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Physical Oceanographic Assessment of the Nautilus EIS for the Solwara 1 Project

Prepared for the Deep Sea Mining Campaign

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John has over twenty years experience in projects related to ocean monitoring, tidal analysis, and hydrodynamic modelling. He has numerous publications and technical reports as well as wide experience in teaching, consulting, and shipboard observations. Most of his work has been in “marginal seas” similar to the Bismarck Sea, as well as in the deep Pacific Ocean and on the shallower waters of the continental shelf.

His diverse background includes several years in north Queensland modelling residence times in the Great Barrier Reef lagoon, half a year each in Canberra and India modelling coastal freshwater aquifers, and a similar amount of time in Alaska co-authoring a book on tides. His previous shipboard research has taken him on two long expeditions through the islands of Indonesia and The Philippines, several crossings of the Tasman Sea, and over a dozen cruises in the Gulf of Alaska. He has also conducted workshops in nine different Pacific Island nations as part of an AusAID program designed to promote local environmental management.

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Foreword

The Nautilus Environmental Impact Statement for the Solwara 1 Project was submitted to the PNG Department of Environment and Conservation (DEC) in 2008. In 2009 DEC issued the final environmental permit for the development of the Solwara 1 project followed by the granting of a 20 year mining lease in January 2011. The mine is scheduled to commence commercial operation in late 2013.

Public concern in PNG over the Solwara 1 mine has grown over the past several years. The outrage expressed by PNG civil society during 2012 is unprecedented. Never before in PNG's history has a development proposal galvanised such wide ranging opposition - from representatives of local communities, students, church leaders, non-government organisations, academics, staff of government departments and national and provincial parliamentarians.

Foremost in people's minds is the fear that PNG is being used as a laboratory for the experiment of sea bed mining and that insufficient research has been conducted on deep sea ecosystems and the impacts of sea bed mining on marine species and coastal communities. Already, the people of New Ireland Province have witnessed cloudy water, dead tuna, and the lack of response of sharks to the age old tradition of shark calling. These changes are attributed to Nautilus's pre-mining activities in the lead up to commercial mining and raise great concern about the sustainability of local livelihoods and customs.

The [Environmental Impact Statement \(EIS\)](#) was the key document considered by the PNG National Government in the granting of the environmental permits and operating licence to Nautilus. The EIS should provide a clear and rigorous assessment of potential hazards and impacts. It should provide the groundwork for comprehensive risk analysis and the development of mitigation strategies. Most importantly the

EIS should have provided a solid basis for the Government of PNG to decide whether to approve this project and if so, under what conditions.

This review demonstrates that the EIS fails to provide solid ground for informed decision-making.

We are aware that a review of the oceanographic components of the EIS was conducted in 2009 by Cardno Investments Pty. Ltd., an Australian based company specializing in coastal engineering and infrastructure developments. We have not been able to obtain a copy of this review. Nautilus advises that the recommendations of the review have been addressed by the PNG Department of Environment and Conservation in the permit conditions. But these also are not in the public domain.

Solwara 1 is the world's first deep sea mining experiment. As such it demands extremely careful attention to scientific detail and transparency in decision making. Important next steps are to make available the full data set behind the EIS, the earlier Cardno review of oceanographic components of the EIS and the conditions of the permits issued by DEC.

This information must be made available in a form that can be readily understood by the people of Papua New Guinea and especially by the people of New Ireland and East New Britain provinces who are most at risk from Solwara 1. I re-iterate the words of the author of this review, "The people of PNG deserve better."

Dr. Helen Rosenbaum
Coordinator,
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Preface

As I prepared this review of the physical oceanographic elements of the [Nautilus Environmental Impact Statement \(EIS\)](#), what struck me most was how nothing seems to have been learned in the two decades since the original Ramu Nickel EIS was written. My critique of the Ramu EIS (on behalf of the Mineral Policy Institute in 2001) could be summarised as “great data set, shame about the analysis”. And pretty much the same describes my response to the Nautilus EIS.

Ramu Nickel Limited and its partners wanted to discharge the mine tailings into the coastal ocean. Local Madang landowners opposed the plan, and it led to a case before the National Court. The landowner’s case was largely based on scientific evidence that my colleagues and I provided. My testimony was that the oceanographic consultants had done the field work well, but their analysis of it was weak. For example, they presented plots which implied that the bottom currents at the shallow dumping site were onshore, and that upwelling currents would quickly sweep the dissolved fraction up into surface waters. Despite these plots indicating worrying risks to local communities, they were presented without analysis – in fact, without comment.


The Nautilus EIS shows much the same pattern. In fact, the same company (Coffey Natural Systems, then known as NSR) did the physical oceanography for both, so perhaps it should not come as a surprise. The physical oceanography and hydrodynamic components of the EIS are, to put it kindly, second-rate. The modeling is completely unacceptable by scientific standards. Moreover, every error and every omission in the analysis downplays the risk. This is also what I saw in the Ramu Nickel EIS. For example, in the Nautilus EIS, an instrument was deployed to monitor surface currents, but the data was not presented.

Most of my work as an oceanographer has been in so-called “marginal seas” similar to the Bismarck Sea, as well as in the deep Pacific Ocean and on the

shallower waters of the continental shelf. But the real point is that one does not have to be a “deep-sea” or “marginal-sea” or any other oceanographic specialist to pick out the shortcomings in the oceanographic elements of the Solwara 1 EIS. They are so basic that I could have written the same review 27 years ago while still a student.

While working on this review, I contacted Nautilus and the modellers to seek further details. This led to three important pieces of information. Firstly, Nautilus confirmed that surface current data existed, but did not consider it to be relevant to an environmental impact statement, hence had deliberately omitted it. (The implications of this are described in Section 3 of this report.) Secondly, the modellers (APASA) claim to have done sensitivity studies and other analysis that would have lent their results some credibility, but had chosen not to mention them in their report. Thirdly, the sediment deposition and plume data (the subjects of sections 4 and 5 of this review) were reviewed by an independent consultant to the PNG Government. It has not been possible to obtain a copy of the reviewer’s report. Thus it is not known whether or not this review led to changes to the predicted impacts. According to Nautilus and the consultants responsible for the EIS’s oceanographic modeling, the reviewer ran their own model with the same inputs and obtained the same results as in the EIS. So perhaps this does address concerns about the accuracy of the models. However, this approach fails to address the findings that data inputs to the modeling were flawed (see Sections 4 and 5 below). By inputting the wrong data, the reviewer could well have made same wrong predictions about impact.

In regards to the modeling, I decided to base my review only on what is included in the EIS, because this is what was submitted to the PNG government. As far as the public can tell, the EIS was the basis on which the PNG Government granted the 20 years operating licence to Nautilus. I accept that the modeling validation may have

A photograph of two young children playing in the water. The child in the foreground is holding a large, dark blue inflatable ring. The child in the background is partially visible, also in the water. The water is clear and blue, and the background shows a shoreline with some vegetation.

The EIS fails to provide the basic information needed to assess the risk of pollution of the environment or the risk to local communities.

been more comprehensive than was reported, and that there may be additional work that supports the results in the EIS. However, that remains to be seen, and it does not lend support to the PNG Governments' decision to issue the operating licence

The people of PNG deserve better. They should be able to feel confident that the approvals process is open and based on the best available science. *The EIS fails to provide the basic information needed to assess the risk of pollution of the environment or the risk to local communities.*

As time goes by, the people of PNG seem to be increasingly concerned that government agencies are letting them down. Hopefully, companies like Nautilus will also come to see that ramming through an EIS based on second-rate science is not in their own best interest.

I conclude with three suggestions for future development proposals:

- Companies need to make it clear to the consultants that they are not looking for “greenwash”. The purpose of the EIS is to aggressively look for every potential source of risk, to properly evaluate it, and to spell it out clearly.
- It should be ensured that EISs are subject to strong independent review by third party experts completely dissociated from the local approvals process and that the results of such reviews be made publicly available.
- If mining work then commences, the original EIS consultants should have nothing to do with the environmental monitoring.

Finally, lest it be thought that I am anti-mining, I have worked for mining, gas and oil companies in Australia, Papua New Guinea, Saudi Arabia, California and Alaska, and continue to do so. If I am against anything, it is against incompetence, especially in environmental impact studies.

Dr John Luick
5 November 2012

List of Abbreviations

ADCP	Acoustic Doppler Current Profiler
APASA	Asia Pacific Applied Science Associates
ASA	Applied Science Associates
CHEMMAP	Chemical Discharge Model System
EIS	Environmental Impact Statement
HYCOM	Hybrid Coordinate Ocean Model
NOAA	National Oceanic Atmospheric Administration
ROV	Remotely Operated Vehicles
PVD	Progressive Vector Diagrams

1. Introduction

The Canadian mining company Nautilus Minerals Inc. (Nautilus) is set to embark on the unprecedented extraction of metals from the deep sea floor. The mining project, known as Solwara 1, will extract gold and copper from the floor of the Bismarck Sea in Papua New Guinea. It is the first of a potentially large number of deep sea mining projects within the wider Pacific Islands Region.

The Solwara 1 deposit lies at approximately 1,600 metres depth. The site is bordered on the north and east by the island of New Ireland (only 30 km away at its nearest point) and to the south by the island of New Britain. The deep sea mining site is 50 km north of the town of Rabaul in East New Britain Province.

This review was commissioned by the [Deep Sea Mining Campaign](#), an affiliate of [Friends of the Earth Australia](#), for the purpose of providing a detailed analysis of the adequacy with which the Nautilus Solwara 1 Environmental Impact Statement (EIS) (Coffey Natural Systems, 2008) addresses physical oceanographic aspects of the proposed mining operation.

In particular, the report is intended to identify shortcomings in the [Nautilus EIS](#) and describe the implications of these in terms of possible environmental management risks. It assesses the Nautilus EIS on physical oceanographic water properties and currents for accuracy and completeness, with emphasis on the presentation and analysis of the field data and computer modelling contained in the EIS.

