off Peniche, Portugal
- Teaching and working on Finnish shipwrecks
- HMS *Sirius* (1790) flagship of the First Fleet off Norfolk Island
- World War II aeroplanes and warships in Chuuk Lagoon
- Corrosion survey of shipwrecks in Fathom Five underwater park, Lake Huron, Canada.

He project managed the move of 3.5 million objects and the building of an integrated collection storage and research facility during the period 2003-2005 at a cost of $11 million.