Understanding these oceanographic properties is essential to assess the level of risk that human and ecological communities are likely to face from metals and other contaminants associated with the Solwara 1 mining operation. Of particular concern is whether upwelling and currents could carry pollutants up out of the deep sea or from spills and leakages into marine food chains where they may poison marine species and the humans that

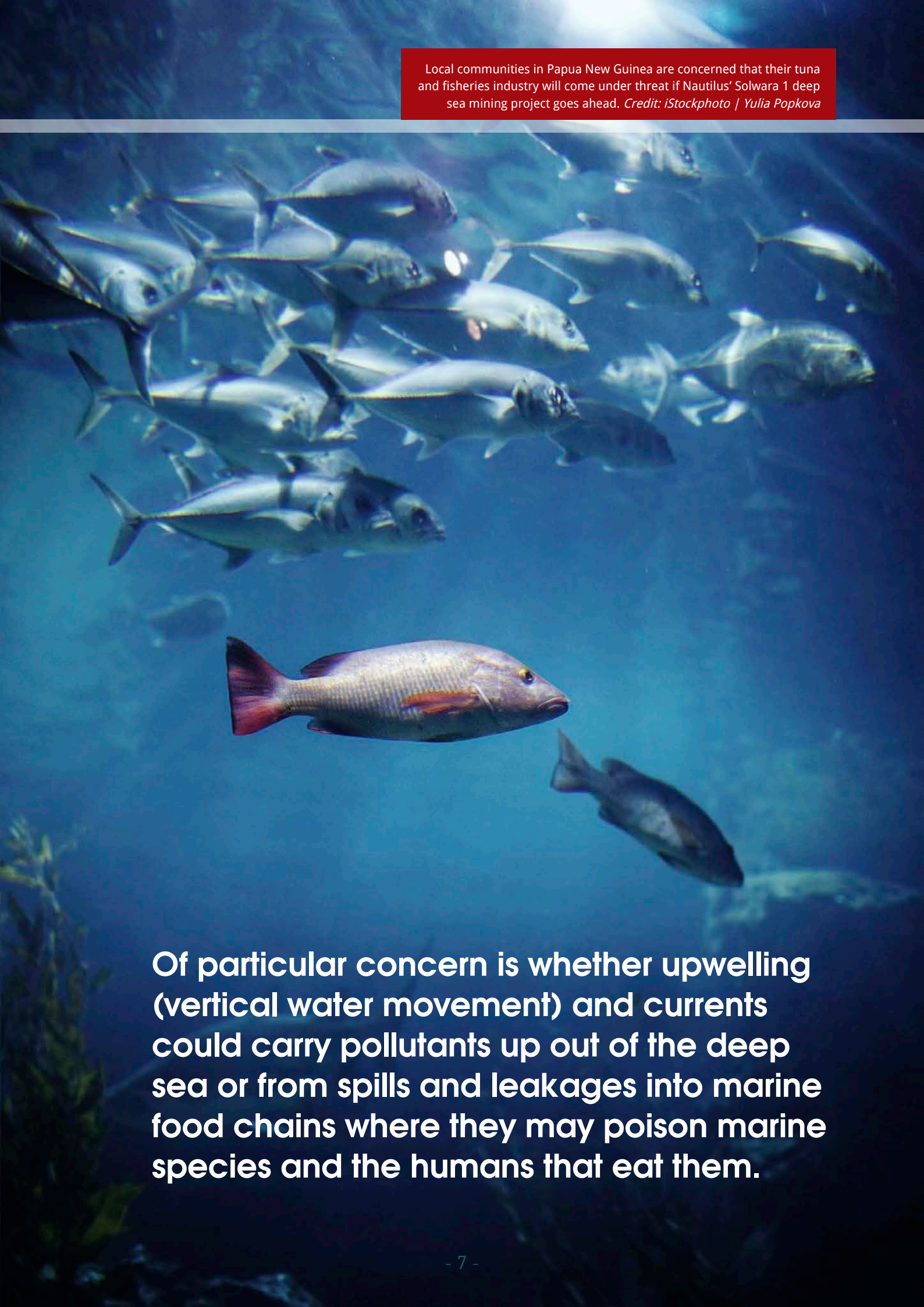
eat them. Two key sources of pollution are a focus: the settlement and dispersion of waste material removed pre-mining; and the spread of the plume created by the discharge of return water.

A previous review of the Nautilus EIS was conducted by Professor Rick Steiner on behalf of the Bismarck-Solomon Seas Indigenous Peoples Council ([Steiner, 2009](#)). It provides a valuable project overview and a critique of the impacts projected in the EIS. Unfortunately, at the time of that review, the important information contained in the Appendices to the Main Report was unavailable. Thus Steiner had to rely on the main report only, which contains only sketchy references to the physical oceanography and sedimentation modelling.

This review assumes the reader has access to [Steiner \(2009\)](#) as well as the full EIS. The reader can find overviews of the Solwara 1 project in both of those documents and also in the Deep Sea Mining Campaign's, [Out of Our Depth: Mining the Ocean Floor in Papua New Guinea](#).

What is Upwelling?

The process by which deep ocean water is brought towards the surface. Usually, the motion is mostly sideways with a small upwards component.



Local communities in Papua New Guinea are concerned that their tuna and fisheries industry will come under threat if Nautilus' Solwara 1 deep sea mining project goes ahead. *Credit: iStockphoto / Yulia Popkova*

Of particular concern is whether upwelling (vertical water movement) and currents could carry pollutants up out of the deep sea or from spills and leakages into marine food chains where they may poison marine species and the humans that eat them.

2. The Contents of this Report

As described in the introduction, this review is primarily concerned with the sections of the EIS that describe currents, upwelling, and other oceanographic properties that may bring coastal communities and marine ecosystems into contact with pollution associated with the operation of the Solwara 1 mine.

The report is structured to provide the reader with an overview of key issues and the conclusions drawn for each aspect reviewed. A detailed technical analysis then follows to support and explain each overview. We hope this enables the non-scientist to understand the review's key findings while providing other readers with a greater level of detail

Thus the review focuses on the following sections of the EIS:

The Main Report (which is Volume A of the EIS) contains several references to oceanography and hydrodynamics including Section 2.2.5 (which mentions a few general past reports), Section 7.1.3 (which reviews recent tsunamis in the area), Section 7.5 (which reviews the regional oceanography) and Section 9.5 (which discusses plume dispersion and sediment deposition).

Section 2.2.5 of the Main Report references four supporting studies. Only one of these (Coffey Natural Systems, 2008) is included in the EIS and reviewed here. Of the other three, one (Cresswell, 2007) is a compilation of existing oceanographic information, one (Triton, 2006) summarises commercial sources of meteorological and oceanographic data, and the final (RPS Metocean, 2008) “summarises the analysis carried out and the data prepared to determine specific meteorological and oceanographic design criteria for the components of the mining system”. In other words, the Cresswell and Triton reports were intended as background information, and the RPS Metocean report is directed to engineering requirements. Some of the contents

are alluded to in the EIS, but do not appear to be critical to its findings.

Section 7.5 of the Main Report reviews the oceanographic fieldwork and data analysis conducted by Coffey Natural Systems (Coffey). The discussion of oceanography in the Main Report is rather general with the most relevant parts contained in Appendix 3.

Appendix 3: Oceanography at Solwara 1 (located in Volume B Appendices 1-3, p247). Written by Coffey, this brief Appendix describes the measurement of currents and the presentation and analysis of current data. It is reviewed in Section 3 of this report.

Appendix 11: Modelling the Dispersion and Settlement of Sediment Removal Operation Prior to Mining at the Solwara 1 Mining Lease, Papua New Guinea (located in Volume B Appendices 8-15, p 159). This Appendix is by Asia Pacific Applied Science Associates (APASA). It attempts to quantify the dispersion and settlement patterns of waste material removed prior to mining. It relies on computer modelling (using SSFATE) and forms the basis of Section 4 of this report.

Appendix 12: Modelling the Dispersion of the Return Water Discharge Plume from the Solwara 1 Seabed Mining Project Manus Basin, Papua New Guinea (located in Volume B Appendices 8-15, p 179). In this Appendix APASA use the CHEMMAP model to attempt to quantify the spread of the plume created by the discharge of the return water. It is reviewed in Section 5 of this report.

3. Currents around the Solwara 1 Site

3.1 Overview of the Review's Findings

The EIS relies on three “tools” to present data relating to the direction and speed of currents at different depths in the vicinity of the Solwara 1 site. These tools are Progressive Vector Diagrams (PVDs), “current roses” and colour-banded time series. Nautilus’ data about currents is provided by meters known as Acoustic Doppler Current Profilers. The placement of these meters is represented in Figure 3.5, Appendix 3 [Figure 1 in this review].

Although much of the oceanographic data is to a high standard, its analysis is not. The presentation of data using the three tools mentioned above is uninformative - to the extent where this could be construed as misleading.

The PVDs do not contain sufficient information to tell us about the speed of currents. In addition, no current measurements are presented for surface and near surface waters. The only mention of surface currents in the EIS (section 7.5.1) implies that they flow to the northwest, avoiding landfall before entering the Pacific Ocean. This is significant, as in this respect the EIS disagrees with published research showing that surface currents at this site flow southeast, towards New Ireland Province for much of the year (Hristova and Kessler, 2012).

Nautilus maintains that surface current data was collected but not presented in the EIS as it does not expect surface spills to occur under normal operations due to the company’s careful engineering design (Personal Communication, 24 October 2012). According to Nautilus, an accidental spill response will be addressed by the Environmental Management Plan. However, the omission of the surface data from the EIS remains of concern in the light of the independent research showing currents flowing towards New Ireland and also the possibility of upwelling which is discussed below.

The other analytical tools used in the EIS – the current roses and colour-banded time series – are rarely

used in scientific publications because they lack the depth of information required to accurately present and analyse data. The Nautilus EIS further adds to these deficiencies with questionable data and poor analysis.

The legends for the current roses [Figure 2] imply that all currents, including those with speeds below the accuracy threshold of the ADCP are measured. Including such currents is likely to distort the results. This means that the EIS’s interpretations of current direction and the relative duration of current speeds are unreliable.

From the time series data presented in Figures 3.6 and 3.7, Appendix 3 [Figure 3 in this review], Coffey confidently concludes that vertical currents generally move downward above the Solwara 1 mound with some periodic upward velocities (upwelling). However, an examination of the time series yields the opposite conclusion – that there are sustained periods of upwelling of nearly 1000 m/day. Clearly this conclusion carries significant implications for the possibility of pollution from Solwara 1. A rigorous analysis is required to determine the extent of this risk.

Tides in the Bismarck Sea are known to be strong with tidal excursions¹ over 20 km at certain times (Lyard et al, 1994). Given that Solwara 1 is only 30 km offshore, it is important to determine how close to New Ireland Province the tides may be able to transport mine derived pollution. The EIS fails to examine this aspect.²

In summary, there are serious omissions and flaws in information presented in the EIS about surface currents, the speed and direction of currents at different depths, and about tides. These deficiencies mean that several important risks to the marine environment and to local communities cannot be determined. These include the risks of pollution from spills from vessels at the surface, leakage from the riser or discharge pipes, and of upwelling dis-

persing metals from the mining activity or from the discharge water. The implications of these risks – especially for the people of New Ireland and possibly also East New Britain Province – demands that a thorough and independently verified analysis of currents be conducted as a basis for a comprehensive risk assessment.

The key aspects of this overview are explained further below.

3.2 Detailed Technical Review of Current Measurements, Presentation and Analysis

3.2.1 Lack of Surface Current Data

No data for the surface currents is presented. The only mention of surface currents misleadingly implies they flow to the northwest, avoiding landfall before entering the Pacific Ocean. The uppermost level of currents shown is from 243 metres below the surface. These are representative of the St Georges Under-Current, whose flow is independent of the surface currents.

Other sources are readily available for estimating the prevailing surface currents and should have been presented in the EIS, along with any direct observations made by Coffey. For example, ARGO float data (Hristova and Kessler, 2102) are in the public domain, and these indicate that the surface currents are shoreward (towards New Ireland) for much of the year. Given the worrying implications of this research for New Ireland Province, the EIS should have made a concerted effort to analyse surface current data. As described in Section 3.1 above, Nautilus maintains such an analysis was unnecessary for the EIS.

Several well-established operational numerical models, including the HYCOM global model and the NOAA suite of Pacific Ocean regional models, are also publicly available. These all provide surface current estimates over a number of years. It appears that Coffey chose not to use any of these well-known models. This seriously compromises the EIS,

as knowledge of the surface currents is critical to assessing risk.

3.2.2 Current Measurements and Presentation: Progressive Vector Diagrams

Figures 7.13 in Section 7.5 of the Main Report and 3.12, Appendix 3 [Figure 4 in this review] present PVDs based on ADCP observations. The PVDs and the accompanying text comprise the bulk of the contribution made by the EIS towards understanding current characteristics at the Solwara 1 site. (As explained below, the other diagrams employed are of little value for interpreting the flow regime).

PVDs are based on observations at a single point. In essence, they show the path that a molecule or small volume of water would follow if all of the surrounding currents were the same as at the ADCP. For example, in the upper left hand column in Figure 3.12 [Figure 4] the molecule or small volume would have travelled to the northwest at an apparently uniform speed. The axes are marked off in kilometres, and the observations span a period of one year. Naturally, the surrounding currents are not all the same, so the diagram is simply a compact way of providing an integrated view of the currents recorded by the ADCP.

In normal oceanographic practice, PVDs are presented with dates at regular intervals along the path. This enables the reader to deduce something about the velocities. The PVDs in the EIS do have arrowheads along the path, but the dates are not indicated. We are told that the total length of time is twelve months, but we cannot assume that the arrowheads divide the path into equally-spaced four-month intervals because different panels have different numbers of arrowheads (i.e., the arrowheads may have been manually placed at random). Thus we learn nothing about the current speeds during different periods. This unprofessional presentation seriously reduces the scientific value of the diagram.

In addition, the PVDs suffer from the serious omission of surface and near surface level data. As described above, the shallowest level PVD shown is at 243 metres below the surface.

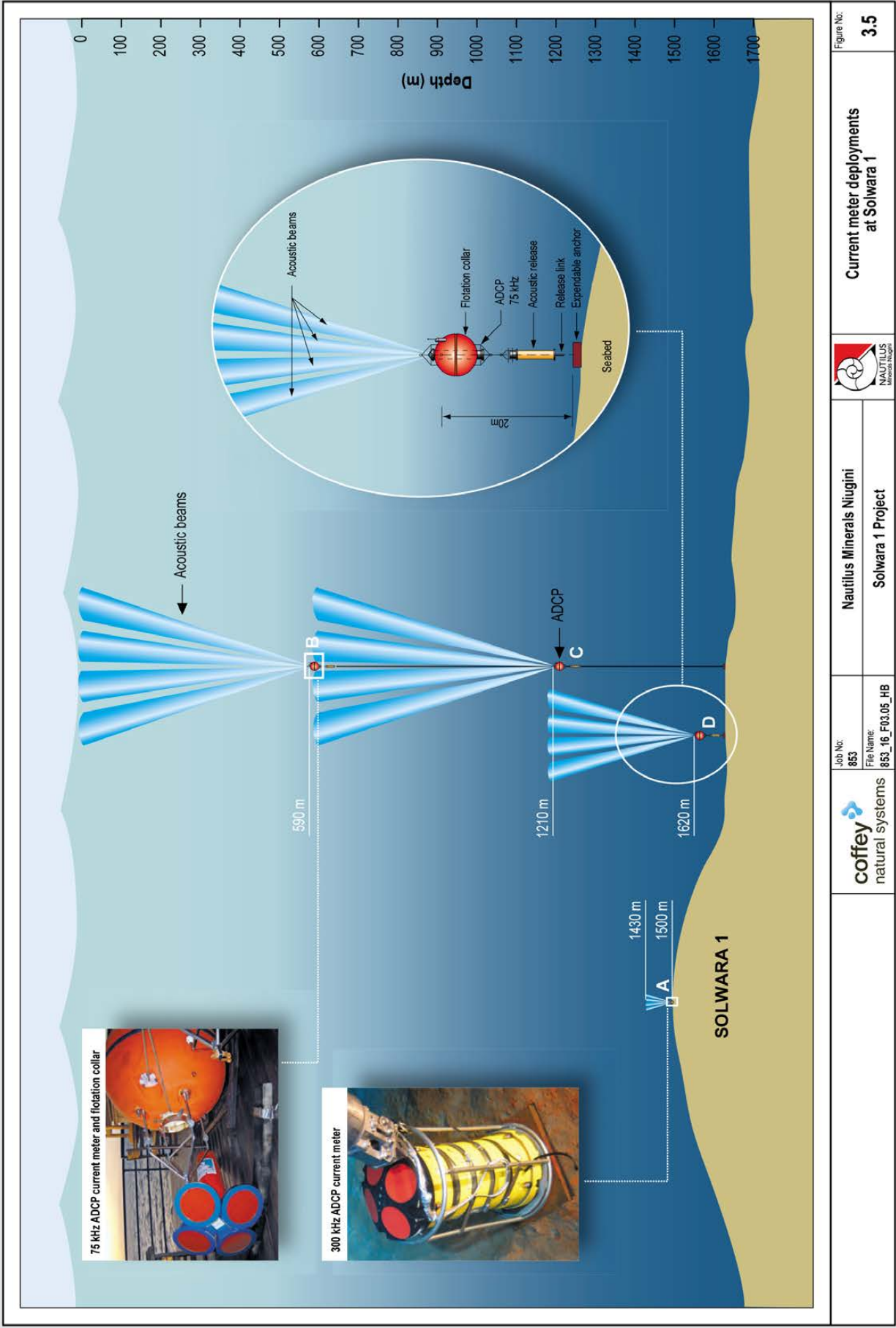


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Volume B - Supporting Studies, Figure 3.5, Appendix 3, p265

Figure 1: Nautilus' data about currents is provided by meters known as Acoustic Doppler Current Profilers (ADCP), the placement of these meters is shown in the diagram above.

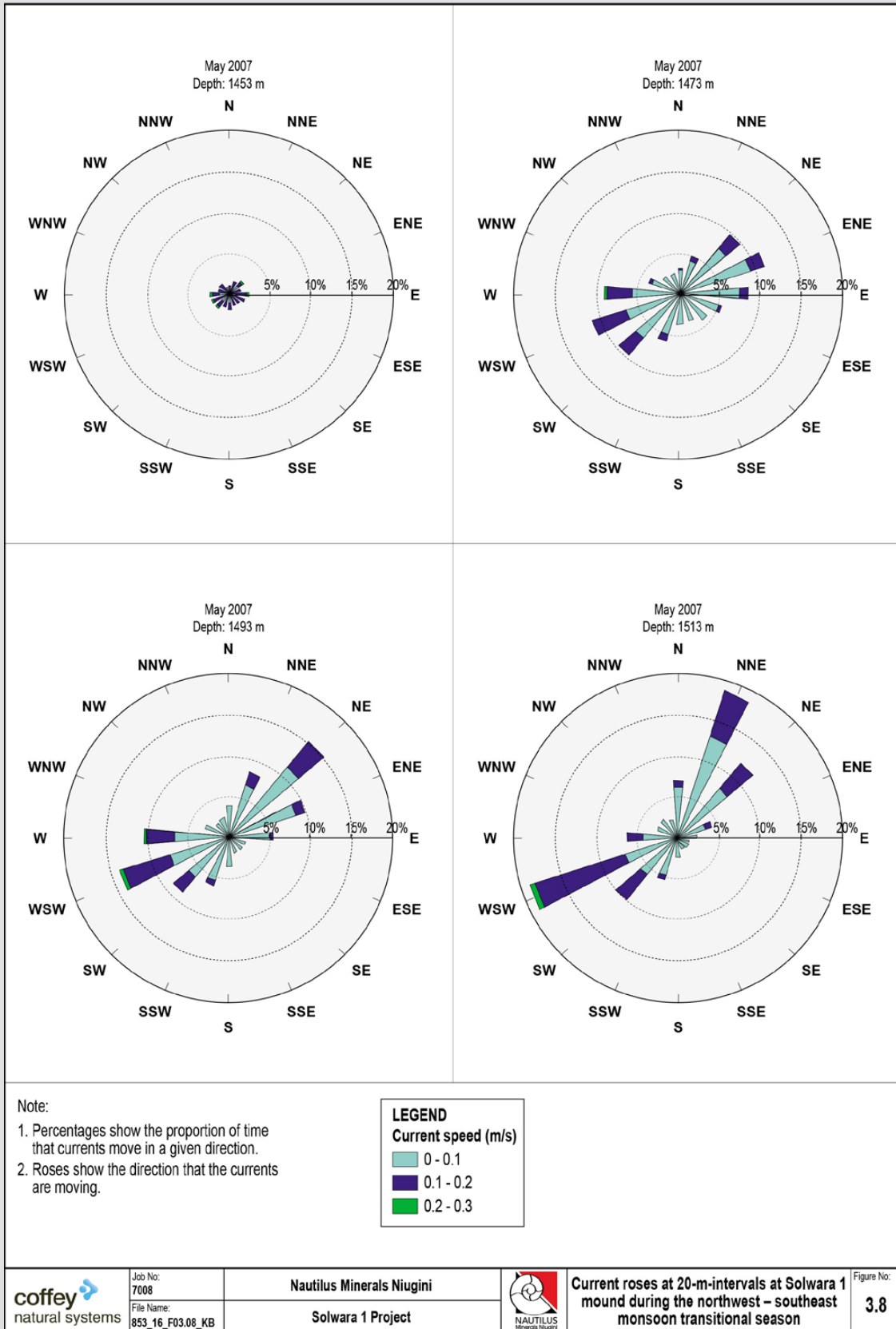


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Volume B - Supporting Studies, Figures 3.8-3.11, Appendix 3, p270-273

Figure 2: The legends for the current roses imply that all currents, including those with speeds below the accuracy threshold of the ADCP are measured. Including such currents is likely to distort the results. This means that the EIS's interpretations of current direction and the relative duration of current speeds are unreliable.

3.2.3 Current Measurements and Presentation: “current roses” and colour-banded time series

Appendix 3 of the EIS provides additional information on the oceanographic fieldwork and data analysis in the form of “current roses” (Figures 3.8 - 3.11 and 3.13 – 3.16, Appendix 3) and colour-banded time series of the vertical profile of currents (Figures 3.6 and 3.7, Appendix 3). These latter diagrams are automatically generated by the ADCP software.

The type of colour-banded time series that were used can be useful for verifying instrument performance but lack the depth of information required to accurately present and analyse time series data. This is particularly the case for assessing vertical velocity. Hence they are rarely found in scientific publications.

Despite this, Coffey appears to confidently conclude from Figures 3.6 and 3.7, Appendix 3, that vertical current velocities are generally downward above the Solwara 1 mound, with some occasional upward velocities. This conclusion is unsubstantiated by the data presented. One could equally conclude from the plots that there are sustained periods of upwards velocity at over one cm/second, or nearly 1000 m/day. (Upwards velocity of at least 1 cm/second, is indicated by the colour yellow in the vertical velocity plots.)

If this alternative upwelling scenario were to be verified by further analysis, it would have serious implications for risk from the dispersion of metals and other contaminants. However, the EIS uses its own interpretation to downplay the possibility of upwelling and thus of risks. Careful statistical analysis is required to determine the extent to which upwelling does occur. In all likelihood, the ADCP data contains vital information regarding upwelling throughout the water column, particularly near the seabed and the layer directly above, however the Coffey analysis does not consider this scenario.

Almost no standard time series analysis tools were used in the EIS. These could have provided valuable information about the tidal harmonics, tidal ellipses, velocity variances, spectra and vertical shear

(a key to turbulent exchange in the vertical). All of these properties are essential to understanding the physical environment of the Solwara 1 site and to determining risk.

Current roses are the other type of plot used in the EIS. They are also rarely found in oceanographic literature, as they are open to misinterpretation. For example, consider the third panel of Figure 3.8 above (1,453 m depth). Adding up the percentages, the 16 wedges each average about two or three per cent, so the total is perhaps 40%. This means that only around 40% of the currents are included in the plot. Normally, a small radius (e.g. a 4% circle) would be drawn to show that 4% of the time the current speeds are too small to measure. Then the rest of the wedges (including the approximate 40% wedge) would add up to around 96%. The legend, however, implies that all currents (down to 0 m/s) are included. Including currents with speeds below the threshold of the instrument could completely distort the lengths of all the wedges. So we are left knowing next to nothing about the direction of the currents or about the relative duration that the current speeds were within certain limits.

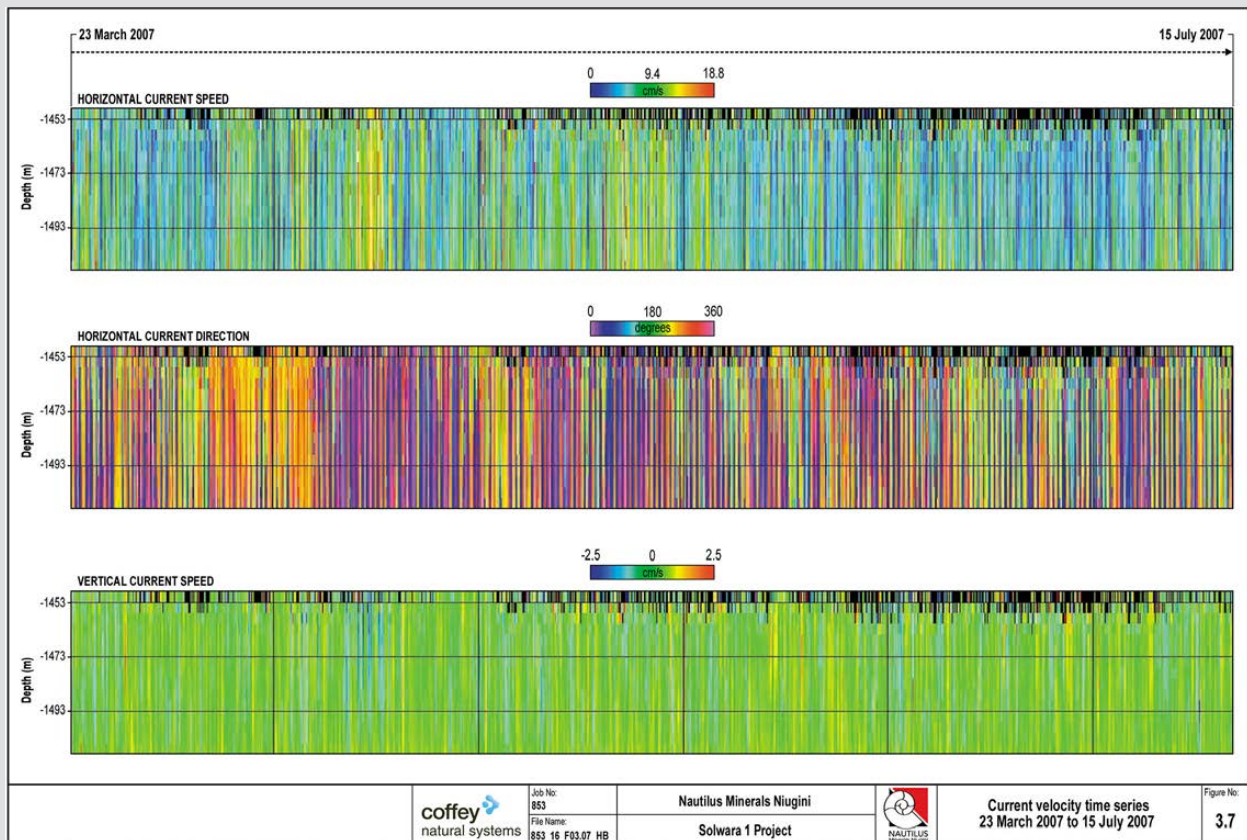
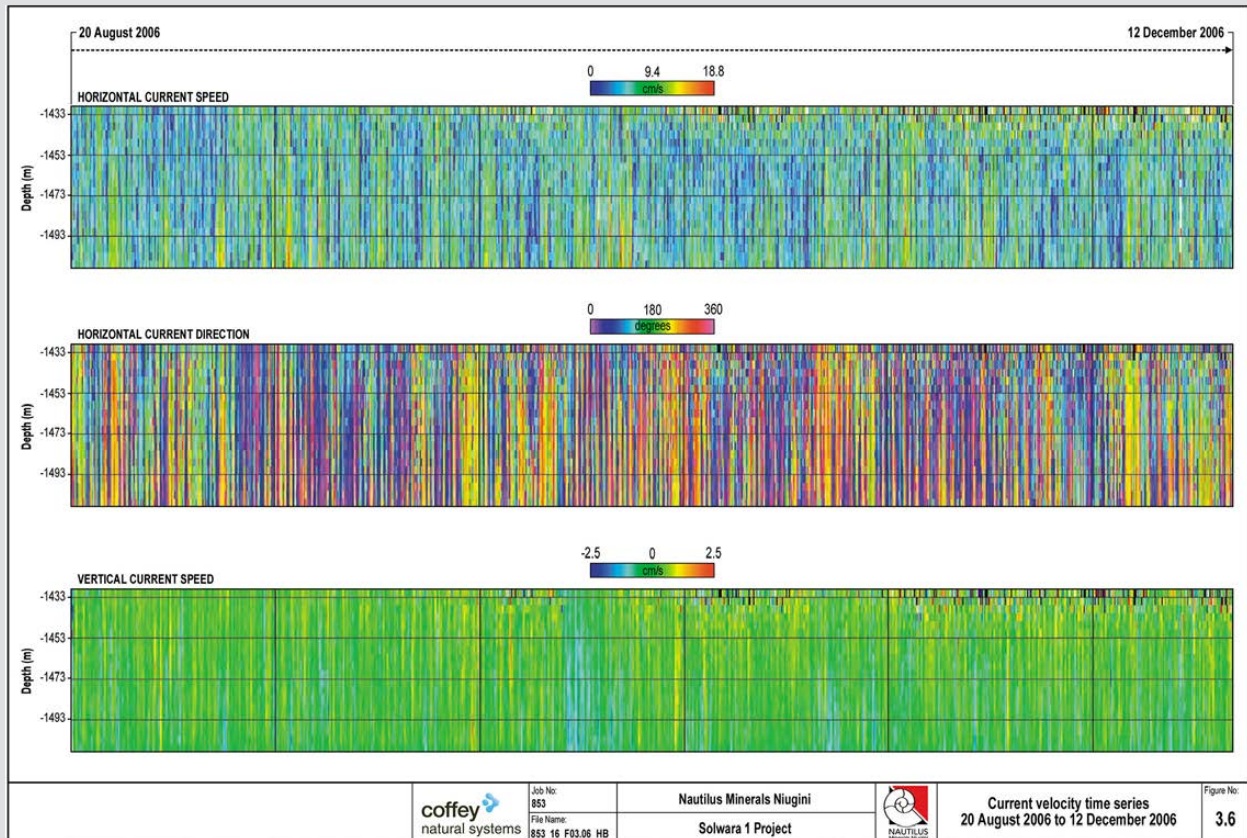


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Volume B - Supporting Studies, Figure 3.5, Appendix 3, p267-268

Figure 3: Coffey appears to confidently conclude that vertical current velocities are generally downward above the Solwara 1 mound, with some occasional upward velocities. This conclusion is unsubstantiated by the data presented. The colour yellow in the vertical velocity plots indicate upwards velocities of at least 1 cm/second.

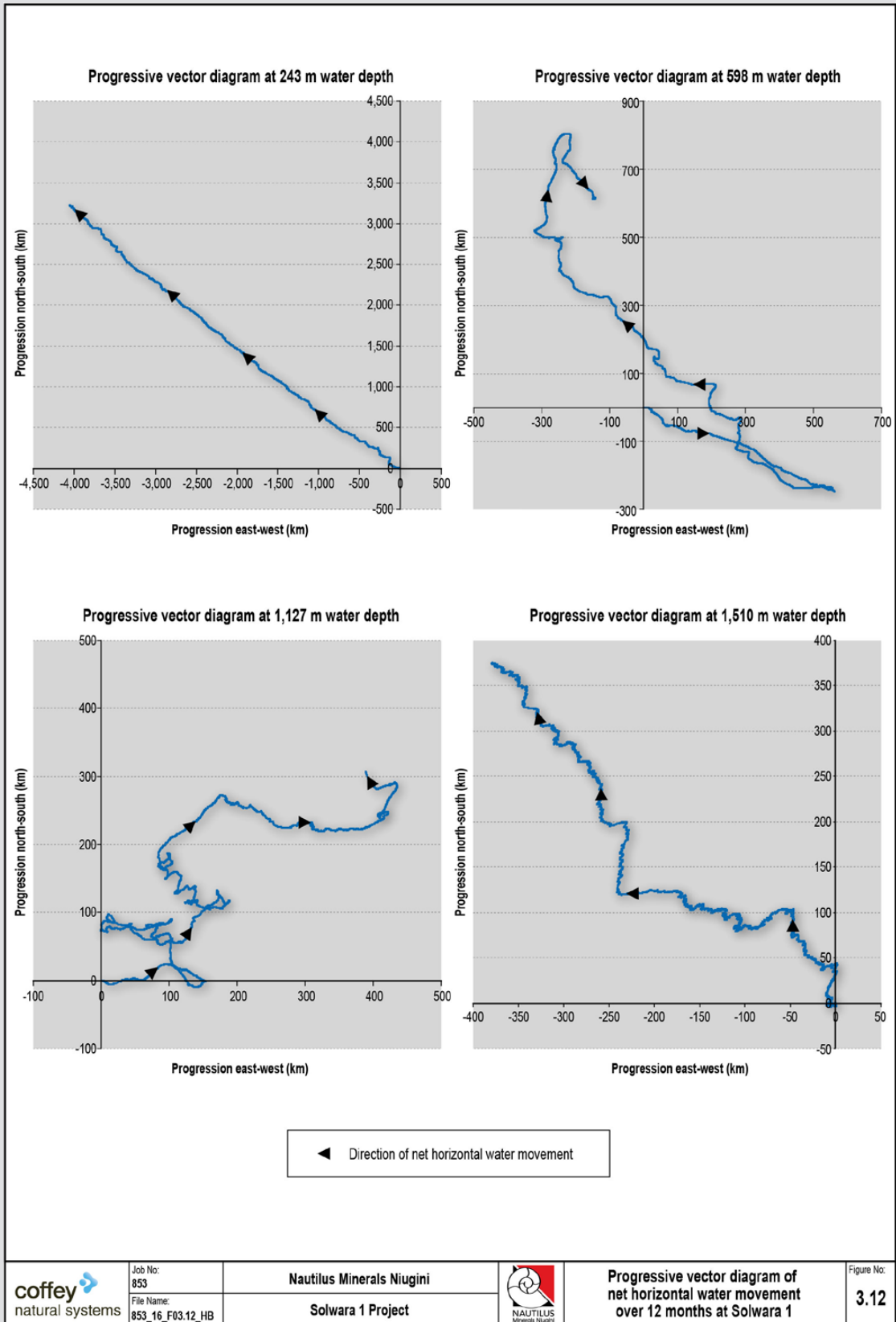


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Main Report, Figure 7.13 in Section 7.5 and Volume B - Supporting Studies, Figure 3.12, Appendix 3, p270-273.

Figure 4: In normal oceanographic practice, PVDs are presented with dates at regular intervals along the path. The PVDs in the EIS do have arrowheads along the path, but the dates are not indicated. This seriously reduces the scientific value of the diagram as nothing is learnt about the current speeds during different periods.

4. Removal of Waste Sediment and Rock from the Solwara 1 site

4.1 Overview

The ore body at Solwara 1 is covered by a layer of sediment and rock that must be removed prior to mining. Section 9.5 and Figure 5.11 of the EIS Main Report [Figure 5 in this review] describes the process whereby two Remotely Operated Vehicles (ROVs) remove unconsolidated sediment from five mining zones which is then dumped at adjacent tip sites. The waste material is expected to spread out from the disposal points (or tip heads) according to particle mass as seen in Table 9.4 of the Main Report. Approximately 130,000 tonnes of unconsolidated sediment and 115,000 tonnes of rock will be disposed of in this manner over a 20 month period.

The EIS predicts that a portion of this material will be carried away from the mining zones by currents as a cloud or plume of sediment. As described in *Out of Our Depth: Mining the Ocean Floor in Papua New Guinea*. (Rosenbaum, 2011, Section 6.2), sediment plumes pose an environmental risk due to their physical as well as chemical properties. Physically, sediment particles settling out of the plumes are likely to smother seabed ecological communities; interfere with bioluminescence and the ability of deep ocean species to function; and to clog hydrothermal vents, cutting off the food supply and effectively starving vent communities.

The natural sedimentation rate in the vicinity of the Solwara 1 site is extremely low. APASA estimates a rate of 0.18 mm/20 months, or 0.108 mm/year (Appendix 11, page 10). In such an environment, one would expect that additional sedimentation from mine derived plumes to have significant consequences.

If currents were to carry plumes closer to the ocean surface (as suggested in Section 5 of this review), the resultant turbidity could reduce photosynthesis and nutrients from the deep water could result in algal blooms (Rosenbaum, 2011, Section 6.2). Sedi-

ment plumes may also expose marine food chains to heavy metals through bioaccumulation. Nautilus is yet to release research showing it has modelled the risk of exposure to heavy metals associated with Solwara 1 plumes for marine species and humans.³

According to the modelling in the EIS, the majority of sediment should remain at the tip head (Section 9.5.3 of the Main Report). However, as described in section 4.2 below, mistakes regarding the current data inputted to the model and the lack of error analysis means that the “footprint” of sediment deposition could be up to 10 times that predicted by the EIS. Thus the maximum deposition thickness could be as much as five metres (not half a metre), and the footprint could extend over an area of 35 km².

On the basis of the information supplied in the EIS, the modelling cannot be relied on to provide an accurate estimate of the area covered by rock and sediment and how thickly it is covered. APASA has since explained that the EIS does not provide a complete description of the modelling it conducted (Personal communications, 19 October 2012). APASA has asserted that the concerns raised in this review would be addressed by the full set of data. This may be true, and we will continue remind the reader of this below, while at the same time basing this review on what is actually in the EIS. Without the full data set being made available, the credibility of the EIS’s estimates of the deposition footprint must be questioned.

At a minimum, the EIS should address the following key questions relating to risk from the waste removal process:

- What will be the total area covered by waste material adjacent to the mining zones and to what thickness?
- How much sediment will be carried as a plume by currents?

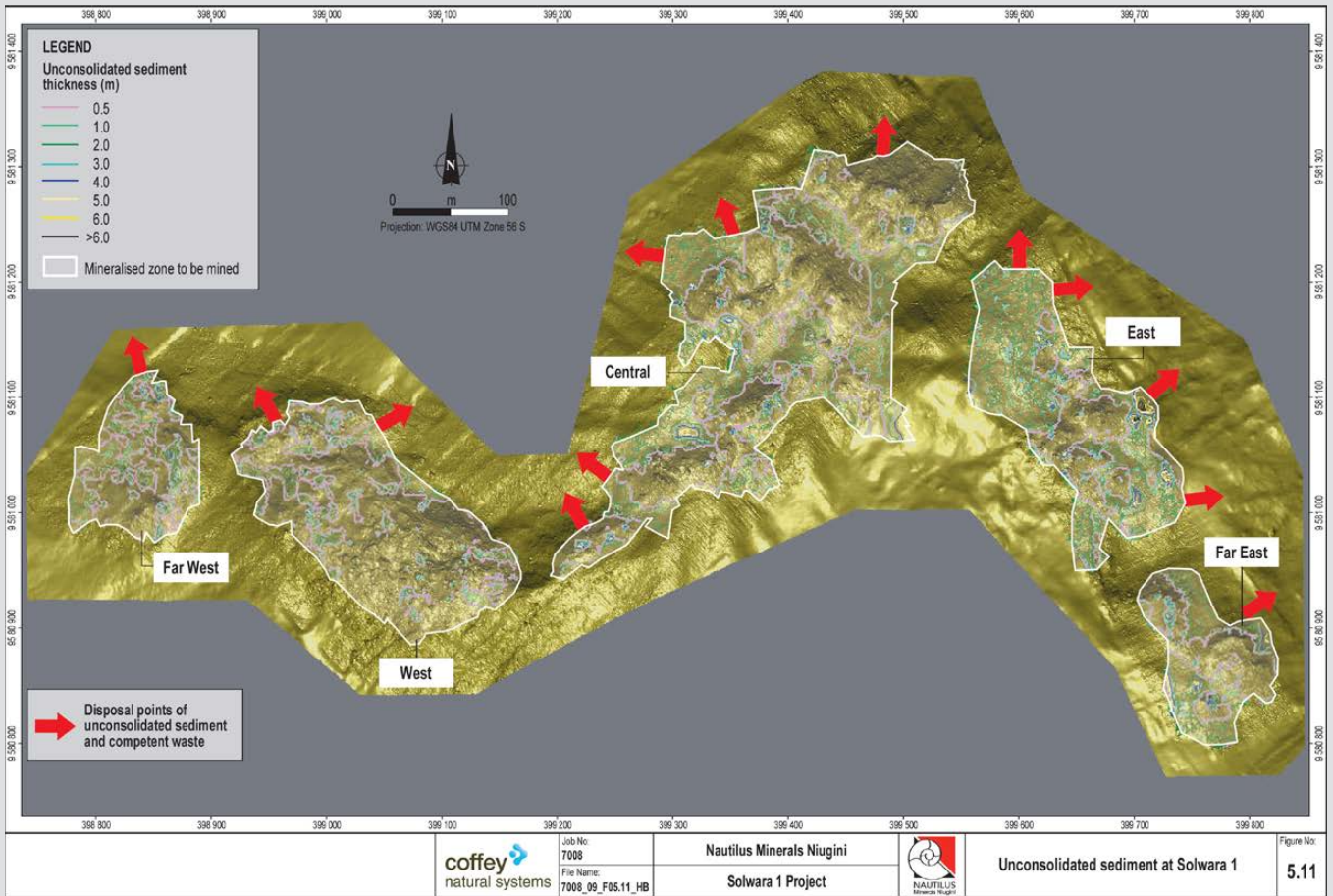


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Main Report, Figure 5.11 in Section 9.5 and Table 9.4

Figure 5: The ore body at Solwara 1 is covered by a layer of sediment and rock that must be removed prior to mining. The waste material is expected to spread out from the disposal points (or tip heads) according to particle mass as seen in the table below. Approximately 130,000 tonnes of unconsolidated sediment and 115,000 tonnes of rock will be disposed of in this manner over a 20 month period. On the basis of the information supplied in the EIS, the modelling cannot be relied on to provide an accurate estimate of the area covered by rock and sediment and how thickly it is covered. Nautilus is yet to release research showing it has modelled the risks of exposure to heavy metals associated with Solwara 1 plumes for marine species and humans.

Table 9.4 Deposition of unconsolidated sediment and competent waste rock

Depositional Thickness (mm)	Depositional Area (km ²) from Point of Discharge	Maximum Distance from Disposal Point (km)
0.18 to 0.5	2.343	0.972
0.1 to 1	1.798	0.710
1 to 5	1.568	0.660
5 to 10	1.047	0.615
10 to 50	0.801	0.565
50 to 100	0.278	0.264
100 to 500	0.166	0.166
> 500	0.003	0.036

- Where does the sediment carried in the plume settle? How far do the plumes travel?

Answers to these questions can then be combined with eco-toxicological studies of the metals contained in the sediment and the sediment plume to enable a rigorous assessment of the risks associated with waste removal.

4.2 Detailed Technical Review of the Modelling of Sediment Deposition

Appendix 11 of the EIS contains estimates based on modelling by APASA of the expected deposition footprint of the waste removal process for the entire

Solwara 1 mining lease site, including all five mining zones. APASA employs a computer model written by its parent company, Applied Science Associates (ASA). The model is known by the acronym SSFATE.

According to the SSFATE results in Figure 3.1, Appendix 11 [Figure 6 in this review], the footprint will be roughly elliptical and will cover about 2 km by 1.5 km or 3.5 km². It is estimated that the seabed within this impacted area will be covered to a thickness of more than half a meter over an area within 360 m from each tip head, reducing to a millimetre or less at a distance of around 700 m from each tip head.

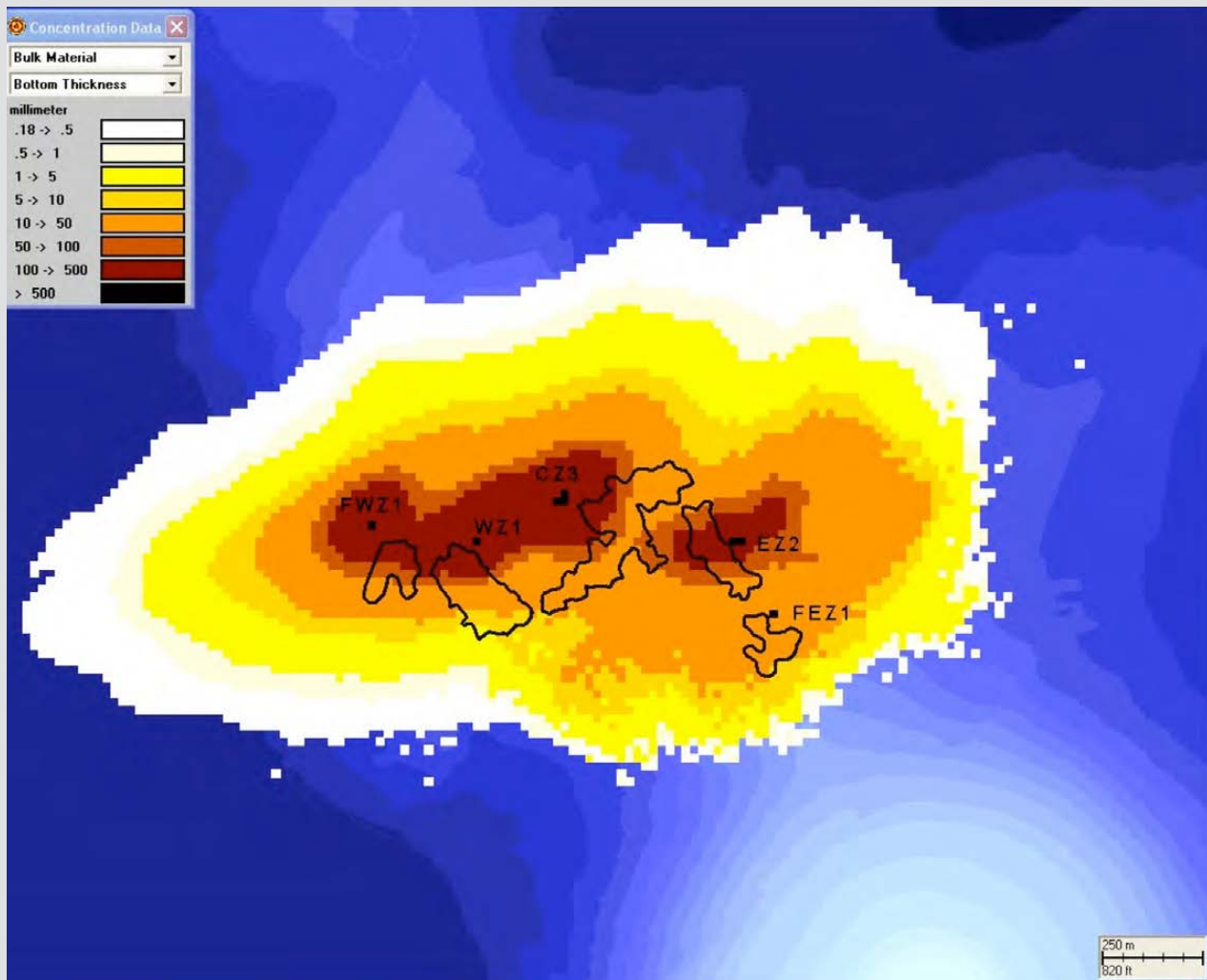


Image source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Volume B - Supporting Studies, Figure 3.1, Appendix 11, p168

Figure 6: According to the SSFATE results in the figure above the footprint will be roughly elliptical and will cover about 2 km by 1.5 km or 3.5 km². Without access to the full modeling results and data, the credibility of the APASA estimates of the deposition footprint from the waste removal process is highly questionable.

The sediment deposition results in Appendix 11 rely heavily upon the ambient currents. Figure 2.1, Appendix 11 summarises the current data used. The data is said to be from “the ADCP at 6 m above the seabed”. However, the plot is clearly labelled as being 1,493 m below the surface. This is actually 23 metres above the seabed (which is at 1,516 m at the ADCP mooring). Currents at 23 m are likely to be stronger and quite possibly flow in a different direction than those at 6 m above the seabed. In other words, as far as can be surmised from the information presented in the EIS, APASA used the wrong currents to model the deposition. If so, this would badly skew the results - the footprint is likely to be broader and in a different direction. Without detailed modelling combined with sensitivity studies it is impossible to determine the full extent and direction of the impact.

Using the wrong currents to drive the SSFATE deposition model is a systematic error. This raises the question of model accuracy. Accepted scientific practice requires some form of model validation. This is normally done by comparison against actual deposition thickness data. In the absence of appropriate data, parallel studies can be cited to show that the model correctly predicted deposition footprints elsewhere. No such evidence is provided and the only reference provided for the model is a 2007 conference presentation. The latter does not appear to be in the public domain and could not be obtained by the author of this review. An internet search on SSFATE also failed to identify the model’s specifications. It was necessary to contact APASA, who promptly provided the requisite details.

Lacking validation or “pedigree”, there are limited ways to provide confidence in the model’s results. One option APASA could have chosen is mass conservation, which involves checking whether the total mass in the footprint approximates the mass of waste to be added over the simulation period. Since the Lagrangian⁴ particles are assigned mass in the EIS this should have been possible. Likewise, there are no “error bars” to indicate the range of likely values. In the absence of mass conservation calculations or error bars, the deposition figures can only be assumed to be accurate to within an order of magnitude (i.e. within a factor of ten). It is pos-

sible the real accuracy is higher, but further data is required to demonstrate this.

An order of magnitude estimate on the EIS deposition figures tells us that the maximum deposition thickness could be as much as five metres (not half a metre), and the footprint could extend over an area ten times as large (35 km²).

In response to a written request for details, APASA explained that the EIS does not provide a complete description of the modelling conducted (Personal Communications, 19 October 2012). For example, APASA states it did conduct sensitivity analysis and that the correct current data was input to the model. However, without access to the full modelling results and data, the credibility of the APASA estimates of the deposition footprint from the waste removal process is highly questionable.

5. The Dispersion of Return Water Discharge

5.1 Overview

Nautilus plans to pump the ore in the form of a slurry from the sea floor to a mining support vessel at the surface. The ore will then be separated from the slurry through a dewatering process that results in “return water” (the water removed from the ore slurry) being pumped from the Mining Support vessel back down to the deep sea. It will be released at 25 to 50 metres above the seabed from a pair of U-shaped outlets that will discharge the water vertically upwards. The return water is expected to form a plume rather like the plume that can be seen rising from a smoke-stack.

The process is briefly described in Section 9.5 of the Main Report and is depicted in Figure 5.8 [Figure 7 in this review]. The return water is comprised of about 80% sea floor water (used to pump the ore to the surface) and about 20% surface water (added after dewatering at the surface).

Lack of assessment of the toxicity of the seabed plume was cited by [Steiner \(2009\)](#) and discussed in [Out of Our Depth: Mining the Ocean Floor in Papua New Guinea](#). (Rosenbaum, 2011, Section 6.2) as a deficiency of the EIS. Whether or not the discharge plume presents a hazard to marine or human life is outside the scope of this review. Here we ask whether the EIS adequately assessed the risk that the plume may come into contact with communities and marine life.

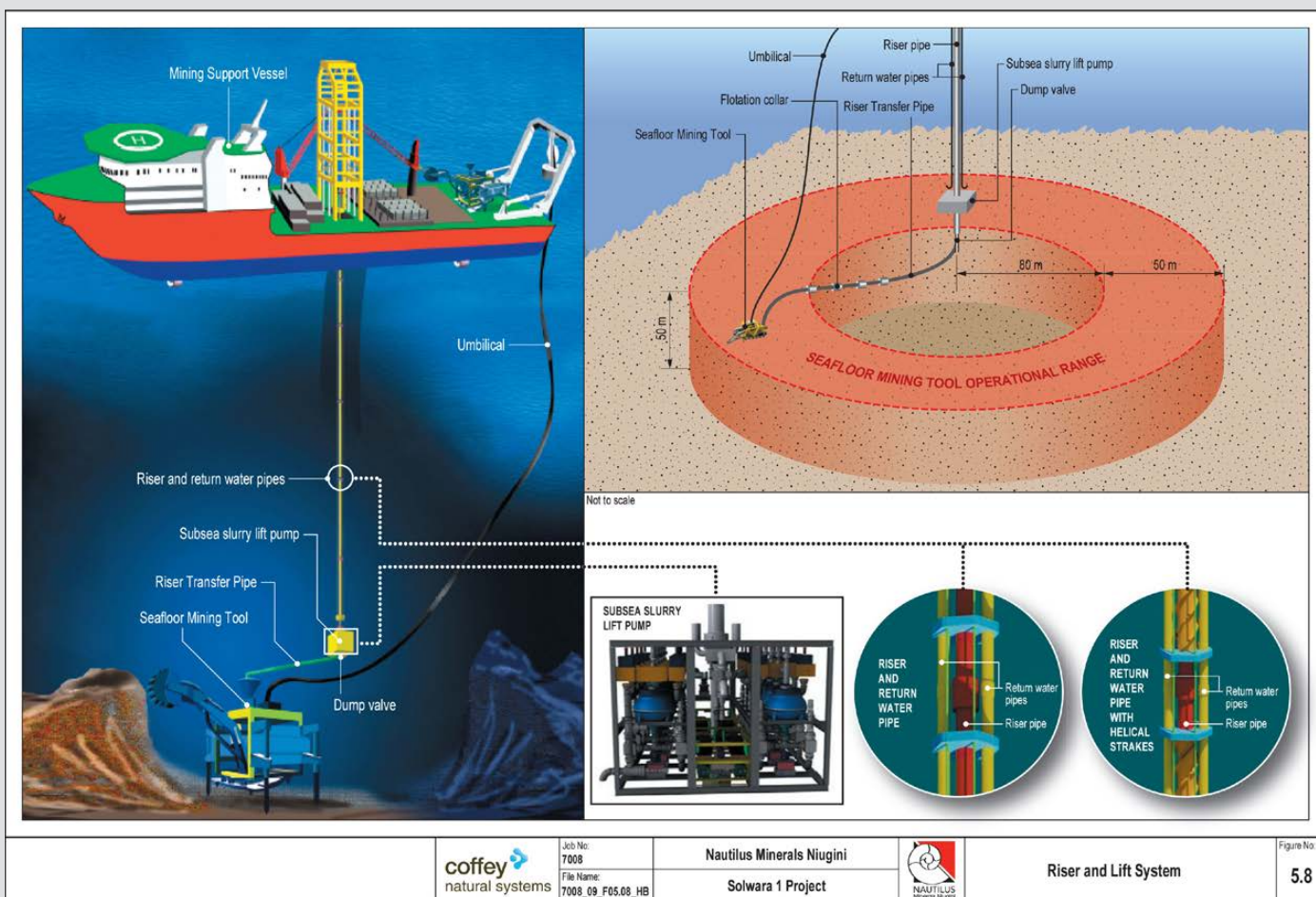
The fact that modelling was seen as necessary presumably means that there was a perceived concern that the plume could carry metals suspended in solution that could be harmful to coastal communities of New Ireland and New Britain, coral reefs, or free-swimming pelagic organisms including tuna and other fish consumed by local coastal population. Steiner (2009) also noted the potential harm to the unique biological communities of the deep and mid-depths: to free-swimming organisms as well as the huge variety of bottom-dwellers, the majority of which have not yet been identified.

The purpose of the plume modelling is to predict the likely plume pathways and rates of dilution. APASA used a computer model known as CHEMMAP to estimate the horizontal spreading of the return water plume and made predictions of the vertical movement of the plume based on buoyancy. A detailed technical review of the modelling and predictions follows. However, in summary there are four key problems with the plume dispersion estimates:

- the absence of sensitivity studies and/or error analysis means that an order of magnitude (factor of 10) multiplier should be applied to the EIS’s findings: resulting in an estimate of the plume spreading 50 km in one in every 10 days
- the failure to consider the effect of the lower salinity of surface water (which makes up 20% of the return water) on buoyancy means that the plume may rise as much as twice as high as predicted by APASA and to within the influence of currents that flow towards New Ireland Province.
- the use of an inappropriate horizontal current velocity to input to the CHEMMAP model means that the horizontal spreading estimates are unreliable and
- the failure to factor in upwelling. Section 3 of this review notes that there appears to be periodic upwards velocities above the Solwara 1 mound of up to 1000 m/day.

As a result of these deficiencies, APASA’s modelling and predictions cannot be used to identify risk to human communities and marine and coastal species. Instead of representing the “worst-case” scenario, as claimed by APASA, the EIS presents something closer to a “best-case” scenario⁵.

A worst case scenario would factor in 1,000 m/day upwelling combined with 50 km horizontal spreading. The consequence of these condi-



Source: Nautilus Minerals, Solwara 1 Environmental Impact Statement Main Report, Figure 5.8 in Section 9.5.

Figure 7: The figure above briefly explains the dispersion of return water discharge. Section 5 of this review draws out key problems with the plume dispersion estimates in the EIS.

tions is that the plume would regularly impact on the shallow near-shore zone of New Ireland. The absence of error analysis or sensitivity studies means this risk cannot be ruled out by the EIS.

5.2 Detailed Technical Review of the Modelling of Return Water Discharge

5.2.1 The CHEMMAP Model

APASA employed a computer model known as CHEMMAP to simulate the horizontal spreading and dispersion of the return water plume under assumed ambient flow conditions based on the Coffey current meter data (Appendix 12).

CHEMMAP is another in-house model owned by APASA's parent company ASA. Scant detail is provided in the EIS on the CHEMMAP physics and

numerical strategy, but there are references to several technical and scientific publications. One of these (French McCay and Isaji, 2003) was obtained by the author of this review. From this report it was found that CHEMMAP is an "offline model". This means it is not a hydrodynamic model, but rather it imports a pre-determined three dimensional field of current data either taken from a hydrodynamic model or (as in this case) observed data – the ADCP measurements conducted by Coffey and examined in Section 3 of this review. The three-dimensional velocity field, including horizontal currents, up- or down-welling, and buoyancy effects are completely prescribed by the modeller. Thus the CHEMMAP's value is limited by the accuracy of these factors – which is questioned in Sections 5.2.2 and 5.2.3 below.

APASA does not explicitly state in the EIS whether CHEMMAP was run as a two-dimensional or three-dimensional model, or if it is three dimensional, how many vertical levels were employed. The numerical grid is described as “500 x 500 grid cells, each at 60m x 60m resolution” (Appendix 12, Section 2.4). The height (thickness) of the cells is also unstated. To a modeller, the lack of vertical specification implies that the model is two-dimensional, like a slab sitting flat at the bottom. APASA have advised that the model had five layers, thus allowing limited vertical transfer of material within the slab (Personal Communications, 19 October 2012), but the reader is left to assume that in this model the plume is constrained to move only horizontally.

The way the model works is that the computer solves a set of equations to predict the amount of material moving between cells. At the start, the concentration is zero everywhere except at the central cell. The concentration at the central cell is prescribed in accordance with the rate and concentration of return water. As time goes on, the cells surrounding the central cell receive material from the central cell in accordance with the relative concentrations, water velocities, etc. (as calculated by the model), and following this the cells adjacent to those begin receiving material. Within any one cell, there is no variation in concentration, water velocity, temperature or any other water property. The horizontal “resolution” of the model is the horizontal size of the cells (i.e. 60 m).

APASA describes CHEMMAP as a “stochastic” model.⁶ What this means in this context is that there were 100 eight-day simulations for each of two scenarios, namely at discharge temperatures of 5.8°C and 11.4°C. These temperatures were judged to represent the extremes of the likely range of discharge temperature. The start time for each simulation was chosen randomly from periods for which time series of current meter data were available. Everything about the environment (e.g. advective currents, turbulence, diffusion, temperature, salinity and vertical velocities) was assumed to be known from the data or estimated, with no spatial variability.

5.2.2 Horizontal spreading of the plume according to CHEMMAP

Section 4 of this review found that APASA used the wrong value for horizontal current velocity for the SSFATE modelling of the deposition of waste material.⁷ The same is true of the CHEMMAP modelling.

The source of the velocity error can be found in Section 2.3 of Appendix 12 of the EIS, where it is assumed that the total depth was 1,500 m when in fact it is 1,516 m. It is well known that currents vary vertically within the bottom boundary layer, so this error will translate into an incorrect current velocity. APASA also did not allow for the height of the ADCP or the fact that the nominal depth of the bottom-most data is at least a metre above it. This means that the horizontal spreading estimates, which depend critically on the velocity, are unreliable. This systematic error is not reduced by the stochastic approach.

Plume concentration probabilities are presented as functions of distance from point of discharge for two different discharge temperatures (5.8°C and 11.4°C). These temperatures are chosen to encompass the likely range. The results are presented in terms of how far and how often a certain upper limit concentration extends from the outlet. For example, according to Table 3.3, on one out of ten days (the 10% level), given a discharge temperature of 11.4°C, the plume cloud will travel horizontally five kilometres at a concentration exceeding the 1:5,000 threshold. On the other nine days, the concentrations caused by the plume will be confined to a smaller area. The dilution ratio 1:5,000 was the most dilute ratio reported, but whether this dilution is considered to represent a toxicological or physical impact threshold (and if so, on what basis) is unclear.

APASA have stated that sensitivity studies for CHEMMAP were performed, though not reported in the EIS. Without seeing the data it is not possible to verify this claim. If we can assume that the results are accurate to within an order of magnitude, a factor of ten can be applied to the results. This would suggest that instead of one out of ten days

(as per the EIS), the five km limit of concentrations greater than 1:5000 would be reached every day at a discharge temperature of 11.4 °C. Alternatively, if we retain the one out of ten days, but multiply the extent of the plume by ten, it could spread to 50 km. It may well be that the model accuracy is better than a factor of ten, but we have no way of knowing from the information provided.

On the basis of the logic above, if it flowed to the east, the plume would reach the shores of New Ireland (the nearest point being about 30 km from Solwara 1on at least one out of ten days. This may be beyond the actual spreading limit for the 1:5000 dilution, but unless the data from sensitivity studies are made publicly available, this level of dispersion cannot be ruled out. It should be noted that as it neared shore, the plume would remain at depth unless brought upwards by other forces. However, as is discussed below, this is a distinct possibility.

5.2.3 The vertical movement of the discharge plume

APASA's estimates of how high the plume will rise are provided in the absence of upwelling, as a result of buoyancy alone (Section 3.2, Appendix 12). Buoyancy is the primary driver for upwards mixing of the plume at these depths and is critical to estimating the height to which the plume rises after discharge.

APASA makes a critical miscalculation which causes an under-estimate of the height. In calculating the buoyancy of the plume, APASA made no allowance for variations of surface salinity. This is significant as the return water is 20% surface water and it can result in a significant under-estimate of buoyancy. As indicated in Figure 3.2, Appendix 12, surface salinity is often half a unit, and on at least one occasion more than one full unit, below that of the water drawn from the seabed. If the sea water is one unit less saline at the surface than at the seabed, the density deficit caused by salinity in mixing surface water to 20% of the volume would be nearly as large as that caused by temperature. In

other words, the return water is then nearly twice as buoyant as would be expected on the basis of temperature alone.

If the return water is twice as buoyant as APASA predicts, the estimates for the vertical rise of the plume are under-estimated by a factor of two. In such a case, the plume rises twice as high as is estimated in the EIS. This means that rather than a maximum rise of 145 metres above the seafloor, the 11.4°C plume will then rise to 290 metres above the seafloor (to 1,210 metres below the surface). The third PVD in Figure 3.12, at 1,127 metres, tells us that at this depth the plume would then be carried by a current flowing to the northeast towards New Ireland. In other words, a modest decrease in surface salinity would cause the plume to rise to a level where the flow is towards landfall and coastal communities.

APASA apparently did not consider upwelling in their estimate of how high the plume rises. This is a grave omission but unsurprising in light of the fact that the ADCP data was not analysed for upwelling velocity. However, as noted in Section 3 of this review, there are episodes when upwards velocities over the Solwara 1 mound appear to reach 1000 m/day. This upwelling velocity, whenever it occurs, must be added to the buoyancy velocity.

APASA claims that its calculations represent the worst-case scenario, but have not allowed for vertical upwelling or the possibility of a salinity deficit in the discharge water. These are significant omissions in relation to risk of harmful substances rising to a level where horizontal currents could carry them to the coast of New Ireland Province.

6. Conclusion and Implications

This report reviewed the data and analysis of physical oceanography, sediment deposition and plume dispersal as presented in the Nautilus EIS. It finds that each of these aspects of the EIS suffers from a lack of rigour with regard to the modelling, presentation and analysis of data. Based on the EIS, it is not possible to accurately identify environmental risks associated with oceanographic characteristics and therefore to manage them. Given the nature of this project – a mine located on the deep sea floor - this is a grave indictment of Nautilus and of the PNG Government that issued the company with a 20 year operating licence on the basis of this EIS.

The oceanographic field measurements were generally well conceived, designed and executed. However, an important criticism is that the EIS did not include plots or estimates of surface currents. As described in Section 3.1 of this review, Nautilus maintains that surface current data was collected but not presented in the EIS as Nautilus does not expect surface spills to occur under normal operations due to the company's careful engineering design.

However, the omission of the surface data from the EIS is of significant concern in the light of independent research showing currents flowing towards New Ireland and also the possibility of upwelling as discussed in section 5.2.2 of this review. In combination, these horizontal and vertical water movements mean that not only are the people of New Ireland and marine ecosystems at risk of pollution from surface spills but also from possible leakage from the riser or discharge pipes, and of upwelling dispersing metals from the mining activity or from the return water.

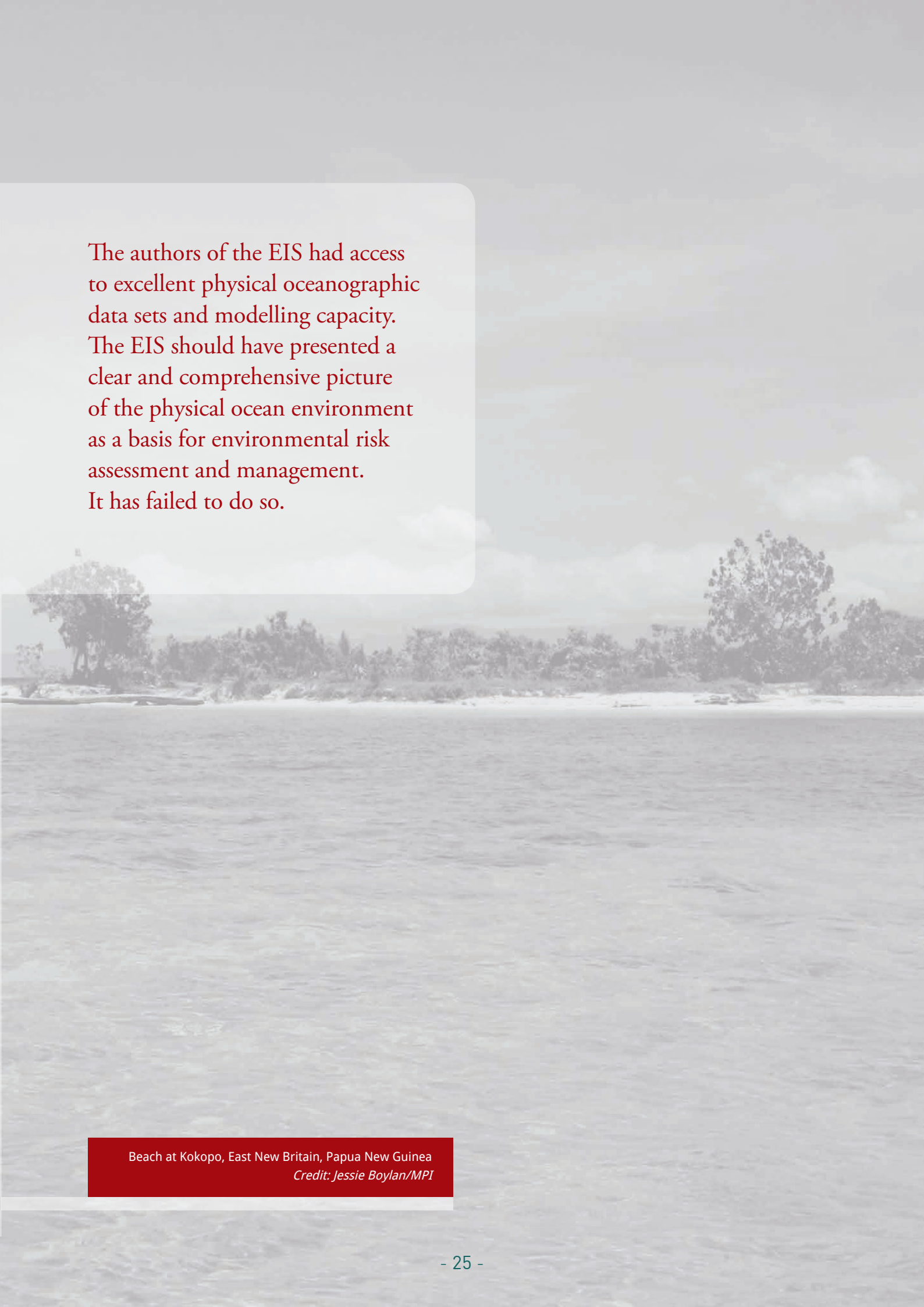
Despite its critical importance, the analysis of the physical oceanographic data is almost non-existent. Appendix 3 of the EIS ("Physical Oceanography at Solwara 1") is most notable for its small size at only

32 pages. Tides are virtually ignored – it is not clear that the authors even considered their importance. In its discussion, Coffey provides only a few qualitative remarks about the horizontal currents during different monsoons. Almost nothing is said about vertical velocities. The EIS appears to assume that the vertical velocities are so small that they can be ignored. However, data presented in the EIS (though not discussed) show episodes of strong upward velocity near the seabed and throughout the entire water column.

The assumption about the insignificance of the vertical movement of water above the Solwara 1 site flows through to the modelling of the deposition and dispersal of waste material and of the dispersion of the return water plume (Appendices 11 and 12 of the EIS). This seriously compromises the reliability of the estimates of these impacts. Further compounding this is the finding (based on the information provided in the EIS) that incorrect horizontal velocities were used by APASA in the modelling of both of these aspects of the mining operation.

Another critical error relating to the miscalculation of the buoyancy of the discharged return water underestimates the height to which the return water plume could rise (section 5.2.2). This height is critical because a more accurate calculation of buoyancy takes the plume up into a layer characterised by currents that flow shoreward towards New Ireland. It is also possible that these same currents may result in the plume moving towards East New Britain. Rigorous detailed analysis is required to determine these risks.

The removal of waste material and the discharge of return water are key potential sources of pollution from the Solwara 1 operation. However, the EIS provides no meaningful assessment of their likely impact.



The authors of the EIS had access to excellent physical oceanographic data sets and modelling capacity. The EIS should have presented a clear and comprehensive picture of the physical ocean environment as a basis for environmental risk assessment and management. It has failed to do so.

Beach at Kokopo, East New Britain, Papua New Guinea
Credit: Jessie Boylan/MPI

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Endnotes

[1] The tidal excursion is the maximum horizontal distance water moves back and forth due to tides in the course of a tidal cycle. It is the diurnal (once per day) components of the tide that contribute to this in the Bismarck Sea.

[2] The very brief and general reference to tidal axis on [Page 1-19, Appendix 3](#) is the only discussion of tides in the EIS

[3] Requests to Nautilus for relevant research papers by the Deep Sea Mining Campaign have been unsuccessful.

[4] Modellers use the term “Lagrangian” to denote virtual particles that trace out flow paths in response to model currents

[5] APASA have advised that the information in the EIS is incomplete and that more detailed modelling was conducted. However, until the full data set is made publicly available, the extent to which it addresses these deficiencies cannot be assessed.

[6] An explanation of stochastic modelling is provided in [Appendix 12, section 2.2](#)

[7] Although APASA have advised that the information in the EIS is incomplete and that more detailed modelling was conducted, the full data set have not been made available. Thus use of correct current measurements cannot be verified.

[8] See, for example, <http://ocean.jpl.nasa.gov/AQUARIUS/chapter1.pdf>

Notes

Notes

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